

Safety at Speed - S@S  
**VERIFICATION AND VALIDATION  
PROCEDURE/ SCHEME - MAIN CAUSES  
DELIVERABLE No. D5.1.0**

Document ID Code: S105.10.02.053.001

Date: 2002-01-dd

Contract No. G3RD-CT-2001-00331

## CLASSIFICATION AND APPROVAL

Classification: Confidential

## DEFINITION

### Public after Review:

The document may be freely distributed after successful EC review. given the EC's permission. Publication is governed by the EC Contract and the S@S Consortium Agreement

### Confidential for the Duration of the Project:

As for 'Confidential'. but only for the duration of the Project. After final Project Approval by the EC, status for reports classified 'Confidential for the Duration of the Project' are automatically down-graded to 'Public'.

### Confidential:

The document is for use of the G3RD-CT-2001-00331 Contractors within the S@S Consortium, and shall not be used or disclosed to third parties without the unanimous agreement within the S@S PMC and subsequent EC approval since document classification is part of the EC Contract.

Any executive summary specifically intended for publication may however be made known to the public by the author and/or the Coordinator.

## AUTHORS:

Name	Date	Signature
<i>A. Cagnet JC. Astrugue</i>	<i>2002-02-20</i>	_____
<i>J. McGregor R.Birmingham</i>	<i>2002-02-10</i>	_____

## APPROVAL:

Approved for release by:

Name	Date	Signature
<i>NN3</i>	<i>yyyy-mm-dd</i>	_____

## DOCUMENT HISTORY:

Issue:	Date:	Initials:	Revised pages:	Short description of changes: File name:

## DISCLAIMER

Use of any knowledge, information or data contained in this document shall be at the user's sole risk. Neither the S@S Consortium nor any of its members, their officers, employees or agents accept shall be liable or responsible, in negligence or otherwise, for any loss, damage or expense whatever sustained by any person as a result of the use, in any manner or form, of any knowledge, information or data contained in this document, or due to any inaccuracy, omission or error therein contained.

The European Community shall not in any way be liable or responsible for the use of any such knowledge, information or data or of the consequences thereof.

## CONTENTS

<b>1. EXECUTIVE SUMMARY SUITABLE FOR PUBLICATION.....</b>	<b>5</b>
<b>2. INTRODUCTION.....</b>	<b>5</b>
<b>3. METHODOLOGY.....</b>	<b>5</b>
<b>4. RESULTS .....</b>	<b>6</b>
4.1 GENERIC DIAGRAM.....	6
4.2 WP1 TO 4 RESULTS.....	6
<b>5. COMPARISON WITH SCHEDULE OF WORK.....</b>	<b>9</b>
5.1 ROUGH RESULTS.....	9
5.2 INTERPRETATION.....	12
<b>6. CONCLUSION .....</b>	<b>13</b>
<b>7. REFERENCES .....</b>	<b>14</b>
<b>1. APPENDIX 1 - FMECA TABLES OF WORKSHOP.....</b>	<b>15</b>
<b>2. APPENDIX 2 - BRIEF PRESENTATION OF FSA .....</b>	<b>18</b>
2.1 INTRODUCTION .....	18
2.2 FSA – PROBLEM DEFINITION .....	18
2.3 FSA – STEP 1: HAZARD IDENTIFICATION .....	19
2.4 FSA – STEP 2: RISK ASSESSMENT .....	22
2.5 FSA – STEP 3: RISK CONTROL OPTIONS.....	29
2.6 FSA – STEP 4: COST BENEFIT ASSESSMENT.....	29
2.7 FSA – STEP 5: RECOMMENDATIONS FOR DECISION MAKING.....	30
2.8 REFERENCES.....	31
<b>3. APPENDIX 3 – RISK ANALYSIS TOOLS.....</b>	<b>32</b>
3.1 WHAT-IF ANALYSIS.....	32
3.2 WHAT-IF/CHECKLIST ANALYSIS.....	33
3.3 HAZARD AND OPERABILITY (HAZOP) ANALYSIS.....	34
3.4 FAILURE MODES AND EFFECTS ANALYSIS (FMEA).....	36
3.5 FAULT TREE ANALYSIS (FTA) .....	38
3.6 EVENT TREE ANALYSIS (ETA).....	40
3.7 REFERENCES.....	41
<b>4. APPENDIX 4: FMECA RESULTS.....</b>	<b>43</b>

## 1. EXECUTIVE SUMMARY SUITABLE FOR PUBLICATION

This deliverable reviews, in the context of accepted IMO Formal Safety Assessment (FSA) practices, the results of the workshop held in November 2001, which aimed at facilitating the development of the deliverables 110. 210. 310. and 410.

S@S is the acronym for Safety at Speed. a project supported by the European Commission under the Growth Programme of the 5TH Framework Programme. The support is given under the scheme of RTD. Contract No. G3RD-CT-2001-00331.

## 2. INTRODUCTION

This deliverable reviews, in the context of accepted FSA practices, the results of the workshop held in November 2001, which aimed at facilitating the development of the deliverables 110. 210. 310. and 410.

The objective of task 5.1 is to verify and validate the techniques during their development in Work Package 1 to 4 against typical, real-life designs, current rules and regulations and techniques made available from other industrial sectors to assure the applicability and quality of results. A workshop was organised during month 5 in order to facilitate the development of the deliverables 110. 210. 310., and 410. The outputs from the workshop have been reviewed in the context of accepted FSA practices.

## 3. METHODOLOGY

The FMECA (Failure Modes and Effects and Criticality Analysis) is a method currently used in risk assessment with the aim of listing all single cause failures of a system and is recommended by the HSC Code. More details are given in Appendix 3, while Appendix 2 roughly presents (FSA), the maritime way of processing risk analysis, and how it is applied.

The purpose of this study is to support other technical documentation in the assessment of the main factors affecting controllability (WP1), ship motions (WP2), and foundering (WP3), and in the identification of points of interest in the containment of damage and fire (WP4).

In agreement with the scope of work, the FMECA was kept to a high level, as the system under study was a generic HSC, subdivided into 8 subsystems:

- crew,
- general arrangement,
- hull-form,
- operation,
- payload,

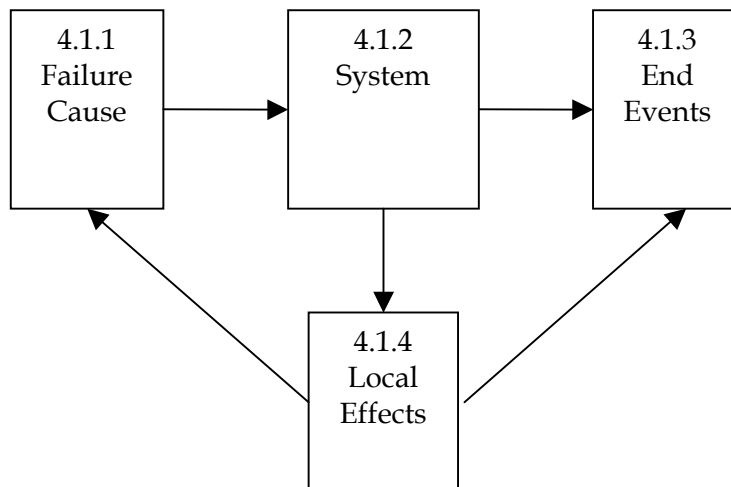
- safety systems and
- structure.

The FMECA workshop was held in Newcastle from November 19<sup>th</sup> to 21<sup>st</sup> and chaired by the University of Newcastle.

Remark: Due to the high level of this application and as some multiple cause failures were also retrieved in the result, it is preferable to use the word HAZID (Hazard Identification) instead of FMECA to describe what has been done.

## 4. RESULTS

### 4.1 generic diagram



### 4.2 WP1 to 4 results

The following table compiles the results obtained for WP1 to 4:

WP	OBJECTIVES	RESULTS
WP1	Confirm what was foreseen at the proposal level in terms of factors (human and technical) affecting the reference hazards (collision and grounding).	By comparing the prioritised failure modes with the Schedule of Work for the Work package the following can be noted: <ul style="list-style-type: none"> <li>• High risk hazards included in the Work package are:                             <ol style="list-style-type: none"> <li>1. Manoeuvring equipment failure</li> <li>2. Environmental degradation of Crew</li> <li>3. Failure to follow procedures</li> </ol> </li> </ul>

		<ol style="list-style-type: none"> <li>4. Movement of cargo-including people</li> <li>5. Lack of directional control</li> <li>6. Improper use of equipment</li> <li>7. Failure to Contact Shore-Based Assistance</li> <li>8. Navigational equipment failure</li> <li>9. Navigational error in open and congested waters</li> <li>10. Navigational error in traffic</li> </ol> <ul style="list-style-type: none"> <li>• High risk hazards not included in the Schedule of Work that could be considered by the Work Package are: None</li> <li>• Areas of work in the Work Package not identified as high risk are: None</li> </ul>
<p>WP2</p>	<p>Review hazards related to ship motions and associated environmental loading, and of the relevant affecting factors.</p>	<ul style="list-style-type: none"> <li>• All areas of work defined in the work programme for WP2 are identified as high risk.</li> </ul> <p>main hazards related to ship motions:</p> <ul style="list-style-type: none"> <li>• Crew and passengers disorientation and injury</li> <li>• Large ship loading causing structural failure and foundering</li> <li>• Loss of ship control</li> </ul> <p>These hazards can be related to the occurrence of the next events :</p> <ul style="list-style-type: none"> <li>• Excessive ship motions and accelerations</li> <li>• Excessive elastic ship vibrations</li> <li>• Excessive local and global wave loads</li> <li>• Dynamic capsize (broaching)</li> <li>• Excessive noise, vibration levels and bad indoor climate</li> </ul> <p>The main factors affecting these hazards are as identified in the work programme, that is :</p> <ul style="list-style-type: none"> <li>• Human factors</li> <li>• Hull design (including hull shape and weight distribution)</li> <li>• Operational practice, that is ship operation (speed/heading) for the encountered sea conditions.</li> </ul>

<p>WP3</p>	<p>Confirmation of main causes is undertaken to ensure that the hazards identified in the project are in fact those that could lead to failure.</p>	<p>High risk hazards included in the Work package are:</p> <ul style="list-style-type: none"> <li>❖ First Order             <ol style="list-style-type: none"> <li>1. Unexpected Loads (Global &amp; Local Failure)</li> <li>2. Excessive Motions accelerations (Local Failure)</li> <li>3. Failure of Deck Structure (Local)</li> <li>4. Structural Failure of Subdivision (Global &amp; Local)</li> <li>5. Local Failure of Decks</li> </ol> </li> </ul> <p>High risk hazards not included in the Schedule of Work that could be considered by the Work Package are:</p> <ul style="list-style-type: none"> <li>❖ None</li> </ul> <p>Areas of work in the Work Package identified as not high risk are:</p> <ul style="list-style-type: none"> <li>❖ First Order             <ol style="list-style-type: none"> <li>1. Lack of directional control (due to hull form)</li> <li>2. Local failure of shell leading to global failure</li> <li>3. Global failure</li> <li>4. Structural failure of sub-division</li> <li>5. Local failure of decks</li> <li>6. Failure of openings</li> <li>7. Local failure of bow</li> <li>8. Failure of bow</li> </ol> </li> </ul>
<p>WP4</p>	<p>Confirmation of the main means relevant for the containment of damage and fire that are available for consideration during the concept design stage of a HSC.</p>	<p>It makes a list and draws preliminary conclusion for the various means for containment:</p> <ul style="list-style-type: none"> <li>- Human factor</li> <li>- Passive design system             <ul style="list-style-type: none"> <li>- External</li> <li>- Internal</li> <li>- Operational Measures</li> </ul> </li> <li>- Active design system             <ul style="list-style-type: none"> <li>- LSA</li> <li>- Fire fighting systems</li> </ul> </li> </ul>

## 5. COMPARISON WITH SCHEDULE OF WORK

### 5.1 Rough results

Results of FMECA are presented under the form of fault trees in Appendix 4 and as a table in Appendix 1.

Appendix 1 gives a link to the FMECA worksheet as delivered by UNEW.

In Appendix 4, failure modes are represented as fault trees. Then each work package has been assigned one colour so that in the fault trees, each event has been attributed to the relevant work package(s), as indicated in the [deliverables](#).

This helped in high lighting which hazard and failure causes were unassigned and how the work packages could interpenetrate each other.

In these documents we tried to distinguish the failure modes handled by one or more WP, from those that were discarded.

Then for each failure mode, we highlighted which failure cause/consequence is the responsibility of whom. In that we were helped by the preliminary work done by WP2 and WP3, which was just that. We should also add that the case for WP4 is different, as it does not so much aim at identifying hazards than at studying means of containment of fire and flood. Therefore highlights in the relevant colour indicates more areas of interest for WP4 when evaluating the different means of containment rather than causes/hazards for whatever accident.

The Rank value was calculated by awarding points for calculated risks, with an unacceptable risk being 133 points, ALARP1 being 12 points, and ALARP 2 1 point. It should be noted that there was a possible highest score of 1100 as there was a possibility of 8 unacceptable risks and 3 ALARP1 risks.

- Some **failure modes** are not allocated to any work-package:

RELATED 'SYSTEM'	FAILURE MODE	RANK
• General Arrangement	- insufficient/ poor area access	295
	- excessive noise	37
	- loss of safety fixtures	17
• Payload	- carrying unsuitable cargo	317
	- incorrect cargo movement during loading/unloading	99
	- inappropriate passenger action	76
• Safety systems	- escape routes not efficient	15
	- escape routes unusable	14
	- insufficient first aid on board	14

- The following **failure causes** are not allocated to any work-package:

The majority of them is related to the non-studied failure modes, but some others are left aside as no WP is clearly responsible for them. The last ones are presented in the table below:

RELATED 'SYSTEM'	FAILURE MODE (RANK)	FAILURE CAUSE
Crew	environmental degradation (450)	Visibility
		Disruptive passengers
		Smoke
	Communication failure (40)	Usage of equipment
General Arrangement	damage or failure to closure at sea (328)	Poor maintenance
	excessive vibration (65)	Poor maintenance
Hull-form	insufficient stability (42)	over manoeuvring
		door failure (closing)
	loss of buoyancy (41)	closing device failure inadequate reserve of buoyancy
machinery		
operation		
Safety systems	Failure to deploy from liferaft (133)	Mechanical
		Poor maintenance(Also PFD)
		Human error
		Improper design/installation
		Improper installation(ALSO PFD)
		MOB Can't be deployed
		Training(Also PFD)
	MOB vessel can't be recovered	
structural failure for subdivision (38)	Bad Maint. Unintentional openings	
Failure of VTS (5)	Electronic fault	
structure	local failure of shell structure (64)	Grounding
		Fire
		Poor construction
		Vibration
		Lack of maintenance
	local failure of decks (31)	Collision
		Overloading with cargo
		Fire
		Poor construction
		Lack of maintenance
	local failure of bow (30)	Cargo shift
		Poor construction
		Failure to secure
		Mechanical failure of closing devices
	failure of openings (30)	Lack of maintenance
		Failure to secure
Mechanical failure		
		Fire

	local failure of bulkheads (29)	Inappropriate design
		Collision
		Grounding
		Fire
		Poor construction
		Lack of maintenance
		Cargo shift

Note: WP1 has been allocated all human errors mentioned as failure causes of the failure modes it is responsible for. No distinction has been made here. (WP2, 3 and 4 may be more explicit about the human factors they will study and give WP5 some feedback in order to relieve WP1 from the work they give to it)

- In the following table are indicated the **failure consequences** that may be left unassigned though the relevant failure is studied, as they are not explicitly included in the work package in charge of the failure mode.

RELATED 'SYSTEM'	FAILURE MODE (RANK)	FAILURE CONSEQUENCE
Crew	environmental degradation of crew (450)	Damage to systems
	improper use of equipment	Damage to other systems
	failure to follow procedures	Damage to systems
	communication failure (40)	Damage to systems
General Arrangement	damage or failure to closure at sea	Down-flooding
		Fire
	excessive vibration	Human fatigue Equipment failure
Hull-form	insufficient stability	cargo shift
		capsize
		flooding
	excessive motions/accelerations	cargo shift
machinery	auxiliaries failure	Loss of domestic services
		Fire
		Flooding (sea water inlet valve/bilge system failure)
	electrical generation failure	Fire
		Flooding
operation	navigational error in open and congested water	Discomfort of passengers
		Delays
		Penalty
		Structural damage
	navigational error in harbour	Discomfort of passengers
		Delays
		Penalty
		Structural damage
		Damage to other vessels

	navigational error in traffic	Discomfort of passengers
		Delays
		Penalty
		Damage to other vessels
	navigational equipment failure	Discomfort of passengers
		Delays
		Penalty
		Structural damage
	manoeuvring equipment failure	Discomfort of passengers
		Delays
		Penalty
		Damage to other vessels
communication equipment failure	Poor co-ordination between crew/passengers	
	Confusion of passengers	
	Delays	
	Penalty	
Payload	movement of cargo including people	Large-scale cargo shift
		Localised cargo shift
		Fire
Safety systems	structural failure for subdivision	Progressive flooding
		Reduction in stability
		Increased heeling/trim
		Accelerate path to end event
	failure to deploy from liferaft. Epirb, other Isa	Can't evacuate
		Delayed rescue(EPIRB)
		People in water without rafts
		Inadequate personnel buoyancy
		Unrecovered person in the water
Structure	local failure of bulkheads	Loss of transverse/longitudinal strength
	local failure of decks	Flooding
		Damage of cargo
		Minor physical injury
	local failure of bow	Flooding
		Global failure

## 5.2 Interpretation

- Some of the discarded failure modes rank high on the scale developed in the FMECA session. However, the description of work of the project does not mention them, the focus of the project is on some other points which are just as critical or even more than these ones. As a consequence, no work-package cover them, but it will be mentioned in

the conclusion of the project that some work is needed in the domain of safety systems (as shown in the table above), payload and general arrangements of high speed crafts. *(Who agrees ? please give us feedback )*

During the meeting, the question of cargo shift was raised, WP2 notes in its deliverable “ The occurrence of cargo shift has been identified as a risk for minor and major damage to ship and for minor to hazardous damage to cargo. The cause of cargo shift is a combination of large ship motions/accelerations/ list/trim with lashing equipment failure (defect, lack of maintenance, inappropriate design) and possibly with human error (failure to close lashing equipment). The prediction of large ship motions/accelerations/ list/trim can be performed within WP2. However, the modelling of other causes cannot be considered in WP2”. Therefore, we may have some elements to tackle this problem, but if we were to solve it, the lashing equipment would have to be studied in more details. This point needs to be further examined.

- Some failure modes include failure causes that are out of the domain of competence of the work package in charge of it. In several cases, as a first approximation, the result of another work-package result could fill that gap, and therefore help in the construction of the model. As an example, WP2 will give WP3 results about ship motions, but WP1 could help both of them if some of its results could be extrapolated to human errors WP2 and WP3 have to deal with.

A very strong collaboration is needed here between all work-packages.

This is illustrated by WP2 “ Structural failure is dealt with in WP3 [and] will not be considered in WP2. However, the prediction of environmental loading, which can lead to structural failure, will be performed in WP2, and will be transferred to WP3 as input parameter for structural analysis.”

This is shown in Appendix 4 by the stripped events.

- Though WP4 is not particularly interested in hazards themselves, in cases where a failure cause is a fire or a flood, it may have an interest in it and study how fire and flood containment means might impede the failure mode. This has been indicated in the ‘trees’ by an orange striped background in the cell.

## 6. CONCLUSION

Work done by the different work-packages showed that the FMECA results confirmed what they had already found important by other means. We may therefore assume that the work-packages have well identified the important parameters to build the tools upon.

However, not all failure modes identified at the FMECA were allocated to a work-package. Some of them are rather hazardous.

We believe that:

- the failure mode ‘insufficient/ poor area access’, ‘escape routes not efficient’, ‘escape routes unusable’ could be included in work-package 4.

- the others should be left apart: they concern the payload, or safety fixtures, for which the project does not have the necessary expertise. We nevertheless will recommend to the EU that further actions be taken in that direction.

## 7. REFERENCES

1. IMO MSC 74 FSA Guidelines
2. IMO HSC code (Annexes 3 and 4)
3. S@S deliverable 1.1.0
4. S@S deliverable 2.1.0
5. S@S deliverable 3.1.0
6. S@S deliverable 4.1.0
7. MCA research project P404 FSA trial application to HSC
8. European funded project FSA for HSC
9. European funded project FASS (Fast Ship Safety)
10. European funded project NEREUS
11. European funded project SAFETY FIRST

## 1. APPENDIX 1 - FMECA TABLES OF WORKSHOP

cf. summarytable.xls [SummaryTable.xls](#)

The ship under scope was divided into 8 systems:

1. Hull-form
2. Machinery
3. Structures
4. General arrangement
5. Payload
6. Safety systems
7. Crew
8. Operations

During the FMECA session, 50 failure modes were identified.

A scale has been set up in order to assess the frequency of an event (table 1). Then, for each level of consequence shown in table 1, the frequency of one End Event occurring due to the failure mode under study has been assessed.

Using the basic formula  $risk = frequency \bullet consequence$ , a risk matrix has been built and therefore, for each end event, a risk figure has been obtained. The risk scale has been chosen as follow: negligible, ALARP 2, ALARP 1 and unacceptable (table 3).

Then in turn, the risk scale was quantified:

- negligible        0
- ALARP 2         1
- ALARP 1         12
- unacceptable    133

An overall risk figure for each failure mode has been obtained by summing up the number of occurrences of one risk level by the corresponding figure.

CODE	PROBABILITY	DEFINITION
Fr	Frequent	Likely to occur often during the operational life of a vessel
Rp	Reasonable probable	Unlikely to occur but may occur several times during the operational life of a vessel
Re	Remote	Unlikely to occur to every vessel of a type but may occur to a few crafts of a type over their operational life
Er	Extremely remote	Unlikely to occur when considering the life of a number of vessels of the type but nevertheless should be considered as being possible
Ei	Extremely improbable	An event that is so extremely remote that it should not be considered as possible to occur

Table 1: FMECA frequency table

FMECA CODE	END EVENT	DETAILS	CONSEQUENCE
EE1	Minor damage to ship	Delays, cancellation of one crossing e.g. minor equipment failure	Minor (MI)
EE2	Major damage to ship	Major disruption to service e.g. very limited service only, many cancellations major equipment failure	Major (MA)
EE3	Hazardous damage to ship	Service suspended, no service for a limited period of time	Hazardous (HA)
EE4	Catastrophic damage to ship	Uncontrollable fire, capsizes, sinks, abandon ship	Catastrophic (CA)
EE5	Minor damage to cargo	e.g. Dents and scratches to cars on car deck	Minor (MI)
EE6	Major damage	e.g. Loss of 2 or 3 cars	Major (MA)
EE7	Hazardous damage to cargo	e.g. Loss of more than 3 cars	Hazardous (HA)
EE8	Minor injury	Cuts and bruises minor first aid required	Minor (MI)
EE9	Major injury	Requires first aid and possibly a trip to casualty	Major (MA)
EE10	Hospitalisation	Broken limbs, major cuts or burns anything that may require a stay in hospital	Hazardous (HA)
EE11	Death or permanent disability	Death, loss of limbs, life threatening injuries to crew, passengers, public, other marine industries, shore crew and survivors	Catastrophic (CA)

Table 2: FMECA end events

		CONSEQUENCE			
		Minor	Major	Hazardous	Catastrophic
PROBABILITY	Frequent				
	Reasonable probable				
	Remote				
	Extremely remote				
	Extremely improbable				

Legend :  Negligible       ALARP1  
 ALARP2       Unacceptable

Table 3: FMECA risk matrix

The Rank value was calculated by awarding points for calculated risks, with an unacceptable risk being 133 points, ALARP1 being 12 points, and ALARP 2 1 point. It should be noted that there was a possible highest score of 1100 as there was a possibility of 8 unacceptable risks and 3 ALARP1 risks.

The highest ranking obtained here is 572, and the smallest one is 5.

The 10 most critical failure modes are presented below:

NO.	SYSTEM	FAILURE MODE	RANK
8,5	Operations	Manoeuvring equipment failure	572
7,1	Crew	Environmental degradation of Crew	450
7,3	Crew	Failure to follow procedures	450
5,2	Payload	Movement of cargo-including people	374
4,2	General Arrangements	Forgetting to Close a W/T Fitting or closing improperly, Improper Opening	328
4,3	General Arrangements	Damage or Failure of Closure at Sea	328
5,1	Payload	Carrying Unsuitable Cargo	317
4,1	General Arrangements	Insufficient/ Poor Crew Area Access	295
1,1	Hull form	Unexpected loads	196
6,8	Safety Systems	Failure of the Fire Subdivision and Resistance(SFP, Smoke)	173

## 2. APPENDIX 2 – BRIEF PRESENTATION OF FSA

### 2.1 Introduction

Formal Safety Assessment (FSA) is a structured and systematic methodology, aimed at enhancing maritime safety, including protection of life, health, the marine environment and property, by using risk and cost/benefit assessments.

FSA contains the following steps:

1. Identification of hazards
2. Assessment of the risks arising from the hazards identified
3. Identification of options to control the risks
4. Cost/benefit assessment of the risk control options
5. Recommendations for decision making, based upon the information derived in the previous steps.

The safety of an aspect under consideration is assessed by evaluating the risk accompanied with this aspect, e.g. a specific operation. The decision upon the acceptability of that risk is done by employing risk acceptance criteria.

The main advantages of FSA, compared to the current approach are:

- FSA is pro-active rather than reactive.
- The risk is explicitly evaluated.
- The pro-active approach ensures that no action should be taken on an ad-hoc basis or due to the influence of public pressure, but rather based on a thorough and systematic analysis of the problem at stake.
- FSA aims at developing a “performance based regulation”, where requirements specify explicitly the safety goals and functional requirements to achieve.

### 2.2 FSA – Problem Definition

In order to perform an FSA efficiently some preparatory tasks are required. The purpose and the objectives of the FSA study have to be clarified, and the safety matter under consideration needs to be clearly defined in order to limit the scope of the study. The scope could be limited to a certain ship type, or size, specific accident scenarios, specific operational conditions, typical design and operation concepts, etc. The scope could be also limited to a specific type of risk to be considered, e.g.: risk to human beings, risk to property (e.g. ship. cargo), or risk to the environment. In order to include the experience from the past into the considerations within the FSA study, relevant accident, incident and reliability data needs to be collected.

As the risks to be identified in the FSA will have to be assessed regarding their acceptability, risk acceptance criteria need to be specified. It should be noted that currently no

international risk acceptance criteria are available. However, as long as acceptance criteria have been defined and documented for the FSA study, decisions made on the basis of these criteria can be traced at a later stage.

## **2.3 FSA - Step 1: Hazard Identification**

### Purpose

Identify all relevant hazards of the safety matter under consideration. Not only already experienced hazards are to be identified, but also those possible failures, which are hidden in the system or operation which have not yet been experienced, but nevertheless represent a hazard.

### Method

- It should be performed by a group of typically six to ten selected experts from different fields, in order to provide all the necessary expertise for the topic of the analysis. The team composition is depending on the analysis topic, e.g.: a naval architect, a structural engineer, a machinery engineer, a surveyor, a marine officer, a human element expert, the team facilitator and the person recording.
- The HAZID is a brainstorming type of exercise. It consists of a combination of both creative and analytical techniques so as to identify as many hazards as possible. It makes use of the experience of the experts employed as well as of the accident, incident and reliability data collected prior to the study. Several structured analysis methods are available for the HAZID process, e.g.: FMEA (Failure Mode and Effects Analysis), HAZOP (Hazard and Operability Study), SWIFT (Structured What-If Technique). Figure 1 presents a typical HAZID worksheet, which is used to document the analysis process in a HAZID meeting. This worksheet is based on the FMEA method.
- Each hazard identified is coarsely analysed in terms of possible causes for its occurrence, its possible effects (it is possible that several scenarios can develop from the hazard), and foreseen safeguards to prevent the hazard and/or possible scenarios developing from it, or mitigate the effects/consequences. Each scenario is also assessed regarding the likelihood or frequency of its occurrence and regarding the severity of its possible effects/consequences.



**FMECA Worksheet**

**Ship:** *High Speed Craft*

**Date:** *04/03/1996*

**System:** *Propulsion System*

**Sheet :** *1 of 1*

**Reference Drawing:** *Dwg. 15*

**Analyst:** *Mr. Safety*

Item n°	Item Id.	Item Function	Failure modes and causes	Failure effects	Failure detection	Safeguards	Severity Category	Probability of Occurrence	Criticality Level	Actions/ Remark
1	Main Diesel Engine MDE	Propulsion power generation	Fails while running due to mechanical failure	Total loss of relevant propulsion line. Loss of craft's speed	Engine failure alarm	Use of other propulsion lines	Minor	Frequent	Low	
2	Local Control Unit LCU	Main diesel engine local control	Command failure due to false signal	Loss of control of relevant propulsion line. Loss of craft's control	Control failure alarm	Engine shutdown Declutching of the line and use of other propulsion lines	Major	Remote	Medium	

Qualitative terms are normally used for the assessment at this stage of the analysis, specifying the frequency and severity. Certain combinations of frequency and severity present intolerable, acceptable or tolerable risk levels. (These levels have to be defined under the task of specifying risk acceptance criteria.) Figure 2 presents a typical risk matrix used for evaluating the risk a hazard could potentially represent.

		CONSEQUENCE			
		Minor	Major	Hazardous	Catastrophic
FREQUENCY	Frequent			Intolerable	Risk
	Reasonable				
	Remote				
	Extremely remote	Negligible	Risk		

Figure 2: Risk matrix

The scenarios identified are sometimes ranked regarding their risk level in order to prioritise scenarios for further detailed analysis in subsequent FSA steps. Thus, the subsequent analysis may exclude some hazards and scenarios from further analysis, and will focus on the issues with highest risk contribution.

Results

Document describing the analysis performed, including the basic assumptions, any relevant limitations, and the results of the analysis, providing a list of hazards and prioritised scenarios, agreed upon by the experts involved.

**2.4 FSA – Step 2: Risk Assessment**

Purpose

Extend the coarse analysis in the HAZID exercise of those scenarios, which have been prioritised in Step 1. In order to get a better picture of the risk accompanied with each scenario a more detailed analysis is performed. It consists of two parts: the cause and frequency analysis and the consequence analysis for each scenario. From this analysis a risk figure can be calculated, and the risk is assessed regarding its acceptance against risk acceptance criteria.

Cause and frequency analysis:

The purpose of this analysis is twofold.

1. The scenario is analysed in detail with the aim of breaking it's occurrence down into all the initiating events (causes) and their interactions. This will provide a detailed understanding of the causes of the scenario.
2. To be able to estimate the frequency or occurrence probability of the scenario more accurately than performed in the coarse analysis in the HAZID exercise.

A frequently used method for this analysis is the Fault Tree Analysis. Figure 3 presents a fault tree.

#### Consequence analysis:

The purpose of this analysis is to provide a detailed understanding of the possible outcomes and their magnitudes of the scenario under consideration. A coarse analysis of possible effects of the identified hazard has been performed in the HAZID exercise of Step 1. For the scenarios prioritised in Step 1 this analysis is now extended.

Analysing each scenario possible further sequences of events, leading to different types and magnitudes of consequences/loss may be identified, e.g. fatalities, damage costs, production loss, pollution are analysed. Consequence assessment models may be applied in order to calculate the magnitude of consequences/loss, e.g. models to calculate the oil spill size, the release rate from a leak, or CFD calculations of a fire scenario.

A frequently applied tool for consequence analysis is the Event Tree Analysis. Figure 4 presents an Event Tree.

#### Risk summation:

From the results of the frequency/probability analysis, and the consequence analysis the risk for a scenario analysed can be calculated. The procedure of how to calculate the risk has to be defined and specified at the beginning of the study in combination with the definition and specification of risk acceptance criteria.

In the case that frequency/probability and consequences were assessed using qualitative terms such as shown in figure 2, often a risk figure is established by allocating indices on a defined scale to each qualitative term. The risk is then presented by a risk index, which is the combination of the index for frequency/probability and for the index for consequences of a scenario.

If both frequency/probability and consequence are assigned a strictly logarithmic scale the two indices may be added to a risk index since in the case that frequency/probability and consequences were quantified, the risk is the product of both frequency/probability and consequence.

#### Risk assessment:

The risk is assessed in terms of acceptability or intolerability. Risk acceptance criteria that define acceptable and intolerable risk levels are used for this purpose.

For a qualitative analysis a risk matrix may be used to present the risk evaluated in the analysis, (figure 5), as well as the combinations of frequency/probability and consequence, that are acceptable or intolerable.

For a quantitative analysis, the risk can also be presented in a risk matrix and compared to acceptable risk values. Often, when the risk for a group or a society of people has to be assessed, so-called FN-diagrams (figure 6) are used presenting the frequency of N or more fatalities versus the number of fatalities. The principle of ALARP is employed for the

assessment procedure, meaning that risk is acceptable if it is As Low As Reasonably Practicable.

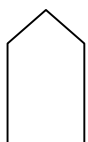
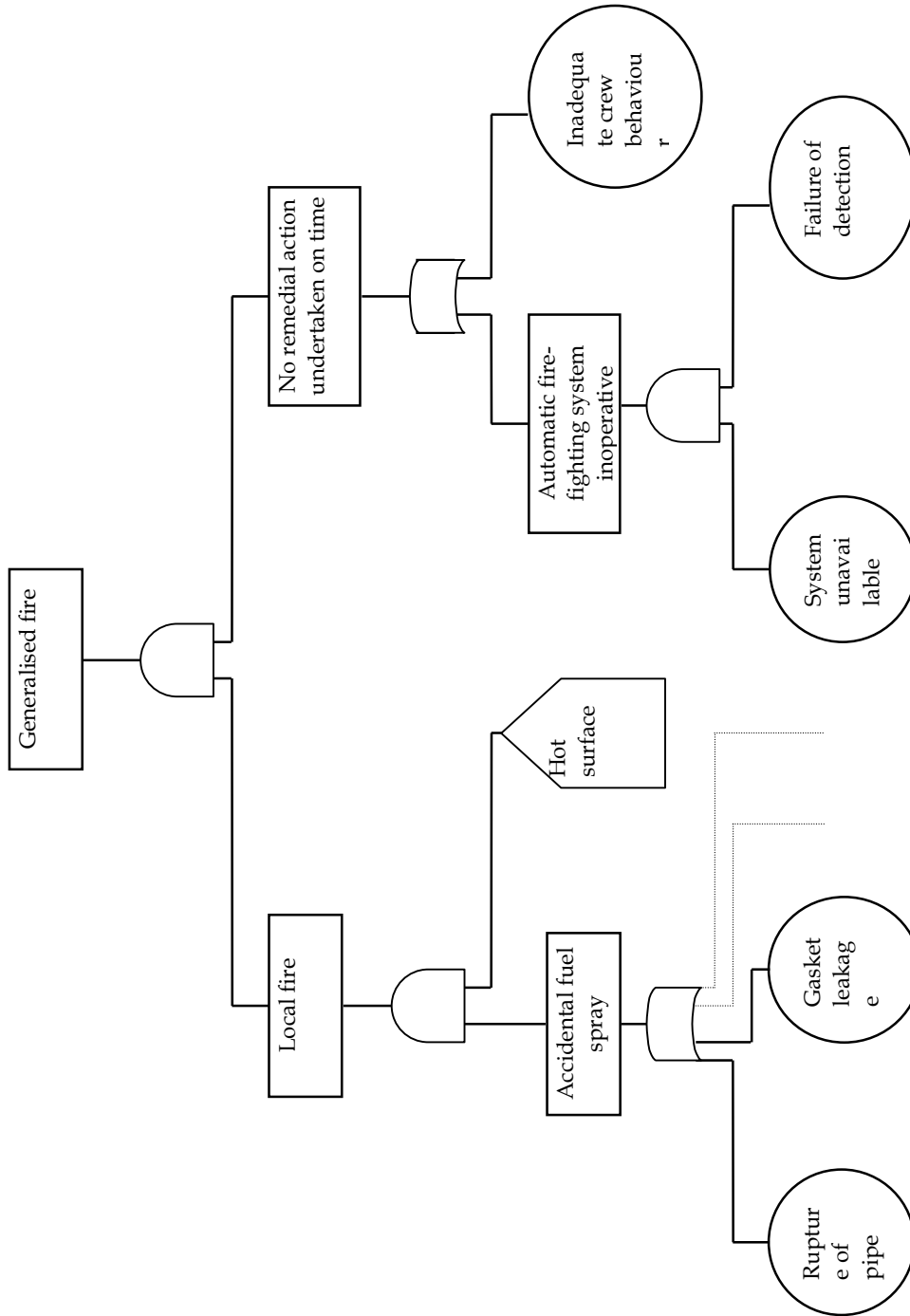
#### Risk contribution tree:

The risk model established throughout the Step 2 analysis is constituted by event trees and fault trees. In the current IMO's FSA Interim Guidelines the combination of these trees is referred to as the Risk Contribution Tree, as shown in Figure 7. The goal of creating a Risk Contribution Tree is to provide an overview of where the main risk contributors are located in the risk model. Main risk contributors may exist as primary events in the fault trees of the risk model. They may also exist in the event trees of the risk model, as insufficient or missing escalation barriers.

#### Result

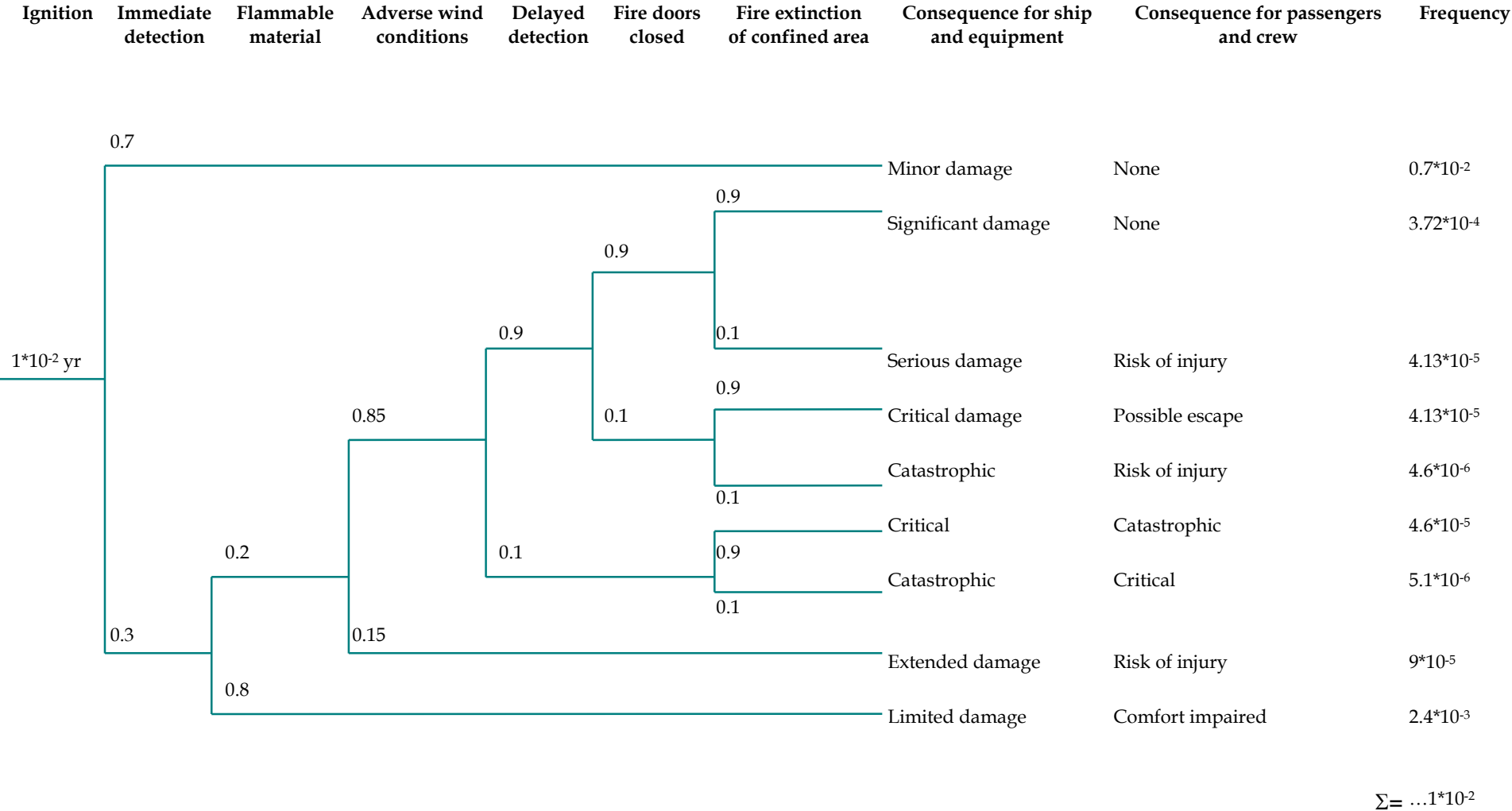
Documented analysis identifying the areas of high risks, the main contributors to the risk and the sum total of the risk.

Figure 3: Fault Tree



: corresponds to a boundary condition

Figure 4: Event Tree



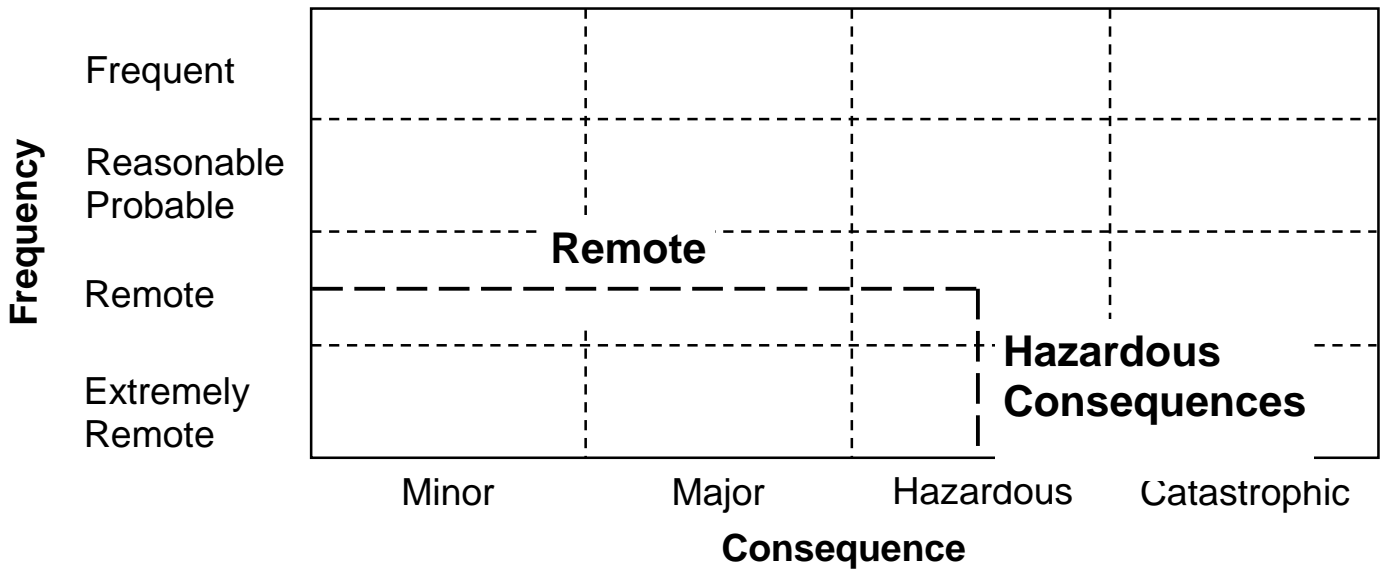


Figure 5: Qualitative risk matrix

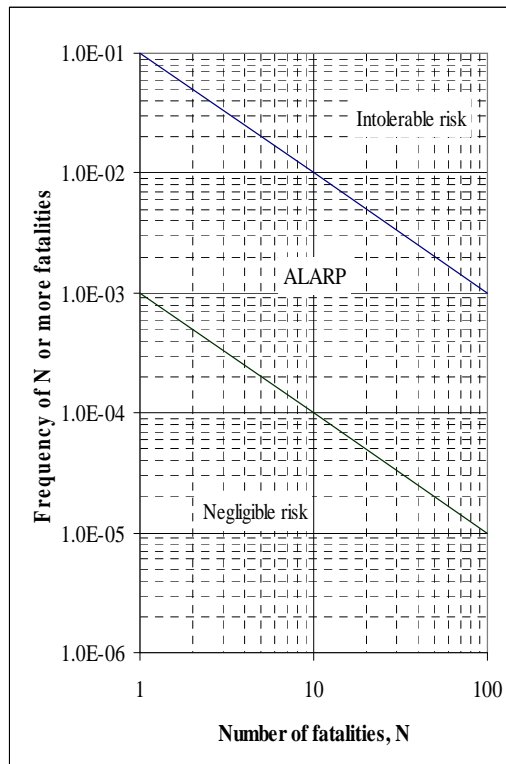


Figure 6: F-N Diagram

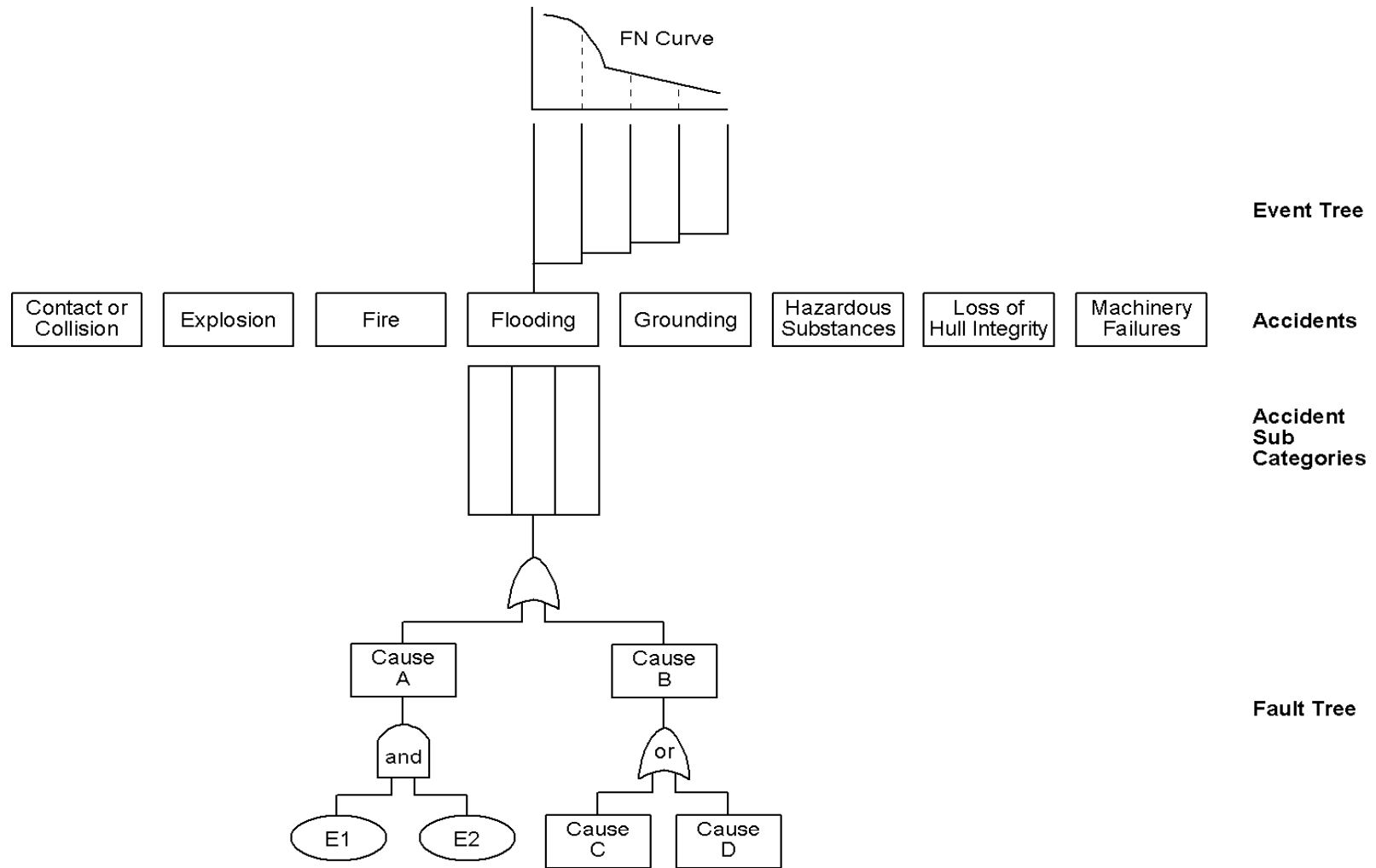


Figure 7: Risk Contribution Tree for accident category "flooding"

## 2.5 FSA – Step 3: Risk Control Options

### Purpose

To focus on the areas of high risk contribution in the risk model, and on the main risk contributors as identified in Step 2, and to propose a comprehensive range of potential measures for reducing the risk. These measures can either be preventive, i.e. reducing the probability of an event, or mitigating, i.e. reducing the severity of the outcome.

### Method

The identification of risk control options (RCO) should be done by a team of selected experts. They should be able to competently address all relevant aspects regarding controlling the risk of the area under consideration. These aspects are technical, Operational, human and organisational.

The identification of risk control options should aim at areas, where:

- the risk analysis in Step 2 showed a high level of risk
- the risk level is acceptable, however, the severity of the consequences is very high
- the risk level is acceptable, however, the probability is very high
- there are large uncertainties in probability and/or severity estimation .

The team identifies and decides on a number of suitable and practical risk control options for the areas mentioned above. A risk control option may be a single risk control measure, e.g. a safety feature built in or added to a system, or the implementation of a specific operational procedure. It could also be a group of individual risk control measures, which in isolation would possibly not work.

Having identified the risk control options, the risk of the relevant areas is re-evaluated by "implementing" the risk control options into the risk model used in Step 2. It is evaluated, if and how much each of the risk control options would reduce the risk.

### Result

Documented investigation into possible practical and suitable risk control options and their risk reduction ability.

## 2.6 FSA – Step 4: Cost Benefit Assessment

### Purpose

To identify benefits and costs associated with the implementation of each risk control option identified and defined in Step 3.

### Method

Risks should be As Low As Reasonably Practicable (ALARP-principle). Reasonable may be decided on the cost effectiveness of the risk control option. Two ways of cost effectiveness assessment of RCO's are currently discussed and in use. One way is the

application of ICAF (Implied Costs of Averting a statistical Fatality) or GCAF (Gross Cost of Averting a Fatality), the other the application of CURR (Costs per Unit Risk Reduction) or NCAF (Net Cost of Averting a Fatality):

$$\text{GCAF} = \frac{\text{Cost Increase}^*}{\text{Risk Reduction}} \quad \text{NCAF} = \frac{\text{Cost Increase}^* - \text{Benefits}}{\text{Risk Reduction}} \quad \begin{array}{l} * \text{ Cost Increase} \\ \text{due to} \\ \text{implementation} \\ \text{of RCO} \end{array}$$

For NCAF the benefits are transformed to monetary units, i.e. damage costs avoided.

Costs could be related to e.g.: Compliance with new regulations (requiring the RCO), operating the RCO, training of personnel to operate the RCO, inspection and certification of the RCO.

Benefits could be expressed in terms of damage costs avoided, e.g. by: reduced fatality frequency, reduced injury frequency, reduced casualty frequency, increased vessel life, reduced environmental damage, reduced clean up costs.

The cost increase can be measured by establishing the so-called base case, which is the existing situation before implementation of the risk control option. Existing costs, e.g. losses frequently experienced are evaluated. Then the situation after implementing the risk control option is evaluated. Costs for implementation, maintenance, etc. of the risk control option are evaluated and then compared with the base case.

The IMO's FSA Guidelines suggest to evaluate the costs and benefits for all those interested entities (stakeholders), which are most affected by the problem under consideration. The aim should be to balance costs and benefits to the best ability between those entities. Interested entities in this instance would be ship owner, charterer, flag state, port state, crew, classification society, designer, etc.

### Result

Documented investigation into the costs and benefits of risk control options and their cost effectiveness.

## **2.7 FSA - Step 5: Recommendations for Decision Making**

### Purpose

To specify the recommendations for risk control options to the decision-makers for further consideration.

### Method

The recommendations are based upon the results achieved in the previous Steps 1 to 4, i.e. comparison and ranking of hazards and their underlying causes; the comparison and ranking of risk control options as a function of associated costs and benefits; and the identification of the RCOs which keep risks as low as reasonably practicable.

### Results

Objective comparison of alternative options, based on their potential in reducing risks and cost effectiveness, in areas where regulations should be reviewed or developed.

The final report should present the scope of the analysis, any limitations and assumptions made, and the results achieved, providing a clear explanation of the reasoning behind the conclusions made.

## **2.8 References**

1. IACS, FSA training
2. IMO, FSA guidelines MSC
3. RTD funded project FSA for HSC, 1996, methodological guidelines TEC-00-02 WP0, Remy Giribone

### 3. APPENDIX 3 – RISK ANALYSIS TOOLS

reproduire ici la description des methodes AR (FMECA, FTA, etc.) qu'on trouve dans le rapport RG methodological guidelines TEC-00-02 WP0 de FSA HSC ATA414A en les adaptant si nécessaire au projet.

The following is a list of the most common techniques that can be used in the maritime industry:

- *What-If Analysis*
- *What-If/Checklist Analysis*
- *Hazard and Operability Analysis*
- *Failure Modes and Effects Analysis*
- *Fault Tree Analysis*
- *Event Tree Analysis*
- *HRA High Level Task Analysis*

The following sections contain brief overviews of each of the techniques.

#### 3.1 What-If Analysis

##### *Description*

The What-If Analysis method is a brainstorming technique in which the collation of information (identification of hazards) is performed by asking a series of questions that begin with 'What If?' For example:

- What if the crew leaves the door open?
- What if the operator opens valve B instead of valve A?
- What if a given mistake is made?
- What if a piece of equipment fails?

The questions are formulated based on experience. Any safety concern can be voiced, even if it is not phrased as a "What If" question.

The questions asked are divided into specific areas of investigation and a team of one or more knowledgeable people subsequently addresses each area.

##### *Characteristics*

The What-If Analysis method is a flexible technique, not as structured as other techniques (i.e. FMEA, HAZOP), which allows easy adaptations to specific

applications. It is useful to give a first assessment of hazards. It is heavily reliant on the experience of the team members carrying out the review and therefore the results are prone to be incomplete depending on the experience of the team members. Also, there is no assurance that the questions asked are sufficient in either breadth (coverage) or depth (detail) to identify all the hazards.

#### *Types of Results*

The What-if Analysis technique generates a list of questions and answers about the problem. It may also produce a tabular listing of hazardous situations, their consequences, safeguards, and possible recommendations for risk reduction. Table 1 shows the typical format for a What-If Analysis Worksheet.

Table 1: Typical Format for What-If Table

What-If	Consequence / Hazard	Safeguard	Recommendation

### **3.2 What-If/Checklist Analysis**

#### *Description*

A What-If /Checklist Analysis is a hybrid technique that is based on the brainstorming features of the What-If method, and adds a more systematic nature by introducing the use of a pre-generated experienced-based checklist. This checklist is a written list of items that help to identify known types of hazards, design efficiencies, and potential accident situations associated with the system, equipment or operation. They can be used to look at specific items of a system, or at procedures. Traditional checklists vary widely in level of detail and are frequently used to indicate compliance with standards and practice. The checklists are limited by their authors' experiences; therefore, they should be developed by authors with varied backgrounds who have extensive experience with the systems under analysis. Checklists should be audited and updated regularly to assure up to date applicability. If the checklist is not complete, then the items not on the list can be overlooked easily and the HAZID may not effectively address all hazardous situations. The checklist can be of various degrees of detail, depending on the scope, existing data, personal preferences, etc.

In summary, in the What-If/Checklist Analysis method, the team uses the What-If Analysis method to brainstorm the various types of accidents that can occur within the process, guided by the use of a checklist.

#### *Characteristics*

The What-If/Checklist technique uses the creative, brainstorming features of the What-If method, plus an experience-based checklist to make it more systematic. However, items not listed in the checklist run the risk of being overlooked.

It should be stressed that there is no single standard approach to construct the checklists, making this a flexible technique which may be modified for each

application. The What-If/Checklist technique is less labour-intensive than more structured techniques such as HAZOP or FMEA.

The analysis procedure is the following:

A What-If/Checklist Analysis consists of the following steps:

- 1) Preparing for the review
- 2) Developing a list of What-If questions and issues
- 3) Using a checklist to cover any gaps
- 4) Evaluating each of the questions and issues
- 5) Documenting the results.

The order of steps 2 and 3 may be reversed, or performed in a merged fashion, depending on the preference of the HAZID team.

#### *Types of Results*

The team usually generates a table containing the following:

- potential accident situations.
- effects.
- safeguards to suggest ways for reducing the risk

### **3.3 Hazard and Operability (HAZOP) Analysis**

#### *Description*

The Hazard and Operability (HAZOP) Analysis is a formal, systematic method of identifying hazards by postulating 'deviations' from normal operation, and assessing the consequences of those deviations. The deviations are generated by using a set of predefined guide-words, which help structure and stimulate the creative process of exploring potential deviations. Those deviations that are identified as being capable of producing significant consequences are further analysed by identifying the possible causes of such deviations.

The HAZOP technique is perhaps the most widely used technique for the identification and analysis of hazards in the process industry. Developed in the chemical industry, for some time it has been a key tool in carrying out safety analysis in the process (and other) industries. HAZOP deals mainly with operability concerns.

The central activity or the key feature of HAZOP is structured investigation (brainstorming), by a multidisciplinary team, of a description of the system under consideration. HAZOP is usually carried out not on the physical system itself, but on a representation of a system called the '*design representation.*' In principle, there is no restriction on the form of it as long as it is clearly documented and understood by all the team members. Examples of the design representation are:

- Piping and instrumentation diagram (P&IDs)
- Block diagram of the system
- Detailed drawings
- Operating instructions
- Procedures
- Circuit diagram for an electrical system

*Types of Results*

The results are the team's findings, which include a list of identified hazards and operating problems and recommendation's for further analysis. The results of team discussions concerning the causes, effects, and safeguards for deviations for each node or section of the process are recorded in a column-format table. Table 2 shows the format of a typical HAZOP Worksheet.

Table 2: Typical Format for a HAZOP Analysis Worksheet

Team :		Drawing Number :			
Date :		Revision Number :			
Item	Deviation	Causes	Consequences	Safeguards	Actions

The HAZOP final report normally contains the following:

- executive summary
- introduction and organisation of report
- objectives and scope
- study approach
- process description
- HAZOP results. including:
  - hazards (meaningful deviations) identified
  - causes, consequences and safeguards, etc
  - questions raised during the meeting
- Conclusions and recommendations

*Guide-words and Parameters*

A guide-word is a word or phrase that expresses and defines a specific type of deviation from design intent. The basic guide-words used are:

- No. Not. None
- Less
- More
- Also
- Other
- Early
- Late
- Reverse

A parameter or attribute is defined as 'features' or properties of the design such as temperature, pressure, flow, pitch, roll, etc.

The structure of the HAZOP consists of combining the parameters with each guide-word, and considering the consequences of such combination. When the guide words

chosen have all been applied to the parameter, the other parameters of the entity under consideration are applied and examined in turn. This process is repeated for each entity on the study node, and then on the design representation.

The use of the guide-words helps structure and simulates the creative process of exploring potential deviations. The following is an example of creating deviations using guide-words and parameters:

Table 3: Example of combining guide-words and parameters

<u>Guide Words</u>		<u>Parameter</u>		<u>Deviation</u>
No	+	Flow	=	No Flow
More	+	Pitch	=	High Pitch
Other Than	+	Operation	=	Maintenance

Some combinations of guide words and parameters will make no sense (e.g. "reverse + temperature"), or will yield no sensible deviation (e.g.. "as well as + pressure"), and therefore they can be discarded. Also, some specific parameters may require some modification of the guide-words to be meaningful.

### 3.4 Failure Modes and Effects Analysis (FMEA)

#### *Description*

Failure Modes and Effects Analysis (FMEA) is a systematic method in which the analyst considers the various failure modes of equipment items and evaluates the effects of these failures on the system. FMEA accounts for single equipment failures that either directly result in or contribute significantly to an accident, but not for failure combinations. Generally, hazard analysts use FMEA as a qualitative technique, although it can be extended to give a priority ranking based on failure severity and probability.

#### *Characteristics*

It requires knowledge of each failure mode of the components of product, vessel or system. In FMEA, each individual failure is considered as an independent occurrence, with no relation to other failures in the system, except for the subsequent effects that it might produce.

Human errors are usually not examined directly in an FMEA, however the effects of a wrong operation caused by human error are usually considered by an equipment failure mode

The FMEA procedure contains three steps:

1) Defining the study problem.

This step identifies the specific items to be included in the FMEA and the conditions under which they are analysed. Defining the problem involves establishing an appropriate level of resolution for the study and defining the boundary conditions for the analysis. A detailed problem definition is a necessary ingredient to perform a thorough and efficient FMEA.

2) Performing the review.

The FMEA should be performed in a deliberate, systematic manner to reduce the possibility of omissions and to enhance the completeness of the FMEA. The detailed steps in carrying out an FMEA are:

- Describe the system;
- List all system components (items);
- Select a component;
- Identify its function;
- Identify all failure modes for each component;
- Identify the local effects (the effects of the failure on the immediately affected other components of the system);
- Identify system effects (the effects on the system as a whole);
- Identify methods of protection (safeguards) from the effects of the failure;
- Make recommendations.

3) Documenting the results.

Table 4: Typical Format for an FMEA Worksheet

Date :		Page :				
Plant:		System :				
Reference:		Analyst(s) :				
Item	Identifi- cation	Description	Failure Modes	Effects	Safeguards	Actions

*Equipment identification*

A unique equipment identifier that relates the equipment to a system drawing, process, or location. This identifier distinguishes between similar pieces of equipment that perform different functions within the same system.

*Equipment description*

The equipment description should include the equipment type, operating configuration, and other service characteristics

*Failure modes*

The analyst should list all of the failure modes for each component that are consistent with the equipment description. Considering the equipment's normal operating

condition, the analyst should consider all conceivable malfunctions that alter the equipment's normal operating state.

#### *Effects*

For each identified failure mode, the analyst should describe both the immediate effects of a failure at the failure location and the anticipated effects of the failure on other equipment, as well as on the overall system or process.

#### *Safeguards*

For each identified failure mode, the analyst should describe any safety features or procedures associated with the system that can reduce the likelihood of a specific failure occurring or that can mitigate the consequences of the failure.

#### *Actions*

For each identified failure mode, the analyst should list any suggested corrective actions for reducing the likelihood of causes or effects associated with the failure mode.

#### *Type of results*

An FMEA generates tables containing qualitative, systematic reference list of equipment, with corresponding failure modes, and effects. The results of an FMEA are usually documented in tabular format, equipment item by equipment item. Recommended action/suggestions for further analysis are also included. Table 4 shows a typical FMEA worksheet.

### **3.5 Fault Tree Analysis (FTA)**

Fault tree analysis provides a disciplined, rigorous approach to the identification and quantification of system failures. An important characteristic of the fault tree technique, is that it allows the examination of multiple failures (as opposed to other common risk assessment techniques like FMEA)

The objective of a Fault Tree Analysis is to identify the potential combination of events that can make a system fail to perform its function.

Fault trees provide qualitative and quantitative information.

- **Qualitative information**

Even in case of missing data, a Fault Tree Analysis can provide significant insights regarding the causes leading to the top event. By studying the logical interactions of the individual primary events in the Fault Tree the significance/importance of each primary event regarding its contribution to the development of the top event can be estimated. This importance analysis helps identifying the primary events with high priority. A Boolean reduction of the fault tree logic will identify the minimal cutsets, which are a set of the smallest combination of failures that can cause the top event.

- Quantitative information

It can be obtained by evaluating the frequencies of the minimal cutsets, therefore obtaining the frequency of the top event (e.g. probability of system failure). Different importance measures can also be defined and computed, to estimate different types of contributions to risk. Relevant data may be extracted from accident/incident databases or, in case of machinery component failure events, from reliability databases (e.g. failure rates, availability of back-up systems). If data is not available expert judgement may be used.

Figure 1 shows part of a sample fault tree. The box at the top represents the top event, and it is a specific statement that describes the undesired state of the system, or other undesired event of interest.

At the level below the top event, the events that can cause the top event are found. In this case, there are two events, connected by an AND gate, meaning that both events have to occur simultaneously for the event above to occur. Next, each of these events is examined separately. The event on the right, has two events at the next level below, connected by an OR gate, meaning that either one of them can cause the above event. The events at this lower level are called Basic Events.

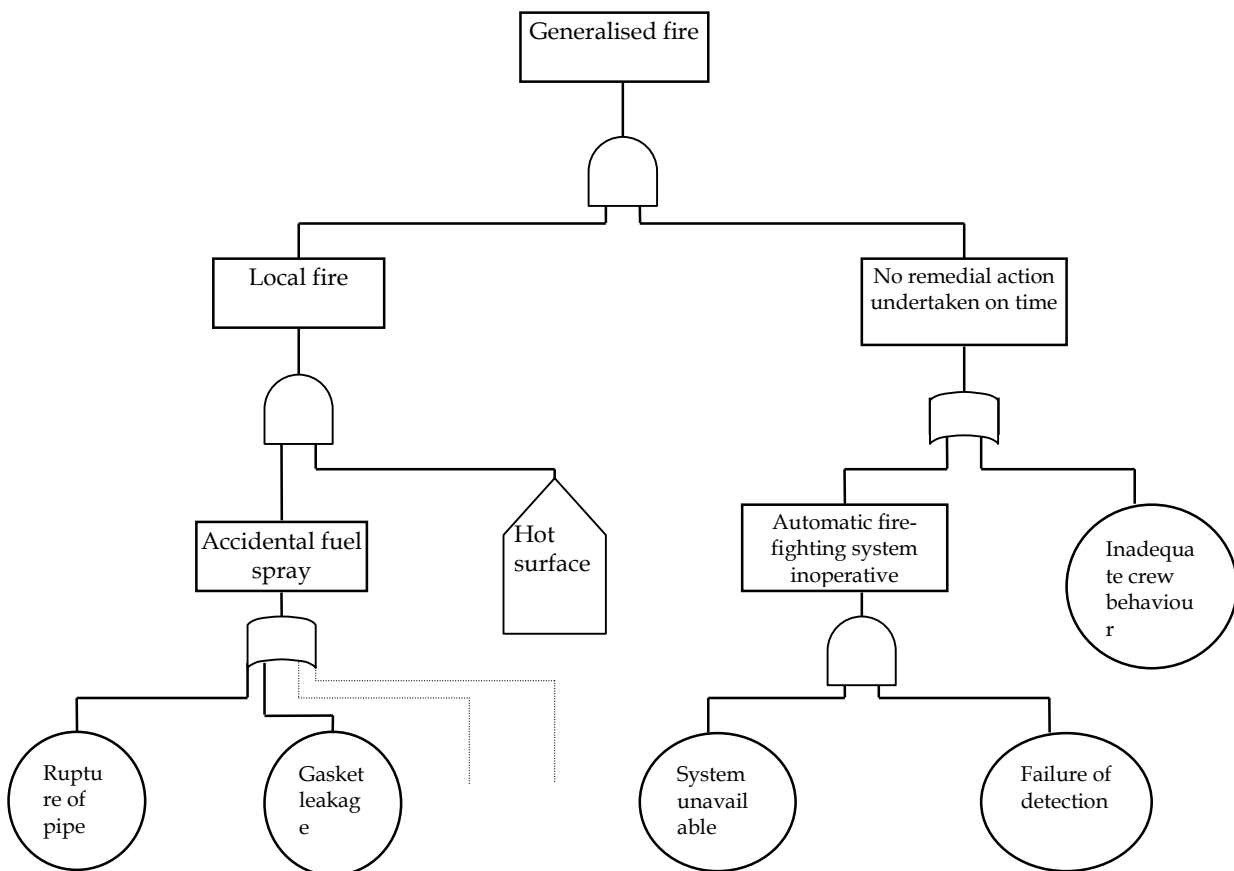


Figure 1: Sample Fault Tree

### 3.6 Event Tree Analysis (ETA)

An event tree graphically models the possible outcomes of an initiating event capable of producing an end event of interest (usually undesirable, like an accident). It provides a systematic means of delineating accident sequences in terms of the system and/or event successes and failures that make up those sequences.

Event Tree Analysis can provide:

- Qualitative descriptions of potential problems (combinations of events producing various types of problems from initiating events)
- Quantitative estimates of event frequencies or probabilities of each outcome, which assist in demonstrating the relative importance of various failure sequences

An event tree starts with one initiating event, and terminates in multiple end states, considering all possible outcomes. Therefore, one event tree is required for each group of initiating events (as identified after the grouping of initiators). End states are determined by evaluation of the expected consequence of each specific combination of events.

A sample event tree is shown in Figure 2. The top of the tree contains the headings of the tree, which represent the different events considered in that tree. The first event heading is always the initiating event for that tree. Subsequent headings model the pivotal events, that is the response from the vessel systems and/or crew in an effort to bring the vessel back to a normal state. The event tree analysis proceeds by postulating the success or failure of each system in the context of all the previous system states. It is also possible to include event tree headings that require more than two possible outcomes (e.g. a Fire event with three possible outcomes: No fire, Small Fire, Large Fire which can be modelled by three branches). The outcomes can be either no damage, loss of life, loss of property, catastrophic event... depending on the scope of the study

In order to identify which event tree headings are necessary in an event tree, it is useful to identify first which functions are needed to mitigate the initiating event being considered. Once the functions are identified, the available systems or crew actions available on the vessel to provide those functions are identified, and considered as potential event tree headings (pivotal events). It should be noted that not all the event headings in the event tree require a split in branches. If the success or failure of one event does not change the consequence of that sequence path, then such event may be skipped (cf. Event tree in Appendix 2).

The event tree represents the various possible sequences of events into which an initiating event could possibly develop, taking into consideration both the success and

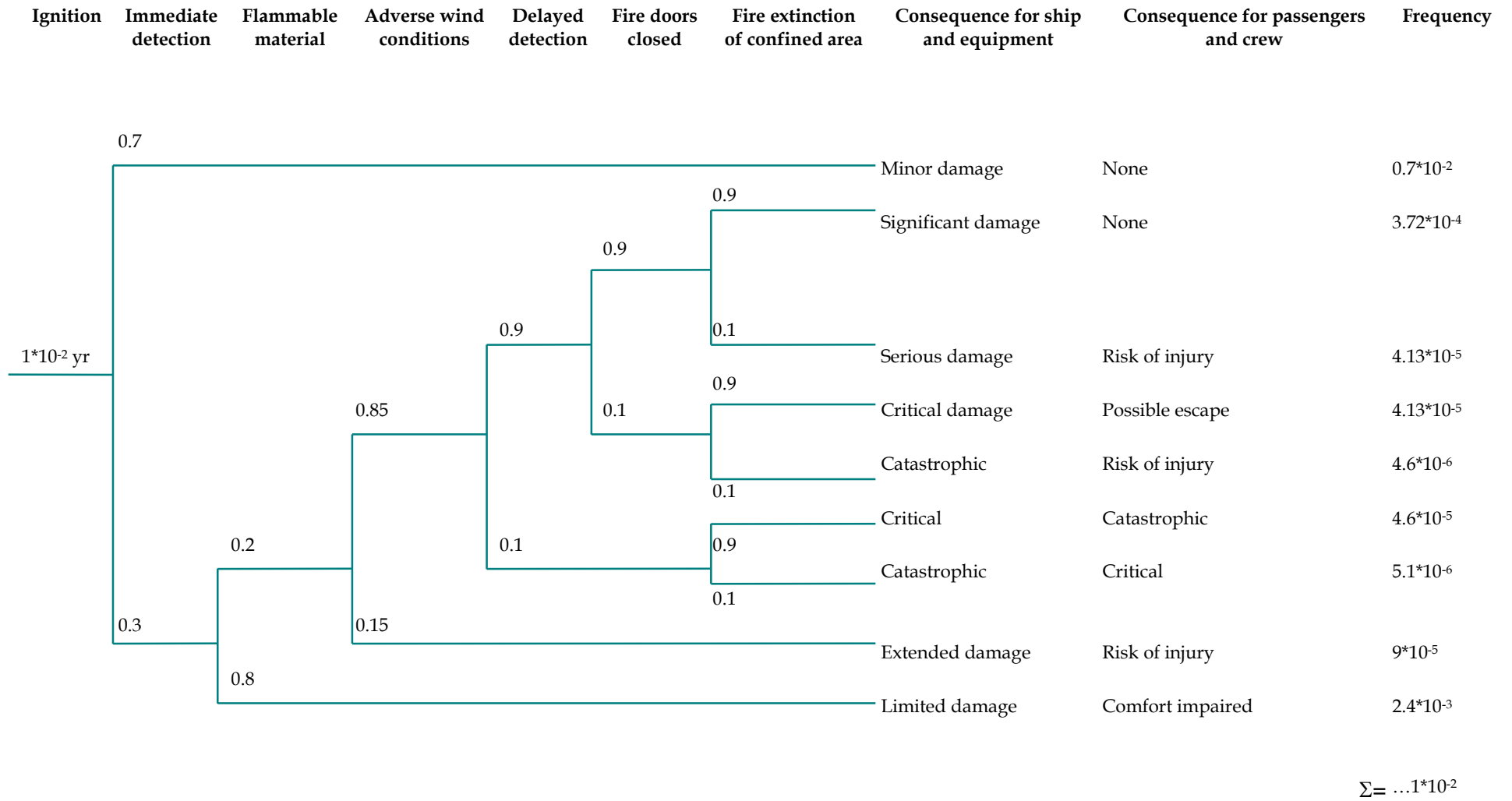
the failure of foreseen safeguards to prevent the development of subsequent events or to mitigate their magnitude.

By estimating the probability that a specific safeguard is successful or not, the probability of each of the possible outcomes from the initiating event can be calculated. However, even if not quantified, the Event Tree provides significant insights, e.g. by indicating where the provision of safeguards may prevent the escalation from becoming more critical (from fire to explosion).

### **3.7 References**

1. IACS FSA training

Figure 2: Event Tree













## 4. APPENDIX 4: FMECA RESULTS

This links lead to the representation of FMECA results as fault trees:

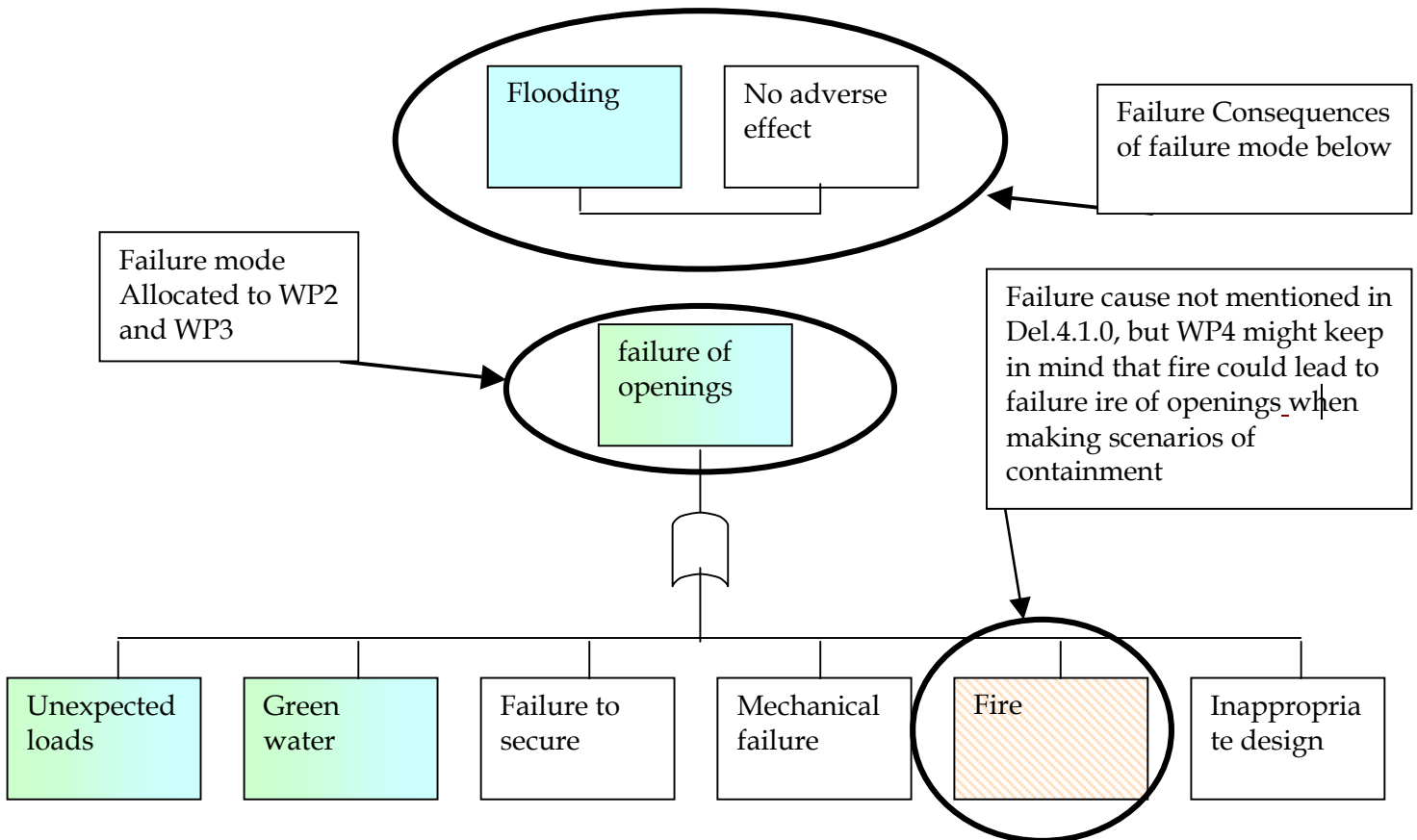
System	Link
- Crew	<a href="C:\crew.doc">C:\crew.doc</a>
- General arrangement	<a href="C:\GA.doc">C:\GA.doc</a>
- Hull-form	<a href="C:\hullform.doc">C:\hullform.doc</a>
- Machinery	<a href="C:\machinery.doc">C:\machinery.doc</a>
- Operation	<a href="C:\operation.doc">C:\operation.doc</a>
- Payload	<a href="C:\payload.doc">C:\payload.doc</a>
- Safety systems	<a href="C:\safety sys.doc">C:\safety sys.doc</a>
- structure	<a href="C:\structure.doc">C:\structure.doc</a>

Legend:

	included in WP1
	included in WP2
	included in WP3
	included in WP4
	included in WP1, 2 and 3
	included in all WP's
	Not included in WP1, but results of WP1 could be of interest here
	Not included in WP2, but results of WP2 could be of interest here
	Not included in WP3, but results of WP3 could be of interest here
	Not included in WP4, but results of WP4 could be influenced here

Shadings of colours in one cell indicate the event is studied in both the WP's the colours indicate.

Example of a tree:



Failure Causes and Consequences can be classified in several categories

For failure causes these are:

- Bad Design (Ship. Bridge. Navigation. Manoeuvring. Ergonomics)
- Collision
- Communication Failure (Equipment. Internal. External. Language)
- Electrical failure (Short Circuit. Overload. Loss of Electrical Generation)
- Environment (Internal. External. Abnormal Weather)
- Excessive Loads (Unexpected. Local. Global)
- Excessive Noise Levels
- Excessive Ship Motions and Accelerations
- Excessive Vibration
- Fire
- Grounding
- Inadequate Maintenance
- Inappropriate Actions by passengers (Unintentional. Intentional)
- Inappropriate Crew Action
- Ingress of Water (Flooding)
- Lack of Information (Missing/Not Available/Incorrect Aids to Operations)

- Lack of Knowledge (Planning. Training. Experience. Procedures. Checklist. Risk Perception. Awareness)
- Loss of Steering Control
- Mechanical/Physical Failure (to any system/equipment)
- Poor Construction/Installation
- Poor Visibility (Internal. External)
- Reduced Operational Condition (Trim. List. Stability)
- Smoke
- structural degradation
- cargo handling (inert)

For failure consequences the different categories are:

- Accelerated Path to End Event
- Broaching
- Cargo (Shift. Leak of Hazardous
- Collision (Increased Likelihood. Minor)
- Crew Performance (Delayed. Inappropriate. Behaviour. Excessive Workload)
- Crew Behaviour (Discomfort. Deafness. Fatigue)
- Damage to Ship
- Delay (Penalty
- Electrical Failure (Loss of Electrical Generation)
- Excessive Loads (Local Internal. Global)
- Excessive Motions/Accelerations
- Failure in evacuation process
- Fire (Delay Fire Suppression. Erroneous Use of System. Uncontrollable. Explosion)
- Grounding
- Human Injury (Major. Minor. Increase Potential. Catastrophic. Panic. Discomfort. Deafness. Stowaways. Sea Sickness
- Ingress of Water (Flooding)
- Loss of Domestic Services
- Loss of Propulsion
- Loss of Manoeuvrability (Steering)
- Loss of Control of Vessel
- Mechanical Failure (Machinery)
- Near Miss
- Negative Passenger Behaviour (Harassment. Unintentional. Intentional. Confusion)
- Smoke (Uncontrollable spread)
- Structural Failure (Local. Global. Permanent Damage. Loss of Global Strength/ Transverse/ Longitudinal Strength)
- Reduced Operational Condition (Trim. List. Stability
- Rescue (Delayed. Unable)
- loss of ship
- no adverse effect
- safety systems degradation
- vibrations

Type	Cause Failure	Failure Mode (Rank)
	Aids to navigation out of place or missing	8.1 (51) – 8.3 (42) – 8.2 (17)
	doors locked	4.1 (295) – 6.3 (14)
	Foreign objects	8.5 (572)
	improper use of vessel	5.1 (317)
	lack of material/ equipment	6.14 (14)
	MOB cannot be deployed	6.12 (133)
	MOB vessel cannot be recovered	6.12 (133)
	Multi ship	8.3 (42)
	object falling / mechanical damage	4.1 (295) – 6.3 (14)
<b>Bad Design (Ship. Bridge. Navigation. Manoeuvring. Ergonomics)</b>	bad arrangement/ system design	6.7 (146)
	Bad Design-increase strength	6.9 (38)
	Complexity of navigational aids	7.1 (450)
	control system inaccessible	6.6 (27)
	improper fire rating	6.8 (173)
	Equipment layout	7.4 (40)
	Inadequate equipment	7.4 (40)
	Inappropriate design	3.3 (64) – 3.1 (39) – 3.5 (31) – 3.6 (30) – 3.2 (30) – 3.4 (29)
	Inappropriate hull form	1.1 (196) – 1.5 (77)
	Inappropriate mechanical/ control law design	2.2 (29)
	insufficient capacity (fire fighting)	6.7 (146)
	poor arrangements (intake. exhaust. doors)	4.5 (37)
	Poor design	4.3 (328 ) – 4.1 (295) – 6.8 (173) – 7.2 (160) – 4.4 (65) – 6.2 (45) – 4.6 (17)
	poor design/ installation location	6.12 (133)
	Poor design of bridge equipment	8.1 (51) – 8.3 (42) – 8.2 (17)
	Poor design of communication equipment	8.6 (29)
	Poor design of external aids to navigation	8.1 (51) – 8.3 (42) – 8.2 (17)
	Poor design of manoeuvring equipment	8.5 (572)
	Poor machinery installation	4.5 (37)
	Poor design of navigational equipment	8.4 (62)
	Poor functionality of bridge equipment	8.3 (42)
	Poor layout	7.2 (160)
unapproved modification	6.8 (173)	
Underestimated design loads	1.1 (196)	
Wrong weight/cargo distribution	1.5 (77) – 1.2 (42) – 1.3 (22)	
<b>Collision</b>	Collision	3.6 (30) – 3.3 (64) – 3.5 (31) – 3.4 (29)

<b>Communication Failure (Equipment. Internal. External. Language)</b>	Language	7.4 (40)
	Local interference	8.6 (29)
	Failure of communication system	6.13 (146)
	PA system fails in physically	6.1 (14)
	Misunderstanding/Communication (Internal and external)	8.1 (51) – 8.3 (42) – 8.2 (17)
	signs confusing	6.1 (14)
	signs missing or obscured	6.1 (14)
<b>Electrical failure (Short Circuit. Overload. Loss of Electrical Generation)</b>	Electrical failure	8.5 (572) – 8.4 (62) – 8.6 (29)
	Electrical generation failure	2.1 (40) – 2.3 (40) – 2.2 (29)
	Short circuit	2.4 (40)
<b>Environment (Internal. External. Abnormal Weather)</b>	abnormal weather	1.1 (196) – 1.5 (77)
	Complexity of route	7.1 (450)
	Environment	8.6 (29)
	excessive environmental condition	1.2 (42)
	hull/environment interaction (resonance)	4.4 (65)
	Sea state	8.5 (572) – 7.1 (450) – 4.3 (328) – 8.4 (62) – 8.1 (51) – 8.3 (42)
	Temperature	8.5 (572) – 8.4 (62) – 8.6 (29)
Wind/Tide	8.2 (17)	
<b>Excessive Loads (Unexpected. Local. Global)</b>	green water	3.2 (30) – 4.6 (17)
	local loads	4.3 (328)
	slamming	4.4 (65)
	Unexpected loads	3.3 (64) – 3.1 (39) – 3.5 (31) – 3.6 (30) – 3.2 (30) – 3.4 (29) – 2.2 (29)
<b>Excessive Noise Levels</b>	Background noise	7.1 (450) – 7.4 (40)
	noise level	6.1 (14)
<b>Excessive Ship Motions and Accelerations</b>	Excessive motions	5.2 (374) – 4.3 (328) – 4.6 (17)
	Excessive ship motions	2.2 (29)
	motions	6.12 (133) – 6.1 (14)
<b>Excessive Vibration</b>	Vibration	8.5 (572) – 7.1 (450) – 4.4 (65) – 3.3 (64) – 8.4 (62) – 3.5 (31) – 3.6 (30) – 8.6 (29) – 3.4 (29)
<b>Fire</b>	Fire	5.2 (374) – 4.1 (295) – 3.3 (64) – 2.1 (40) – 2.3 (40) – 2.4 (40) – 3.5 (31) – 3.6 (30) – 3.2 (30) – 2.2 (29) – 3.4 (29) – 6.3 (14)
<b>Grounding</b>	Grounding	3.3 (64) – 3.6 (30) – 3.4 (29)

<b>Inadequate Maintenance</b>	Bad Maintenance	6.9 (38)
	Inadequate maintenance	2.1 (40)
	Lack of maintenance	3.3 (64) – 3.5 (31) – 3.6 (30) – 8.6 (29) – 3.4 (29)
	Maintenance	8.5 (572) – 8.4 (62)
	poor maintenance	4.3 (328) – 6.12 (133) – 4.4 (65) – 4.6 (17)
	Poor maintenance of equipment	7.2 (160)
<b>Inappropriate Actions by passengers (Unintentional. Intentional)</b>	alcoholism	5.3 (76)
	bad customer relation	5.3 (76)
	confusion	5.4 (99) – 5.3 (76) – 6.2 (15) – 6.14 (14)
	Disruptive passengers	7.1 (450)
	Failure of human action	6.7 (146) – 6.12 (133)
	hostility	5.3 (76)
	lack of attention	5.4 (99)
	inappropriate action	6.5 (14)
	inappropriate securing	5.2 (374)
	incorrect action	6.6 (27)
	robbery	4.6 (17)
	stowaway	5.1 (317)
	terrorism	5.3 (76)
	unawareness	5.3 (76)
	unawareness of rules	5.1 (317)
violation of rules	5.1 (317)	
<b>Inappropriate Crew Action (Time Pressure. Concentration. Attention. Mistake. Fatigue. Risk Taking Behaviour. Excessive Workload. Illness. Lack of Discipline. Lack of Motivation)</b>	bad customer relation	5.3 (76)
	delay in detection	6.7 (146)
	delay in operation	6.7 (146)
	Excessive workload	7.1 (450) – 7.2 (160) – 7.4 (40)
	Failure of human action	6.7 (146) – 6.12 (133) – 6.10 (38) – 6.11 (5)
	failure to close device	1.4 (41)
	failure to perform task	6.2 (15)
	Failure to secure	3.6 (30) – 3.2 (30)
	Fatigue	3.6 (30)
	Fatigue of crew	7.1 (450) – 7.2 (160) – 7.4 (40)
	Heavy workload	7.1 (450) – 7.3 (450) – 7.2 (160) – 7.4 (40)
	Human communication system	6.13 (146)
	Human error	1.6 (161) – 4.6 (17)
	Illness	7.1 (450) – 7.3 (450) – 7.2 (160) – 7.4 (40)
	Inappropriate speed/heading for environmental condition	1.1 (196) – 1.6 (161) – 1.5 (77)
inappropriate operation	3.1 (39)	
Inappropriate securing-crew responsibility	5.2 (374)	

	Incapacity	8.3 (42)
	incorrect action	6.6 (27)
	Lack of attention	7.3 (450) – 7.2 (160) – 5.4 (99) – 8.1 (51) – 8.3 (42) – 7.4 (40) – 8.2 (17)
	Lack of concentration	7.3 (450) – 4.2 (328) – 7.2 (160) – 8.1 (51) – 8.3 (42) – 7.4 (40) – 8.2 (17)
	Lack of discipline	8.5 (572) – 7.1 (450) – 7.3 (450) – 7.2 (160) – 8.4 (62) – 8.1 (51) – 8.3 (42) – 7.4 (40) – 8.6 (29) – 8.2 (17)
	Lack of motivation	7.3 (450) – 7.2 (160) – 7.4 (40)
	no action	4.2 (328)
	Overload	2.4 (40)
	over manoeuvring	1.2 (42)
	Poor interaction	7.4 (40)
	Risk taking behaviour	8.3 (42)
	Route recording error	8.4 (62) – 8.1 (51) – 8.3 (42)
	Time pressure	7.1 (450) – 8.1 (51) – 8.3 (42)
	Unintentional openings	6.9 (38)
	Usage of equipment	7.4 (40)
<b>Ingress of Water (Flooding)</b>	Flooding	4.1 (295) – 2.4 (40) – 1.2 (42) – 6.3 (14)
	Flooding List and trim	5.2 (374)
	Inappropriate securing-passengers responsibility	5.2 (374)
<b>Lack of Information (Missing/Not Available/Incorrect Aids to Operations)</b>	Charts are out of date. not available	8.4 (62) – 8.1 (51) – 8.2 (17)
	Lack of information	7.3 (450) – 7.2 (160) – 7.4 (40)
	Too much information	7.3 (450) – 7.2 (160) – 7.4 (40)
<b>Lack of Knowledge (Planning. Training. Experience. Procedures. Checklist. Risk Perception. Awareness)</b>	Lack of experience	8.5 (572) – 8.4 (62) – 8.1 (51) – 8.3 (42) – 8.6 (29) – 8.2 (17)
	Lack of knowledge	7.3 (450) – 7.2 (160) – 7.4 (40)
	Lack of planning	8.1 (51) – 8.3 (42)
	Lack of procedures/checklist	8.5 (572) – 8.4 (62) – 8.1 (51) – 8.3 (42) – 8.6 (29) – 8.2 (17)

	Lack of training	8.5 (572) – 7.3 (450) – 7.2 (160) – 6.12 (133) – 8.4 (62) – 8.1 (51) – 8.3 (42) – 7.4 (40) – 8.6 (29) – 8.2 (17) – 6.14 (14)
	Loss of situational awareness	8.1 (51) – 8.3 (42) – 8.2 (17)
	Not knowing where others are	8.3 (42)
	Not knowing where you are	8.1 (51)
	Risk perception	8.3 (42)
	unawareness of rules	5.1 (317)
	new regulation inforced/ implemented after design/ construction	5.1 (317)
	bad procedure	4.3 (328)
<b>Loss of Steering Control</b>	Lack of steering capability	1.6 (161)
	loss of steering control	1.1 (196) – 1.5 (77)
<b>Mechanical/Physical Failure (to any system/equipment)</b>	Auxiliary (to electric generation) systems failure	2.4 (40)
	door failure (closing)	1.2 (42)
	door mechanical failure	6.10 (38)
	doors and fire dampers propped open	6.8 (173)
	Electronic fault	6.11 (5)
	Electronic/hydraulic systems failure	2.2 (29)
	Engine essential auxiliary systems failure	2.1 (40)
	Engine mechanical failure	2.1 (40)
	failure of detector (not working or inadequate)	6.4 (27) – 6.5 (14)
	failure of indicator	4.2 (328)
	fire mechanical system failure	6.7 (146) – 6.6 (27)
	Hydraulic failure	8.5 (572)
	loss of power	1.1 (196) – 1.5 (77)
	Mechanical failure of closing devices	3.6 (30) – 1.4 (41) – 3.2 (30)
	mechanical failure LSA system	6.12 (133)
	Mechanical failure of hand brakes. lashing gear. etc.	5.2 (374)
	Mechanical/automation failure	1.6 (161)
	Mechanical/electronic systems failure	2.3 (40)
	Prime mover failure	2.4 (40)
	Propulsion unit mechanical failure (internal/external factors)	2.1 (40)
	Shafting line systems mechanical failure	2.1 (40)
	Stab. system mechanical failure	2.2 (29)
<b>Poor Construction/Installation</b>	Installation problem	8.5 (572) – 8.4 (62) – 8.6 (29)
	Poor construction	5.3 (64) – 3.1 (39) – 3.5 (31) – 3.6 (30) – 3.4 (29)

<b>Poor Visibility (Internal. External)</b>	no light/visibility	4.1 (295)
	Poor visibility	8.1 (51) – 8.3 (42) – 8.2 (17)
	reduced visibility	6.1 (14)
	Visibility	7.1 (450)
<b>Reduced Operational Mechanical Failure (Machinery)Con dition (Trim. List. Stability)</b>	excessive bow trim	1.2 (42)
	excessive heel or trim	4.1 (295) – 6.12 (133) – 6.3 (14)
	inadequate reserve of buoyancy	1.4 (41)
	Insufficient directional stability	1.6 (161)
	position	6.1 (14)
<b>Smoke</b>	Smoke	7.1 (450) – 4.1 (295) – 6.1 (14)
<b>structural degradation</b>	buckling of longitudinals	3.5 (31)
	buckling of stiffeners	3.3 (64) – 3.4 (29)
	Corrosion	3.3 (64) – 6.9 (38) – 3.5 (31) – 3.6 (30) – 3.4 (29) – 4.6 (17)
	excessive local loading	4.6 (17)
	fatigue	3.3 (64) – 3.5 (31) – 3.4 (29)
	loss of local strength	3.1 (39)
	Structural failure	8.5 (572)
	Structural failure due to damage	6.9 (38)
<b>cargo handling (inert)</b>	cargo shift	3.5 (31) – 3.4 (29)
	driving to wrong part of ship (loading)	5.4 (99)
	improper stowage	4.1 (295) – 6.3 (14)
	overloading with cargo	3.5 (31)
	wrong manoeuvring on deck (loading)	5.4 (99)
	wrong location of passenger (loading)	5.4 (99)
	wrong weight/cargo distribution	1.5 (77) – 1.2 (42) – 3.1 (39) – 1.3 (22)

<b>Type</b>	<b>Local effect</b>	<b>Failure mode (Rank)</b>
<b>Accelerated Path to End Event</b>	Accelerate path to end event	6.9 (38) – 6.10 (38)
<b>Broaching</b>	Broaching	1.6 (161)
<b>Cargo (Shift. Leak of Hazardous)</b>	Cargo shift	2.2 (29) – 1.2 (42) – 1.5 (77)
	damage of cargo	3.5 (31)
	hazardous leakage	5.1 (317)
	Large-scale cargo shift	5.2 (374)
	Localized cargo shift	5.2 (374)

<b>Collision (Increased Likelihood. Minor)</b>	Collision	8.2 (17) – 8.6 (29) – 2.1 (40) – 7.4 (40) – 8.3 (42) – 8.1 (51) – 8.4 (62) – 7.2 (160) – 1.6 (161) – 7.1 (450) – 7.3 (450) – 8.5 (572)
	Increased likelihood of collision	6.11 (5)
	minor collision with cargo or vessel	5.4 (99)
<b>Crew Performance (Delayed. Inappropriate. Behaviour. Excessive Workload)</b>	cannot respond	4.1 (295)
	crew trapped	4.1 (295) – 6.2 (15) – 6.3 (14)
	Excessive workload	7.2 (160) – 7.1 (450)
	harassment	5.3 (76)
	Poor co-ordination between crew/passengers	8.6 (29)
<b>Crew Behaviour (Discomfort. Deafness. Fatigue)</b>	response delayed	4.1 (295)
	discomfort	4.5 (37)
	Fatigue of crew	7.2 (160) – 7.1 (450) –4.4 (65) – 4.5 (37)
	Fatigue of crew (bad design → long/ complex access	4.1 (295)
	Human injury	2.2 (29) – 2.4 (40) – 1.2 (42) – 1.5 (77)
	injury or illness goes unchecked	6.14 (14)
	long term hearing damage	4.5 (37)
	minor physical injury	3.5 (31)
	sea sickness	1.2 (42)
<b>Damage to Ship (Other Vessels. Other Systems)</b>	compromising ship systems	5.3 (76)
	Damage to other systems	7.2 (160)
	Damage to other vessels	8.2 (17) – 8.3 (42) – 8.5 (572)
	Damage to systems	7.4 (40) – 7.1 (450) – 7.3 (450)
	damage to vessel	5.3 (76)
	more likely to increase damage to ship	6.4 (27)
<b>Delay (Penalty)</b>	Delays	8.2 (17) – 8.6 (29) – 8.3 (42) – 8.1 (51) – 8.4 (62) – 8.5 (572)
	Penalty	8.2 (17) – 8.6 (29) – 8.3 (42) – 8.1 (51) – 8.4 (62) – 8.5 (572)
<b>Electrical Failure (Loss of Electrical Generation)</b>	Loss of electrical generation	2.3 (40)
<b>Excessive Loads (Local Internal. Global)</b>	excessive bow slam	1.1 (196)
	excessive global internal loads	1.1 (196)
	Excessive loads	2.2 (29)
	green water	1.5 (77)

<b>Excessive Motions/Accelerations</b>	excessive acceleration	1.1 (196) – 1.3 (22)
	Excessive motions/accelerations	1.6 (161)
	Excessive ship motions/accelerations	2.2 (29)
<b>Failure in evacuation process</b>	cannot evacuate	6.12 (133)
	delay evacuation	6.4 (27)
	evacuation more difficult	6.4 (27)
	extended evacuation time	6.1 (14) – 6.2 (15) – 6.3 (14)
	people in water without rafts	6.12 (133)
	unrecovered people in the water	6.12 (133)
<b>Fire (Delay Fire Suppression. Erroneous Use of System. Uncontrollable. Explosion)</b>	delay in fire suppression	6.4 (27)
	difficulty to extinguish	6.8 (173)
	Fire	2.3 (40) – 2.4 (40) – 7.2 (160) – 5.2 (374) – 7.3 (450) – 4.2 (328) – 4.3 (328) – 5.4 (99)
	fire grows	6.7 (147)
	fire spread	6.8 (173)
	increased risk of fire /explosion	5.1 (317)
	uncontrollable fire growth	6.6 (27)
<b>Grounding</b>	(Grounding)	8.6 (29)
	Grounding	8.2 (17) – 2.1 (40) – 7.4 (40) – 8.1 (51) – 8.4 (62) – 7.2 (160) – 1.6 (161) – 7.1 (450) – 7.3 (450) – 8.5 (572)
<b>Human Injury (Major. Minor. Increase Potential. Catastrophic. Panic. Discomfort. Deafness. Stowaways. Sea Sickness)</b>	Discomfort of passengers	7.4 (40) – 7.2 (160) – 7.1 (450) – 7.3 (450) – 8.2 (17) – 8.3 (42) – 8.1 (51) – 8.4 (62) – 8.5 (572) – 4.5 (37)
	Human injury	2.2 (29) – 2.4 (40) – 1.2 (42) – 1.5 (77)
	injury or illness goes unchecked	6.14 (14)
	life risk to stowaways	5.1 (317)
	long term hearing damage	4.5 (37)
	minor physical injury	3.5 (31)
	passenger struck by car/ cargo	5.4 (99)
	sea sickness	1.2 (42)
<b>Ingress of Water (Flooding)</b>	downflooding	4.2 (328) – 4.3 (328)
	Flooding	3.6 (30) – 2.4 (40) – 1.2 (42) – 1.4 (41) – 3.2 (30) – 3.3 (64) – 3.4 (29) – 3.5 (31) – 4.2 (328) – 4.3 (328)
	Flooding (sea water inlet valve/ bilge system failure)	2.3 (40)
	Progressive flooding	6.9 (38) – 6.10 (38)

<b>Loss of Domestic Services</b>	Loss of domestic services	2.3 (40)
<b>Loss of Propulsion</b>	Loss of propulsion	2.3 (40) – 1.5 (77)
<b>Loss of Manoeuvrability (Steering)</b>	loss of steering control	1.5 (77) – 2.1 (40)
	Loss of manoeuvrability	2.4 (40)
<b>Loss of Control of Vessel</b>	Loss of control	8.2 (17) – 7.4 (40) – 8.3 (42) – 8.1 (51) – 7.2 (160) – 7.1 (450) – 7.3 (450) – 8.5 (572)
<b>Mechanical Failure (Machinery)</b>	equipment failure	4.4 (65)
	Machinery failure	2.4 (40)
<b>Near Miss</b>	Near miss	8.2 (17) – 8.6 (29) – 8.3 (42) – 8.1 (51) – 8.4 (62) – 8.5 (572)
<b>Negative Passenger Behaviour (Harassment. Unintentional. Intentional. Confusion)</b>	Confusion of passengers	8.6 (29)
	fatigue	4.4 (65) – 4.5 (37)
	harassment	5.3 (76)
	inappropriate activation of emergency systems	5.3 (76)
	passengers ending up in dangerous area	6.1 (14)
	people trapped	6.2 (15) – 6.3 (14)
<b>Smoke (Uncontrollable spread)</b>	smoke throughout the vessel	6.8 (173)
<b>Structural Failure (Local. Global. Permanent Damage. Loss of Global Strength/ Transverse/ Longitudinal Strength)</b>	Global failure	3.6 (30) – 4.4 (65)
	global fatigue failure	4.4 (65)
	local failure	4.4 (65)
	local fatigue failure	4.4 (65)
	local structural damage	1.5 (77)
	loss of global strength	3.3 (64)
	loss of longitudinal strength	3.5 (31)
	loss of transverse / longitudinal	3.4 (29)
	permanent damage	3.1 (39)
	Structural damage	8.2 (17) – 8.1 (51) – 8.4 (62) – 8.5 (572)
<b>Reduced Operational Condition (Trim. List. Stability)</b>	capsize	1.4 (41)
	Increased heeling/trim	6.9 (38)
	loss of stability	1.5 (77)
	reduced operational capability	4.6 (17)
	Reduction in stability	6.9 (38)
	Speed reduction	2.2 (29) – 2.1 (40)
<b>Rescue (Delayed. Unable)</b>	Delayed rescue or untimely rescue	6.13 (146)
<b>loss of ship</b>	loss of ship	3.1 (39)

---

<b>no adverse effect</b>	no adverse effect	3.2 (30) – 3.3 (64) – 3.4 (29) – 3.5 (31)
<b>safety systems degradation</b>	false alert/ suppression system discharge	6.5 (14)
	false alert/ alarm sounding	6.5 (14)
	isolation of space	6.5 (14)
	increased likelihood of evacuation	6.6 (27)
	inadequate personnel buoyancy	6.12 (133)
	loss of refuge area	6.8 (173)
<b>vibrations</b>	vibration	4.5 (37)