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"Μελέτη επιθεωρήσεων, προβλημάτων και ατυχημάτων σε μέσα διάσωσης (life-saving appliances)"

"Analysis of inspection omissions concerning different types of life-saving appliances"

Διπλωματική εργασία

του

ΝΤΟΥΡΜΑ ΑΓΓΕΛΟΥ

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Table of contents

Acknowledgements 1
Table of contents 2
List of figures 4
List of Tables 6
Abbreviations 8
Περίληψη 10
Abstract 12
1 Literature review 14
2 Vessel Inspections 19
2.1 Introduction 19
2.2 Classification Societies 20
2.2.1 Periodical 21
2.2.2 Non-Periodical 24
2.3 Port State Control 24
2.3.1 Databases 27
2.4 Flag state control 28
2.4.1 Port State Control vs. Flag State Control 29
3 Risk Based Inspection 30
3.1 Definitions 30
3.1.1 Risk 30
3.1.2 Likelihood 30
3.1.3 Consequences 30
3.1.4 Hazard 33
3.1.5 Risk Estimation 33
3.2 Formal Safety Assessment 35
3.2.1 Introduction 35
3.2.2 Hazard Identification (HAZID) (Step 1) 36
3.2.3 Risk Assessment (Step 2) 38
3.2.4 Risk Control Options (Step 3) 43
3.2.5 Cost Benefit Analysis (Step 4) 43
3.2.6 Decision Making (Step 5) 44
3.2.7 RBI Methodology 45
4 Life-Saving Appliances 46
4.1 Critical Components of LSA examined 47

4.1.1 Davit launched lifeboats & liferafts....47
4.1.2 Free-fall lifeboats....51
4.2 Regulations....51
4.2.1 General Cargo ships (SOLAS-Chapter III-Regulation 31)....52
4.2.2 Passenger ships (SOLAS-Chapter III-Regulation 21)....52
4.2.3 Evolution of regulations concerning LSA....53
4.2.4 LSA elements examined in inspections....54
4.3 Potential collective LSA arrangements....55
5 Data acquisition and elaboration....57
5.1 Data set....57
6 Life-saving appliances module....65
6.1 Davit launched lifeboat Fault Tree....67
6.2 Davit launched liferaft Fault Tree....69
6.3 Free-fall Lifeboat Fault Tree....71
7 Simulations....73
Case 1 - Davit Launched Lifeboat....74
Case 2 - Davit Launched Liferaft....76
Case 3 - Free-Fall Lifeboat....78
Cases 4, 5 & 6 – Davit launched lifeboats, davit launched liferafts & free-fall lifeboats for worst case scenarios....80
8 Conclusions....87
REFERENCES....89
ANNEX....91
SOLAS Regulations 21 and 31....91
RESULTS....95
Davit Launched Lifeboats....95
Free fall lifeboats....101
Davit launched liferafts....107

List of figures

Figure 1: Primary causes of Incidents 15

Figure 2: Breakdown of Incidents caused by Equipment Failure 15

Figure 3: Comparison of fatalities connected with lifeboats to those arising from other activities 16

Figure 4: Lifeboat System Failure Frequency Selected Components 18

Figure 5: The time intervals in which the respective surveys must be incorporated during the ship's operations. 23

Figure 6: FSA methodology 35

Figure 7: Event Tree Analysis of Flotel-Platform Collision Probability 41

Figure 8: Fault Tree 41

Figure 9: Bayesian Network example 42

Figure 10: The ALARP methodology is Depicted on an F-N diagram. 44

Figure 11: Release mechanism. 48

Figure 12: Lifeboat davit arrangement 50

Figure 13: Potential LSA arrangement A 55

Figure 14: Potential LSA arrangement B 56

Figure 15: Potential LSA arrangement C 56

Figure 16: Number of inspected deficiencies per ship type 57

Figure 17: Main defective item categories – General cargo 58

Figure 18: Main defective item categories – Passenger ship 58

Figure 19: Causes of defect of lifeboats – General cargo 59

Figure 20: Causes of defect of liferafts – General cargo 59

Figure 22: Deficiencies encountered in PSC inspections for ships of age from 6 to 10 years old 61

Figure 23: Deficiencies encountered in PSC inspections for ships of age from 11 to 15 years old 61

Figure 24: Deficiencies encountered in PSC inspections for ships of age from 16 to 20 years old 62

Figure 25: Deficiencies encountered in PSC inspections for ships of age from 21 to 25 years old 62

Figure 26: Deficiencies encountered in PSC inspections for ships of age of 25+ years old 63

Figure 27: Deficiencies encountered in collective LSA during PSC inspections divided by age group 63

Figure 28: Fatigue cracks in bulkheads from Paris MoU for ships of different age.....65
Figure 29: Conceptual model of the LSA.....66
Figure 30: Developed FT for the calculation of the probability of failure of davit launched lifeboats.....67
Figure 31: Developed FT for the calculation of the probability of failure of davit launched liferafts......69
Figure 32: Developed FT for the calculation of the probability of failure of free-fall lifeboat......71
Figure 33: Depiction of major components affecting failure of davit launched lifeboats 74
Figure 34: Probability of failure of major components & total probability of failure for davit launched lifeboats for case 1 74
Figure 35: Depiction of major components affecting failure of davit launched liferafts 76
Figure 36: Probability of failure of major components & total probability of failure for davit launched liferaft for case 2 76
Figure 37: Depiction of major components affecting failure of free-fall lifeboats 78
Figure 38: Probability of failure of major components & total probability of failure for free-fall lifeboat for case 3.....78
Figure 39: Depiction of major components affecting failure of davit launched lifeboats 80
Figure 40: Probability of failure of major components & total probability of failure for davit launched lifeboats for case 4 80
Figure 41: Depiction of major components affecting failure of davit launched liferafts 82
Figure 42: Probability of failure of major components & total probability of failure for davit launched liferafts for case 5.....82
Figure 43: Depiction of major components affecting failure of free-fall lifeboats 84
Figure 44: Probability of failure of major components & total probability of failure for free-fall lifeboats for case 6 84

List of Tables

Table 1: MAIB 2001 lifeboat study....16
Table 2: Quantitative Frequency Index....31
Table 3: Qualitative Frequency Index....31
Table 4: USCG Consequences Categories Index....32
Table 5: Severity Categories Index in Quantitative approach....32
Table 6: Severity Categories Index in Qualitative approach....33
Table 7: Risk matrix - Information structuring and risk-based inspection for the marine oil pipelines....34
Table 8: Example of HAZOP Analysis.....37
Table 9: Example of SWIFT of Ballast System.....38
Table 10: Example Extract from an FMEA Work Sheet.....39
Table 11: Predefined values matrix....40
Table 12: Probability of failure of main components of lifeboats in case 1....75
Table 13: Probability of failure of sub-components of lifeboats in case 1....75
Table 14: Probability of failure of main components of liferafts in case 2....77
Table 15: Probability of failure of sub-components of liferafts in case 2....77
Table 16: Probability of failure of main components of free-fall lifeboats in case 3....79
Table 17: Probability of failure of sub-components of free-fall lifeboats in case 3....79
Table 18: Probability of failure of main components of lifeboats in case 4....81
Table 19: Probability of failure of sub-components of lifeboats in case 4....81
Table 20: Probability of failure of main components of liferafts in case 5....83
Table 21: Probability of failure of sub-components of liferafts in case 5....83
Table 22: Probability of failure of main components of free-fall lifeboats in case 6....85
Table 23: Probability of failure of sub-components of free-fall lifeboats in case 6....85
Table 24: Comparison of probability of failure of the 4 cases examined....86
Table 25: Probability of failure of hooks for davit launched lifeboats....95
Table 26: Probability of failure of operating cables for davit launched lifeboats....96
Table 27: Probability of failure of control lever for davit launched lifeboats....96
Table 28: Probability of failure of winch general subcomponent for davit launched lifeboats....97
Table 29: Probability of failure of winch gear system for davit launched lifeboats....97
Table 30: Probability of failure of winch break for davit launched lifeboats....98
Table 31: Probability of failure of davit structure for davit launched lifeboats....98

Table 32: Probability of failure of limit switch for davit launched lifeboat................99
Table 33: Probability of failure of lifeboats for davit launched lifeboats...................99
Table 34: Probability of failure of falls, sheaves & blocks for davit launched lifeboats 100
Table 35: Probability of failure of bowsing & tricing for davit launched lifeboats....100
Table 36: Probability of failure of fall wires for davit launched lifeboats 101
Table 37: Probability of failure of hooks for free-fall lifeboats 101
Table 38: Probability of operating cables failure for free-fall lifeboats 102
Table 39: Probability of failure of control lever for free-fall lifeboats 102
Table 40: Probability of failure of davit structure for free-fall lifeboats 103
Table 41: Probability of failure of limit switch for free-fall lifeboat.........................103
Table 42: Probability of failure of winch general subcomponent for free-fall lifeboats 104
Table 43: Probability of failure of winch gear system for free-fall lifeboats 104
Table 44: Probability of failure of winch brake for free-fall lifeboats 105
Table 45: Probability of failure of lifeboat for free-fall lifeboats..............................105
Table 46: Probability of failure of falls, sheaves & blocks for free-fall lifeboat.........106
Table 47: Probability of failure of fall wires for free-fall lifeboats 106
Table 48: Probability of failure of hooks for davit launched liferafts.......................107
Table 49: Probability of failure of operating cables for davit launched liferafts.......107
Table 50: Probability of failure of control lever for davit launched liferafts............108
Table 51: Probability of failure of falls, sheaves & blocks for davit launched liferafts 108
Table 52: Probability of failure of fall wires for davit launched liferafts..................109
Table 53: Probability of failure of davit structure for davit launched liferafts..........109
Table 54: Probability of failure of limit switch for davit launched liferafts..............110
Probability of failure of winch general subcomponent for davit launched liferafts .110
Table 56: Probability of failure of winch gear system for davit launched liferafts ...111
Table 57: Probability of failure of winch brake for davit launched liferafts.............111

Abbreviations

ABS	American Bureau of Shipping
ALARP	As Low As Reasonably Practicable
BN	Bayesian Network
BRS	Bulgarian Register of Shipping
BV	Bureau Veritas
CCS	China Classification Society
CRS	Croatian Register of Shipping
DNV	Det Norske Veritas
DNV/GL	Det Norske Veritas / Germanischer Lloyd
ETA	Event Tree Analysis
FMEA	Failure Modes and Effects Analysis
FMECA	Failure Modes, Effects and Criticality Analysis
FSA	Formal Safety Assessment
FTA	Fult Tree Analysis
GCAF	Gross Cost of Averting a Fatality
HAZID	Hazard Identification
HAZOP	Hazard Operability
HR	Hellenic Register of Shipping
HRS	High Risk Ships
IACS	International Association of Classification Societies
ICS	International Chamber of Shipping
IMO	International Maritime Organization
IR CLASS	Indian Register of Shipping
IRS	International Register of Shipping
ISM	International Safety Management
KR	Korean Register of Shipping
LRS	Low Risk Ships
LSA	Life Saving Appliances
MAIB	Marine Accident Investigation Branch
MoU	Momerandum of Understanding
MSB	Australian Maritime Services Board
MSC	Maritime Safety Committee
NCAF	Net Cost of Averting a Fatality
NK	Nippon Kaiji Kyokai
OCIMF	Oil Companies International Marine Forum
OMCS	Overseas Marine Certification Services
PRS	Polish Register of Shipping
PS	Port Side
PSC	Port State Control
Q	Qualitative
QRA	Quantitative
RBI	Risk Based Inspection
RCO	Risk Control Options
RINA	Registro Italiano Navale

RINAVE	Registro Internacional Naval
RS	Russian Maritime Register of Shipping
RU	The Shipping Register of Ukraine
SB	Starboard side
SIGTTO	Society of International Gas Tanker and Terminal Operators
SOLAS	International Convention for the Safety of the Life at Sea
SQ	Semi-Quantitative
SRS	Standard Risk Ships
SWIFT	Structured what-if checklist
USCG	United States Coast Guard
VLCC	Very Large Crude Carriers

Περίληψη

Η διπλωματική αυτή έχει ως σκοπό να υπολογίσει την πιθανότητα αστοχίας ορισμένων ομαδικών σωστικών μέσων εμπορικών πλοίων μέσω της διαμόρφωσης μοντέλων Fault Trees. Η μελέτη πραγματοποιείται υπό το πρίσμα της προσφοράς δυνατότητας αξιοποίησης των αποτελεσμάτων μέσω των επιθεωρήσεων που βασίζονται στο ρίσκο.

Αρχικά γίνεται αναφορά στις μελέτες που έχουν προηγηθεί γύρω από την αστοχία και τα ατυχήματα ομαδικών σωστικών μέσων. Ακολουθεί η περιγραφή του πλαισίου γύρω από τις επιθεωρήσεις πλοίων από τους διάφορους εμπλεκόμενους φορείς. Δίνεται ιδιαίτερη έμφαση στην επιθεώρηση που βασίζεται στο ρίσκο και την μεθοδολογία της Formal Safety Assessment και τις δυνατότητες που παρέχουν στην βελτιστοποίηση της απόδοσης των επιθεωρήσεων. Στη συνέχεια, παρουσιάζονται τα σωστικά μέσα που επιλέχθηκαν να εξεταστούν και πραγματοποιείται λεπτομερής περιγραφή και ανάλυση σχετικά με τη λειτουργία των κύριων εξαρτημάτων τους. Έπειτα, παρουσιάζεται το πλαίσιο κανονισμών γύρω από την επαρκή επάνδρωση πλοίων με σωστικά μέσα καθώς και η εξέλιξη των κανονισμών που εστιάζουν στην ασφαλέστερη λειτουργία τους. Ακολουθεί η αναφορά στις βάσεις δεδομένων που χρησιμοποιήθηκαν και η διατύπωση των μοντέλων και τύπων υπολογισμού των πιθανοτήτων αστοχίας. Τέλος, παρατίθενται τα αποτελέσματα 6 προσομοιώσεων, τα οποία σχολιάζονται.

Στο 1ο κεφάλαιο γίνεται αναφορά σε προηγούμενες έρευνες και μελέτες σχετικές με τα ατυχήματα και τις αστοχίες σωστικών μέσων. Μέσω της βιβλιογραφικής επισκόπησης δίνεται η πληροφορία σχετικά με το ποια σωστικά μέσα εμφανίζουν τον μεγαλύτερο κίνδυνο ατυχημάτων και εξετάζονται οι αιτίες που μπορεί να οδηγούν και να συνδέονται με αυτά.

Στο 2ο κεφάλαιο, περιγράφεται όλο το πλαίσιο γύρω από τις επιθεωρήσεις πλοίων. Αρχικά αναφέρονται ο ρόλος και οι αρμοδιότητες των νηογνωμόνων όσον αφορά στην επίβλεψη της ασφαλούς και σύμφωνης με τους διεθνείς κανονισμούς λειτουργίας των πλοίων. Ακολουθεί παρουσίαση των πιο συνήθων τύπων επιθεωρήσεων που πραγματοποιούνται από τους διάφορους εμπλεκόμενους φορείς. Γίνεται αναφορά στο ρόλο του Port State Control και της σημαίας και εν κατακλείδι, πως οι διάφοροι φορείς επηρεάζουν ο ένας τη λειτουργία του άλλου.

Στο 3ο κεφάλαιο περιγράφεται αρχικά η θεωρία γύρω από τις επιθεωρήσεις πλοίων με γνώμονα το ρίσκο. Στη συνέχεια γίνεται περιγραφή της Formal Safety Assessment, με τα παραδοσιακά της βήματα και τα πιο διαδεδομένα εργαλεία της.

Στο 4ο κεφάλαιο γίνεται λεπτομερής παρουσίαση των σωστικών μέσω που επιλέχθηκαν να εξεταστούν στην παρούσα εργασία. Τα μέσα αυτά είναι οι Davit Launched Lifeboats, Davit Launched Liferafts και οι Free-fall Lifeboats. Αναλύονται

τα εξαρτήματα τους που κρίθηκαν ως άμεσα συνδεδεμένα με την επιτυχή και ασφαλή λειτουργία των σωστικών μέσων. Η διάκριση των κρίσιμων εξαρτημάτων βασίστηκε στη διαθέσιμη βιβλιογραφία και τη γνώμη ειδικών κατασκευαστικής εταιρίας σωστικών μέσων. Έπειτα παρατίθενται οι κανονισμοί που αφορούν στις απαιτήσεις διαθεσιμότητας επαρκών σωστικών μέσων καθώς και η εξέλιξη των κανονισμών που στοχεύουν στην αύξηση της ασφάλειας της λειτουργίας τους τόσο σε περίπτωση ανάγκης, όσο και στις περιπτώσεις ασκήσεων εκπαίδευσης.

Στο 5^{ο} κεφάλαιο παρουσιάζεται η βάση δεδομένων που ήταν χρησιμοποιήθηκε για τη μελέτη αυτή. Τα στοιχεία που χρησιμοποιήθηκαν, προήλθαν από ανώνυμα στοιχεία του Paris MoU καθώς και από μια κατασκευαστική εταιρία σωστικών μέσων.

Στο 6^{ο} κεφάλαιο γίνεται περιγραφή των μοντέλων που δημιουργήθηκαν για τον υπολογισμό των διάφορων. Τα μοντέλα είναι της μορφής “Fault Trees” και χρησιμοποιούν πύλες AND και OR ώστε να υπολογίσουν την πιθανότητα αστοχίας των εξαρτημάτων των σωστικών μέσων και τις ολικές πιθανότητες αστοχίας, ανάλογα της ηλικίας, της κλάση και της σημαίας των πλοίων.

Στο 7ο κεφάλαιο γίνεται προσομοίωση για 6 διαφορετικά σενάρια. Για κάθε μια από τις 3 περιπτώσεις ομαδικών μέσων που εξετάζονται, μελετώνται οι πιθανότητες που προκύπτουν για τα 2 ακραία σενάρια, το ευνοϊκότερο και το δυσμενέστερο με βάση τα χαρακτηριστικά του πλοίου. Τέλος, γίνεται σχολιασμός των συμπερασμάτων που προκύπτουν από την εργασία αυτή.

Abstract

This thesis aims in estimating the probability of failure of several collective life-saving appliances of ships through the conception of Fault Tree models. The study is carried out with the scope of optimizing risk based inspections.

Initially the studies which have been carried out regarding the failure and accidents of life-saving appliances (LSA) are mentioned. Subsequently, the frame around the methodology of inspections concerning the various stakeholders is presented. Emphasis is given on Risk Based Inspections and Formal Safety Assessments and their benefits. Afterwards, the operation of the life-saving appliances which are of interest and their major components are presented in detail. The regulation framework regarding the sufficient availability of life saving appliances on board follows as well as the evolution of regulations concerning the improvement of the safety of their operation. Then, the available data, the models and the equations that emerged are presented. Finally, the results of several simulations are presented along with the conclusions of the thesis.

In Chapter 1, reference is being made on previous studies and research regarding accidents and failure of life saving appliances. Through the literary review, information is gathered about which life-saving appliances pose the greatest hazard and risk of accidents as well as the causes which are associated with that risk.

In Chapter 2, the frame regarding inspections is analyzed. At first, the role of the classification societies is mentioned regarding the safe operation of commercial vessels and their compliance with international law and regulations. The most common types of inspections carried out by the parties of interest are addressed. Finally, the role of the Port State Control and Flag state control is portrayed.

In chapter 3 the philosophy of Risk Based Inspections is defined. The methodology and nature of Formal Safety Assessments is described and its most common and valuable tools are described.

In chapter 4, detailed description of the life-saving appliances which were chosen to be addressed in this research is given. The life-saving appliances examined are the Davit Launched Lifeboats, Davit Launched Liferafts and Free-Fall Lifeboats. Their major components and their operation which are linked with their safe and proper functionality are presented. The major components were identified based on past research and opinions of experts of a LSA manufacturing company. Afterwards, the regulations with regard to the sufficient availability of LSA on board of the vessels are listed as well as potential arrangements of the LSA on board and the evolution of the regulations concerning the safety of LSA on emergencies and drills.

In chapter 5, information regarding the database which was utilized in this study is presented. The data originates form anonymized data from Paris MoU and a LSA manufacturing company.

In chapter 6, the models which were formed are described. The models are “Fault Tree” models which utilize AND & OR gates to calculate probabilities of failure of the main and sub-components of the LSA as well as the total probabilities of failure, depending on the age, class and flag of a vessel.

In chapter 7, 6 different scenarios are simulated. Two scenarios for each of the three LSA examined. At first the best case scenarios regarding the potential ship particulars are simulated and then the worst case scenarios follow. Finally, some comments are made regarding conclusions which can be drawn from the results of this study.

1 Literature review

Accidents involving different types of life saving appliances which result in the loss of life and serious injury continue to occur despite industry-wide efforts to address the problem. In fact, in many cases, the drills undertaken to train the crewmembers and help them prevent loss of life during actual emergency situations have the opposite result by leading to injuries and even fatalities.

There are no comprehensive global statistics available, though industry studies and accident investigations over the past decades are representative of an unacceptably high number of accidents and have identified common causative factors.

In 1994, Oil Companies International Marine Forum (OCIMF) became aware of a high frequency of lifeboat accidents and investigated further this issue. They published the results and conclusions formed by a questionnaire concerning davit launched totally enclosed lifeboats, distributed worldwide to Flag State administrators, the international Chamber of Shipping (ICS), ship operators and national authorities. Reports of 92 accidents were analyzed and information such as the activity during which the accident happened (drill, inspection, maintenance etc.), the underlying causes (human error, equipment failure, design fault, etc.), key component failure and the extent of the consequences were drawn.

In 2000, OCIMF expanded on the 1994 investigation, this time examining a wider range of LSA. A questionnaire was distributed to Members of INTERTANKO, OCIMF and Society of International Gas Tanker and Terminal Operators (SIGTTO). It was anticipated and eventually verified that most reports involved davit launched lifeboats due to the complexity of their design. The 89 reports gathered, were analyzed in a similar manner as in the 1994 investigation. Equipment failure was the greatest cause of incidents in all categories, followed by lack of proper maintenance, design faults and a relatively small number of procedural faults. Incidents directly caused by poor training and communication errors were minimal (Figure 1).

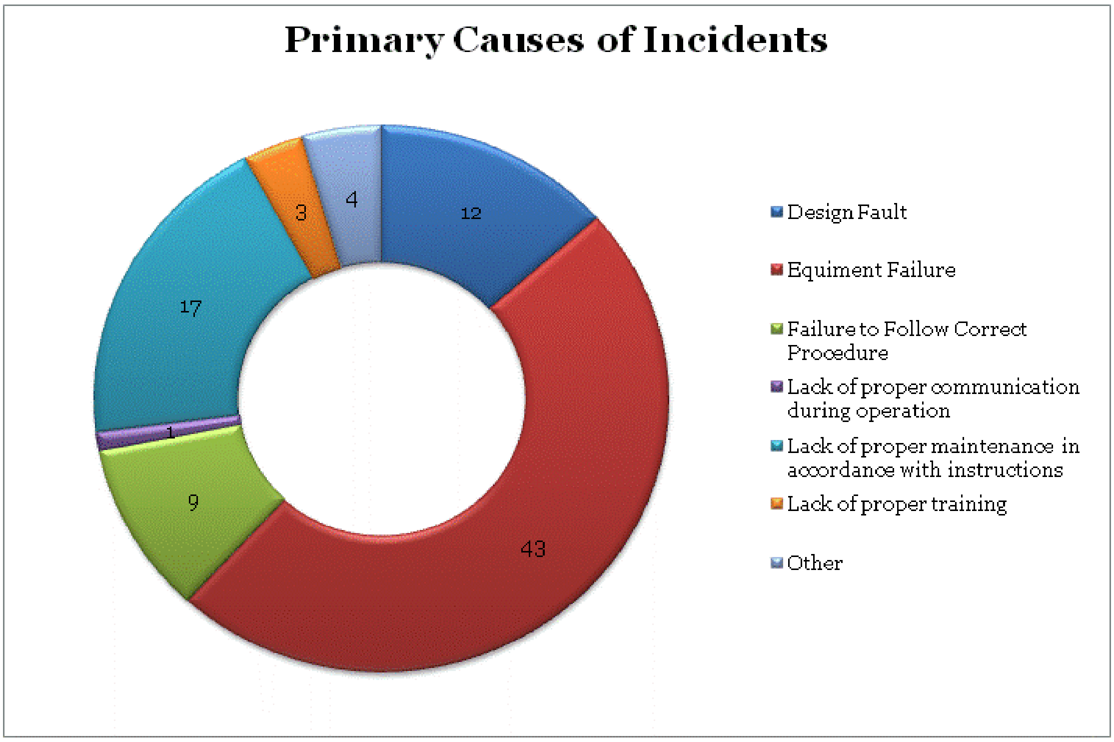


Figure 1: Primary causes of Incidents

Hook/Hook Quick Release Mechanism failure was the largest group, relating to inability to engage or release hooks correctly due to cable failure or mislocated safety mechanisms. Other major types of failure were winch brake related, caused by internal mechanism or remote controls for brake releases. "Others" included retrieval of free-fall lifeboats (Figure 2).

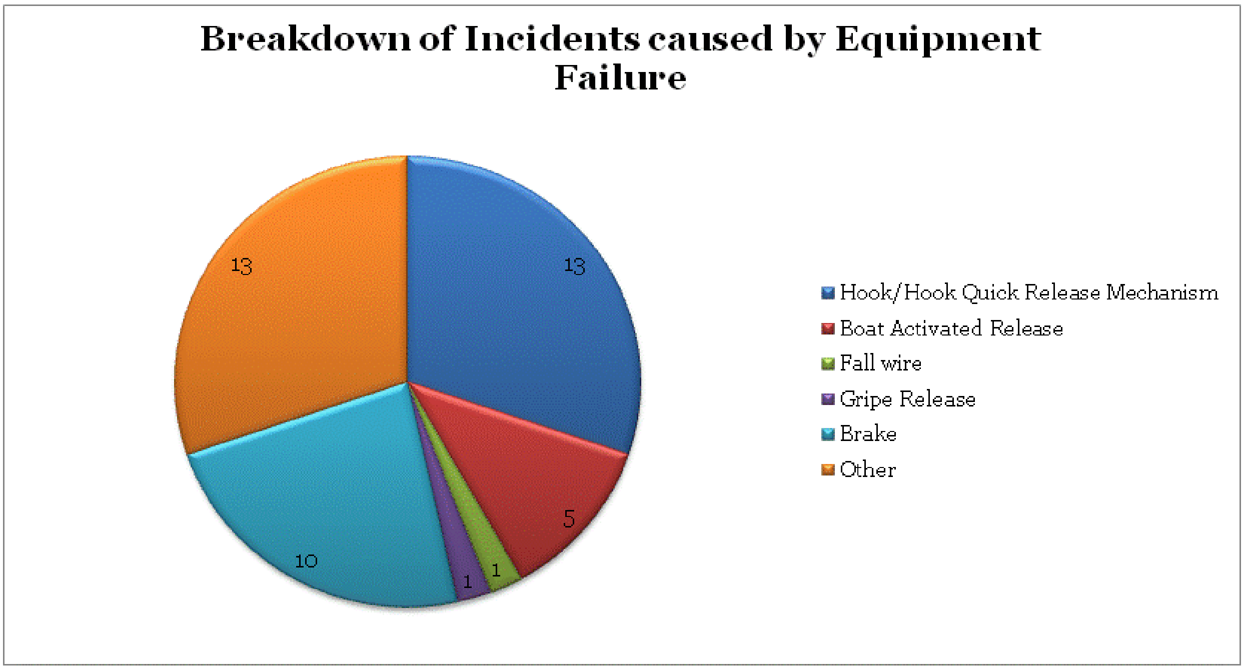


Figure 2: Breakdown of Incidents caused by Equipment Failure

A study investigating a small (125) number of accidents involving lifeboats in the UK from 1989 to 1999 was conducted by the Marine Accident Investigation Branch (MAIB) in 2001 (Table 1). The study put a spotlight on design, maintenance and training issues associated with several key components (e.g. winches, falls, tricing & bowsing gear, davits, hooks etc.) of lifeboat launch systems which were connected to the accidents. The MAIB highlighted the importance of the need to take appropriate measures as the number of injuries & fatalities was diagnosed as troubling. Furthermore, the report compared fatalities connected with lifeboats to those arising from other activities (Figure 3Figure).

Table 1: MAIB 2001 lifeboat study

Classification	*Number of incidents*	*Injuries*	*Lives Lost*
Hooks	11	9	7
Tricing and bowsing	10	5	2
Falls, sheaves and blocks	12	19	2
Engine and Starting	18	15	0
Gripes	12	10	0
Winches	32	8	0
Davits	7	7	0
Free-fall	2	1	0
Weather	2	0	0
Not otherwise classified	19	13	1
TOTALS	**125**	**87**	**12**

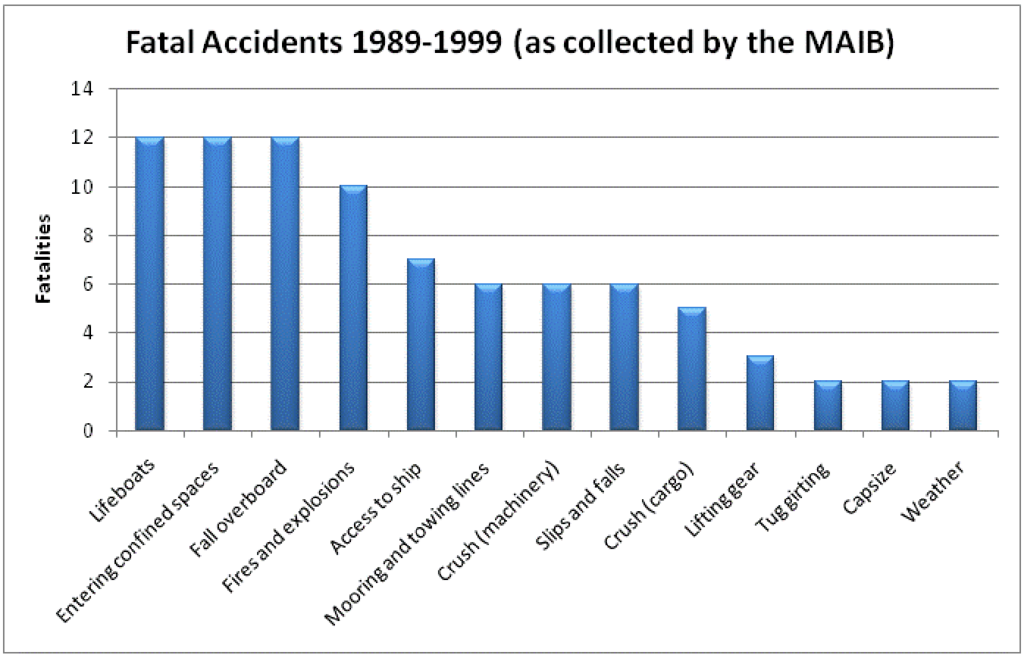


Figure 3: Comparison of fatalities connected with lifeboats to those arising from other activities

The MAIB was not the only maritime agency to analyse issues connected with lifeboats. In 1999 the Australian Maritime Services Board (MSB) submitted a summary of lifeboat accidents covering a seven year period to the IMO. The report consisted of nine accidents involving lifeboats and highlighted deficiencies in design, training and equipment as being the main contributory factors. Furthermore, the Norwegian Maritime Directorate issued a safety message containing statistics taken from personal injury reports from 1989 to 2001 that showed 1.6% of all accidents occurred in connection with lifeboat drills. The human cost was five fatalities, accounting for 2% of total deaths recorded, and 190 injuries; 65 leading to incapacity for further work. In Norway from 1996 to 1999 there was an average of twenty-four lifeboat accidents a year – two accidents every month

During 2000-2001, a Formal Safety Assessment concerning collective LSA of Bulk carriers was carried out by a project team from the Norwegian Maritime Directorate, Umoe Schat-Harding, Norwegian Union of Marine Engineers, Norwegian Shipowners' Association, International Transport Workers' Federation, MARINTEK and DNV. The FSA is broken down into 4 main parts. Annex I comprises the hazard identification of davit launched lifeboats (pre and post 1986), free-fall lifeboats, throw overboard liferafts and davit launched liferafts. Annex II embodies the risk assessment part of the study for the aforementioned categories of LSA based on incident data for 1991-1998, producing models of fatality risks in evacuations. Annex III focuses on free-fall lifeboats as a risk control option. Finally, annex IV examines risk control options in general. In the context of this FSA, 117 of bulk carrier evacuations were identified during 1991-98 and further analysed.

A study concerning lifeboat accidents was elaborated by Ross in support of his MSc in Environmental & Occupational Health and Safety Management (2006). The study initially identified design, maintenance, training and operation issues related to the lifeboat launching mechanisms. The data gathered from the questionnaire distributed shed light on accident cause and effect, and focused on the seafarers' hazard perception and confidence related to the operational issues and demands of lifeboat davit launching sub-systems. The investigation reports identified a wide range of accidents caused by component failure. However, given the limited scope of this project, and the need to keep the questionnaire within reasonable boundaries, the decision was made to focus on five major components of the lifeboats (Figure 4).

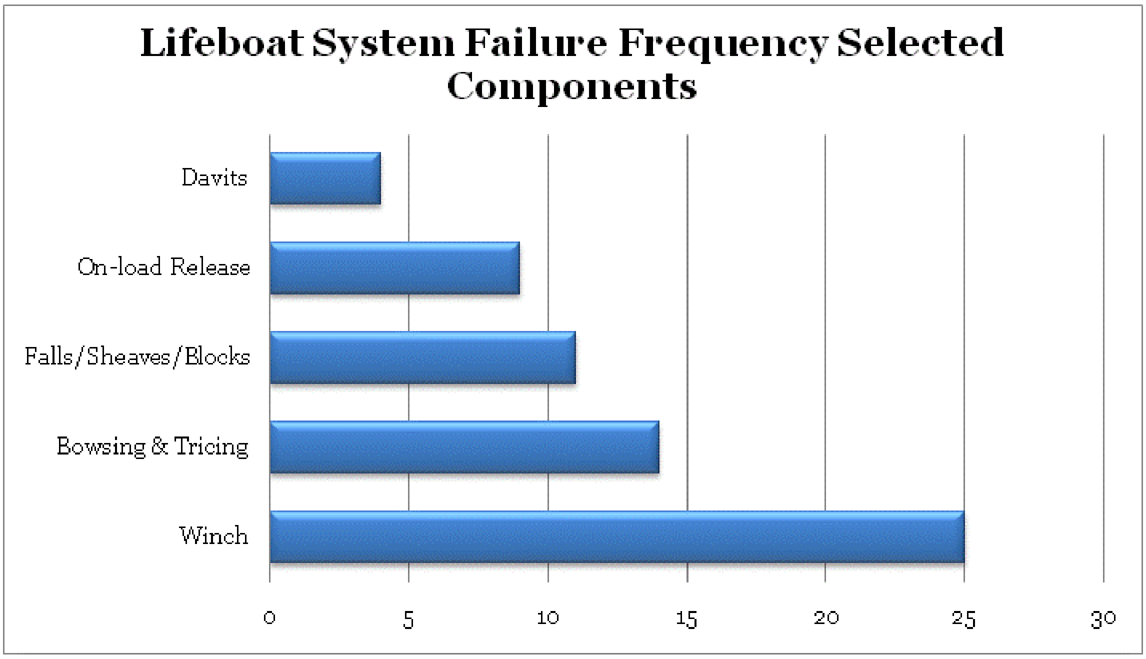


Figure 4: Lifeboat System Failure Frequency Selected Components

Finally, to these may be added the Lifeboat Safety Survey run by Maritime Accident Casebook in 2011, in which a higher frequency of accidents involving free-fall launching systems is noticeable compared to previous studies. The survey included modules from seafarers and offshore workers, shipowners, P&I Clubs and lifesaving appliance manufacturers.

2 Vessel Inspections

2.1 Introduction

The international shipping industry accounts to around 90% of world trade with over 50,000 commercial ships in operation according to the International Chamber of Shipping. The world fleet carries over 150 different banners of nations with over a million seafarers manning it. The shipping industry enables an immense variety of products to be traded in low-cost manner; trade volume enjoys a steady rise with international conventions and organizations continually strengthening the vessels' safety (International Chamber of Shipping, 2017).

Ship and personnel safety is undoubtedly a primary concern for every ship owner. The consequences of sea accidents can scale to disastrous extent depending on the size of the accident, from structural damage to personnel loss and pollution. Aside from the economic damage and possible penalties the maritime companies seek to avoid, there is their reputation also to preserve. Societies are sensitive on the subject of human and environmental safety, which can be observed on the outcry followed after serious accidents. The degree of the consequences and outcry, may lead to consideration of new regulations increasing safety measures.

The infamous titanic disaster, leaving 1517 dead in 1912, lead to the Safety of life at sea (SOLAS) convention in 1914. In the first version, it prescribed life-saving appliances capacity on board and other emergency equipment and in later versions expanded on the obligations of merchant ships. In 1978 the grounding of VLCC Amoco Cadiz caused an oil spill and led to the establishment of the Paris Memorandum of Understanding, which among other things, highlighted the need of port state control through inspections on the condition of ships accessing ports. In 1987 the capsizing of Ro-Ro ferry Herald of free Enterprise and the frustration it provoked due to the 193 casualties, called for the conception of the ISM code by SOLAS.

Satisfactory condition of the various systems and equipment of merchant ships is therefore a subject of interest for different parties. Ship owners, maritime organizations and nations are all concerned from a different perspective on the subject and therefore the need of vessel inspections emerges. Inspections are now mandatory for a ship to prove its seaworthiness by providing the necessary certification, in order to be allowed to operate. The effectiveness of these surveys is not solely dependent on the frequency of the surveys but also by their quality. As it is the interest of a number of parties that the ships operate safely, this leads to different kinds of inspections, depending on the party ordering it.

2.2 Classification Societies

A classification society is a nongovernmental technical organization involved in determining regulations and technical standards concerning the construction and operation of ship buildings and offshore structures as well as placing them in classification. The role of the classification society is not limited to setting the technical rules but furthermore to ensure that standards are met during construction and will continue to be met throughout the subject's operation. This is accomplished by organizing the necessary inspections of all critical features and the ship's general state and is confirmed by awarding the appropriate and essential certificates and documents.

Lloyd's Register, the first classification society was formed in 1760 in Lloyds Coffee House in London. The classification society issued the first rules concerning surveys and classification in 1834. Over the 18th century new classification societies were established such as Bureau Veritas in France, the Norwegian DNV, RINA in Italy and Nippon Kaiji Kyokai in Japan. In 1968, 12 prominent Classification Societies formed the International Association of Classification Societies (IACS) headquartered in London.

IACS members

- American Bureau of Shipping (ABS) formed in 1862 with its head office based in Houston.
- Bureau Veritas (BV) formed in 1828 with its head office based in Paris.
- China Classification Society (CCS) formed in 1956 with its head office based in Beijing.
- Croatian Register of Shipping (CRS) formed in 1949 with its head office based in Split.
- Det Norske Veritas Germanischer Lloyd (DNV GL) formed in 1864 with its head office based in Oslo.
- Indian Register of Shipping (IR Class) formed in 1975 with its head office based in Mumbai.
- Korean Register of Shipping (KR) formed in 1960 with its head office based in Busan.
- Lloyd's Register (LR) formed in 1760 with its head office based in London.
- Nippon Kaiji Kyokai (NK/ClassNK) formed in 1899 with its head office based in Tokyo.
- Polish Register of Shipping (PRS) formed in 1936 with its head office based in Gdańsk.
- Registro Italiano Navale (RINA) formed in 1861 with its head office based in Genoa.
- Russian Maritime Register of Shipping (RS) formed in 1913 with its head office based in Saint Petersburg.

There exist more than 90 classification societies which are not members of IACS. Some of the most well-known are:

- The Hellenic Register of Shipping (HR) formed in 1919 with its head office based in Piraeus.
- The Bulgarian Register of Shipping (BRS) formed in 1950 with its head office based in Varna.
- The Registro Internacional Naval (RINAVE) formed in 1973 with its head office based in Lisbon.
- The International Register of Shipping (IRS) formed in 1993 with its head office based in Miami.
- The Shipping Register of Ukraine (RU) formed in 1998 with its head office based in Kiev.
- The Overseas Marine Certification Services (OMCS) formed in 2004 with its head office based in Panama.

Classification Societies' Mandatory Surveys

During their operational lifetime, ships are required to undergo some mandatory inspections by their classification society to formalize their seaworthiness as well as their compliance with international regulations. These inspections vary depending on the ship type. The surveys are subcategorized by the IMO in periodical and non-periodical surveys. In 2000 the IMO adopted a harmonized system for surveys which facilitates smoother coordination of the obligatory ship inspections covering international shipping regulation. The mandatory inspections take place every year and scheduling can be an issue as they take time to be completed and the ship inspected cannot be active during the process. The harmonized system aims to reduce this hiatus by providing a flexible period during which a ship can go through with the respective inspection.

2.2.1 Periodical

Every ship is obligated to go through successfully the following periodical surveys before designated deadlines in order to continue its operations. The whole process of each survey can be split in smaller parts as long as deadline is met.

<u>Annual</u>

The annual survey is mandatory every year after the ship's initial classification. It must be carried out in a 6 month interval starting 3 months prior to the classification anniversary and up to 3 months after the date. This survey aims to verify the steady compliance with class and international regulations, as certain certificates concerning hull, equipment, machinery and various systems require annual endorsement verifying their appropriate condition. For all sort of tankers, the survey should favorably be carried out during a loading or discharging operation.

Intermediate

The intermediate survey must be carried out either during the 2nd or 3rd anniversary date of the classification of the vessel, within a 6 month timespan starting 3 months prior to and up to 3 months after the respective year. Compared to the annual surveys, the intermediate survey involves an even more thorough inspection of the hull, machinery and various equipment and systems, verifying they are fit for service for the ship's operations.

Complete

The various machinery, systems and equipment must undergo a complete survey every 2.5, 5, or 15 years. The time interval is varied per system/equipment. Usually the complete survey of the elements requiring it is combined with the renewal survey.

Renewal

The classification certificate granted at each ship expires after 5 years, with passenger ships being the only exception where their certificate expires every year. In order for a vessel to maintain a class, a renewal survey is required. The survey must be completed before the 5th anniversary date of classification and therefore should begin between the 4th and 5th year, every 5 years of the ship's operation. In the renewal survey a detailed examination is required, with tests when necessary, of the systems and equipment associated with the relevant certificates needed. The vessel must be found fit to operate properly from every aspect. The renewal survey should additionally check that all documentation, such as certificates, operation manuals etc., is properly arranged. If during the survey, need of repairing actions is encountered, they must be completed before it's the survey's termination.

Bottom

During every 5 year period, the outside of the ship's bottom shall be inspected a minimum of 2 times. Every bottom survey must be conducted no longer than 36 months after the previous one. The survey must insure that the ship's bottom and related items are in fit condition. The survey should favorably be conducted with the ship in a dry dock.

Propeller Shaft

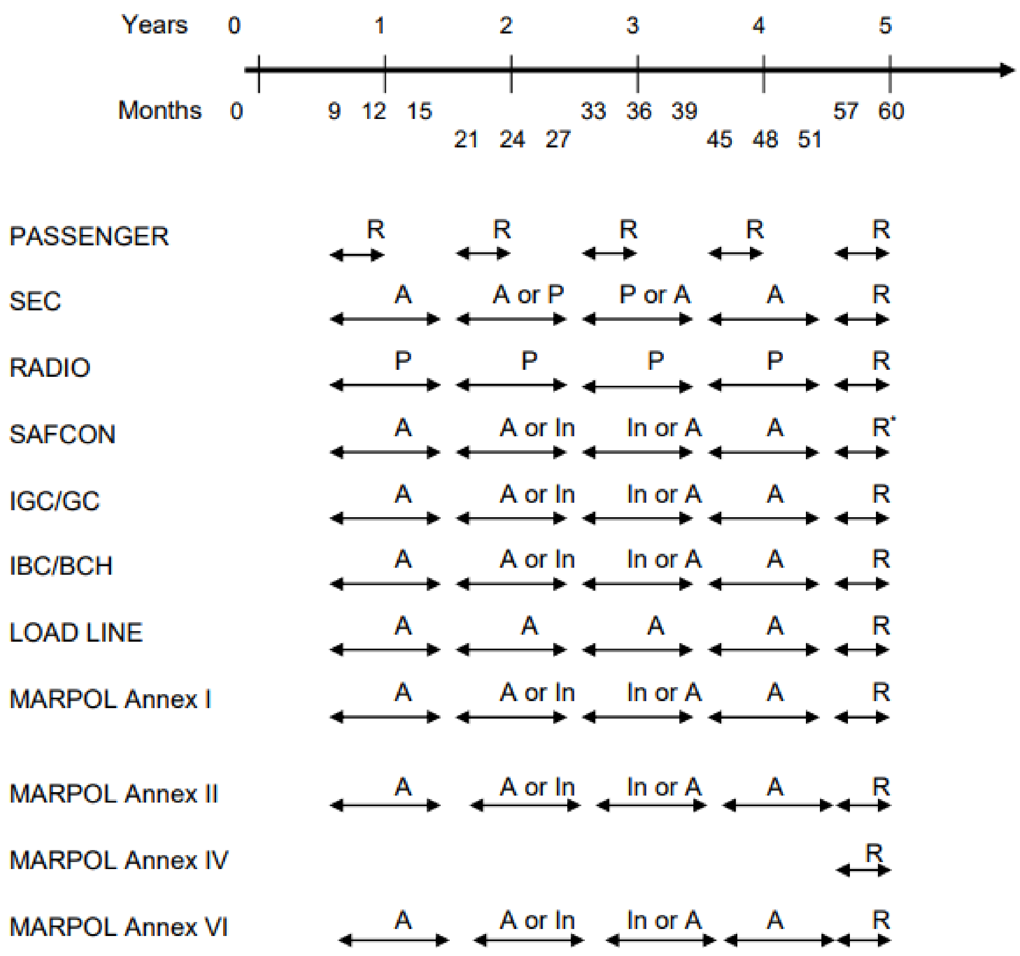
The condition of the propeller shaft must be inspected out every 5 years. The inspection should be carried out in coordination with the complete survey, while the ship is in a dry dock.

Propeller Connection

The condition of the propeller connection must be inspected out every 5 or 15 years. The inspection should be carried out in coordination with the complete survey. Keyless propeller connections are the focus of the survey at 5 years, while flanged propeller connections are also taken into account at 15 years.

Boiler

During every 5 year period, the boilers shall be inspected a minimum of 2 times. Every boiler survey must be conducted no longer than 36 months after the previous one. Every renewal survey shall be accompanied with a boiler survey.



Code of types of survey:

R – Renewal
P – Periodical
In – Intermediate
A – Annual

Figure 5: The time intervals in which the respective surveys must be incorporated during the ship's operations,(IMO, 2011). A distinctive difference can be observed concerning the renewal survey of passenger ships, in contrast with other ship types, as they are required to complete it every 12 months. This can be justified by the much higher amount of people affected by its operation (passengers)

2.2.2 Non-Periodical

Over the course of a ship's operation, occasions might rise where non periodical unscheduled surveys are required to take place by different parties such as the PSC and the maritime companies. Such occasions might be:

- The upgrade of classification documents in cases in which a ship undergoes the change of owner, ship name or flag.
- Failure or suspected failure of any element of any component or system of a ship.
- Surveys required after repairs.
- Port State Control inspections

Throughout a ship's life, unwelcome events might occur which can compromise the safety of the personnel or the environment. These are cases in which structural damage has occurred and a non-periodical survey on time is mandatory to ensure that the vessel is in fit condition to continue performing safely its operations. Following all actions taken to repair possible damage, the surveyor then re-examines the ship's status to ensure that it is in proper condition.

2.3 Port State Control

The Port State control embodies the right and authority of any port and coastal state to ensure through inspections that foreign ships and its equipment are in accordance to international regulations when it comes to general and equipment condition, as well as it being properly manned and operated.

If a ship is surveyed and fails to pass inspection, the PSC can take further action and restrict the vessel's operation until appropriate measures have been taken. Then, after it has undergone all needed actions, the port re-examines the vessel to assure it is safe to resume its operation. In a case in which a ship continues to fail numerous port inspections, severe penalties may be imposed, even banning it from re-entering ports. The extent of the effect of such penalties from an economic perspective (time wasted, cargo condition compromised) is immense and this motivates ship owners to respect the rules.

In 1978, the Hague memorandum was developed by several European countries addressing labor conditions aboard vessels. However, just as it was about to come to effect, an accident causing an immense oil spill in the coast of Brittany (France) due to the grounding VLCC 'Amoco Cadiz' led to the Paris MoU. This MoU expanded on the Hague MoU, covering safety of life at sea, prevention of pollution by ships as well as living and working conditions at sea. The Paris MoU was followed by additional similar treaties from other countries resulting in the nine parties of MoU today.

Paris MoU

Following the political and social outcry around the 'Amoco Cadiz' oil spill, the Paris MoU was signed in 1982 and it consists of 27 maritime administrations. Initially signed by 14 European countries, its current members are: Belgium, Bulgaria, Canada, Croatia, Cyprus, Denmark, Estonia, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Latvia, Lithuania, Malta, the Netherlands, Norway, Poland, Portugal, Romania, the Russian Federation, Slovenia, Spain, Sweden and the United Kingdom.

By categorizing ships according to performance, inspection on higher risk ships is prioritized. Ships are categorized to Low Risk Ships (LRS), Standard Risk Ships (SRS) and High Risk Ships (HRS). Depending on a ship's category, the maximum interval after last inspection is determined. Therefore, while high risk ships have an interval of up to 6 months, low risk ships benefit from a 24-36 month interval. The interval for standard risk ships is 10-12 months. Flag performance is a key factor of the treatment of the vessels in case of detentions. A black flag ship will be banned in case it gets a third detention in a 36 month period, in contrast to the 24 month period of grey flag ships. If an additional detention follows a ban, the ship will be banned again. High risk profile ships get included with chemical & oil tankers, gas carriers, bulk carriers and passenger ships over 12 years old which are demanded to apply a 72 hour notification requirement before arriving in a port.

To clarify the subject of the PSC inspections the major categories and subcategories of deficiencies examined in a survey are presented, as listed by the Paris MoU:

1. Certificates & Documentation
    a. Certificates & Documentation - Ship Certificate
    b. Certificates & Documentation - Crew Certificate
    c. Certificates and Documentation – Document
2. Structural condition
3. Water/Weathertight condition
4. Emergency Systems
5. Radio communication
6. Cargo operations including equipment
7. Fire safety
8. Alarms
9. Working and Living Conditions
10. Safety of Navigation
11. Life-saving appliances
12. Dangerous Goods
13. Propulsion and auxiliary machinery
14. Pollution Prevention
    a-f. Pollution Prevention - MARPOL Annex I through Annex VI
    g. Pollution Prevention - Anti Fouling
    h. Pollution Prevention – Ballast Water

15. ISM
16. ISPS

17. Other
18. MLC, 2006
    a. Minimum requirements to work on a ship
    b. Conditions of employment
    c. Accommodation, recreational facilities, food and catering
    d. Health protection, medical care, social security

Latin America region (Vina del Mar)

Vina del Mar followed in 1992 and the current members involved are Argentina, Brazil, Chile, Colombia, Cuba, Ecuador, Guatemala, Honduras, Mexico, Panama, Peru, Dominican Republic Uruguay and Venezuela.

Asia-Pacific region (Tokyo MoU)

In 1993 the Tokyo MoU, known also as Pacific-Asian MoU, was established. The 20 members: Australia, Canada, Chile, China, Fiji, Hong Kong, Indonesia, Japan, Republic of Korea, Malaysia, Marshall Islands, New Zealand, Papua New Guinea, Peru, Philippines, Russian Federation, Singapore, Thailand, Vanuatu and Vietnam. As is the case with Paris MoU, Tokyo MoU also categorizes ships according to risk with the maximum periods between inspections being slightly lower. For LRS the interval is set to 9-18 months, 5-8 months for SRS and 2-4 for HRS.

Caribbean region (Caribbean MoU)

Formed in 1996, this party's members are Antigua and Barbuda, Aruba, Bahamas, Barbados, Belize, Cayman Islands, Cuba, Curaçao, Grenada, Guyana, Jamaica, the Netherlands, St. Christopher and Nevis, Suriname and Trinidad and Tobago, as well as France as an associate member.

Mediterranean region (Mediterranean MoU)

Formed in 1997, it was signed eight Countries: Algeria, Cyprus, Egypt, Israel, Malta, Morocco, Tunisia and Turkey. Late 1997 the Mediterranean MoU was signed by Lebanon & in July 1999 by Jordan.

Indian Ocean region (Indian Ocean MoU)

Established in 1998, this party's members are Australia, Eritrea, India, Sudan, South Africa, Tanzania, Mauritius, Sri Lanka, Iran, Kenya, Maldives, Oman, Yemen, France, Bangladesh, Comoros, Mozambique, Seychelles and Myanmar.

Black Sea region (Black Sea MoU)

The Black Sea MoU was formed in 2000 and consists of member states: Bulgaria, Georgia, Romania, Russian Federation, Turkey and Ukraine.

West and Central Africa region (Abuja MoU)

Formed in 1999, the party's full members are Benin, Nigeria, Congo, Senegal, Gabon, Sierra Leone, Ghana, Gambia, Guinea Conakry, Togo and Cote d'Ivoire.

Arab States of the Gulf (Riyadh MoU)

The newest MoU part, formed in 2004 and consists of member states: Oman, UAE, Qatar, Bahrain, Kuwait, and Saudi Arabia.

Port State Control in the United States (USCG)

The US are not a member of any MoU but have assumed a supervisor role in many MoUs and its United States Coast guard performs PSC duties in cooperation with other MoUs.

2.3.1 Databases

Inspection of every ship entering a port is impossible due to time consumed for each inspection and high amount of ships entering ports. Therefore the need arose to prioritize which vessels have a higher risk of having defections and therefore safety measures are needed.

In 1994, USCG addressed the subject of identifying ships, owners, classification societies and flag Administrations which possibly operated below standards set by regulations by performing inventive risk management. On the same course, Qualship 21 a new program coming in effect in 2001, which is still in practice, aims in identifying high quality ships. In addition, the USCG's Port State Control and Environmental Protection Compliance Targeting Matrix is a tool which determines ship risk probability, based on factors associated with a vessel. Such factors are flag state, detention ratio, ship management, vessel history (i.e. time passed since last inspection, involvement in an accident) and ship particulars such as age and ship type.

The ships are categorized in Priority I, II and Non-Priority Vessels through a system which attributes scores based on the factors mentioned. Priority I vessels are not allowed access to a port until a safety control is exercised by PSC. Priority II vessels are not permitted cargo operation until the Sector Officer allows so. Non-Priority Vessels are considered safe bur PSC may perform an inspection at any time.

In this manner, other port states have also adapted the method of having continually updated databases such as SIRENAC, APCIS and EQUASIS to keep track of vessel history and risk, making ship risk assessment more sufficient. Major factors in identifying need of inspection on such databases are:

- Ship age
- Ship flag performance
- Ship owner
- Ship type
- Cargo
- Inspection history
- Ships reported by another authority
- Ships reported by their personnel about working and living conditions
- Ships involved in an accident on their voyage
- Past suspensions

Port State Control inspections shall be performed in timely fashion as any unjustified delays will lead to compensation to the ship owner. PSC surveys can be carried out by port state officers or may be handled by other recognized organizations or inspectors. The surveyor commences with an initial inspection, examining general condition of the vessel. This is followed by checking that all documentation is up to date. This includes certificates for all the equipment and systems of the vessel. If the surveyor is not satisfied with his first impression, he shall continue to a more detailed inspection. Agreements determine when claims of need for a detailed inspection are valid. A complete tour of the ship and inspection of all equipment, machinery, systems and safety mechanisms follows. If any significant deficiencies are identified, the ship will be detained. After all necessary repairs and actions have been taken, the ship’s condition will be re-evaluated by the surveyor and only if the deficiencies have been dealt with, the ship can continue its operations.

2.4 Flag state control

Every merchant ship which operates in international waters is required to be registered to a flag state. Each flag state has fixed conditions and regulations that all ships under its flag are obligated to follow. A ship does not need to be registered under the flag of the nationality of the owner. Any country can be included in the list of flags as long as it possesses the appropriate infrastructure and complies with IMO regulations and methods. The flag state must exercise its jurisdiction and make sure that its vessels follow regulations concerning technical and social matters and every ship is bound by the law of its flag state. In case any ship fails to do so, the country needs to be capable to impose the necessary penalties on the respective vessel. In order for a flag state to be able to follow through these responsibilities, it needs to be able to practice inspections. The flag state must either have the qualified personnel to complete surveys or assign them to a recognized organization. The nature of these surveys is the same as the surveys conducted by the PSC. The inspector must be assured that the inspected vessel carries the necessary documentation and facilities which certify the safety of personnel and pollution prevention measures.

2.4.1 Port State Control vs. Flag State Control

Since the 1920's ship owners are not restricted in the choice the flag under which their merchant ship operates. Application for change of flag may also be requested during the vessel's life or upon transfer of ownership. A ship owner may decide that he wants to avoid regulations or operating costs of his country or even detentions and therefore operate his vessel under a different flag with a more tolerant law and regulations frame. The problem encountered over the last decades was that several flag states opted to enforce lower standards than others in order to attract ship owners and this led to cases where ships operated in low standards. These flags are known as "Flags of convenience". In case the flag state fails to ensure that a ship maintains the necessary standards of operation, the PSC acts as an additional safety measure, protecting the ship's crew and the environment.

3 Risk Based Inspection

3.1 Definitions

3.1.1 Risk

Risk is always a present concern in an economic activity. Specifically, in maritime industry, risk is a factor continuously, and is considered in issues such as the investing of funds, the inspection policy of a shipping company as well as the sea environment itself. *Shipping's significance means that events occurring at ports or along maritime routes can have widespread and profound effects – the six-day West Coast port lockout in 2002 caused by strike action incurred over $5 billion in losses to the American economy (World Economic Forum, 2018).* Decisions are needed to be taken constantly and their risk needs to be measured in some manner.

There are many definitions of risk with the most common considering risk to be the product of the possibility of an undesirable event multiplied by the measurable consequences. Such events can be the failures of equipment in the maritime environment.

$$Risk = Likelihood \times Consequences$$

3.1.2 Likelihood

Likelihood characterizes the probability of an event taking place. In the maritime industry, likelihood indicates the possibility of degradation. Such can be the possibility of cracking developing on a mechanical component. Likelihood can be evaluated in two different ways; qualitative and quantitative. The two approaches are presented in tables 2 & 3.

3.1.3 Consequences

Consequences can be defined as the results of an unwelcome event, be them positive or negative. When examining from a safety aspect, consequences are the negative outcome of an event. In the maritime industry, these consequences most usually are included in one of the following categories:

1. Personnel safety, which varies from minor injury to loss of human life
2. Environmental consequences, which usually indicates pollution caused by an oil spill or the financial cost of the process which follows it to confine it and eventually remove it.
3. Economic consequences, which reveal the expenses in units of money required to deal with the unwelcome event

As is the case with likelihood, consequences can also be evaluated in a qualitative or quantitative approach. When determining and examining consequence, each one accounted should be measured and examined separately due to the different types of natures. The two approaches are presented in tables 4, 5 & 6.

Table 2: Quantitative Frequency Index [MSC. Circ. 1023]

Frequency Index			
FI	FREQUENCY	DEFINITION	F (per ship year)
7	Frequent	Likely to occur once per month on one ship	10
5	Reasonably probable	Likely to occur once per year in a fleet of 10 ships, i.e. likely to occur a few times during the ship's life	0.1
3	Remote	Likely to occur once per year in a fleet of 1000 ships, i.e. likely to occur in the total life of several similar ships	10^{-3}
1	Extremely remote	Likely to occur once in the lifetime (20 years) of a world fleet of 5000 ships.	10^{-5}

Table 3: Qualitative Frequency Index (HSE, 2001)

ACCIDENT FREQUENCY	OCCURRENCE (During operational life considering all instances of the system)
Frequent	Likely to be continually experienced
Probable	Likely to occur often
Occasional	Likely to occur several times
Remote	Likely to occur some time
Improbable	Unlikely, but may exceptionally occur
Incredible	Extremely unlikely that the event will occur at all, given the assumptions recorded about the domain and the system

Table 4: USCG Consequences Categories Index (HSE, 2001)

Level of Effect	Types of Effects*			
	Safety/Health	Equipment/Property	Mission Interruption	Environmental
A	An injury or illness results in a fatality or pemanent total disability	The cost of reportable property damage is $1,000,000 or more	Vessel/base is unable to respond to accomplish critical missions	Substantial offsite impact (ocean life effects or offsite health effects) extending beyond the local area
B	Any injury and/or illness results in partial disability Five or more people are inpatient hospitalized	The cost of property damage is $200,000 or more, but less than $1,000,000	Major impact on ability of vessel/base to rapidly accomplish critical missions Significant command attention	Major local area/ offsite impact (ocean life effects or offsite health effects)
C	A nonfatal injury or illness results in loss of time from work for four or more work/ duty days	The cost of property damage is $10,000 or more, but less than $200,000	Moderate impact on ability of vessel/base to rapidly accomplish critical missions Limited capabilities, but able to respond if needed	Significant local area/ offsite impact (enough for an international treaty violation, community alert, or awareness)
D	A nonfatal injury or illness occurs that does not meet the criteria above A person is overboard, an accidental firearms discharge occurs, or an electric shock occurs, none of which meets the criteria of a higher classification	The cost of property damage is less than $10,000	Minor impact on ability of vessel/base to rapidly accomplish critical missions Operational nuisance	Vessel/onsite release of a substance with minor/no offsite effects Possible personnel exposure

Table 5: Severity Categories Index in Quantitative approach (HSE, 2001)

SI	SEVERITY	EFFECTS ON HUMAN SAFETY	EFFECTS ON SHIP	S (fatalities)
1	Minor	Single or minor injuries	Local equipment damage	0.01
2	Significant	Multiple or severe injuries	Non-severe ship damage	0.1
3	Severe	Single fatality or multiple severe injuries	Severe casualty	1
4	Catastrophic	Multiple fatalities	Total loss	10

Table 6: Severity Categories Index in Qualitative approach (HSE, 2001)

CATEGORY	DEFINITION
Catastrophic	Multiple deaths
Critical	A single death; and/or multiple severe injuries or severe occupational illnesses
Marginal	A single severe injury or occupational illness; and/or multiple minor injuries or minor occupational illness
Negligible	At most a single minor injury or minor occupational illness

3.1.4 Hazard

Hazard is the presence of a situation or a phenomenon which has the potential to lead to an undesirable event which is accompanied by unfavorable consequences such as those mentioned above. Hazard should not be confused for likelihood as it does not translate to possibility but solely the potential of undesirable consequences.

3.1.5 Risk Estimation

All industries grasp the concept that their activities are accompanied with risk. The need for risk estimation therefore arises in order to identify processes or installations with high risk and pursuit actions which can reduce the risk or other safest ways to achieve the same goal. It is common practice for risk to be presented via a "risk matrix" which uses two axes; the two parameters of risk, likelihood and consequences, to measure risk. There is a variety of alternative risk matrix forms. *An alternative, more up-to-date approach is given in the draft international standard 17776 (ISO 1999). This provides a 5 x 5 risk matrix with consequence and likelihood categories that are easier for many people to interpret* (DNV/HSE, 2001). A similar risk matrix is presented in figure 7. Likelihood of the event is presented on the vertical axis and consequences on the horizontal axis. Each event's likelihood and consequences are ranked from 1 to 5 and their risk is then evaluated from the matrix. Level of risk is higher on the upper right "red zone" and lower on the lower left "green zone".

- Green color depicts acceptable risk as either likelihood of failure is low, consequences are minor or both. Extra measures may be taken to ensure that risk is kept at this level.
- Yellow depicts medium risk. Measures are needed to avoid reaching high risk situations
- A risk matrix may also have an orange are which depicts medium-high risk and measures are necessary to avoid high risk situations
- Red depicts high risk situations and measures are needed to be taken in order to reduce either the likelihood or the potential consequences until risk reaches an acceptable level.

Table 7: Risk matrix - Information structuring and risk-based inspection for the marine oil pipelines (Bernard Kamsu-Foguem 2016)

PoF Ranking	PoF Description	A	B	C	D	E
5	(1) In a small population, one or more failures can be expected annually. (2) Failure has occurred several times a year in the location.	YELLOW	RED	RED	RED	RED
4	(1) In a large population, one or more failures can be expected annually. (2) Failure has occurred several times a year in operating company.	YELLOW	YELLOW	RED	RED	RED
3	(1) Several failures may occur during the life of the installation for a system comprising a small number of components. (2) Failure has occurred in the operating company.	GREEN	YELLOW	YELLOW	RED	RED
2	(1) Several failures may occur during the life of the installation for a system comprising a large number of components. (2) Failure has occurred in industry.	GREEN	GREEN	YELLOW	YELLOW	RED
1	(1) Several failures may occur during the life of the installation for a system comprising a large number of components. (2) Failure has occurred in industry.	GREEN	GREEN	GREEN	YELLOW	YELLOW
CoF Types	Safety	No Injury	Minor Injury Absence < 2 days	Major Injury Absence > 2 days	Single Fatality	Multiple Fatalities
	Envirnoment	No pollution	Minor local effect. Can be cleaned up easily.	Significant local effect. Will take more than 1 man week to remove.	Pollution has significant effect upon the surrounding ecosystem (e.g. population of birds or fish).	Pollution that can cause massive and irreparable damage to ecosystem.
	Business	No downtime or asset damage	< € 10.000 damage or downtime < one shift	< € 100.000 damage or downtime < 4 shifts	< € 1.000.000 damage or downtime < one month	< € 10.000.000 damage or downtime one year
CoF Ranking		A	B	C	D	E

3.2 Formal Safety Assessment

3.2.1 Introduction

"Formal Safety Assessment (FSA) is a rational and systematic process for assessing the risks relating to maritime safety and protection of the marine environment and for evaluating the costs and benefits of IMO's options for reducing these risks" (IMO, 2002). FSA is a tool used in evaluation potential new regulations aiming in safety enhancement and environmental pollution prevention. A FSA additionally examines the harmony of operation and technical issues. FSA are followed through by a Member Government or a consultative organization and propose adjustments or different routes to reduce risk. The FSA process is divided in the following 5 steps (Figure 6):

1. Hazard Identification
2. Risk Assessment
3. Risk Control Options
4. Cost Benefit Analysis
5. Decision Making

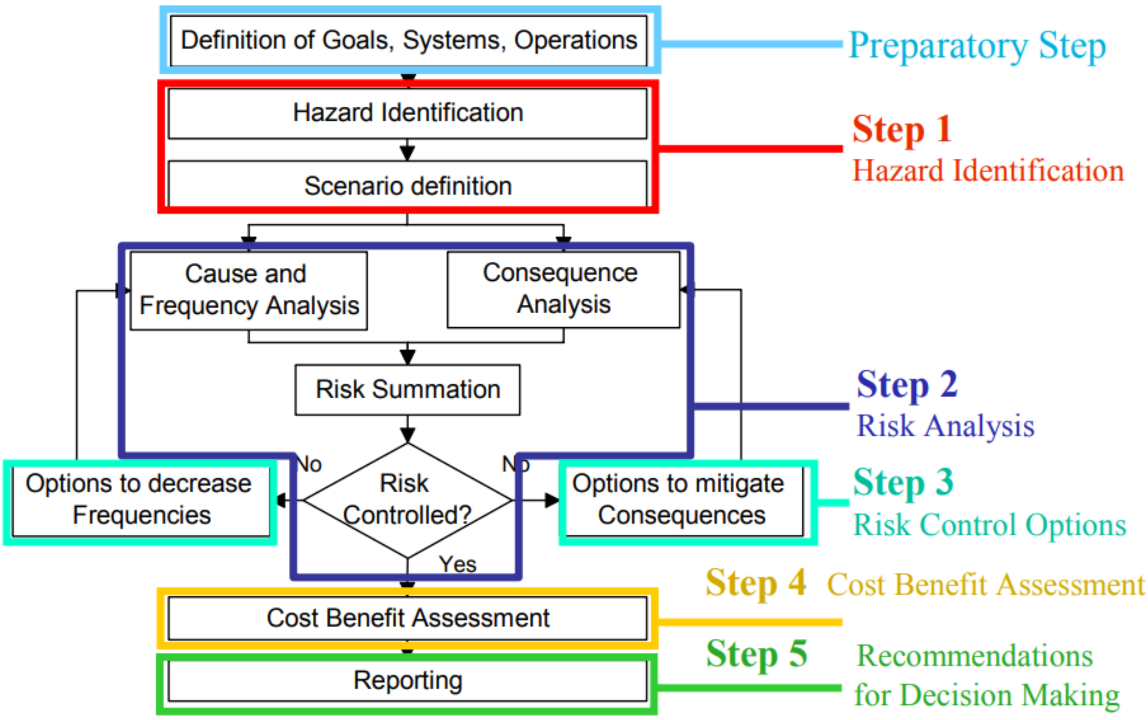


Figure 6: FSA methodology (DNV, 2003).

3.2.2 Hazard Identification (HAZID) (Step 1)

Identifying all hazards is crucial in evaluating risk, as neglecting one might jeopardize the whole procedure and the effectiveness of the risk control decisions. All hazards need to be identified and evaluated. The system is broken down to subcomponents in order to make hazard identification easier and then the whole process is usually based on the experts' judgment with a qualitative approach being typical.

Hazard identification techniques, although they may differ, optimally should embody some essential characteristics. The process needs to be creative, having the potential in recognizing hazards which might not be possible without the FSA. Additionally, the process needs to set a distinct structure of work, examining the situation from a wide perspective, not overlooking unnoticeable threats. Furthermore, the history of accidents needs to be taken into account and analyzed as it holds information of certain hazards. In the end, a FSA needs to be clear about hazards which may have been left out for any reasons. Five popular techniques of hazard identification are presented:

- Hazard review
- Hazard checklists
- Hazard Operability
- Failure models, effects and criticality analysis
- Structured what-if checklist

<u>Hazard Review</u>

A qualitative approach based on previous accidents, experience and assessment, which utilizes a series of guidelines. The presence of an expert is not mandatory and the technique may be implemented by one person. The simplicity of the technique allows it to be performed at low-cost and without a large amount of information being a necessity.

<u>Hazard Checklists</u>

This narrow method involves completing a well defined safety questionnaire which examines a wide range of safety concerns aiming to collect crucial information. The method does not have synergy with a brainstorming process but is aiming towards the prevention of accidents similar to previous ones. Therefore, it is best suited in recognizing specific hazards in some industries.

Hazard Operability (HAZOP)

This technique involves a group of experts, under the leadership of a supervisor, examining possible anomalies of all recognizable sub-systems compared to the initial designs. The whole method utilizes guidelines. The next step consists of a process of attempting to conceive the range of consequences and how additional safety measures might alter them. Additional strengths of this method are that it is widely used, that it relies on group considerations and thorough brainstorming and therefore its capabilities and limitations are familiar and that it can be effective for technical faults as well as human errors. On the contrary, the weak point of this method is that it relies on the abilities of the experts undertaking it and that it is based on standard hazards. An example of HAZOP analysis is depicted in Table 8.

Failure models, effects and criticality analysis (FMECA)

This method attempts to project failure modes. The critical components are identified and the consequences of their failure are evaluated. It can be characterized as a straight-forward, low-cost method which is widely adopted. It must be mentioned however that it does not take into consideration the human error parameter which is significant in safety issues.

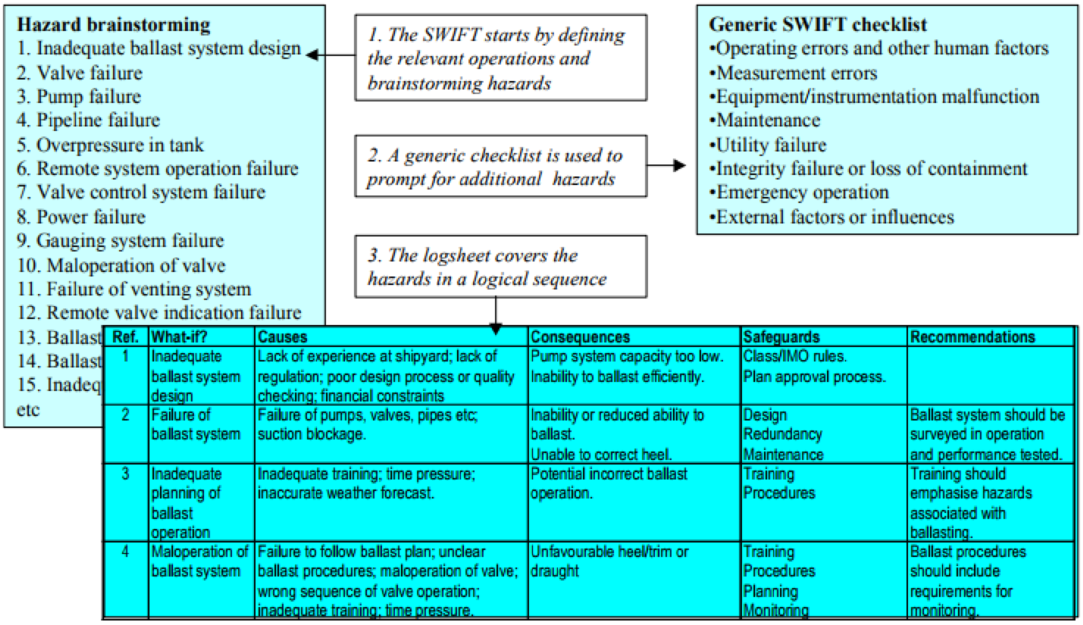
Structured what-if checklist (SWIFT)

SWIFT is another brainstorming process of experts under the supervision of a specialist, as is the case with HAZOP. It faces the same issues of the HAZOP method in the manner of its effectiveness but on the opposing hand it is a versatile approach. A SWIFT example is depicted in Table 9.

Table 8: Example of HAZOP Analysis (American Bureau of Shipping, 2003).

Hazard and Operability Analysis of the Vessel's Compressed Air System						
Item	*Deviation*	*Causes*	*Consequences*	*Safeguards*	*Risk Ranking (Consequence, Likelihood)*	*Recommendations*
1. Intel Line for the Compressor						
1.1	High flow		No mishaps of interest			
1.2	Low/no flow	Plugging of filter or piping (especially at air intake) Rainwater accumulation in the line and potential for freeze-up	Inefficient compressor operation, leading to excessive energy use and possible compressor damage Low/no air flow to equipment and tools, leading to production inefficiencies and possibly outages	Pressure/vacuum gauge between the compressor and the intake filter Periodic replacement of the filter Rain cap and screen at the air intake	Medium Risk (Consequence: Medium, Likelihood: Medium)	Make checking the pressure gauge reading part of someone's daily rounds OR Replace the local gauge with a low pressure switch that alarms in a manned area

Table 9: Example of SWIFT of Ballast System (HSE, 2001).



Ref.	What-if?	Causes	Consequences	Safeguards	Recommendations
1	Inadequate ballast system design	Lack of experience at shipyard; lack of regulation; poor design process or quality checking; financial constraints	Pump system capacity too low. Inability to ballast efficiently.	Class/IMO rules. Plan approval process.	
2	Failure of ballast system	Failure of pumps, valves, pipes etc; suction blockage.	Inability or reduced ability to ballast. Unable to correct heel.	Design Redundancy Maintenance	Ballast system should be surveyed in operation and performance tested.
3	Inadequate planning of ballast operation	Inadequate training; time pressure; inaccurate weather forecast.	Potential incorrect ballast operation.	Training Procedures	Training should emphasise hazards associated with ballasting.
4	Maloperation of ballast system	Failure to follow ballast plan; unclear ballast procedures; maloperation of valve; wrong sequence of valve operation; inadequate training; time pressure.	Unfavourable heel/trim or draught	Training Procedures Planning Monitoring	Ballast procedures should include requirements for monitoring.

3.2.3 Risk Assessment (Step 2)

Once the first step is concluded and the potential hazards have been successfully identified and analyzed, the risk can be defined in the second step which is risk assessment. Risk assessment is categorized in three approaches

- Qualitative (Q)
- Semi-Quantitative (SQ)
- Quantitative (QRA)

The most distinct difference among them is that each method requires different form of inputs and returns a specific form of output. Risk is the product of likelihood and consequence and therefore the nature of these two parameters defines which method is best suited. The selection additionally depends on magnitude and complexity of the problem as well as the level of risk. Qualitative approach is well-suited for simple low risk problems and contrariwise.

<u>Qualitative method</u>

This method requires some kind of estimation for likelihood and the consequences. The distinctive difference between this and the other methods is that the estimation is not bound to be presented in a numerical form in this case. A numeric estimation can be units of money, lives lost or time period whereas non-numerical estimation can be descriptions such as “high chance” or “total failure”. The decision of the nature of the estimation is based on the information provided for each problem as well as the skill of the person performing the task. Depending on the form of the input, such will be the form of the results of the method. Some common qualitative risk assessment methods are:

Failure Modes and Effects Analysis (FMEA)

This systematic and comprehensive method is appropriate for well-defined systems of electrical or mechanical nature. The failure modes of the various components and then the possible consequences are identified. It is a method widely used, which can be performed by a single analyst. An example of FMEA is depicted in Table 10.

Table 10: Example Extract from an FMEA Work Sheet (HSE, 2001).

Filling ballast tanks under gravity							
Ref.	**System /Equip. Failure**	**Cause**	**Effect**	**Detection**	**Mitigation-Compensation-System Response-Safeguards**	**Overall assessment**	**Overall criticality**
1BF	Sea Chest	1. Blocked	Tanks do not fill. Reduced stability, change of heel/trim increased hull stresses	* Valve position indicators. * Ballast tank level radar/sounding system. * If severe, angle of heel/trim.	i) Clean chest with steam. ii) Redundancy 3 other sea chests	In a worst case where failure was not acted upon quickly then a degraded state could arise where the ballasting operation of several tanks could be affected	D
1BF	Sea Chest	2. Loss of sea chest grid integrity.	Ingress of foreign bodies possible blockage of control valves and suction piping. Tanks do not fill. Build up of debris in system. Reduced stability, change of heel/trim increased hull stresses	* Valve position indicators. * Ballast tank level radar/sounding system. * If severe, angle of heel/trim.	i) Clean chest with steam. ii) Redundancy 3 other sea chests	In a worst case where failure was not acted upon quickly then a degraded state could arise where the ballasting operation of several tanks could be affected	D
2BF	Sea Chest	1. Partial Blockage	Reduced filling rate.	* Valve position indicator. * Ballast tank level radar/sounding system.	i) Clean chest with steam ii) Redundancy 3 other sea chests	Overall effect considered incipient due to detection ability and redundancy	I
3BF	Sea Chest	1. Leak at sea chest	Loss of ballast control in affected tank. Change of heel/trim	* Valve position indicator. * Ballast tank level radar/sounding system.	i) Continuously pumped to maintain correct level. ii) Isolate with sea chest blanks. iii) Equalises to exterior sea height in affected tank.	Loss of control in a tank is considered as degraded	D

Risk Matrix

This method was described in section 3.1.5.

Predefined value matrix

This method uses three parameters; resource value, vulnerability and threats. The parameters are given a range of values based on the specific problem, with higher values representing the more unfavorable situations. As shown in Table 11, a value for risk is produced.

Table 11: Predefined values matrix (Segudovic, 2006)

	Threat	0			1			2		
	Vulnerability	**0**	**1**	**2**	**0**	**1**	**2**	**0**	**1**	**2**
Resource Value	**0**	0	1	2	1	2	3	2	3	4
	1	1	2	3	2	3	4	3	4	5
	2	2	3	4	3	4	5	4	5	6
	3	3	4	5	4	5	6	5	6	7
	4	4	5	6	5	6	7	6	7	8

Quantitative method

High risk profile situations require a quantitative approach. Failure modes are identified and probability of failure of the various components is estimated on an annual or lifetime failure probability. Consequences are also given specific values depending on the nature of the failure, as mentioned in section 3.1.3.

There are different ways to approach likelihood estimation:

Historical Accident frequency data

Information of past accidents or near accidents is utilized to estimate likelihood. It is a simple process which cannot however be performed if the necessary information is not available and can only be used on existing technology.

Fault Tree Analysis (FTA)

In this method an incident is analyzed in the simplest causes possible. This method includes the human error factor. The method utilizes past information as well as the human judgment and aims to achieve an all-around understanding of the potential accidents.

Simulation

This method uses simulation models to estimate likelihood of accidents.

Event Tree Analysis (ETA)

In this method an initiating event is branched into following events (usually an event is followed by two branches, a Yes and a No branch) all the way through all the possible final events. For the final events probability is given based on the probability of each event following up to it.

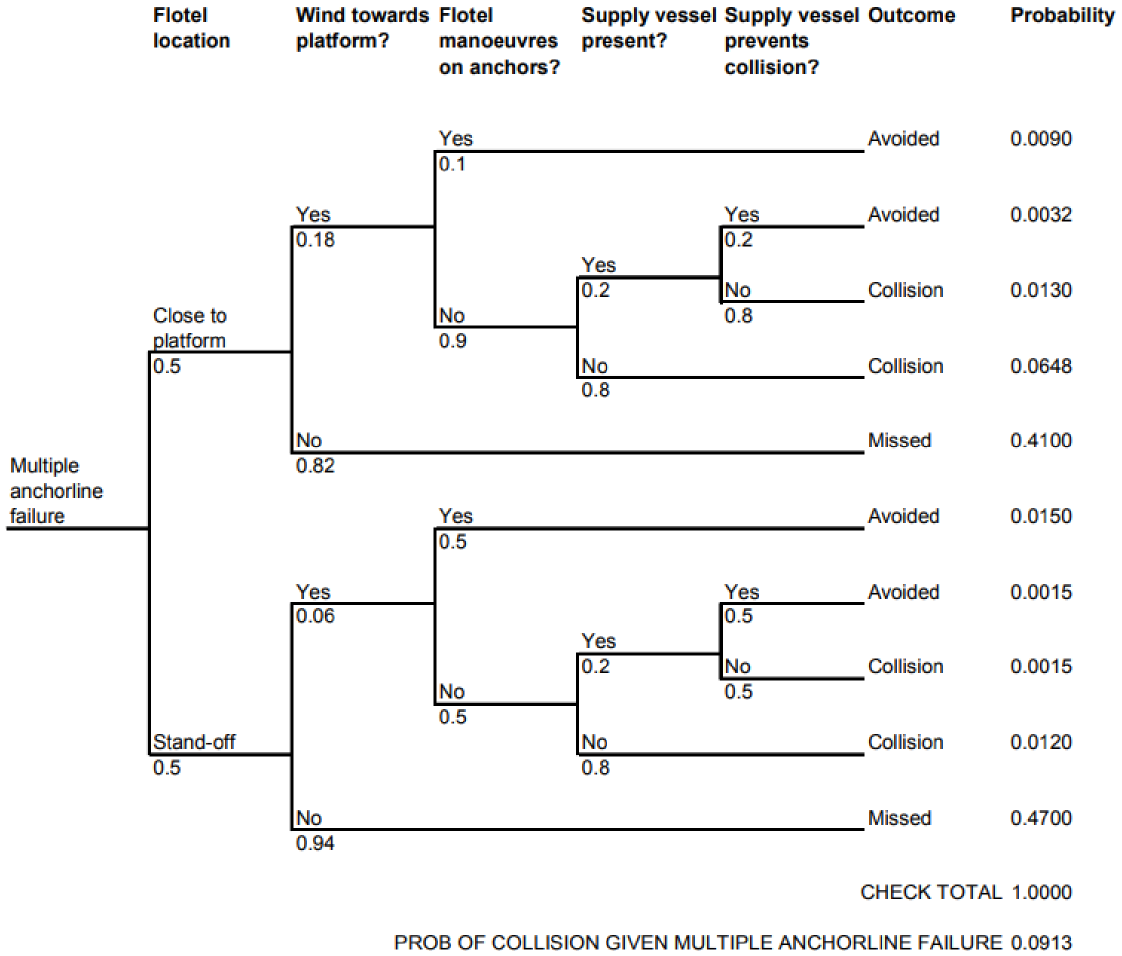


Figure 7: Event Tree Analysis of Flotel-Platform Collision Probability (OCB/Technica 1988)

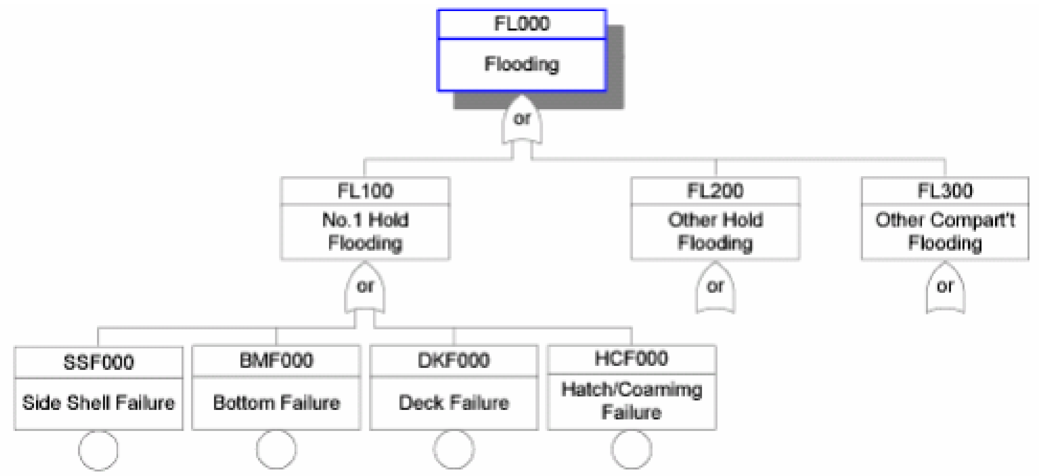


Figure 8: Fault Tree (Kontovas, 2005).

Human reliability analysis

This method aims to produce input for use in fault tree analysis or event tree analysis which derives from the modeling of the influence of human error in accidents.

Judgment evaluation

This method utilizes the judgment acquired from experienced work force. This method is best used in simple scenarios or in cases where no other approach is well suited.

Bayesian Network (BN)

Bayesian networks (BN), also known as belief networks (or Bayes nets for short), belong to the family of probabilistic graphical models (GMs). These graphical structures are used to represent knowledge about an uncertain domain. In particular, each node in the graph represents a random variable, while the edges between the nodes represent probabilistic dependencies among the corresponding random variables. These conditional dependencies in the graph are often estimated by using known statistical and computational methods. Hence, BNs combine principles from graph theory, probability theory, computer science, and statistics. (Ben-Gal I. Bayesian Networks, 2008 .)

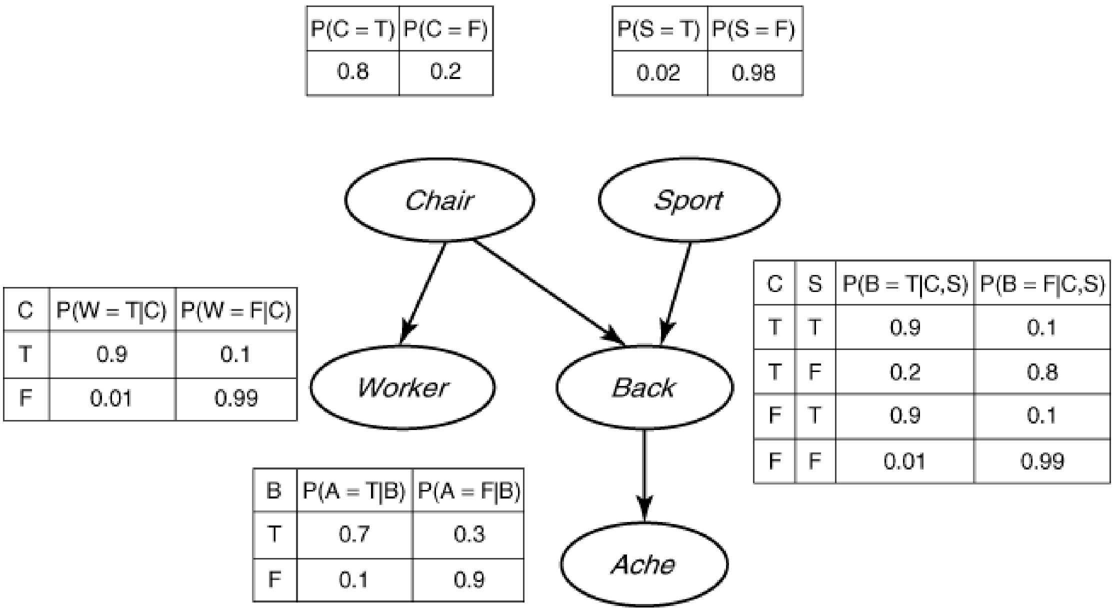


Figure 9: Bayesian Network example (Ben-Gal I. et al., 2007)

A quantitative approach will be more efficient if more than one of these methods are utilized. Solid assessment of the consequences is integral to properly estimating risk. Every FSA has tools at its disposal such as experts and work force judgment, event & fault tree analysis and simulations. Additionally, examining past accidents or near accidents can help the understanding of potential hazards as well as estimating likelihood and the range of consequences, if the historical database is sufficient. This information is also helpful in gaining perspective for the actions needed to enhance safety as well as applying a preemptive approach which is integral for FSAs.

3.2.4 Risk Control Options (Step 3)

Once risk estimation has been established in the second step of an FSA, the next phase requires the promotion of safety measures. Countermeasures are considered which aim in reducing the likelihood of failure modes, the extent of the consequences or both. The measures proposed might be changes applicable on the procedures, the equipment or the personnel. To form an improved perspective of the different available actions, a chain of events technique helps break down a situation into all the smaller steps which might lead to an accident and then measures can be conceived for the separate smaller stages. Once this process is through, a repetition of the risk assessment is required in order to verify that the measures conceived are sufficient in reducing risk to acceptable levels. If not, new risk control options need to be pursued.

3.2.5 Cost Benefit Analysis (Step 4)

In this step the costs and benefits of the risk control options assembled in step 3 are determined and are examined in contrast. The concept of cost includes everything that can be translated in some form of cost such as initial costs (i.e. replacement of equipment), operating costs, training cost, inspections etc. On the other hand, benefits refer to restraint of loss of life, injuries, pollution, structural damage and repairs. The expression of cost and benefit in a strictly determined manner is established with several indicators:

- Gross Cost of Averting a Fatality (GCAF):

$$GCAF = \frac{Cost\ Increase}{Risk\ Reduction}$$

- Net Cost of Averting a Fatality (NCAF):

$$NCAF = \frac{Cost\ Increase - Economic\ Benefits}{Risk\ Reduction}$$

For the NCAF, the various benefits, such as the cost of the accident averted, need to be interpreted in units of money.

In the end of this step the conclusion of whether the measures proposed are rational and advisable is decided. The conclusion of an R.C.O. analysis can be accompanied with the ALARP (As Low As Reasonably Practible) approach of risk, which takes into consideration the resources and means available.

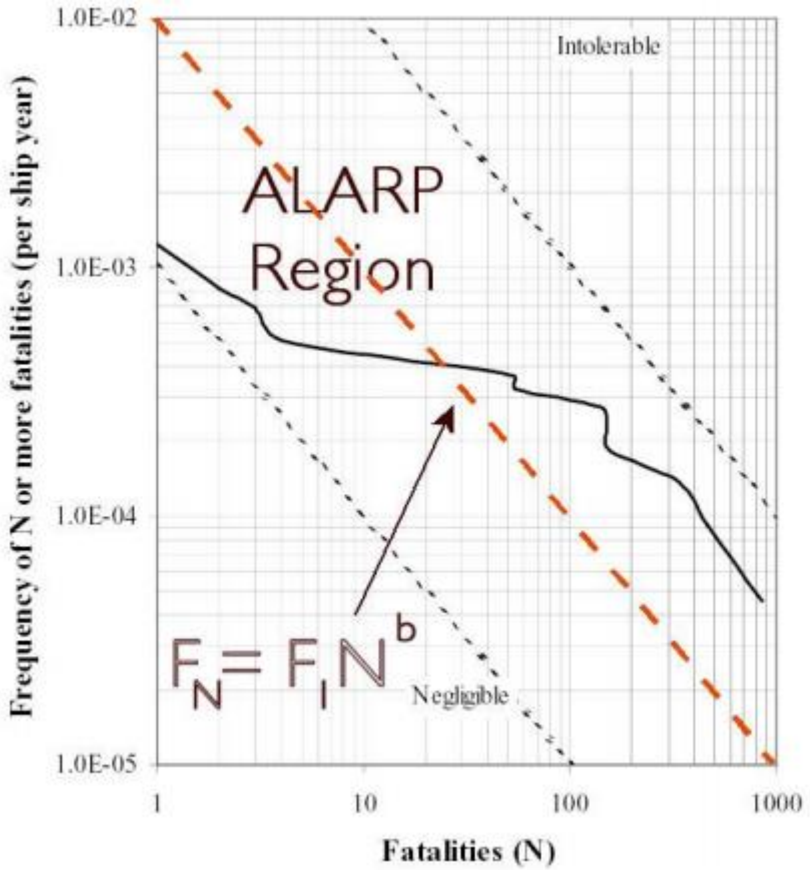


Figure 10: The ALARP methodology is Depicted on an F-N diagram (Kontovas, 2005).The results are separated in three zones; negligible, ALARP and intolerable. The later insists that safety measures need to be taken for the situation to enter the ALARP zone.

3.2.6 Decision Making (Step 5)

Every F.S.A. concludes with several proposals and decisions left to be taken. Decision making weighs some important factors in order to provide productive solutions. First of all, the risk levels must be at an acceptable range. Additionally, the decisions taken shall have a satisfying correlation of the effect of the measures and their cost. Costly propositions with minor progress in risk limitation might not be worth it. The maximum period of time the work force is exposed to hazardous situations, the limit of the risk of serious accidents with a large amount of deaths or serious injuries are elements to be taken into consideration. Operational, social, environmental and political factors play a role in the maritime industry handling of risk.

It is evident that the decision making stage is a complex process which needs to accumulate a plethora of information, weigh different factors whose relation and effect of one on another may not be easy to distinguish and finally, the solution needs to be an efficient one.

3.2.7 RBI Methodology

Inspection policy can be counter efficient depending on its planning approach and utilization. One such approach is to conduct a minimal number of inspections and only replace items after failure, a reactive approach which is objectionable. On the opposite side, high inspection frequency can be costly and inefficient.

Maritime industries have therefore adopted a Risk Based Inspection approach which attempts to optimize the process and results of inspections. RBI methodology aims to do this by prioritizing inspections of high-risk equipment such as the hull, the fuel and ballast tanks, the engine room and the superstructures, while not neglecting at the same time the lower risk components. In this manner, RBI improves the inspecting method and optimizes their frequency, intervening to classical surveys which are not the most advantageous.

The necessity and benefits of mandatory classical surveys carried out by the various organizations (PSC, Flag states, Classification Societies) must not be devalued. Nonetheless, shipping companies have the choice of enhancing safety on their ships by performing fitter inspection methods whenever they feel it necessary.

4 Life-Saving Appliances

Introduction

Since the life-saving appliances become mandatory to be available for everyone on board, many design features and components have changed aiming at the reduction of the risk of injury or death in the event of a marine accident by meeting simultaneously different requirements; demands for larger lifeboat capacity and ease of operation. These changes were derived mainly from serious maritime accidents where many human lives were lost (e.g. Titanic in 1912 and Estonia in 1994). The effectiveness of life-saving appliances depends heavily on good maintenance by the crew and their use in regular drills. The degree of deterioration of the equipment relies mainly on the inspection process. As a result, the inspection ensures the safe operation of the LSA either in a case of an actual evacuation or in a drill.

Types of LSA

The different life-saving appliances may be categorised as follows:

- Individual life-saving appliances;
- Collective life-saving appliances.

The performed analysis is focused only on the collective LSA. As a result, the LSA that are installed in the general cargo vessels and the passenger ships and are selected for further elaboration are presented subsequently:

- Davit launched lifeboats;
- Free-fall lifeboats;
- Davit launched liferafts;
- Marine evacuation systems.

The LSA are analysed into main components whose failure alone, based on the literature and the feedback from LSA manufactures, leads to failure of the LSA.

Marine evacuation systems will be left out due to the nature of their structure which is unaffected from the failure modes examined in this research but is accompanied with other types of hazardous situations.

4.1 Critical Components of LSA examined

4.1.1 Davit launched lifeboats & liferafts

The identified crucial components for the safe operation of these LSA are the following:

- Davits

The davit systems are responsible for bringing a lifeboat/liferaft from a stowed position, to the embarkation and finally lowering it to the launching position (and vice versa for the retrieving of the LSA from sea). Therefore, some maneuvering of the davit such as sliding or rotating (mainly for liferafts) is required in order for an LSA to be launched successfully. In addition, it is responsible for receiving the load of the LSA and the passengers.

The davit systems consist mainly of davit arms, a limit switch, the winch, the fall wires and tricing pennants in some cases. Most lifeboat davit systems consist of two davit arms while the liferaft davits most commonly consist of one davit arm. The winch and the fall wires are referred to separately due to their importance. The davit arm's utility is the davit's main utility which is mentioned above.

The limit switch is a component of the davit system responsible for the speed of recovery of the fall wire. While retrieving the LSA, if the limit switch is not working properly, the fall wire may be recovered with high velocity resulting in some components (such as the sheaves) colliding with the davit and eventually resulting in the snapping of the fall wires.

- Release mechanism

The release mechanism is an integral part of both the davit launched and the free-fall concept. Its purpose is to release the LSA when it is embarked and it is lowered to appropriate height. A significant percentage of the accidents involving LSA is correlated with release mechanism failure. The first release mechanisms were off load systems which were released after the lifeboat was put on sea. A SOLAS requirement for lifeboats on ships built after 1 July 1986 made on load systems mandatory. In the present time, off-load release systems are the exception.

The release mechanism's main subcomponents are the hooks, the operating cables and the control lever. Failures of the hooks and operating cables especially can lead to hazardous repercussions. Lifeboat installations have two hooks, one placed forward and one aft. Liferaft installations have one hook. Most release mechanism related lifeboat accidents involve the involuntary release of one or both hooks which result in the boat being dropped in the sea from high altitude or swinging by one of its hooks. There is a variety of release mechanism designs such as mechanical or hydrostatic release mechanisms, most of which however face the same issues. The accidental release may be caused by corrosion and damage on the hook or operating cables, which can be supported if the hooks are not reset properly, a case which is quite frequent.

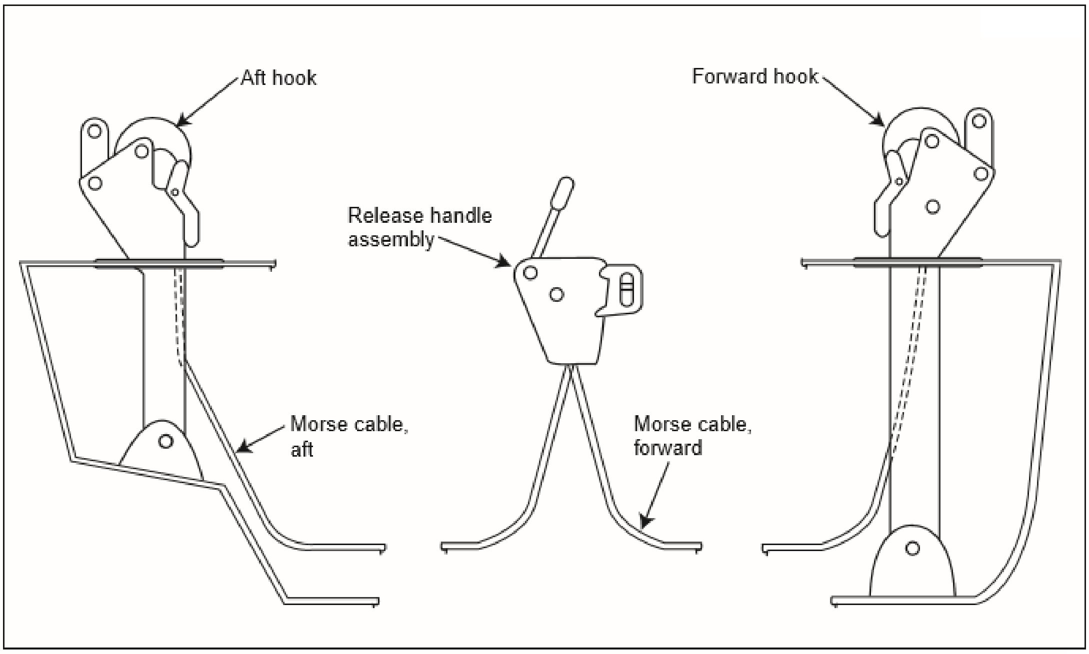


Figure 11: Release mechanism (MAIB, 2001).

- Winch

Winches are an important part of the davit system. Many LSA accidents can be attributed to winch failure. Winch brakes, motors, their safety back-up mechanisms and winch gear systems are the subparts of a winch which are usually connected with these accidents. Failures in the winch brakes or gear system can lead to the inability of moving the LSA to a safe embarkation and then launching position or even the fall of the LSA with high speed on the sea which can either damage crew members onboard. The back-up mechanisms found on some winch models are safety measures for cases such as black-outs. Winches are susceptible to corrosion due to water ingression, fatigue cracking and according to the literature, maintenance is often neglected leading to overuse of oil or grease, incorrect adjustment etc.

- Falls, sheaves & blocks

Falls, sheaves and blocks are found in almost every davit installation and are minor parts whose malfunction leads to failure of safe davit operation. Failure of such parts can lead to failures of fall wires from overloading or impair specific movement of the loaded object.

- Tricing & bowsing

In some davit launched lifeboat installations, the lifeboat is not ready to be boarded in stowed position and must be lowered to an embarkation platform. The lifeboat is being lowered to embarkation level by the davit while the tricing pennants pull it to the desired position in order to be boarded safely. When reaching the desirable position, the blocks are constrained with the help of bowsing tackles and the tricing pennants are then disconnected. This procedure is shown in Figure 12 along with a common davit lifeboat davit arrangement. If the tricing pendants are not working, the lifeboat cannot be boarded. If the bowsing tackles are not available, part of the load received by the davit may be transferred to the tricing pennants which are not designed for such a purpose. Tricing pennant failure can lead to excessive swinging of the boat, a danger for anyone boarding at the moment.

- Lifeboat

Data gathered for inspection reports showcases that on some occasions the LSA on its own is not in condition to be launched. That may vary from damage resulting in loss of water integrity, to the lifeboat not being stowed in stowed position in order to be operational.

- Fall wires

Fall wires along with the hooks are the components which encounter the most severe loads and environment. They are responsible for transferring the LSA load to the davit. Those loads can be amplified significantly in harsh sea state. On top of that, fall wires come across highly corrosive environmental conditions.

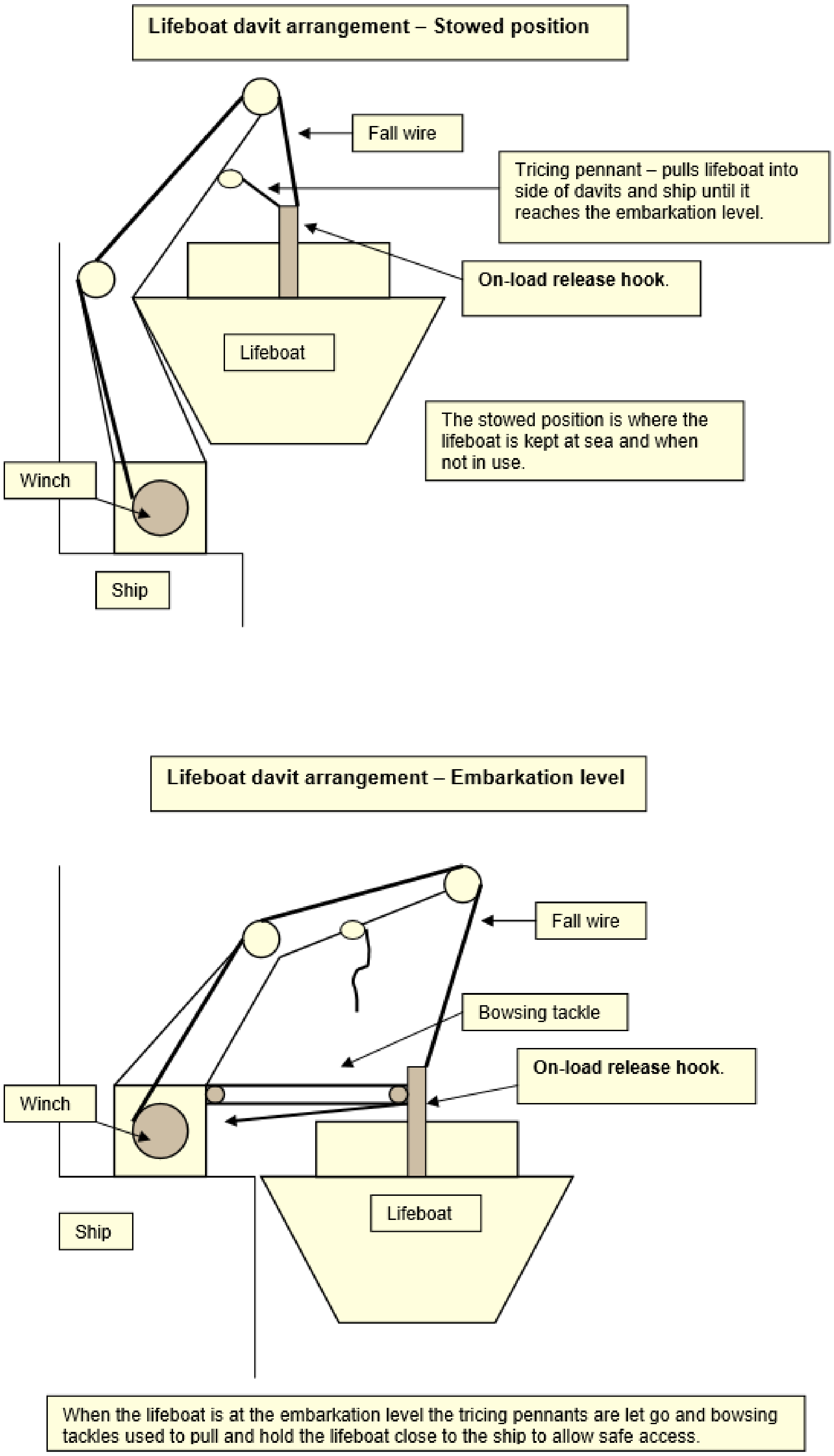


Figure 12: Lifeboat davit arrangement (Ross, 2006)

4.1.2 Free-fall lifeboats

The identified main components for the safe operation of the free-fall lifeboats are the following:

- Davits

Davits in free-fall installations are quite different than davit launched installations. In the free-fall concept, the lifeboat slides on two rails which are part of the davit structure once the hooks have been released. The davit arm's purpose is to help recover the lifeboat from water and in some designs, to be used as a davit launched back-up safety mechanism, in case the lifeboat cannot be launched via the free-fall method. This might happen if there are obstacles blocking the fall (such as containers) or some kind of damage on the free-fall mechanism. For example, the distance between the rails may be altered due to deformation. In a free-fall unit, the lifeboat is always stowed on the davit structure.

- Release mechanism

The release mechanism of the free-fall installations is similar to the davit launched installationin the manner in which it operates. It too consists of the same main sub-components (hooks, operating cables, Control lever). It is important to mention however that accidental release of the hook, even though still hazardous, is not as detrimental as in the davit launched case, due to the rails of the davit which still guide the lifeboat to the same fall as if it were released voluntarily. Nevertheless, there is still the possibility that crew members may not be tied down yet or the existence of an obstacle in the stern of the ship. Hydrostatic release systems are encountered more frequently in free-fall installations.

- Winch

In free-fall systems, a winch is used primarily for retrieving of the lifeboat and with the davit launched back-up safety mechanism which can be found on some free-fall installations. The winches of the free-fall installations face the same problems as the winches in the davit launch installations which are mentioned above in section 4.1.1.

The rest of the significant components (falls, sheaves & blocks, Lifeboat and fall wires) have the same operational characteristics as in the davit launched lifeboats.

4.2 Regulations

The SOLAS regulations concerning the collective life-saving appliances on passenger & cargo ships are described analytically in Chapter III. The principal requirements regarding the number and capacities of collective LSA with respect the selected ship types are presented briefly afterwards.

4.2.1 General Cargo ships (SOLAS-Chapter III-Regulation 31)

Cargo ships shall carry one or more totally enclosed lifeboats of such aggregate capacity on each side of the ship as will accommodate the total number of persons on board. In addition, one or more inflatable or rigid liferafts, of a mass of less than 185 kg and stowed in a position providing for easy side to-side transfer at a single open deck level, and of such aggregate capacity as will accommodate the total number of persons on board. If the liferaft or liferafts are not of a mass of less than 185 kg and stowed in a position providing for easy side-to-side transfer at a single open deck level, the total capacity available on each side shall be sufficient to accommodate the total number of persons on board.

Furthermore, the cargo ships may carry one or more free-fall lifeboats, capable of being free-fall launched over the stern of the ship of such aggregate capacity as will accommodate the total number of persons on board and one or more inflatable or rigid liferafts on each side of the ship, of such aggregate capacity as will accommodate the total number of persons on board. The liferafts on at least one side of the ship shall be served by launching appliances.

Cargo ships of less than 85 m in length shall carry on each side of the ship, one or more inflatable or rigid liferafts of such aggregate capacity as will accommodate the total number of persons on board. Unless the liferafts are of a mass of less than 185 kg and stowed in a position providing for easy side-to-side transfer at a single open deck level, additional liferafts shall be provided so that the total capacity available on each side will accommodate 150% of the total number of persons on board. If the rescue boat is also a totally enclosed lifeboat, it may be included in the aggregate capacity provided that the total capacity available on either side of the ship is at least 150% of the total number of persons on board. Finally, in the event of any one survival craft being lost or rendered unserviceable, there shall be sufficient survival craft available for use on each side, including any which are of a mass of less than 185 kg and stowed in a position providing for easy side.

All survival craft required to provide for abandonment by the total number of persons on board shall be capable of being launched with their full complement of persons and equipment within a period of 10 min from the time the abandon ship signal is given.

4.2.2 Passenger ships (SOLAS-Chapter III-Regulation 21)

Passenger ships engaged on international voyages shall carry partially or totally enclosed lifeboats on each side of such aggregate capacity as will accommodate not less than 50% of the total number of persons on board. In addition, inflatable or rigid shall be carried of such aggregate capacity as will accommodate at least 25% of the total number of persons on board. These liferafts shall be served by at least one launching appliance on each side or equivalent approved appliances capable of being used on both sides.

Passenger ships engaged on short international voyages shall carry partially or totally enclosed lifeboats of such aggregate capacity as will accommodate at least 30% of the total number of persons on board. The lifeboats shall be equally distributed on each side of the ship. In addition, inflatable or rigid liferafts shall be carried of such aggregate capacity that, together with the lifeboat capacity, the survival craft will accommodate the total number of persons on board. The liferafts shall be served by launching appliances equally distributed on each side of the ship and in addition, inflatable or rigid liferafts of such aggregate capacity as will accommodate at least 25% of the total number of persons on board.

A marine evacuation system or systems may be substituted for the equivalent capacity of liferafts and launching appliances. More details regarding the regulations 31 and 21 are summarised in 0A.

4.2.3 Evolution of regulations concerning LSA

Aside from the regulations concerning the availability of LSA on board, additional rules and guidelines surfaced aiming in the enhancement of their safety, with focus given particularly to on-load release systems. Some of the most important recent regulations and guidelines introduced are listed below.

In 2011, SOLAS Regulation III/1.5 (MSC. 317(89)) implemented new requirements involving on-load release mechanism installed on all ships, both old and new constructions, which were to be entered to force beginning in 2013. The cause was the unacceptable amount of casualties and injuries during inspections and drills. The requirements referred to

- The design of the release mechanism in order to provide hook stability
- The locking devices to prevent release due to forces from the hook load
- The hydrostatic interlock mechanism, if present.

In 2015, supplementary restrictions involving the materials of the hooks on the release mechanism were introduced: "*all components of the hook unit, release handle unit, control cables or mechanical operating links and the fixed structural connections in a lifeboat shall be of material corrosion resistant in the marine environment without the need for coatings or galvanizing.*" LSA Code, paragraph 4.4.7.6.9, as amended by resolution MSC.320(89):

In 2017, IMO issued "GUIDELINES ON SAFETY DURING ABANDON SHIP DRILLS USING LIFEBOATS" which focused on frequency as well as the safety manners of the performed drills and highlighted the importance of their organization in a manner through which they would be as beneficial as possible to the competence of the crew members

4.2.4 LSA elements examined in inspections

Concerning the inspections of Life Saving Appliances be that for PSC or classification society initial, periodical and renewal surveys, major elements inspected include:

- All markings leading to muster stations must be in good visible condition.
- All markings relating to access of LSA must be in proper condition.
- All certification is as should be.
- All Manuals, muster stations and instructions are updated and in the required location.
- Condition, provision and stowage of individual and collective LSA is satisfactory.
- Specifically for collective LSA, the surveyor should check the boats, rafts, as well as the equipment related to their operations (launching & recovery) such as release systems, lashes, davits etc.
- Liferafts are easy to transfer to side of ship.
- Examining embarkation arrangements for collective LSA and if possible testing lowering them to embarkation level as well as recovery
- Ensuring that batteries of LSA and flares are not out of date
- All markings on LSA indicating proper usage are in proper condition
- Alarm testing
- Sufficient quantity of LSA (depending on type of ship)

The list of deficiency codes listed by the Paris MoU:

11 - Life saving appliances

- 11101 Lifeboats 11102 Lifeboat inventory
- 11103 Stowage and provision of lifeboats
- 11104 Rescue boats
- 11105 Rescue boat inventory
- 11106 Fast rescue boats
- 11107 Stowage of rescue boats
- 11108 Inflatable liferafts
- 11109 Rigid liferafts
- 11110 Stowage of liferafts
- 11111 Marine evacuation system
- 11112 Launching arrangements for survival craft
- 11113 Launching arrangements for rescue boats
- 11114 Helicopter landing and pick-up area
- 11115 Means of rescue
- 11116 Distress flares
- 11117 Lifebuoys incl. provision and disposition
- 11118 Lifejackets incl. provision and disposition
- 11119 Immersion suits
- 11120 Anti-exposure suits
- 11121 Thermal Protective Aids

- 11122 Radio life-saving appliances
- 11123 Emergency equipment for 2-way comm.
- 11124 Embarkation arrangement survival craft
- 11125 Embarkation arrangements rescue boats
- 11126 Means of recovery of life saving appliances
- 11127 Buoyant apparatus
- 11128 Line-throwing appliance
- 11129 Operational readiness of lifesaving appliances
- 11130 Evaluation, testing and approval
- 11131 On board training and instructions
- 11132 Maintenance and inspections
- 11133 Personal and group survival equipment
- 11134 Operation of Life Saving Appliances
- 11135 Maintenance of Life Saving Appliances
- 11199 Other (life-saving equipment)

4.3 Potential collective LSA arrangements

This section presents potential spatial arrangements of the davit launched lifeboats and the free-fall lifeboats on general cargo ships, always in conjunction with liferafts and rescue boats.

- Cargo ships - Potential Arrangement A (Figure 13)

a) 100% totally enclosed lifeboats SB+PS;

b) 100% liferafts capable of being launched from either side;

c) Additional liferaft if the lifeboats are more than 100m from the bow or stern;

d) Rescue boat.

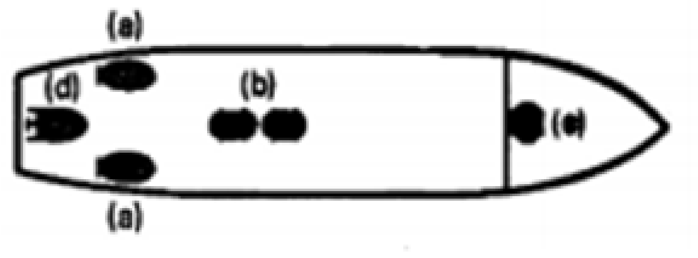


Figure 013: Potential LSA arrangement A

- Cargo ships - Potential Arrangement B (Figure 14)

a) 100% free-fall lifeboat aft;

b) 100% liferafts SB+PS;

c) Rescue boat;

d) Additional liferaft if the lifeboats are more than 100m from the bow or stern.

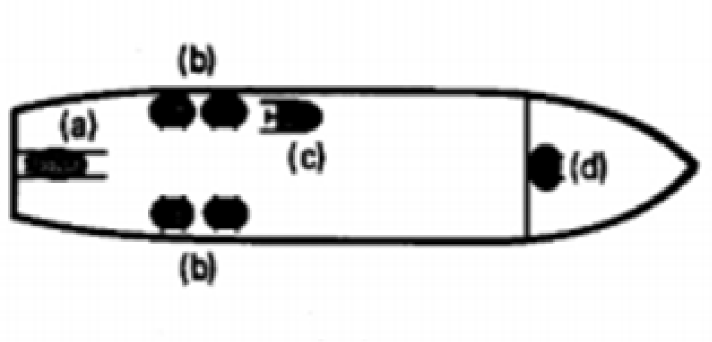


Figure 014: Potential LSA arrangement B

- Cargo ships - Potential Arrangement C for cargo ships with L<85m (Figure 15)

a) 100% liferafts capable of being launched from either side;

b) Rescue boat.

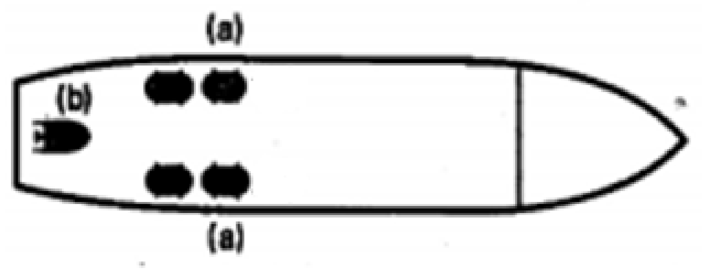


Figure 15: Potential LSA arrangement C

The wide range of passenger capacity in passenger ships leads to a high variety of LSA arrangements which tend to be almost ship specific. LSA on cargo ships on the other hand are intended to carry crew members mainly and therefore common arrangements is more often to be found and identified.

5 Data acquisition and elaboration

This survey and analysis employs data which are collected from Paris MoU completely anonymised and an LSA manufacturing company that volunteered to support this effort with an interest of strengthening the safety regarding the operation of the multiple types of the LSA. The scope of the enquiry was to verify and finalise the structure of the fault trees which are demonstrated in section 6 and to expand the available database involving LSA incidents & accidents and their causes of defect, in order to quantify the respective probabilities of the developed models.

5.1 Data set

Initially, a set of 14,092 records of inspected deficiencies from Paris MoU with respect to LSA for different ship types was elaborated. An overview of the percentage of inspected deficiencies for different life saving appliances is shown in Figure 16. The predominance of deficiencies involving General Cargo ships is evident below.

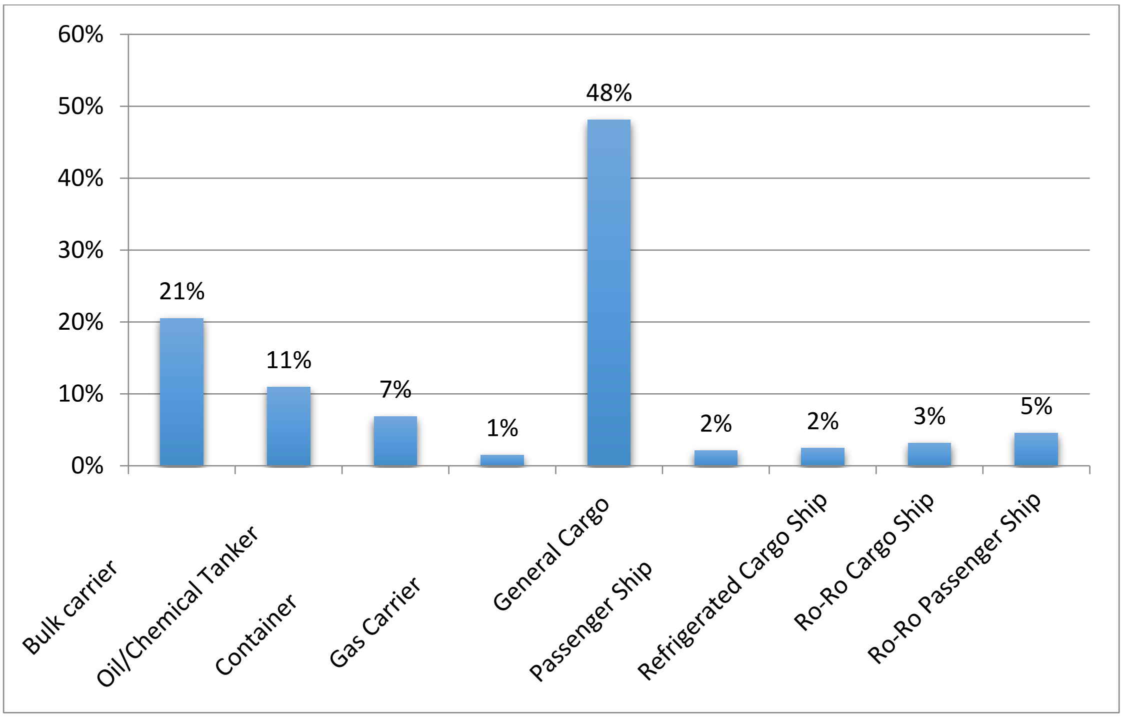


Figure 16: Number of inspected deficiencies per ship type (2011-2013)

A closer look at the data set may allow us to determine which the main defective item categories are. Figure 17 and Figure 18 illustrate the main defective items that have been identified during the inspection process for the general cargo and the passenger ships. 22.1% of the records have been classified as deficiencies concerning the lifeboats, rescue boats and liferafts on the general cargo, whereas these three categories consist of the 25% of the total percentage of deficiencies in passenger ships.

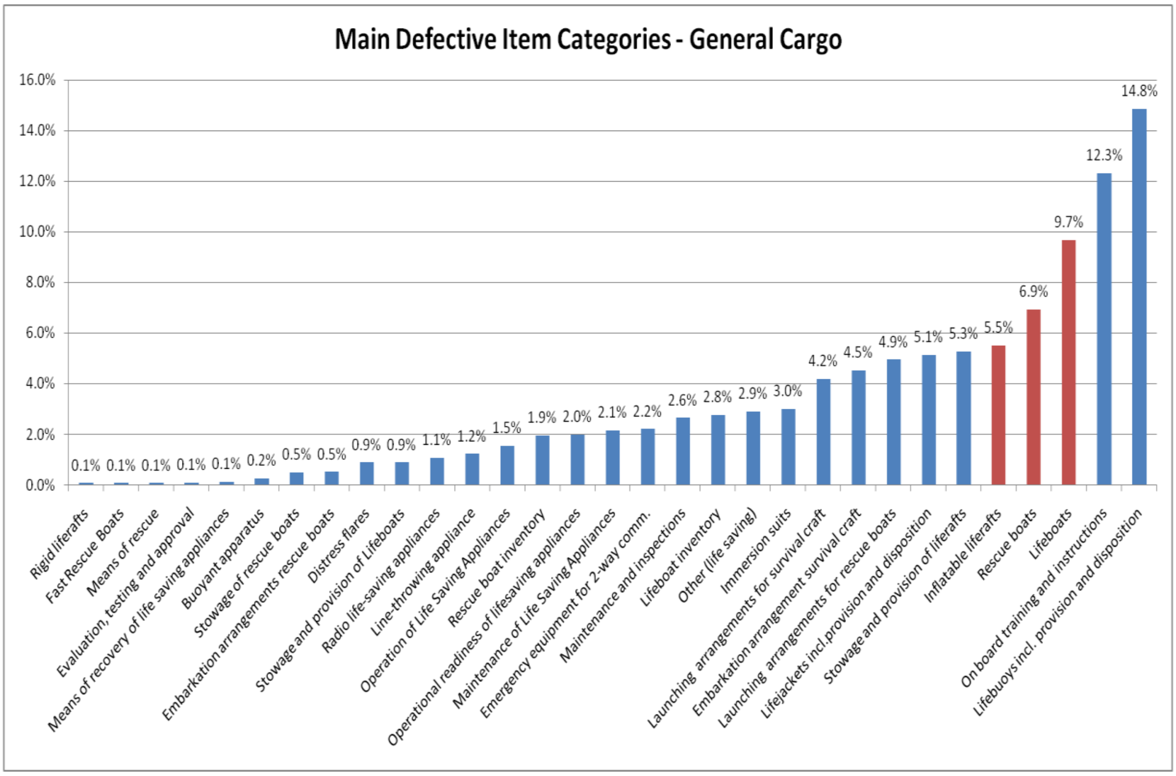


Figure 17: Main defective item categories – General cargo

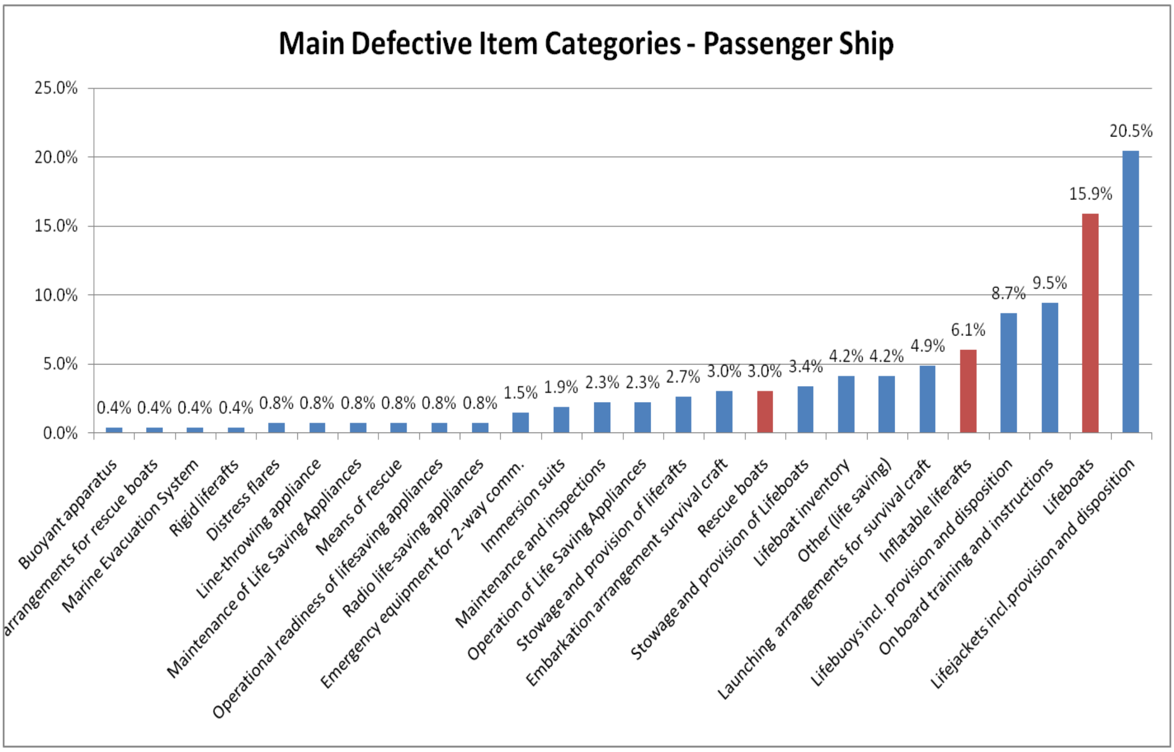


Figure 018: Main defective item categories – Passenger ship

As a result the collective LSA have been identified as key areas of concern regarding the deficiencies during the inspection process of PSC. The next objective is to determine the cause of defect for these LSA. Figure 19 and Figure 20 demonstrate the causes of defect as these have been categorized from PSC with respect to the lifeboats and the liferafts of the general cargo. From these two figures it can easily be concluded that poor maintenance and poor stowage are the most frequent causes of defect for the lifeboats and the liferafts respectively.

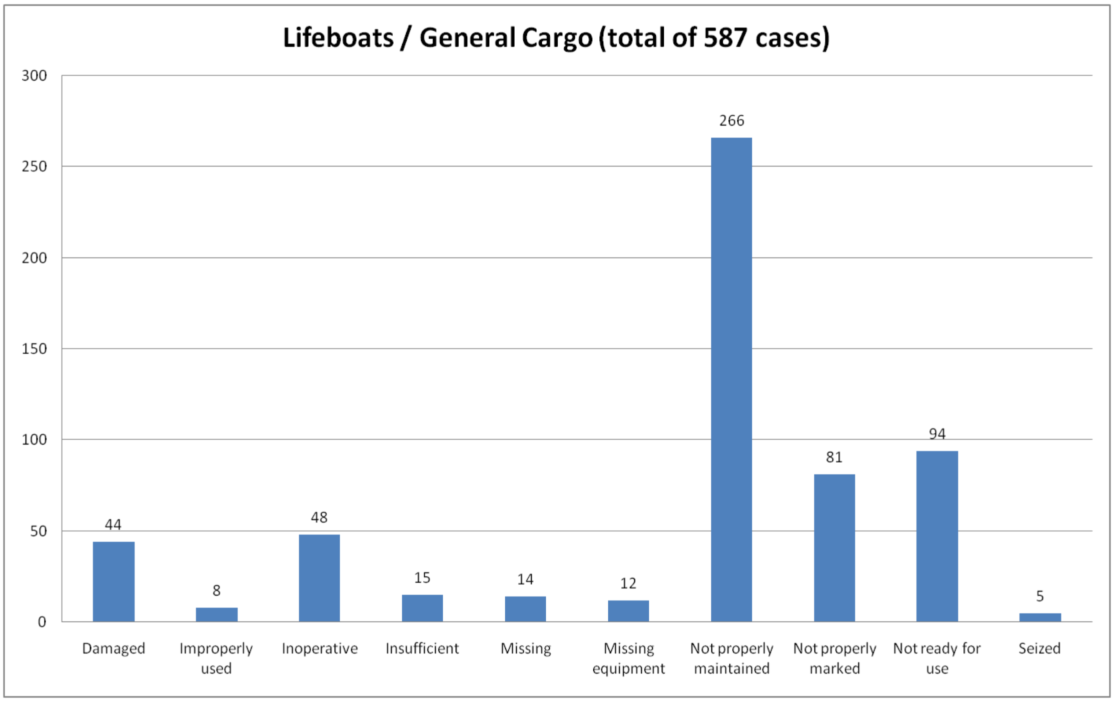


Figure 019: Causes of defect of lifeboats – General cargo

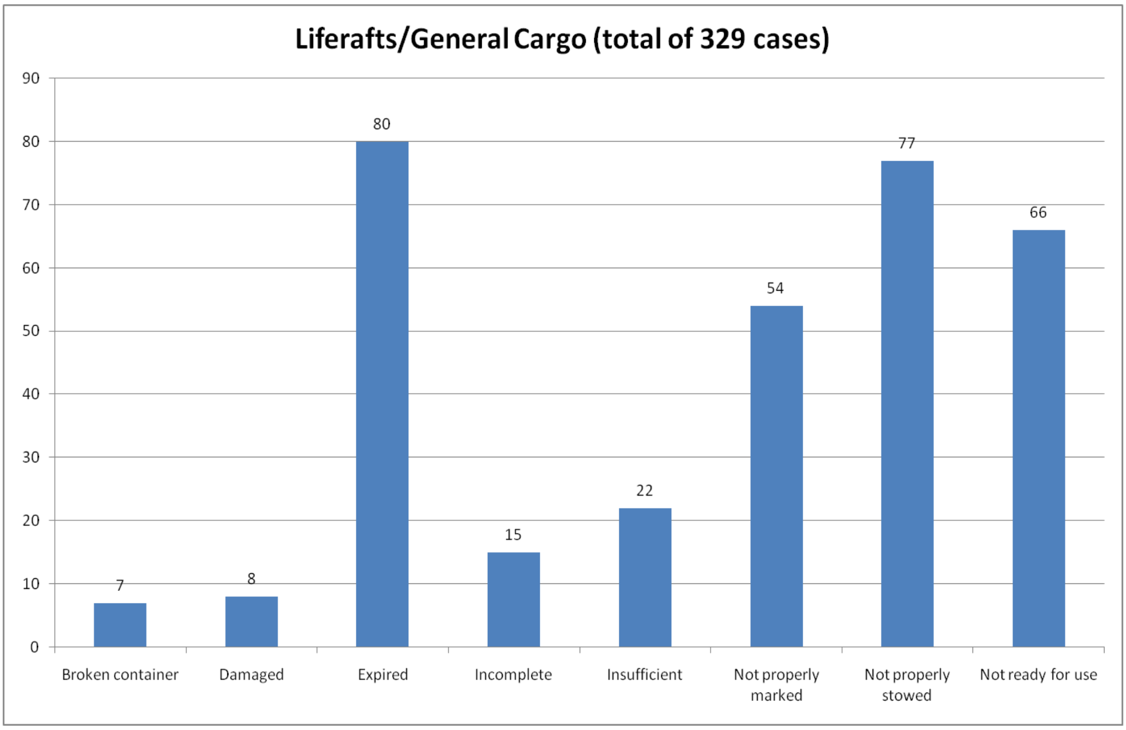


Figure 020: Causes of defect of liferafts – General cargo

The examination of the data at hand by taking ship age as a factor was vital in considering the possibility of discovering possible patterns involving LSA condition. The figures following depict the total number of deficiencies during PSC inspections for ships grouped in 5 years of life intervals

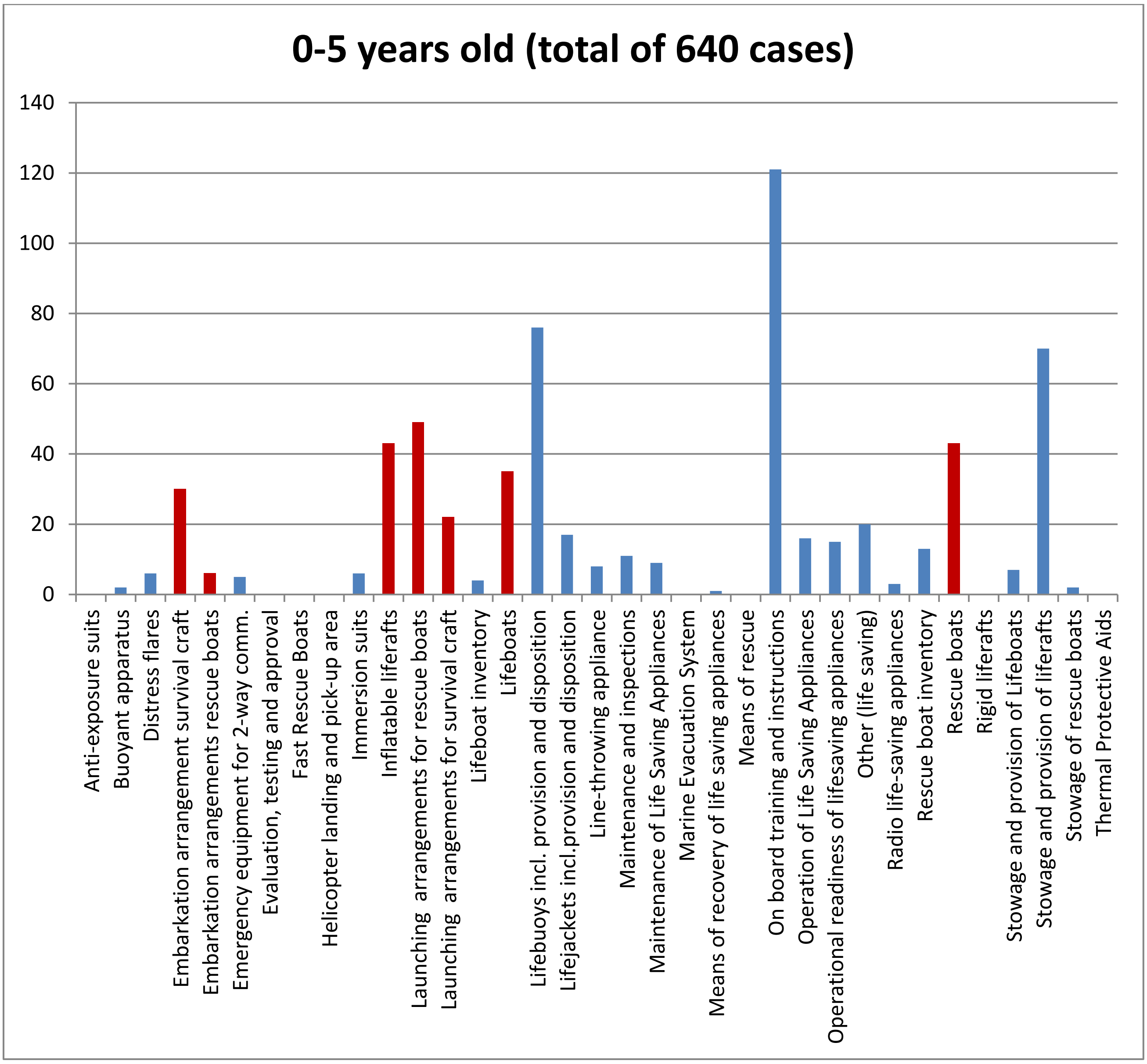


Figure 21: Deficiencies encountered in PSC inspections for ships of age from 0 to 5 years old

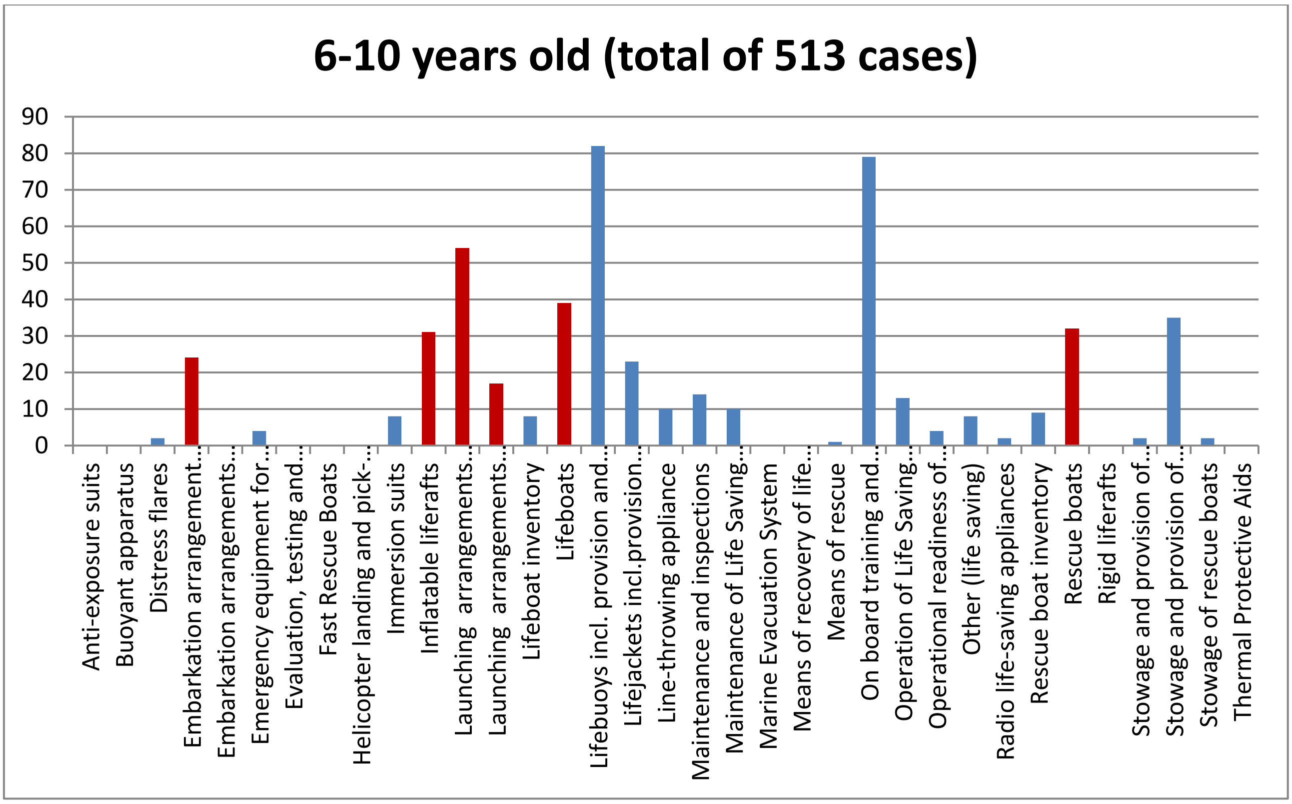


Figure 22: Deficiencies encountered in PSC inspections for ships of age from 6 to 10 years old

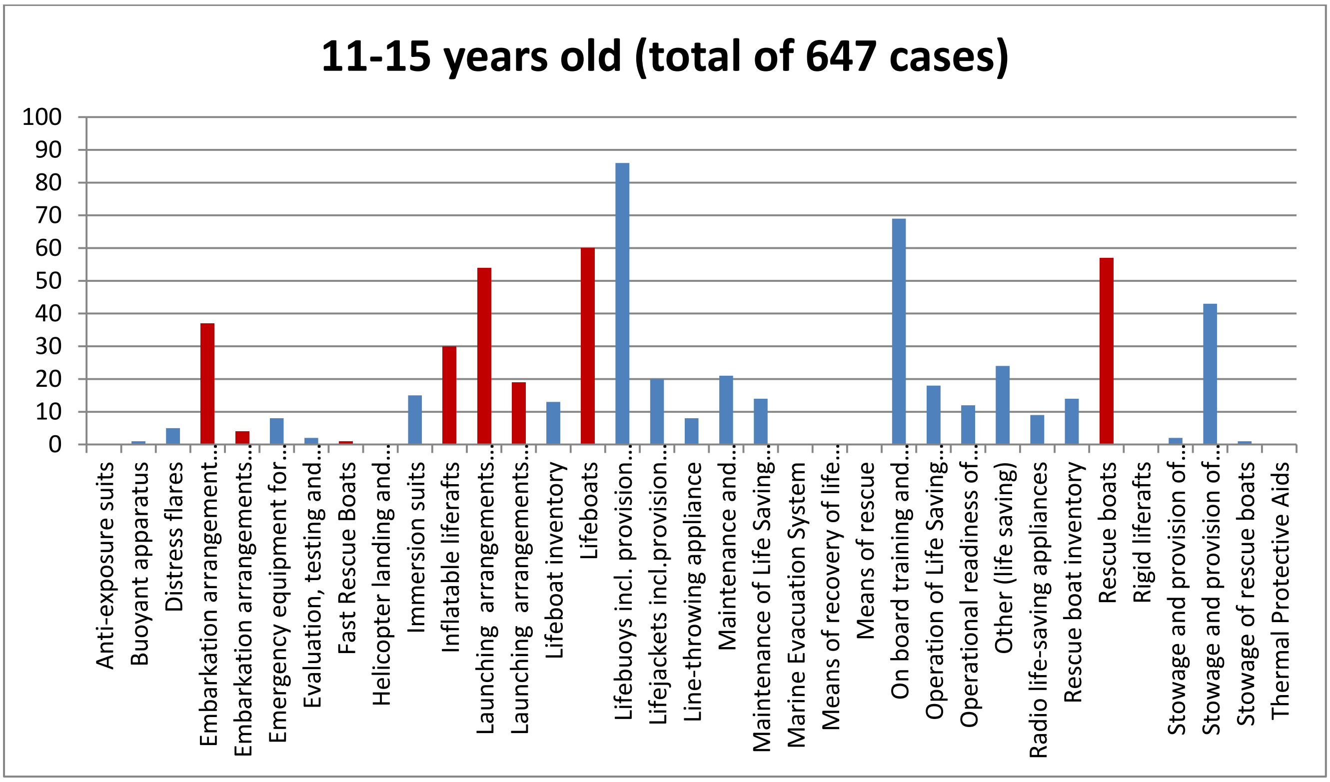


Figure 23: Deficiencies encountered in PSC inspections for ships of age from 11 to 15 years old

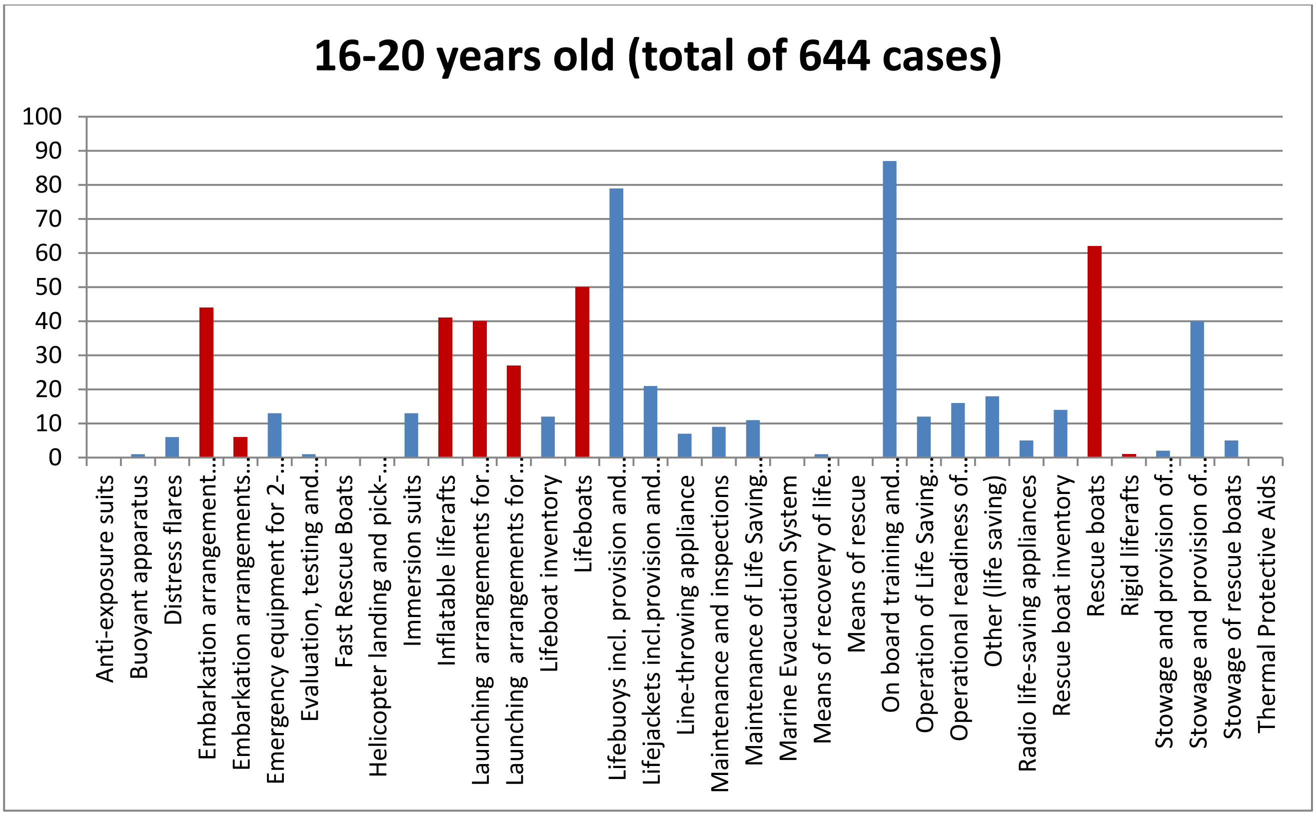


Figure 24: Deficiencies encountered in PSC inspections for ships of age from 16 to 20 years old

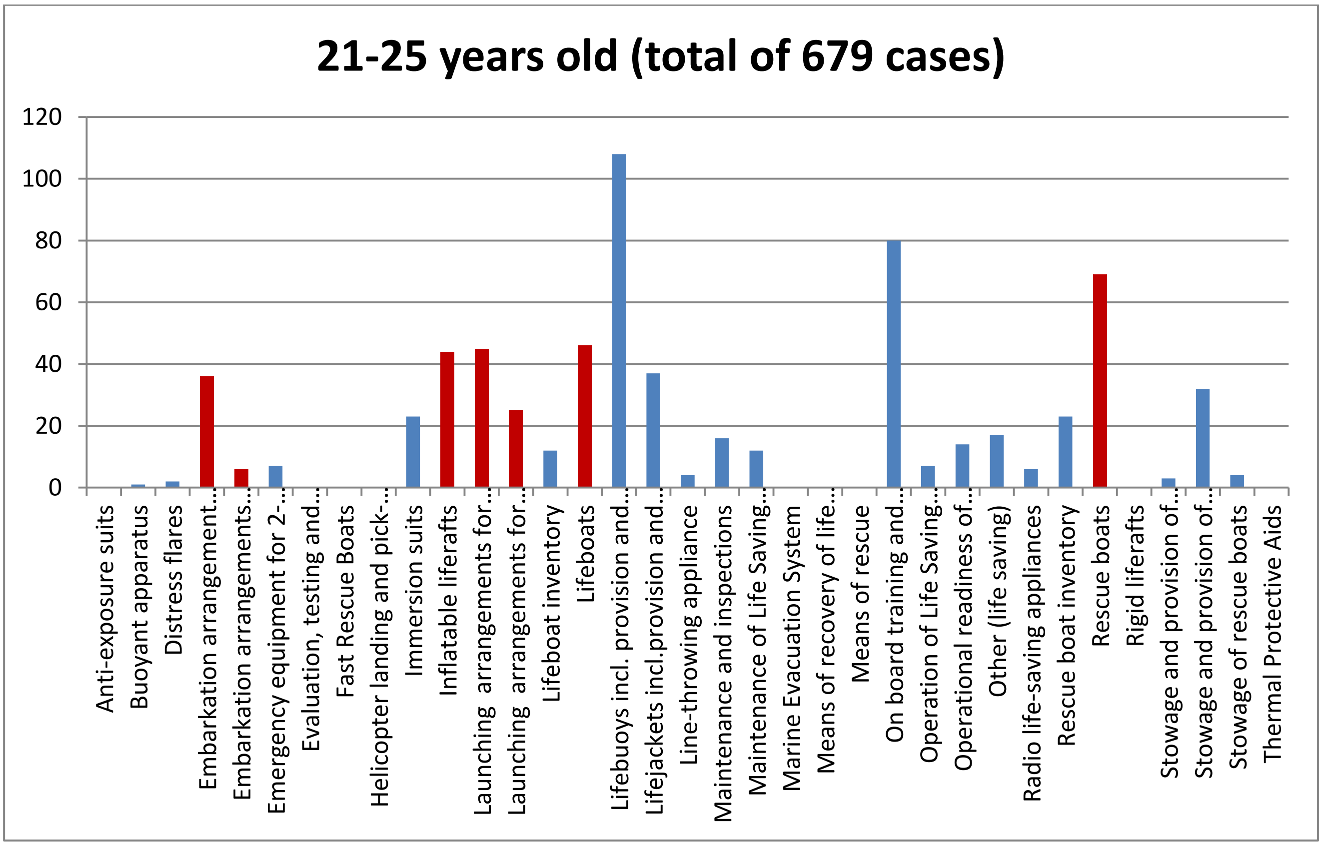


Figure 25: Deficiencies encountered in PSC inspections for ships of age from 21 to 25 years old

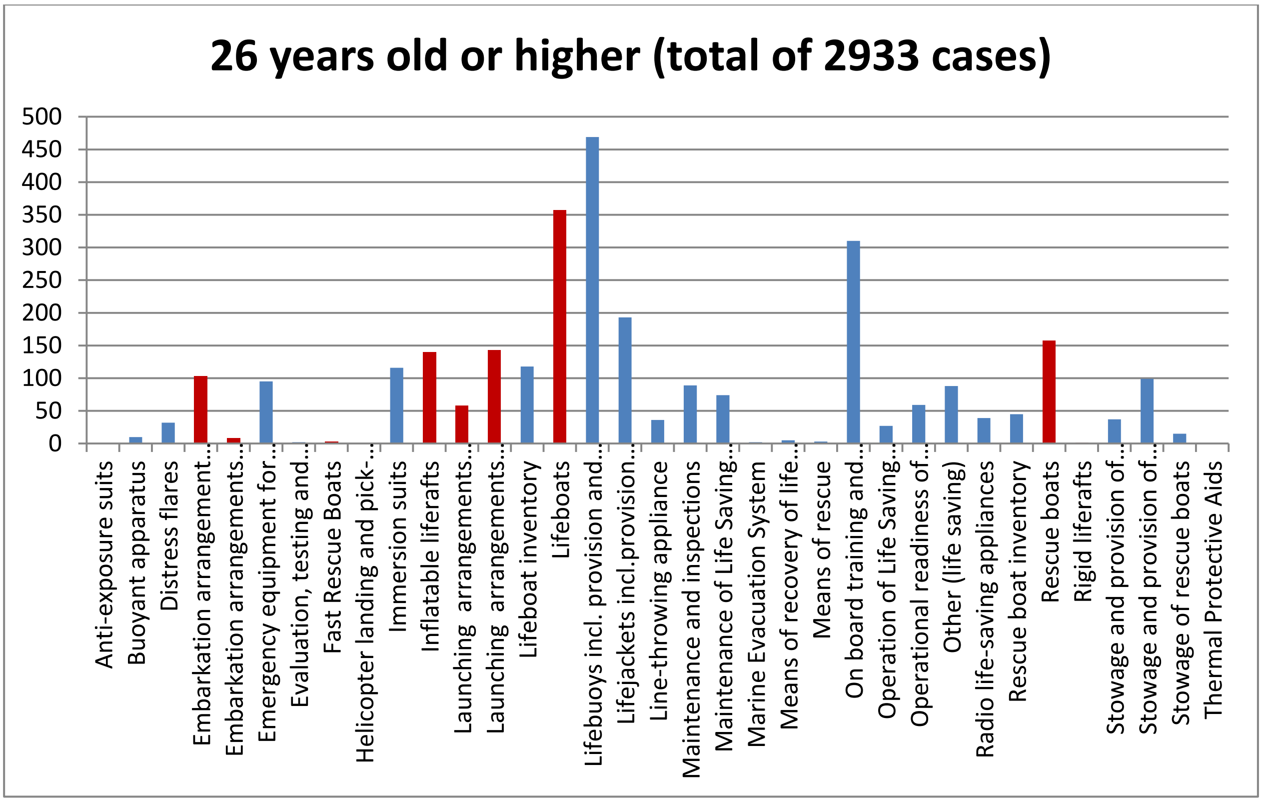


Figure 26: Deficiencies encountered in PSC inspections for ships of age of 25+ years old

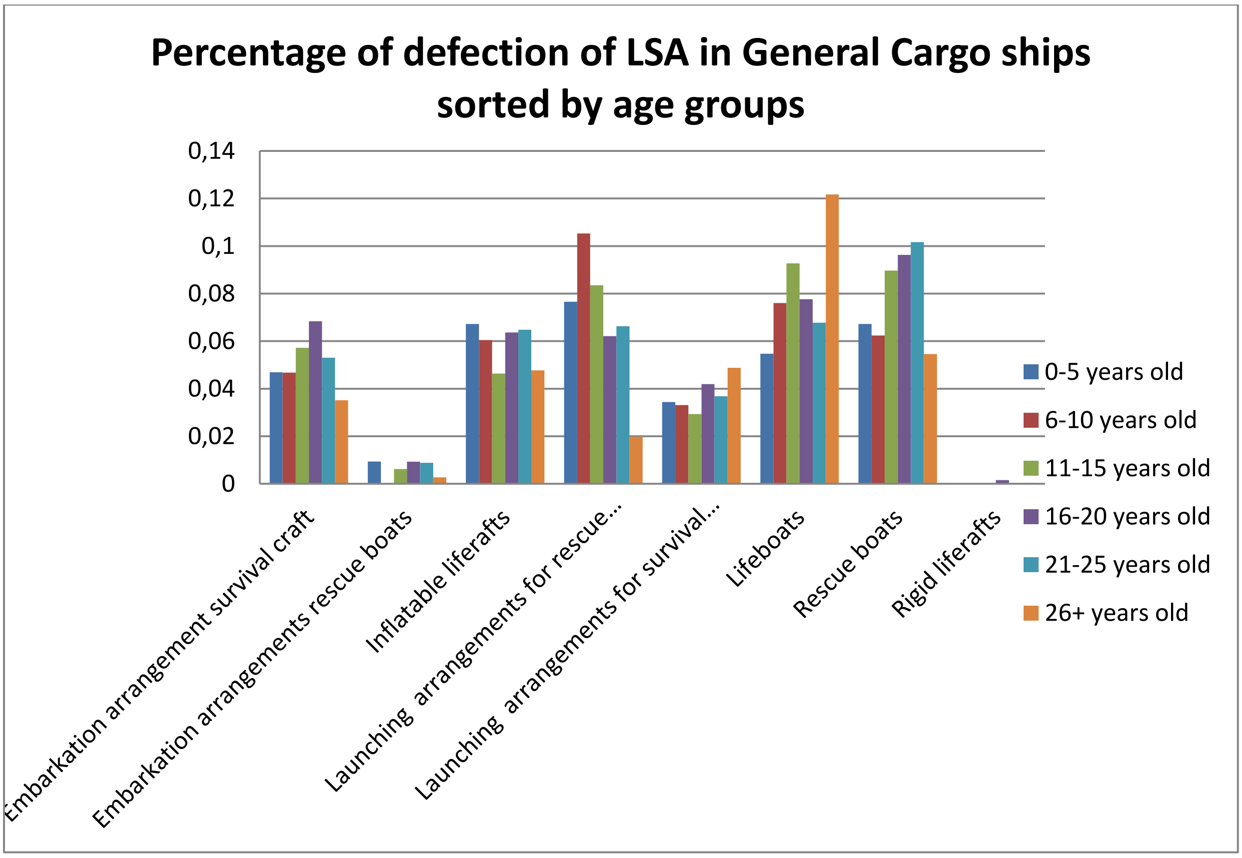


Figure 27: Deficiencies encountered in collective LSA during PSC inspections divided by age group

As is seen in Figures 21-27, deficiencies involving collective LSA are present in all the different age groups. It must be highlighted that not only are collective LSA deficiencies present in all age groups, but they also show up in significant extent. Especially for ships of age of 26 years old or higher, lifeboats prove to be the 2nd most frequent deficiency item, falling only behind lifebuoys provision and disposition. Liferafts also showcase a high number of deficiencies in all age categories as well ranging from 5% to almost 7% of deficiencies of the different age groups. The fact that collective all LSA deficiencies are as frequent in new ships as they are in older vessels is evident and proves that newly designed ships have not yet reached a satisfactory level of dealing with issues of collective LSA safety and that there is additional room for confrontation of the subject.

In terms of scope and suitability, the initial data set from Paris MoU contained only some highly relevant information for risk modelling. The quantification of the developed models requires more detailed inspection reports with respect the LSA. As a result, a more detailed database from the Paris MoU is elaborated as well as reports and claims from LSA manufacturers.

The detailed database consisted of 9,031 records of inspections from the Paris MoU which was reduced by 5,010 records pertaining to individual LSA which are out of the performed analysis. The final detailed data set comprises 5,521 records; 4,021 inspection reports from Paris MoU and 1,500 reports and claims from “Norsafe Water craft Hellas A.E.” The analysis of each record is not a trivial process since each record has to be analyzed manually and the various contributory factors which can potentially lead to failure of the LSA should be identified from a small text description.

6 Life-saving appliances module

The LSA module focuses on the calculation of probability of failure of different types of LSA (e.g. davit launched life boats, free-fall lifeboats etc.) which are implemented into the general cargo vessels and the passenger ships. The model consists of Fault Tree (FT) that handles probabilities for failure of the LSA equipment due to multiple contributory factors; corrosion cracking and deformation. This method mainly relies on a graphical presentation of a series of scenarios leading to and evolving from each identified risk named top event (Figure 28). The fault tree defines all possible cause scenarios of the top event. These causes can be classified into two types namely; the basic causes and the intermediate causes. The relationship between events and causes are represented by logical AND and OR gates. The AND gate means that the frequency of an event requires the happening of all its related causes, whereas the OR gate means that the frequency of an event requires the happening of any of its related causes (Aven, 2012).

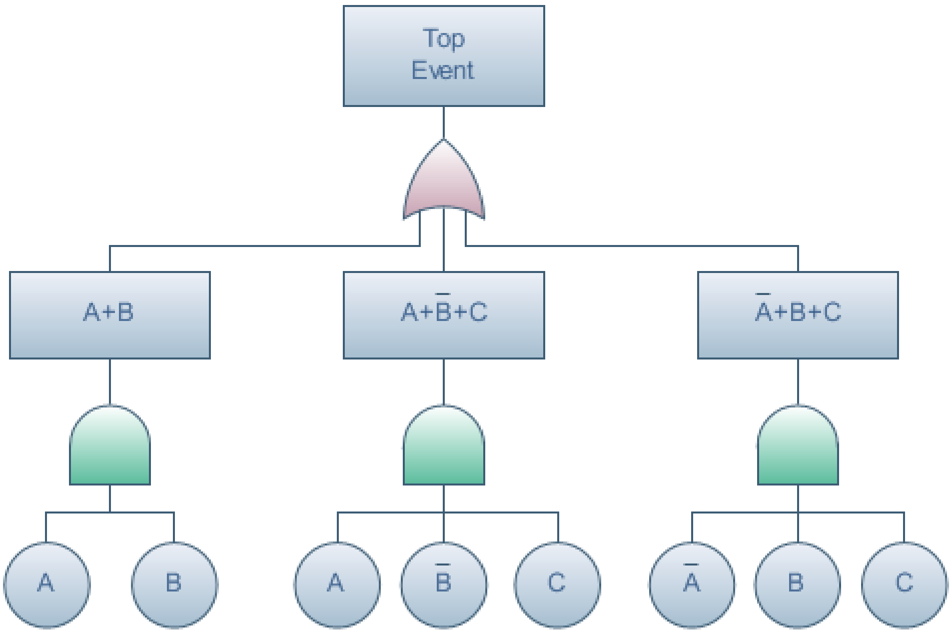


Figure 28: Fatigue cracks in bulkheads from Paris MoU for ships of different age.

The aim of the performed analysis is to break down and identify all causes which may lead up to failure of the specific group. The gathered literature and the feedback from different manufacturers suggest focusing on important mechanical components of each type of LSA, failure of which may lead to the failure of launching the LSA. Furthermore, correlation has been established between the main components and the degradation mechanisms (corrosion and cracking). Figure 29 illustrates the conceptual developed model with respect to the LSA. Based on the aforementioned selected ship types (general cargo ships and passenger ships), the respective collective

LSA will be identified and for each one different type of LSA (e.g. davit launched lifeboat etc.) the probability of failure will be calculated.

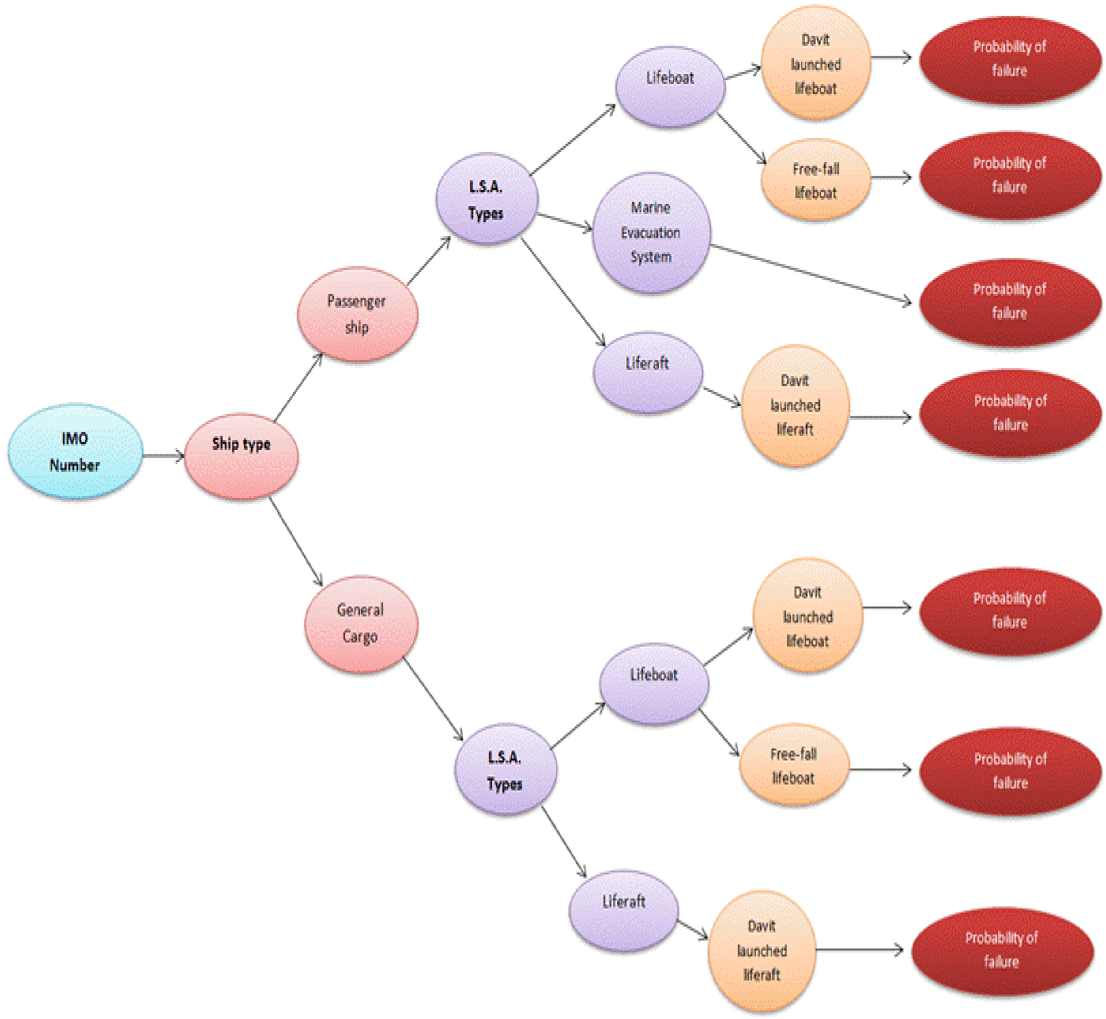


Figure 29: Conceptual model of the LSA

The Fault trees developed are depicted below along with the probability equations which accompany them.

6.1 Davit launched lifeboat Fault Tree

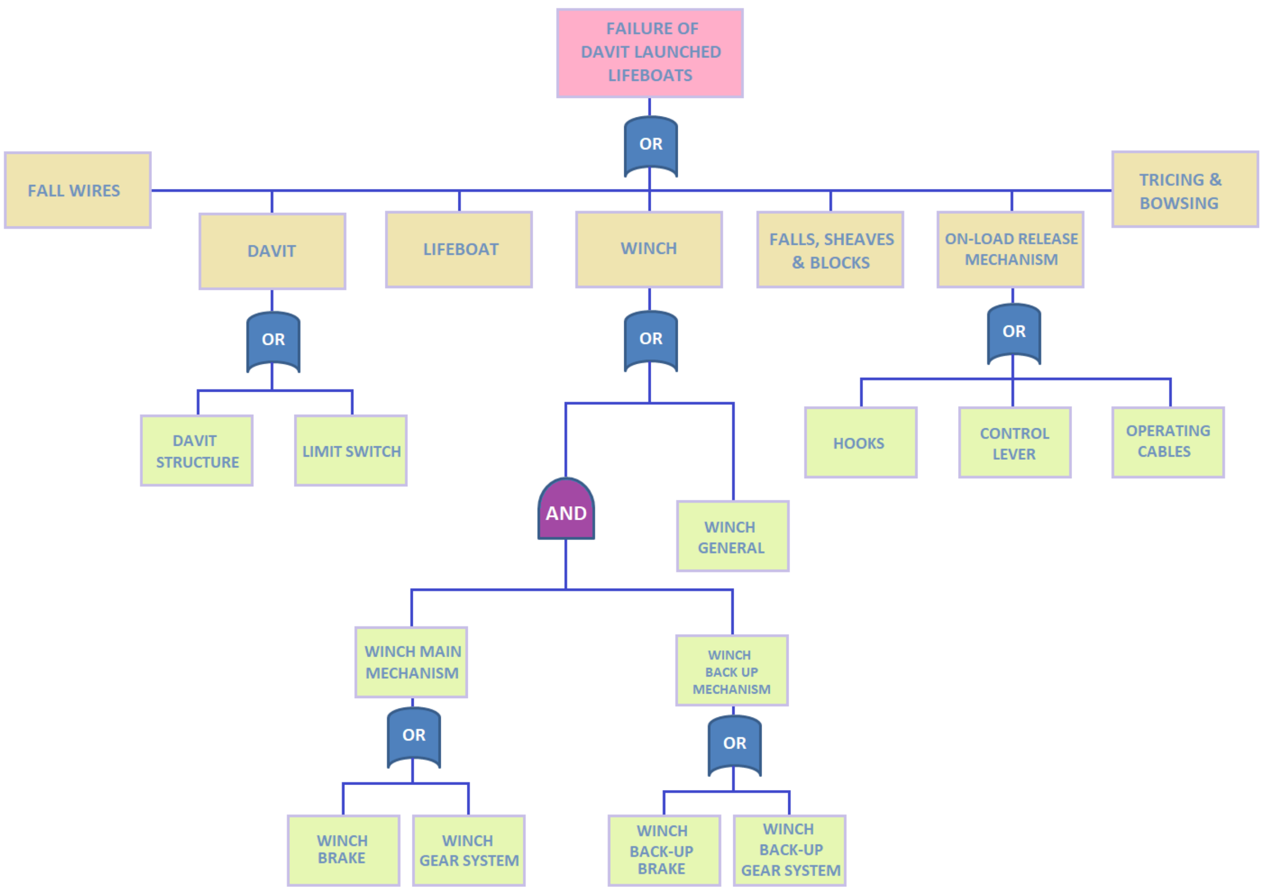


Figure 30: Developed FT for the calculation of the probability of failure of davit launched lifeboats.

The probability values for being unable to operate the davit launched lifeboat are calculated by the following equations:

$$P_{FAILURE\ OF\ DAVIT\ LAUNCHED\ LIFEBOATS} = \mathrm{P}_{\mathrm{DAVIT\ FAILURE}} + \mathrm{P}_{\mathrm{\ WINCH\ FAILURE}} + \mathrm{P}_{\mathrm{\ FALL\ WIRE\ FAILURE}} + \mathrm{P}_{\mathrm{TRICING\ AND\ BOWSING\ FAILURE}} + \mathrm{P}_{\mathrm{LIFEBOAT\ FAILURE}} + \mathrm{P}_{\mathrm{FALLS,\ \ SHEAVES\ \&\ BLOCKS\ FAILURE}} + \mathrm{P}_{\mathrm{ON-LOAD\ RELEASE\ MECHANISM\ FAILURE}}$$

$$\mathrm{P}_{\mathrm{ON-LOAD\ RELEASE\ MECHANISM\ FAILURE}} = \mathrm{P}_{\mathrm{HOOK\ FAILURE}} + \mathrm{P}_{\mathrm{CONTROL\ LEVER\ FAILURE}} + \mathrm{P}_{\mathrm{OPERATING\ CABLES\ FAILURE}}$$

$$P_{\text{DAVIT FAILURE}} = P_{\text{DAVIT FAILURE}} + P_{\text{LIMIT SWITCH FAILURE}}$$

$$\begin{aligned} P_{\text{WINCH FAILURE}} \\ &= P_{\text{WINCH GENERAL FAILURE}} + (P_{\text{MAIN MECHANISM FAILURE}} \\ &\quad * P_{\text{WINCH BACK-UP MECHANISM FAILURE}}) \end{aligned}$$

$$\begin{aligned} P_{\text{WINCH MAIN MECHANISM FAILURE}} \\ &= P_{\text{WINCH BRAKE FAILURE}} + P_{\text{WINCH GEAR SYSTEM FAILURE}} \end{aligned}$$

$$\begin{aligned} P_{\text{WINCH BACK-UP MECHANISM FAILURE}} \\ &= P_{\text{WINCH BACK-UP BRAKE FAILURE}} + P_{\text{BACK-UP GEAR SYSTEM FAILURE}} \end{aligned}$$

6.2 Davit launched liferaft Fault Tree

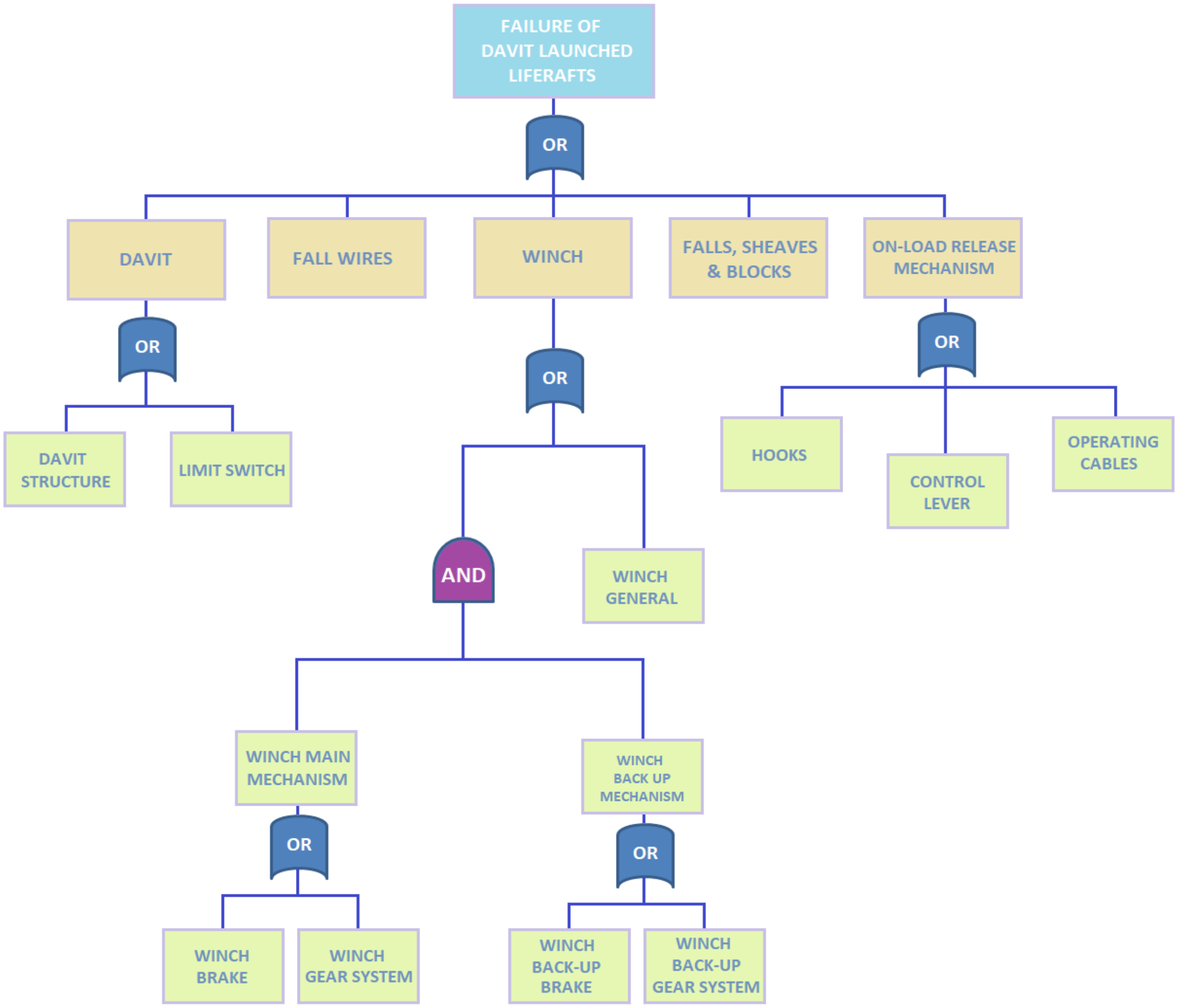


Figure 31: Developed FT for the calculation of the probability of failure of davit launched liferafts.

Figure 31 illustrates the developed model for the calculation of the probability of failure of davit launched liferafts.

The probability values for being unable to operate the davit launched liferaft are calculated by the following equations:

$$P_{\text{DAVIT LAUNCHED LIFERAFTS FAILURE}} = P_{\text{DAVIT FAILURE}} + P_{\text{ WINCH FAILURE}} + P_{\text{ FALL WIRE FAILURE}} + P_{\text{FALLS,SHEAVES \& BLOCKS FAILURE}} + P_{\text{ON-LOAD RELEASE MECHANISM FAILURE}}$$

$$P_{\text{DAVIT FAILURE}} = P_{\text{DAVIT FAILURE}} + P_{\text{LIMIT SWITCH FAILURE}}$$

$$P_{\text{ON-LOAD RELEASE MECHANISM FAILURE}} = P_{\text{HOOK FAILURE}} + P_{\text{CONTROL LEVER FAILURE}} + P_{\text{OPERATING CABLES FAILURE}}$$

$$P_{\text{WINCH FAILURE}} = P_{\text{WINCH GENERAL FAILURE}} + (P_{\text{MAIN MECHANISM FAILURE}} * P_{\text{WINCH BACK-UP MECHANISM FAILURE}})$$

$$P_{\text{WINCH MAIN MECHANISM FAILURE}} = P_{\text{WINCH BRAKE FAILURE}} + P_{\text{WINCH GEAR SYSTEM FAILURE}}$$

$$P_{\text{WINCH BACK-UP MECHANISM FAILURE}} = P_{\text{WINCH BACK-UP BRAKE FAILURE}} + P_{\text{BACK-UP GEAR SYSTEM FAILURE}}$$

6.3 Free-fall Lifeboat Fault Tree

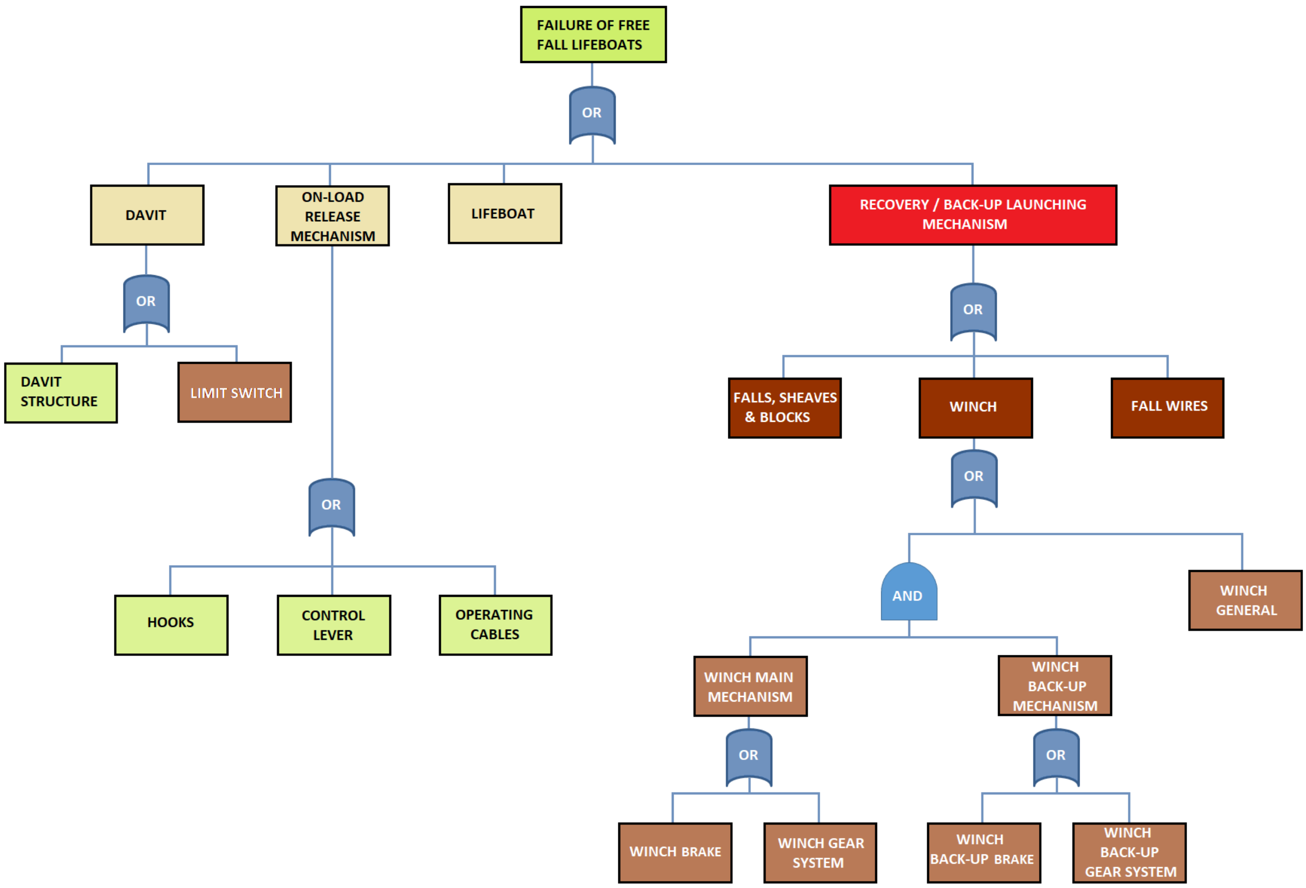


Figure 32: Developed FT for the calculation of the probability of failure of free-fall lifeboat.

Some free-fall lifeboat installations are able to launch the lifeboat in a "davit-launched manner", in case the free-fall mechanism is ruled out for any given reason (insufficient sea depth, obstacles on ship stern, failure of free-fall mechanism etc.). This approach is considered as a backup mechanism for the launch of the free-fall lifeboat and is also used for the recovery of the boat form sea.

The probability values for being unable to operate the free-fall lifeboats are calculated by the following equations. The components and subcomponents not used in the free-fall launching method are in purple color:

$$
\begin{aligned}
P_{\text{FAILURE OF FREE FALL LIFEBOATS}} \\
&= P_{\text{DAVIT FAILURE}} + P_{\text{LIFEBOAT FAILURE}} \\
&+ P_{\text{ON-LOAD RELEASE MECHANISM FAILURE}} \\
&+ P_{\text{RECOVERY / BACK-UP LAUNCHING MECHANISM FAILURE}}
\end{aligned}
$$

$$P_{\text{DAVIT FAILURE}} = P_{\text{DAVIT FAILURE}} + \mathbf{P}_{\textbf{LIMIT SWITCH FAILURE}}$$

$$P_{\text{ON-LOAD RELEASE MECHANISM FAILURE}} = P_{\text{HOOK FAILURE}} + P_{\text{CONTROL LEVER FAILURE}} + P_{\text{OPERATING CABLES FAILURE}}$$

$$\mathbf{P}_{\textbf{RECOVERY / BACK-UP LAUNCHING MECHANISM}} = \mathbf{P}_{\textbf{WINCH FAILURE}} + \mathbf{P}_{\textbf{FALL WIRES FAILURE}} + \mathbf{P}_{\textbf{FALLS,SHEAVES \& BLOCKS FAILURE}}$$

$$\mathbf{P}_{\textbf{WINCH FAILURE}} = \mathbf{P}_{\textbf{WINCH GENERAL FAILURE}} + (\mathbf{P}_{\textbf{MAIN MECHANISM FAILURE}} * \mathbf{P}_{\textbf{WINCH BACK-UP MECHANISM FAILURE}})$$

$$\mathbf{P}_{\textbf{WINCH MAIN MECHANISM FAILURE}} = \mathbf{P}_{\textbf{WINCH BREAK FAILURE}} + \mathbf{P}_{\textbf{WINCH GEAR SYSTEM FAILURE}}$$

$$\mathbf{P}_{\textbf{WINCH BACK-UP MECHANISM FAILURE}} = \mathbf{P}_{\textbf{WINCH BACK-UP BREAK FAILURE}} + \mathbf{P}_{\textbf{BACK-UP GEAR SYSTEM FAILURE}}$$

7 Simulations

Introduction

In this section, the results of the probabilities of failure of the different LSA for the same category of vessel will be displayed so that some comparison can be made. At this point it is essential to point out the distinction between critical and non-critical failure. Failure is considered critical when the component impacted is no longer operational. Non-critical failure describes the situation in which a component's operation capability is degraded but can be tolerated for a short period of time. The results of this study address non-critical failure and are presented in ANNEX B.

The initial 3 simulations involve the three LSA examined in this study (davit launched lifeboats, davit launched liferafts and free-fall lifeboats) for a ship with the following characteristics:

- Flag: White
- Class: IACS
- Age: 5 years old or less

These characteristics represent the most favorable scenario and therefore the values of probability of failure will be the lowest in comparison to the other situations. The values of these simulations will be compared to the values resulting from the worst case scenario, which is the following:

- Flag: Black
- Class: Non IACS
- Age: 6 years old or more

Case 1 - Davit Launched Lifeboat

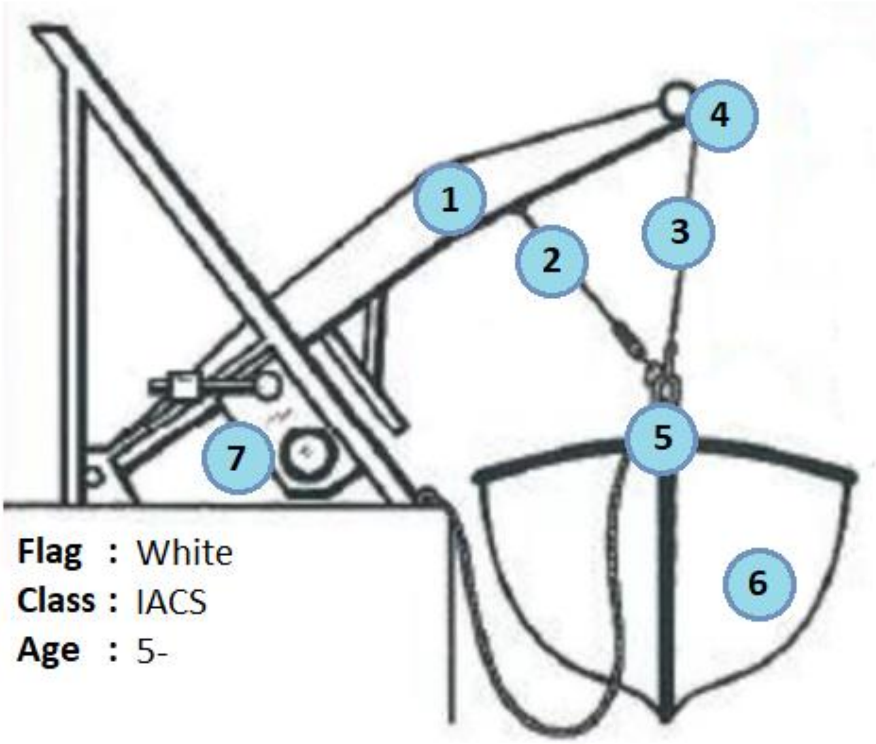


Figure 33: Depiction of major components affecting failure of davit launched lifeboats

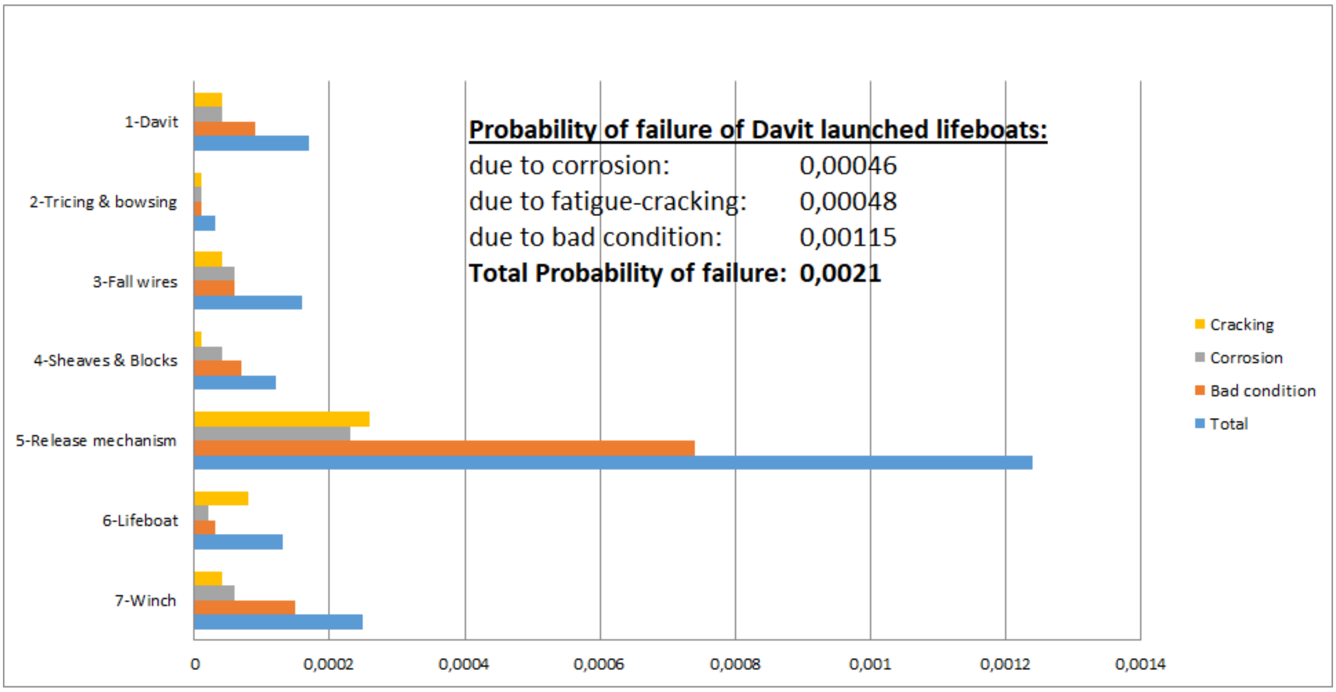


Figure 34: Probability of failure of major components & total probability of failure for davit launched lifeboats for case 1

Table 12: Probability of failure of main components of lifeboats in case 1

	Total	Bad Condition	Corrosion	Cracking
1-Davit	0.00017	0.00009	0.00004	0.00004
2-Tricing & Bowsing	0.00003	0.00001	0.00001	0.00001
3-Fall Wires	0.00016	0.00006	0.00006	0.00004
4-Sheaves & Blocks	0.00012	0.00007	0.00004	0.00001
5-Release Mechanism	0.00124	0.00074	0.00023	0.00026
6-Lifeboat	0.00013	0.00003	0.00002	0.00008
7-Winch	0.00025	0.00015	0.00006	0.00004
Total	0.0021	0.00115	0.00046	0.00048

Table 13: Probability of failure of sub-components of lifeboats in case 1

On-Load Release Mechanism				
Hooks	0.00064	0.00036	0.00021	0.00007
Operating Cables	0.00026	0.00006	0.00001	0.00018
Control Lever	0.00034	0.00032	0.00001	0.00001

Davit				
Davit Structure	0.00005	0.00002	0.00003	0.00001
Limit Switch	0.00012	0.00007	0.00001	0.00003

Winch				
Winch General	0.00009	0.00003	0.00005	0.00001
Winch Brake	0.00014	0.00012	0.00001	0.00001
Winch Gear system	0.00002	0	0	0.00002

As seen in Figure 34, the on-load release mechanism is by a big margin the most hazardous component of the davit launched lifeboat. This result is on board with the findings of the previous research examined on the subject. None of the subcomponents of the release mechanism seem to have an insignificant value of probability of failure as seen in Table 13, with the hooks specifically having the highest. The general bad condition of the release mechanism in particular is responsible for one third of the value of the total probability of failure of the LSA. The rest of the components seem to fluctuate within a narrow range of values. Bad condition in general is a higher failure condition than both the sum of corrosion and fatigue which appear in almost the same level.

Case 2 - Davit Launched Liferaft

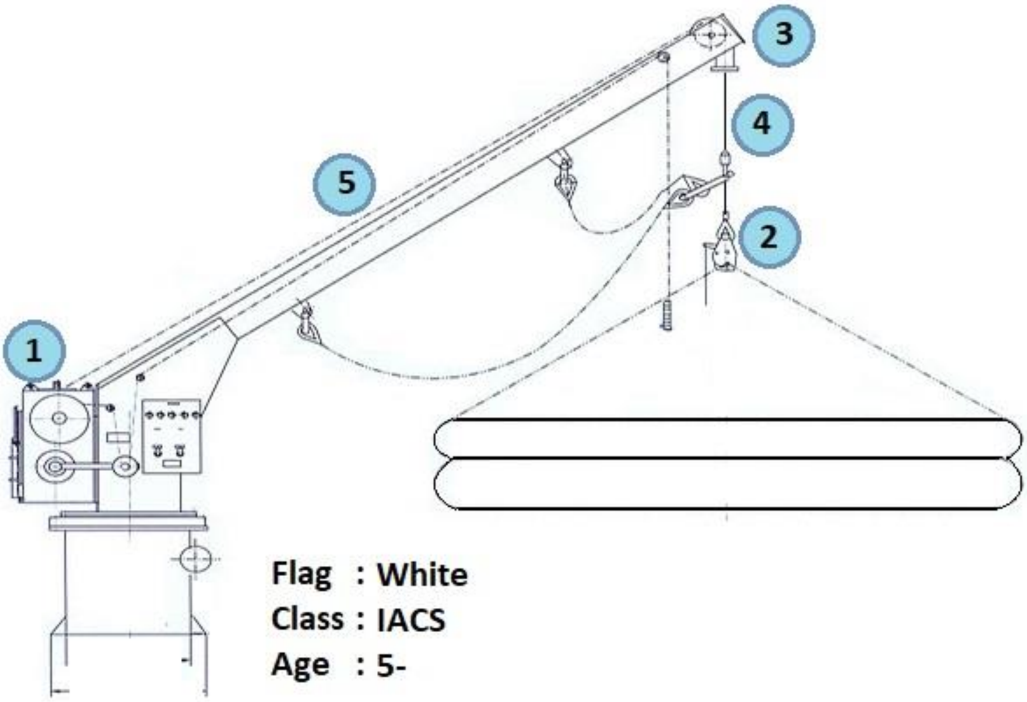


Figure 35: Depiction of major components affecting failure of davit launched liferafts

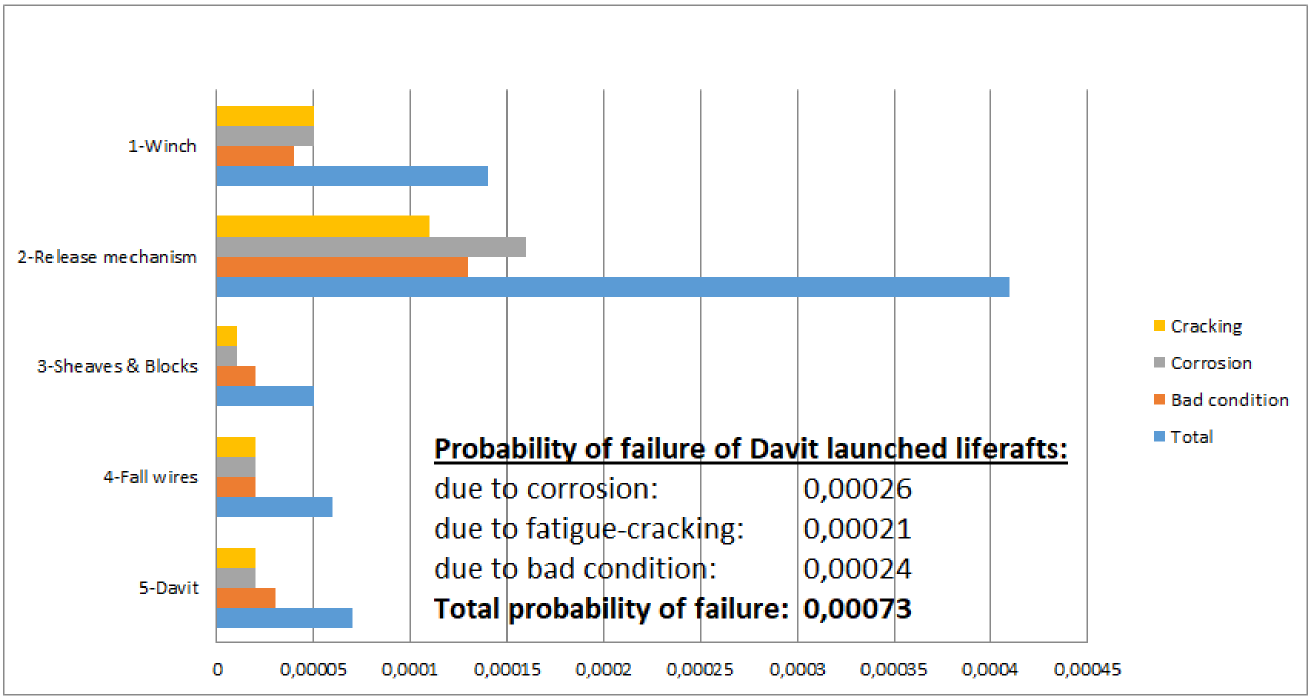


Figure 36: Probability of failure of major components & total probability of failure for davit launched liferaft for case 2

Table 14: Probability of failure of main components of liferafts in case 2

	Total	Bad Condition	Corrosion	Cracking
Davit	0.00007	0.00003	0.00002	0.00002
Fall Wires	0.00006	0.00002	0.00002	0.00002
Sheaves & Blocks	0.00005	0.00002	0.00001	0.00001
Release Mechanism	0.00041	0.00013	0.00016	0.00011
Winch	0.00014	0.00004	0.00005	0.00005
Total	0.00073	0.00024	0.00026	0.00021

Table 15: Probability of failure of sub-components of liferafts in case 2

On-Load Release Mechanism				
Hook	0.0003	0.0001	0.00015	0.00005
Operating cables	0.00008	0.00002	0	0.00005
Control Lever	0.00003	0.00001	0.00001	0.00001
Davit				
Davit structure	0.00003	0.00001	0.00001	0.00001
Limit switch	0.00004	0.00002	0.00001	0.00001
Winch				
Winch general	0.00005	0.00002	0.00003	0.00001
Winch brake	0.00003	0.00001	0.00001	0.00001
Winch gear system	0.00005	0.00001	0.00001	0.00003

As is the case with the davit launched lifeboats, the release mechanism of davit launched liferafts is the most hazardous component as seen in Figure 36, with the condition of the hooks being the principal hazard while control lever failure resting in lower values (Table 14). Of the rest of the components, winch failure is highest. The 3 failure conditions appear in the same extent with corrosion emerging slightly higher than the rest and fatigue-cracking lowest. The total value of probability of failure of this LSA is significantly lower than that of the davit launched lifeboats; almost one third, however the fact that the lifeboat is more seaworthy as a vessel proves to be a vital factor of the bigger picture.

Case 3 - Free-Fall Lifeboat

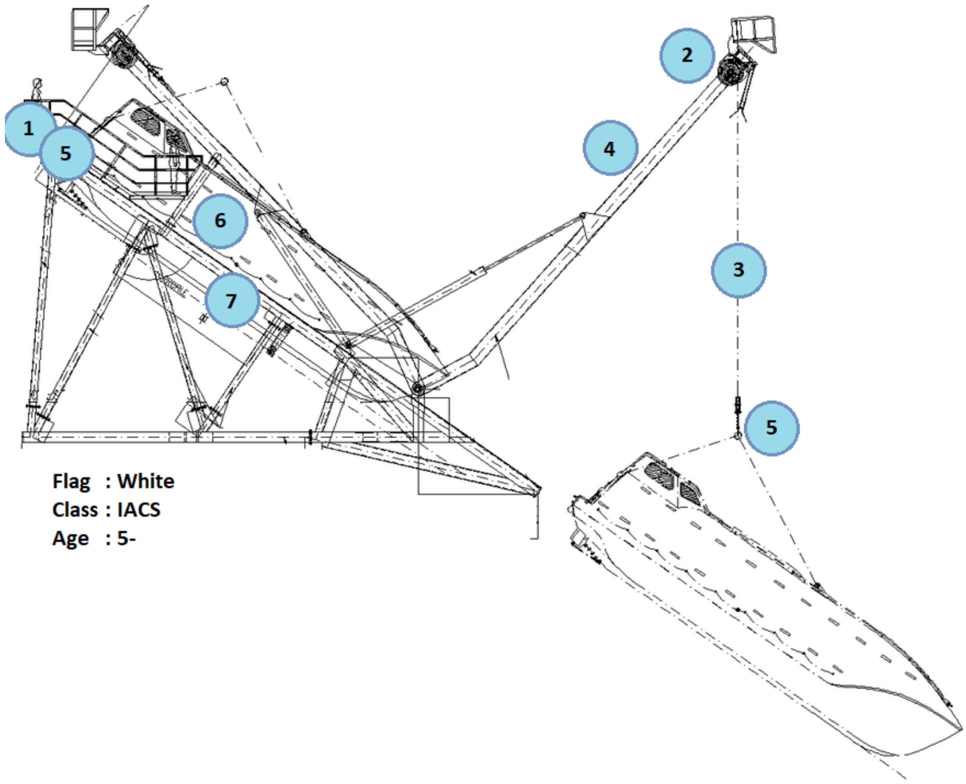
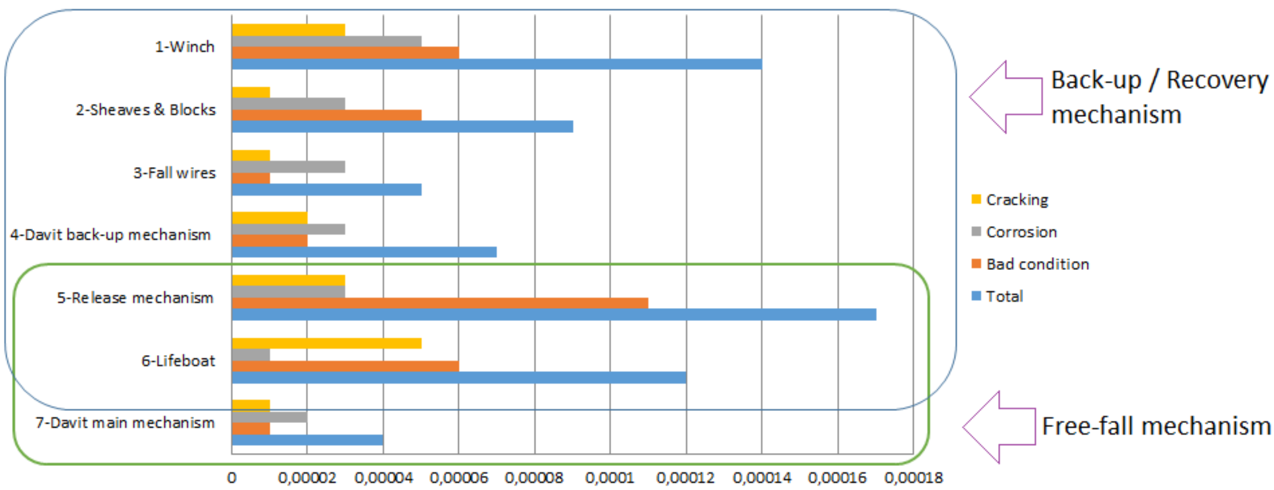


Figure 37: Depiction of major components affecting failure of free-fall lifeboats



Probability of failure of Free-fall lifeboats

Free-fall mechanism:		**Back-up / Recovery mechanism:**	
due to corrosion :	0,00006	due to corrosion :	0,00018
due to fatigue cracking:	0,00009	due to fatigue cracking:	0,00015
due to bad condition:	0,00018	due to bad condition:	0,00031
Total Probability of failure:	**0,00033**	**Total Probability of failure:**	**0,00064**

Figure 38: Probability of failure of major components & total probability of failure for free-fall lifeboat for case 3

Table 16: Probability of failure of main components of free-fall lifeboats in case 3

	Total	Bad Condition	Corrosion	Cracking
Davit Main Mechanism	0.00004	0.00001	0.00002	0.00001
Davit Back-up Mechanism	0.00007	0.00002	0.00003	0.00002
Fall Wires	0.00005	0.00001	0.00003	0.00001
Sheaves & Blocks	0.00009	0.00005	0.00003	0.00001
Release Mechanism	0.00017	0.00011	0.00003	0.00003
Lifeboat	0.00012	0.00006	0.00001	0.00005
Winch	0.00014	0.00006	0.00005	0.00003
Total for Free-fall method	**0.00033**	**0.00018**	**0.00006**	**0.00009**
Total for Davit Launched Method/ Recovery	**0.00064**	**0.00031**	**0.00018**	**0.00015**

Table 17: Probability of failure of sub-components of free-fall lifeboats in case 3

On-Load Release Mechanism				
Hook	0.00008	0.00006	0.00001	0.00001
Operating Cables	0.00006	0.00004	0.00001	0.00001
Control Lever	0.00003	0.00001	0.00001	0.00001
Davit				
Davit Structure	0.00004	0.00001	0.00002	0.00001
Limit Switch	0.00003	0.00001	0.00001	0.00001
Winch				
Winch General	0.00008	0.00004	0.00003	0.00001
Winch Brake	0.00003	0.00001	0.00001	0.00001
Winch Gear System	0.00003	0.00001	0.00001	0.00001

Free-fall lifeboats results showcase that this LSA might be the safest of the three. Especially when launched through the free-fall method. This can be attributed to the simplicity of this launching mode. While being launched through the davit-launched method due to the reasons already discussed or when recovering it, the probability of failure almost doubles but still maintains the lowest value of all three LSA examined. Additionally it is noteworthy that, different components' probabilities do not differ as much as they did for the previous LSA.

Cases 4, 5 & 6 – Davit launched lifeboats, davit launched liferafts & free-fall lifeboats for worst case scenarios.

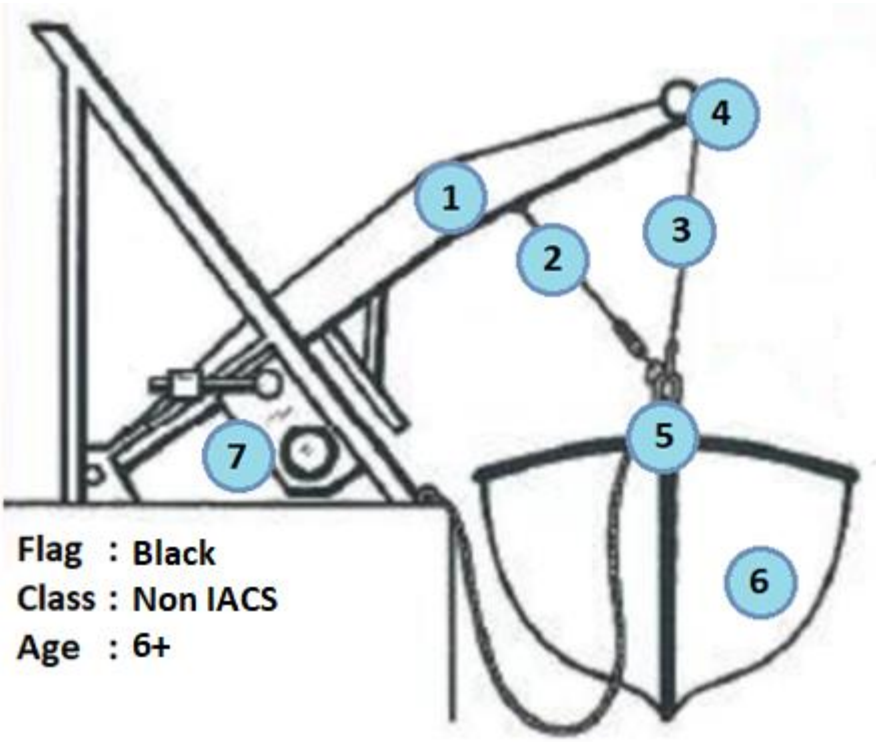


Figure 39: Depiction of major components affecting failure of davit launched lifeboats

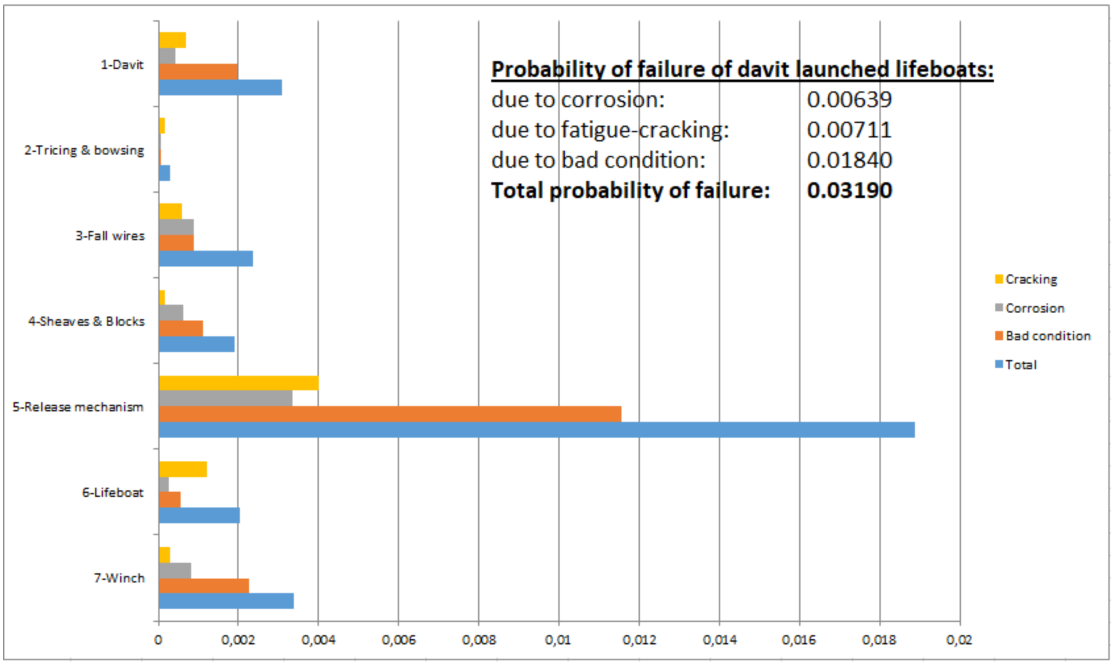


Figure 40: Probability of failure of major components & total probability of failure for davit launched lifeboats for case 4

Table 18: Probability of failure of main components of lifeboats in case 4

	Total	Bad Condition	Corrosion	Cracking
1-Davit	0.00309	0.00198	0.00041	0.0007
2-Tricing & Bowsing	0.0003	0.00006	0.00007	0.00017
3-Fall wires	0.00236	0.00089	0.00088	0.00059
4-Sheaves & Blocks	0.00189	0.00113	0.00061	0.00015
5-Release Mechanism	0.01886	0.01153	0.00333	0.004
6-Lifeboat	0.00203	0.00055	0.00027	0.00121
7-Winch	0.00337	0.00226	0.00082	0.00029
Total	**0.0319**	**0.0184**	**0.00639**	**0.00711**

Table 19: Probability of failure of sub-components of lifeboats in case 4

On-Load Release Mechanism				
Hooks	0.00986	0.00548	0.00328	0.0011
Operating Cables	0.00389	0.00099	0.00002	0.00288
Control Lever	0.00511	0.00506	0.00003	0.00002

Davit				
Davit Structure	0.00141	0.00083	0.00039	0.00019
Limit Switch	0.00168	0.00115	0.00002	0.00051

Winch				
Winch General	0.00125	0.00044	0.0008	0.00002
Winch Brake	0.00186	0.00182	0.00002	0.00002
Winch Gear System	0.00025	0	0	0.00025

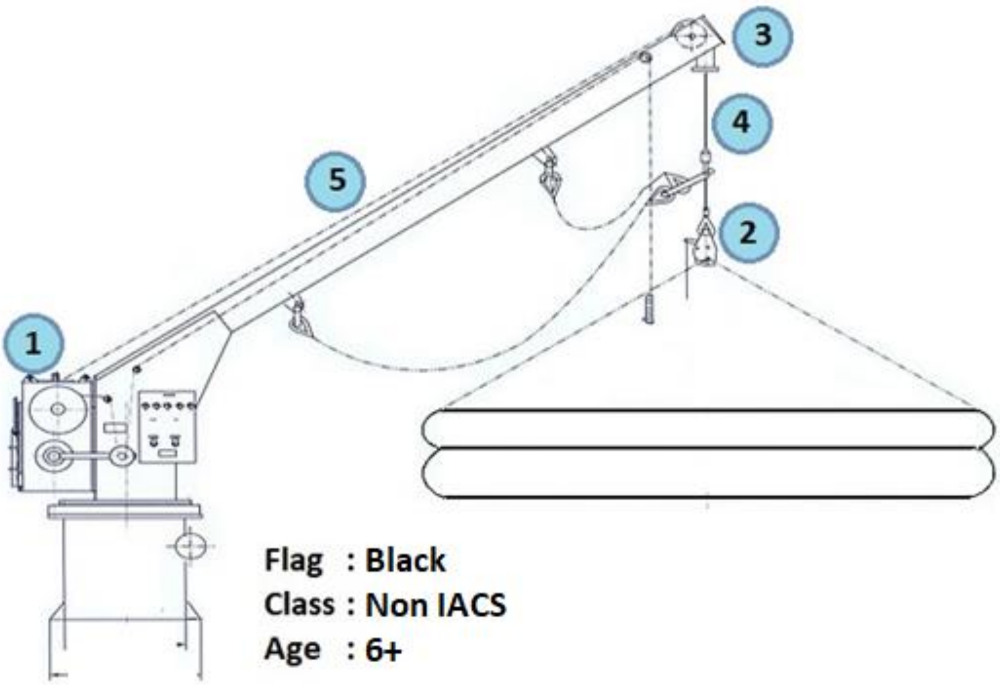


Figure 41: Depiction of major components affecting failure of davit launched liferafts

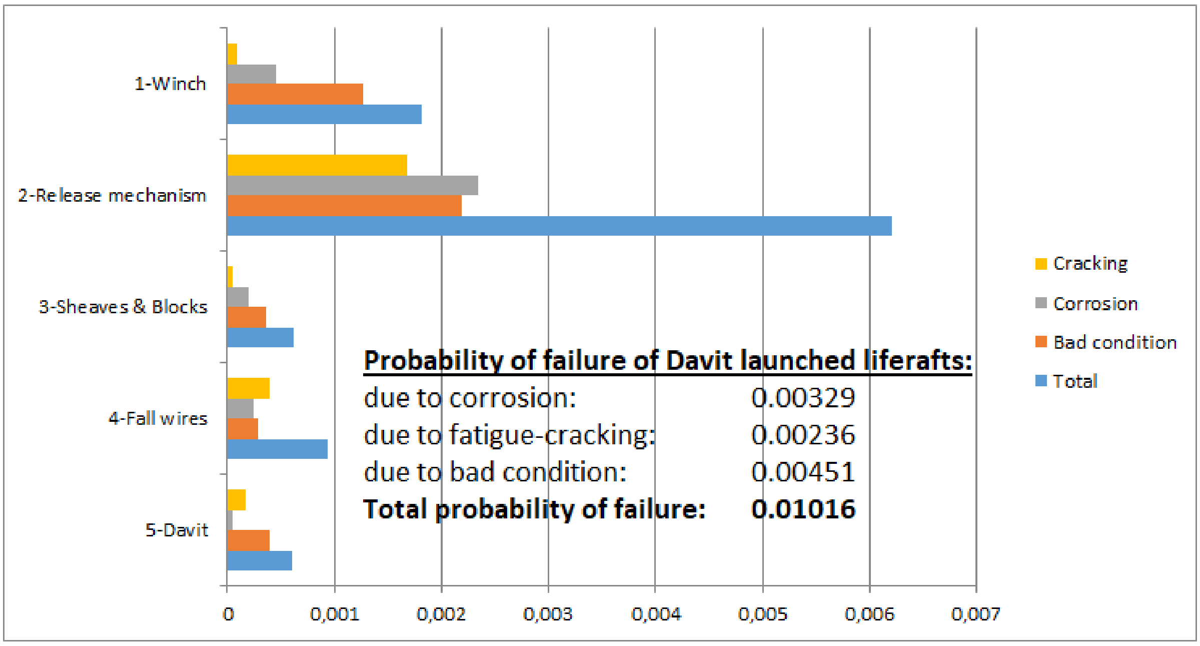


Figure 42: Probability of failure of major components & total probability of failure for davit launched liferafts for case 5

Table 20: Probability of failure of main components of liferafts in case 5

	Total	Bad Condition	Corrosion	Cracking
5-Davit	0.0006	0.00039	0.00005	0.00016
4-Fall Wires	0.00093	0.00029	0.00025	0.00039
3-Sheaves & Blocks	0.00062	0.00037	0.0002	0.00005
2-Release Mechanism	0.0062	0.00219	0.00234	0.00167
1-Winch	0.00181	0.00127	0.00045	0.00009
Total	**0.01016**	**0.00451**	**0.00329**	**0.00236**

Table 21: Probability of failure of sub-components of liferafts in case 5

On-Load Release Mechanism				
Hook	0.00484	0.0018	0.00228	0.00076
Operating Cables	0.00118	0.0003	0.00001	0.00087
Control Lever	0.00018	0.00009	0.00005	0.00004

Davit				
Davit Structure	0.00016	0.00011	0.00004	0.00001
Limit Switch	0.00044	0.00028	0.00001	0.00015

Winch				
Winch General	0.00071	0.00026	0.00042	0.00003
Winch Brake	0.00104	0.001	0.00002	0.00002
Winch Gear System	0.00006	0.00001	0.00001	0.00004

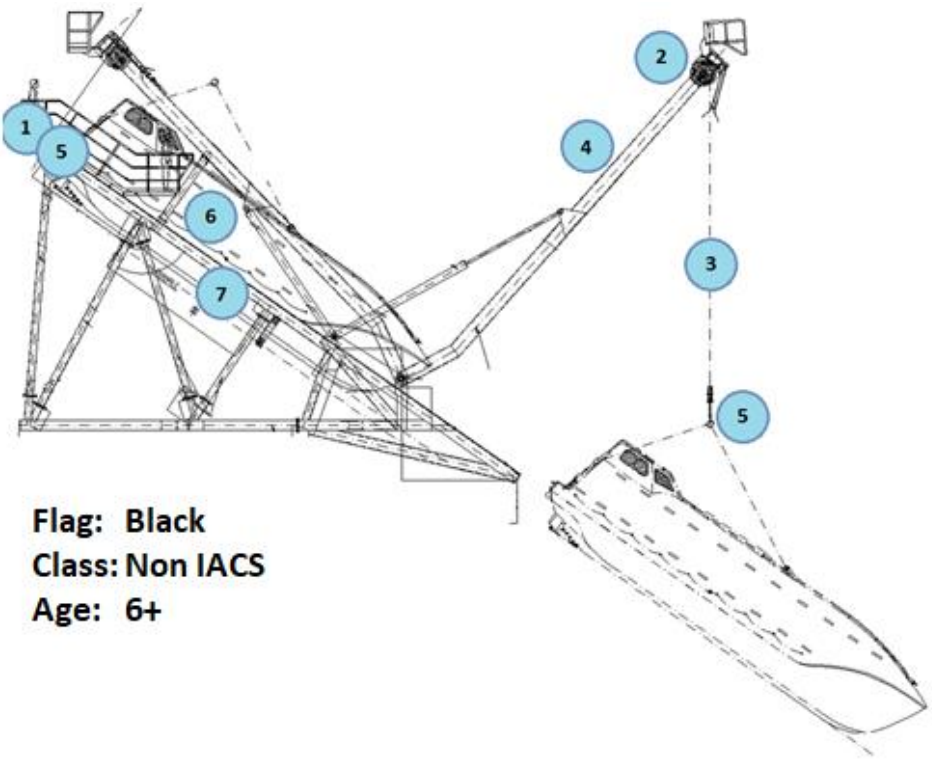
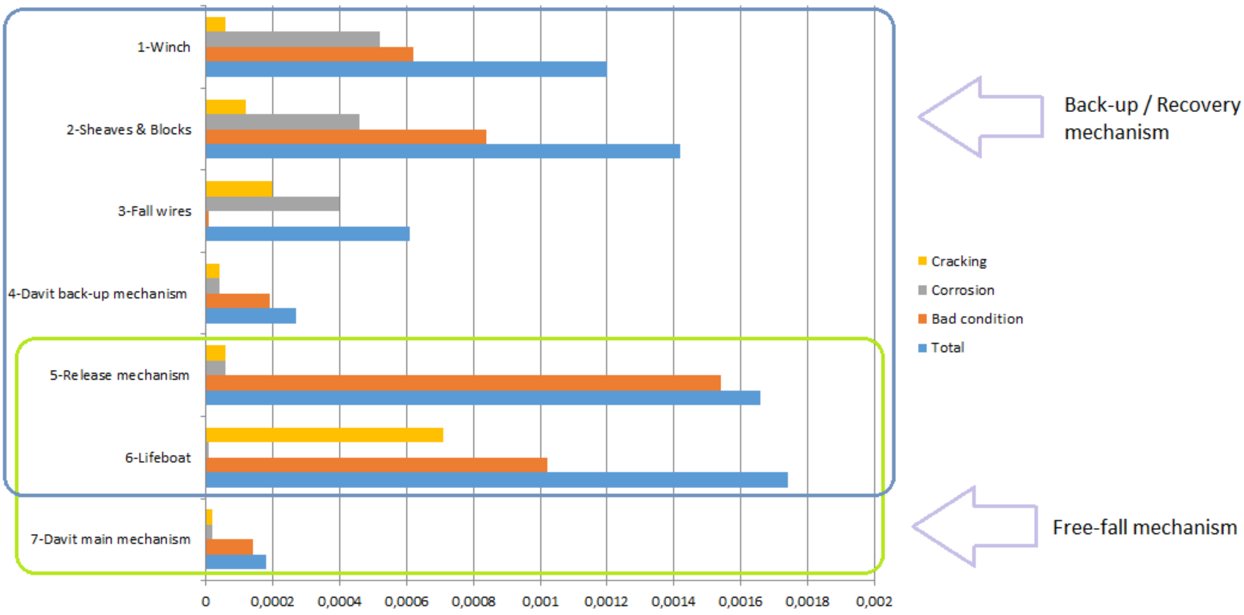


Figure 43: Depiction of major components affecting failure of free-fall lifeboats



Probability of failure of Free-fall lifeboats

Free-fall mechanism:		Back-up / Recovery mechanism:	
due to corrosion:	0.00009	due to corrosion:	0.00149
due to fatigue-cracking:	0.00079	due to fatigue-cracking:	0.00119
due to bad condition:	0.00270	due to bad condition	0.00420
Total probability of failure:	**0.00358**	**Total probability of failure:**	**0.00690**

Figure 44: Probability of failure of major components & total probability of failure for free-fall lifeboats for case 6

Table 22: Probability of failure of main components of free-fall lifeboats in case 6

	Total	Bad Condition	Corrosion	Cracking
Davit Main Mechanism	0.00018	0.00014	0.00002	0.00002
Davit Back-up Mechanism	0.00027	0.00019	0.00004	0.00004
Fall Wires	0.00061	0.00001	0.0004	0.0002
Sheaves & Blocks	0.00142	0.00084	0.00046	0.00012
Release Mechanism	0.00166	0.00154	0.00006	0.00006
Lifeboat	0.00174	0.00102	0.00001	0.00071
Winch	0.0012	0.00062	0.00052	0.00006
Total for Free-fall Method	0.00358	0.0027	0.00009	0.00079
Total for Davit Launched Method/ Recovery	**0.0069**	**0.00422**	**0.00149**	**0.00119**

Table 23: Probability of failure of sub-components of free-fall lifeboats in case 6

On-Load Release Mechanism				
Hook	0.00098	0.00094	0.00002	0.00002
Operating Cables	0.0006	0.00056	0.00002	0.00002
Control Lever	0.00008	0.00004	0.00002	0.00002

Davit				
Davit Structure	0.00018	0.00014	0.00002	0.00002
Limit Switch	0.00009	0.00005	0.00002	0.00002

Winch				
Winch General	0.00108	0.00058	0.00048	0.00002
Winch Brake	0.00006	0.00002	0.00002	0.00002
Winch Gear System	0.00006	0.00002	0.00002	0.00002

Table 24: Comparison of probability of failure of the 4 cases examined

	Davit launched lifeboat	Davit launched liferaft	Free-fall lifeboat
Total probability of failure of LSA – Most favorable scenario	0,0021	0,00073	0,00033/0,00064
Total probability of failure of LSA – Worst case scenario	0.0319	0.01016	0.00358/0.0069

The results presented in tables 16-24 display a significant difference in the results of the favorable and unfavorable scenarios. The probability in the worst case scenarios case raises concerns regarding the safety of the LSA and comes to agreement with the attention attracted on the risk of the LSA in the maritime industry. Davit launched lifeboats particularly showcase the highest probability of failure and should be of first concern. Of all the components, release mechanisms accumulate the highest failure probabilities and especially the hooks.

8 Conclusions

The aim of this study is to examine the cause of failure during the launching of collective Life Saving Appliances and speculate its probability. By determining how hazardous the degraded condition of main and sub components can be and why (i.e. the occurrence of corrosion), priorities can be then set when inspection is scheduled and therefore assist in the increase of efficiency of the surveys, as well as potential emphasis needed in the design of various components.

In this approach, several ship particulars where defined as determinant to the potential of risk of failure and where implemented in the model conceived. These particulars are the ship's age, class and flag performance. The probabilities produced with this premise and the data elaborated enable some conclusions to be made. The davit launched lifeboat seems to have the highest probability of failure of the LSA examined when launching. When compared to the davit launched liferaft, the fact that the lifeboat is safer after being launched needs to be taken into consideration. The free-fall launching method on the contrary appears to be the safest, without having any disadvantages compared to the other two LSA. Of all the components analyzed, the release mechanism exhibits the highest probability of failure and most importantly the hooks. The recent regulation revolving the replacement of all hooks comes to verify this result. Apart from the release mechanism, winch failure is the second most probable in all LSA examined. Of the failure modes, corrosion and fatigue-cracking appear around the same level with the more general bad condition having the highest values when it comes to davit launched and free-fall lifeboats. Finally, it is important to mention that throughout this research, it became quite evident that the quality of the maintenance policy regarding the LSA plays a key role to their condition. Due to the many parts of the LSA being exposed throughout the ship's operation, they may suffer from the weather effects and as a result, proper maintenance is vital. On the same note, crew lack of familiarity with the launching procedures also leads unavoidably to accidents.

The data analyzed and the models created relied on a respectable amount of information, giving the opportunity to make interpretations on the subject at hand but there is room for further and more analytical modeling and research of the matter. Additional information and research can be focused on:

- Further detailed information on the deficiencies encountered during the inspection of ships.
- In particular, information on critical and non-critical failure of the components.
- Additional feedback on the influence of the various main and sub-components of the LSA. Some components might require added gain in order to be better represented on the effect of the total failure of the LSA.
- The possibility of other failure modes not included in this research.

- As there are numerous manufacturers of LSA, there exist many different designs, technologies and methods regarding the launching mechanisms and therefore there is room for different models which approach specific designs.
- The effect of the operation area of a vessel. Depending on the operational area, a ship is confronted by different weather conditions. The effects of these vary, from the potential different corrosion rate of the various components to the effect of the many possible weather conditions. Extreme or mild weather conditions may affect the condition of the LSA, i.e. if not stowed properly.

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ANNEX A

SOLAS Regulations 21 and 31

Regulation 21 Survival craft and rescue boats

1 Survival craft

1.1 Passenger ships engaged on international voyages which are not short international voyages shall carry:

.1 partially or totally enclosed lifeboats complying with the requirements of section 4.5 or 4.6 of the Code on each side of such aggregate capacity as will accommodate not less than 50% of the total number of persons on board. The Administration may permit the substitution of lifeboats by liferafts of equivalent total capacity provided that there shall never be less than sufficient lifeboats on each side of the ship to accommodate 37.5% of the total number of persons on board. The inflatable or rigid liferafts shall comply with the requirements of section 4.2 or 4.3 of the Code and shall be served by launching appliances equally distributed on each side of the ship; and

.2 in addition, inflatable or rigid liferafts complying with the requirements of section 4.2 or 4.3 of the Code of such aggregate capacity as will accommodate at least 25% of the total number of persons on board. These liferafts shall be served by at least one launching appliance on each side which may be those provided in compliance with the requirements of paragraph 1.1.1 or equivalent approved appliances capable of being used on both sides. However, stowage of these liferafts need not comply with the requirements of regulation 13.5.

1.2 Passenger ships engaged on short international voyages shall carry:

.1 partially or totally enclosed lifeboats complying with the requirements of section 4.5 or 4.6 of the Code of such aggregate capacity as will accommodate at least 30% of the total number of persons on board. The lifeboats shall, as far as practicable, be equally distributed on each side of the ship. In addition inflatable or rigid liferafts complying with the requirements of section 4.2 or 4.3 of the Code shall be carried of such aggregate capacity that, together with the lifeboat capacity, the survival craft will accommodate the total number of persons on board. The liferafts shall be served by launching appliances equally distributed on each side of the ship; and

.2 in addition, inflatable or rigid liferafts complying with the requirements of section 4.2 or 4.3 of the Code of such aggregate capacity as will accommodate at least 25% of the total number of persons on board. These liferafts shall be served by at least one launching appliance on each side which may be those provided in compliance with the requirements of paragraph 1.2.1 or equivalent approved appliances capable of being used on both sides. However, stowage of these liferafts need not comply with the requirements of regulation 13.5.

1.3 All survival craft required to provide for abandonment by the total number of persons on board shall be capable of being launched with their full complement of persons and equipment within a period of 30 min from the time the abandon ship signal is given after all persons have been assembled, with lifejackets donned.

1.4 In lieu of meeting the requirements of paragraph 1.1, 1.2 or 1.3, passenger ships of less than 500 gross tonnage where the total number of persons on board is less than 200, may comply with the following:

.1 they shall carry on each side of the ship, inflatable or rigid liferafts complying with the requirements of section 4.2 or 4.3 of the Code and of such aggregate capacity as will accommodate the total number of persons on board;

.2 unless the liferafts required by paragraph 1.5.1 are stowed in a position providing for easy side to-side transfer at a single open deck level, additional liferafts shall be provided so that the total capacity available on each side will accommodate 150% of the total number of persons on board;

.3 if the rescue boat required by paragraph 2.2 is also a partially or totally enclosed lifeboat complying with the requirements of section 4.5 or 4.6 of the Code, it may be included in the aggregate capacity required by paragraph 1.5.1, provided that the total capacity available on either side of the ship is at least 150% of the total number of persons on board; and

.4 in the event of any one survival craft being lost or rendered unserviceable, there shall be sufficient survival craft available for use on each side, including those which are stowed in a position providing for easy side-to-side transfer at a single open deck level, to accommodate the total number of persons on board.

1.5 A marine evacuation system or systems complying with section 6.2 of the Code may be substituted for the equivalent capacity of liferafts and launching appliances required by paragraph 1.1.1 or 1.2.1.

Regulation 31 Survival craft and rescue boats

1 Survival craft

1.1 Cargo ships shall carry:

.1 one or more totally enclosed lifeboats complying with the requirements of section 4.6 of the Code of such aggregate capacity on each side of the ship as will accommodate the total number of persons on board; and

.2 in addition, one or more inflatable or rigid liferafts, complying with the requirements of section 4.2 or 4.3 of the Code, of a mass of less than 185 kg and stowed in a position providing for easy side to-side transfer at a single open deck level, and of such aggregate capacity as will accommodate the total number of persons on board. If the liferaft or liferafts are not of a mass of less than 185 kg and stowed in a position providing for easy side-to-side transfer at a single open deck level, the total capacity available on each side shall be sufficient to accommodate the total number of persons on board.

1.2 In lieu of meeting the requirements of paragraph 1.1, cargo ships may carry:

.1 one or more free-fall lifeboats, complying with the requirements of section 4.7 of the Code, capable of being free-fall launched over the stern of the ship of such aggregate capacity as will accommodate the total number of persons on board; and

.2 in addition, one or more inflatable or rigid liferafts complying with the requirements of section 4.2 or 4.3 of the Code, on each side of the ship, of such aggregate capacity as will accommodate the total number of persons on board. The liferafts on at least one side of the ship shall be served by launching appliances.

1.3 In lieu of meeting the requirements of paragraph 1.1 or 1.2, cargo ships of less than 85 m in length other than oil tankers, chemical tankers and gas carriers, may comply with the following:

.1 they shall carry on each side of the ship, one or more inflatable or rigid liferafts complying with the requirements of section 4.2 or 4.3 of the Code and of such aggregate capacity as will accommodate the total number of persons on board;

.2 unless the liferafts required by paragraph 1.3.1 are of a mass of less than 185 kg and stowed in a position providing for easy side-to-side transfer at a single open deck level, additional liferafts shall be provided so that the total capacity available on each side will accommodate 150% of the total number of persons on board;

.3 if the rescue boat required by paragraph 2 is also a totally enclosed lifeboat complying with the requirements of section 4.6 of the Code, it may be included in the aggregate capacity required by paragraph 1.3.1, provided that the total capacity available on either side of the ship is at least 150% of the total number of persons on board; and

.4 in the event of any one survival craft being lost or rendered unserviceable, there shall be sufficient survival craft available for use on each side, including any which are of a mass of less than 185 kg and stowed in a position providing for easy side

1.4 Cargo ships where the horizontal distance from the extreme end of the stem or stern of the ship to the nearest end of the closest survival craft is more than 100 m shall carry, in addition to the liferafts required by paragraphs 1.1.2 and 1.2.2, a liferaft stowed as far forward or aft, or one as far forward and another as far aft, as is reasonable and practicable. Such liferaft or liferafts may be securely fastened so as to permit manual release and need not be of the type which can be launched from an approved launching device.

1.5 With the exception of the survival craft referred to in regulation 16.1.1, all survival craft required to provide for abandonment by the total number of persons on board shall be capable of being launched with their full complement of persons and equipment within a period of 10 min from the time the abandon ship signal is given.

1.6 Chemical tankers and gas carriers carrying cargoes emitting toxic vapours or gases* shall carry, in lieu of totally enclosed lifeboats complying with the requirements of section 4.6 of the Code, lifeboats with a selfcontained air support system complying with the requirements of section 4.8 of the Code.

1.7 Oil tankers, chemical tankers and gas carriers carrying cargoes having a flashpoint not exceeding 60°C (closed-cup test) shall carry, in lieu of totally enclosed lifeboats complying with the requirements of section 4.6 of the Code, fire-protected lifeboats complying with the requirements of section 4.9 of the Code.

1.8 Notwithstanding the requirements of paragraph 1.1, bulk carriers as defined in regulation IX/1.6 constructed on or after 1 July 2006 shall comply with the requirements of paragraph 1.2.

ANNEX B

RESULTS

Davit Launched Lifeboats

Table 25: Probability of failure of hooks for davit launched lifeboats

key	**key**	**Key**	**Total value**	**Nature of defect**		
class	**flag**	**Age**	**p_Hook mechanism**	**Bad condition**	**Corrosion**	**Cracks**
IACS	white	young	0.00064	0.00036	0.00021	0.00007
IACS	white	Old	0.00741	0.00416	0.00244	0.00081
IACS	grey	young	0.00071	0.00040	0.00023	0.00008
IACS	grey	Old	0.00824	0.00462	0.00271	0.00090
IACS	black	young	0.00078	0.00044	0.00026	0.00009
IACS	black	Old	0.00906	0.00508	0.00298	0.00100
Non_IACS	white	young	0.00070	0.00039	0.00023	0.00008
Non_IACS	white	Old	0.00820	0.00460	0.00270	0.00090
Non_IACS	grey	young	0.00078	0.00044	0.00026	0.00009
Non_IACS	grey	Old	0.00911	0.00511	0.00300	0.00100
Non_IACS	black	young	0.00086	0.00048	0.00028	0.00009
Non_IACS	black	old	0.00986	0.00548	0.00328	0.0011

Table 26: Probability of failure of operating cables for davit launched lifeboats

Key	key	key	Total value	Nature of defect		
class	flag	age	**p_Operating cables**	Bad condition	Corrosion	Cracks
IACS	white	young	0.00026	0.00006	0.00001	0.00018
IACS	white	old	0.00288	0.00073	0.00001	0.00213
IACS	grey	young	0.00029	0.00007	0.00002	0.00020
IACS	grey	old	0.00320	0.00081	0.00001	0.00237
IACS	black	young	0.00031	0.00008	0.00001	0.00022
IACS	black	old	0.00353	0.00090	0.00002	0.00261
Non_IACS	white	young	0.00028	0.00007	0.00001	0.00020
Non_IACS	white	old	0.00318	0.00081	0.00001	0.00236
Non_IACS	grey	young	0.00031	0.00008	0.00001	0.00022
Non_IACS	grey	old	0.00354	0.00090	0.00002	0.00262
Non_IACS	black	young	0.00034	0.00008	0.00001	0.00025
Non_IACS	black	old	0.00389	0.00099	0.00002	0.00288

Table 27: Probability of failure of control lever for davit launched lifeboats

key	key	key	Total value	Nature of defect		
class	flag	age	**p_Control lever**	Bad condition	Corrosion	Cracks
IACS	white	young	0.00034	0.00032	0.00001	0.00001
IACS	white	old	0.00378	0.00375	0.00002	0.00001
IACS	grey	young	0.00040	0.00036	0.00002	0.00002
IACS	grey	old	0.00418	0.00416	0.00001	0.00001
IACS	black	young	0.00041	0.00039	0.00001	0.00001
IACS	black	old	0.00462	0.00458	0.00002	0.00002
Non_IACS	white	young	0.00038	0.00036	0.00001	0.00001
Non_IACS	white	old	0.00418	0.00414	0.00002	0.00002
Non_IACS	grey	young	0.00041	0.00039	0.00001	0.00001
Non_IACS	grey	old	0.00465	0.00460	0.00003	0.00002
Non_IACS	black	young	0.00045	0.00043	0.00001	0.00001
Non_IACS	black	old	0.00511	0.00506	0.00003	0.00002

Table 28: Probability of failure of winch general subcomponent (everything apart from brake and gear system) for davit launched lifeboats

key	key	key	Total value	Nature of defect		
class	**flag**	**age**	**p_winch general**	**Bad condition**	**Corrosion**	**Cracks**
IACS	white	young	0.00009	0.00003	0.00005	0.00001
IACS	white	old	0.00092	0.00032	0.00059	0.00001
IACS	grey	young	0.00011	0.00003	0.00006	0.00002
IACS	grey	old	0.00103	0.00036	0.00066	0.00001
IACS	black	young	0.00011	0.00003	0.00006	0.00001
IACS	black	old	0.00114	0.00039	0.00072	0.00002
Non_IACS	white	young	0.00010	0.00003	0.00006	0.00001
Non_IACS	white	old	0.00102	0.00036	0.00065	0.00001
Non_IACS	grey	young	0.00011	0.00003	0.00006	0.00001
Non_IACS	grey	old	0.00114	0.00040	0.00073	0.00002
Non_IACS	black	young	0.00012	0.00004	0.00007	0.00001
Non_IACS	black	old	0.00125	0.00044	0.00080	0.00002

Table 29: Probability of failure of winch gear system for davit launched lifeboats

key	key	key	Total value	Nature of defect		
class	**flag**	**age**	**p_winch gear system**	**Bad condition**	**Corrosion**	**Cracks**
IACS	white	young	0.00002	0.00000	0.00000	0.00002
IACS	white	old	0.00019	0.00000	0.00000	0.00019
IACS	grey	young	0.00002	0.00000	0.00000	0.00002
IACS	grey	old	0.00021	0.00000	0.00000	0.00021
IACS	black	young	0.00002	0.00000	0.00000	0.00002
IACS	black	old	0.00023	0.00000	0.00000	0.00023
Non_IACS	white	young	0.00002	0.00000	0.00000	0.00002
Non_IACS	white	old	0.00021	0.00000	0.00000	0.00021
Non_IACS	grey	young	0.00002	0.00000	0.00000	0.00002
Non_IACS	grey	old	0.00023	0.00000	0.00000	0.00023
Non_IACS	black	young	0.00002	0.00000	0.00000	0.00002
Non_IACS	black	old	0.00025	0.00000	0.00000	0.00025

Table 30: Probability of failure of winch break for davit launched lifeboats

key	key	key	Total value	Nature of defect		
class	**flag**	**age**	**p_winch_brake**	**Bad condition**	**Corrosion**	**Cracks**
IACS	white	young	0.00014	0.00012	0.00001	0.00001
IACS	white	old	0.00137	0.00135	0.00001	0.00001
IACS	grey	young	0.00015	0.00013	0.00001	0.00001
IACS	grey	old	0.00152	0.00150	0.00001	0.00001
IACS	black	young	0.00016	0.00014	0.00001	0.00001
IACS	black	old	0.00168	0.00164	0.00002	0.00002
Non_IACS	white	young	0.00015	0.00013	0.00001	0.00001
Non_IACS	white	old	0.00151	0.00149	0.00001	0.00001
Non_IACS	grey	young	0.00016	0.00014	0.00001	0.00001
Non_IACS	grey	old	0.00169	0.00165	0.00002	0.00002
Non_IACS	black	young	0.00018	0.00016	0.00001	0.00001
Non_IACS	black	old	0.00186	0.00182	0.00002	0.00002

Table 31: Probability of failure of davit structure for davit launched lifeboats

key	key	key	Total value	Nature of defect		
class	**flag**	**age**	**p_davit structure**	**Bad condition**	**Corrosion**	**Cracks**
IACS	white	young	0.00005	0.00002	0.00003	0.00001
IACS	white	old	0.00061	0.00018	0.00029	0.00014
IACS	grey	young	0.00006	0.00002	0.00003	0.00001
IACS	grey	old	0.00068	0.00020	0.00032	0.00016
IACS	black	young	0.00006	0.00002	0.00003	0.00001
IACS	black	old	0.00075	0.00022	0.00036	0.00017
Non_IACS	white	young	0.00006	0.00002	0.00003	0.00001
Non_IACS	white	old	0.00068	0.00020	0.00032	0.00016
Non_IACS	grey	young	0.00006	0.00002	0.00003	0.00001
Non_IACS	grey	old	0.00075	0.00022	0.00036	0.00017
Non_IACS	black	young	0.00007	0.00002	0.00003	0.00002
Non_IACS	black	old	0.00083	0.00024	0.00039	0.00019

Table 32: Probability of failure of limit switch for davit launched lifeboat

key	key	key	Total value	Nature of defect		
class	**flag**	**age**	**p_limit switch**	**Bad condition**	**Corrosion**	**Cracks**
IACS	white	young	0.00012	0.00007	0.00001	0.00003
IACS	white	old	0.00124	0.00085	0.00001	0.00038
IACS	grey	young	0.00014	0.00008	0.00002	0.00004
IACS	grey	old	0.00137	0.00094	0.00001	0.00042
IACS	black	young	0.00014	0.00009	0.00001	0.00004
IACS	black	old	0.00152	0.00104	0.00002	0.00046
Non_IACS	white	young	0.00013	0.00008	0.00001	0.00004
Non_IACS	white	old	0.00137	0.00094	0.00001	0.00042
Non_IACS	grey	young	0.00014	0.00009	0.00001	0.00004
Non_IACS	grey	old	0.00153	0.00104	0.00002	0.00047
Non_IACS	black	young	0.00015	0.00010	0.00001	0.00004
Non_IACS	black	old	0.00168	0.00115	0.00002	0.00051

Table 33: Probability of failure of lifeboats for davit launched lifeboats

key	key	key	Total value	Nature of defect		
class	**flag**	**age**	**p_boat**	**Bad condition**	**Corrosion**	**Cracks**
IACS	white	young	0.00013	0.00003	0.00002	0.00008
IACS	white	old	0.00150	0.00041	0.00020	0.00089
IACS	grey	young	0.00014	0.00004	0.00002	0.00009
IACS	grey	old	0.00167	0.00045	0.00023	0.00099
IACS	black	young	0.00016	0.00004	0.00002	0.00009
IACS	black	old	0.00183	0.00050	0.00025	0.00109
Non_IACS	white	young	0.00014	0.00004	0.00002	0.00008
Non_IACS	white	old	0.00166	0.00045	0.00022	0.00099
Non_IACS	grey	young	0.00016	0.00004	0.00002	0.00009
Non_IACS	grey	old	0.00184	0.00050	0.00025	0.00110
Non_IACS	black	young	0.00017	0.00005	0.00002	0.00010
Non_IACS	black	old	0.00203	0.00055	0.00027	0.00121

Table 34: Probability of failure of falls, sheaves & blocks for davit launched lifeboats

key	key	key	Total value	Nature of defect		
class	**flag**	**age**	**P_Falls_sheaves & blocks**	**Bad condition**	**Corrosion**	**Cracks**
IACS	white	young	0.00012	0.00007	0.00004	0.00001
IACS	white	old	0.00140	0.00083	0.00045	0.00011
IACS	grey	young	0.00013	0.00008	0.00004	0.00001
IACS	grey	old	0.00155	0.00093	0.00050	0.00013
IACS	black	young	0.00015	0.00009	0.00005	0.00001
IACS	black	old	0.00171	0.00102	0.00055	0.00014
Non_IACS	white	young	0.00013	0.00008	0.00004	0.00001
Non_IACS	white	old	0.00154	0.00092	0.00050	0.00012
Non_IACS	grey	young	0.00015	0.00009	0.00005	0.00001
Non_IACS	grey	old	0.00172	0.00102	0.00055	0.00014
Non_IACS	black	young	0.00016	0.00010	0.00005	0.00001
Non_IACS	black	old	0.00189	0.00113	0.00061	0.00015

Table 35: Probability of failure of bowsing & tricing for davit launched lifeboats

key	key	key	Total value	Nature of defect		
class	**flag**	**age**	**P_Bowsing & tricing**	**Bad condition**	**Corrosion**	**Cracks**
IACS	white	young	0.00003	0.00001	0.00001	0.00001
IACS	white	old	0.00022	0.00004	0.00005	0.00012
IACS	grey	young	0.00005	0.00001	0.00002	0.00002
IACS	grey	old	0.00024	0.00005	0.00006	0.00014
IACS	black	young	0.00006	0.00002	0.00002	0.00002
IACS	black	old	0.00026	0.00005	0.00006	0.00015
Non_IACS	white	young	0.00006	0.00002	0.00002	0.00002
Non_IACS	white	old	0.00024	0.00005	0.00006	0.00014
Non_IACS	grey	young	0.00008	0.00002	0.00003	0.00003
Non_IACS	grey	old	0.00027	0.00005	0.00006	0.00015
Non_IACS	black	young	0.00010	0.00003	0.00004	0.00003
Non_IACS	black	old	0.00029	0.00006	0.00007	0.00017

Table 36: Probability of failure of fall wires for davit launched lifeboats

key	key	key	Total value	Nature of defect		
class	**flag**	**age**	**P_Wires**	**Bad condition**	**Corrosion**	**Cracks**
IACS	white	young	0.00015	0.00006	0.00006	0.00004
IACS	white	old	0.00175	0.00066	0.00065	0.00044
IACS	grey	young	0.00017	0.00006	0.00006	0.00004
IACS	grey	old	0.00194	0.00073	0.00073	0.00048
IACS	black	young	0.00018	0.00007	0.00007	0.00005
IACS	black	old	0.00214	0.00081	0.00080	0.00053
Non_IACS	white	young	0.00017	0.00006	0.00006	0.00004
Non_IACS	white	old	0.00193	0.00073	0.00072	0.00048
Non_IACS	grey	young	0.00018	0.00007	0.00007	0.00005
Non_IACS	grey	old	0.00215	0.00081	0.00080	0.00053
Non_IACS	black	young	0.00020	0.00008	0.00008	0.00005
Non_IACS	black	old	0.00236	0.00089	0.00088	0.00059

Free fall lifeboats

Table 37: Probability of failure of hooks for free-fall lifeboats

key	key	key	Total value	Nature of defect		
class	**flag**	**age**	**p_Hook mechanism**	**Bad condition**	**Corrosion**	**Cracks**
IACS	white	young	0.00008	0.00006	0.00001	0.00001
IACS	white	old	0.00072	0.00069	0.00002	0.00001
IACS	grey	young	0.00009	0.00007	0.00001	0.00001
IACS	grey	old	0.00080	0.00077	0.00001	0.00002
IACS	black	young	0.00009	0.00007	0.00001	0.00001
IACS	black	old	0.00088	0.00085	0.00001	0.00002
Non_IACS	white	young	0.00009	0.00007	0.00001	0.00001
Non_IACS	white	old	0.00080	0.00077	0.00002	0.00001
Non_IACS	grey	young	0.00009	0.00007	0.00001	0.00001
Non_IACS	grey	old	0.00089	0.00085	0.00002	0.00002
Non_IACS	black	young	0.00010	0.00008	0.00001	0.00001
Non_IACS	black	old	0.00098	0.00094	0.00002	0.00002

Table 38: Probability of operating cables failure for free-fall lifeboats

key	key	key	Total value	Nature of defect		
class	**flag**	**age**	**p_Operating cables**	**Bad condition**	**Corrosion**	**Cracks**
IACS	white	young	0.00006	0.00004	0.00001	0.00001
IACS	white	old	0.00045	0.00042	0.00001	0.00002
IACS	grey	young	0.00006	0.00004	0.00001	0.00001
IACS	grey	old	0.00049	0.00046	0.00002	0.00001
IACS	black	young	0.00006	0.00004	0.00001	0.00001
IACS	black	old	0.00054	0.00051	0.00002	0.00001
Non_IACS	white	young	0.00006	0.00004	0.00001	0.00001
Non_IACS	white	old	0.00049	0.00046	0.00001	0.00002
Non_IACS	grey	young	0.00006	0.00004	0.00001	0.00001
Non_IACS	grey	old	0.00055	0.00051	0.00002	0.00002
Non_IACS	black	young	0.00007	0.00005	0.00001	0.00001
Non_IACS	black	old	0.00060	0.00056	0.00002	0.00002

Table 39: Probability of failure of control lever for free-fall lifeboats

key	key	key	Total value	Nature of defect		
class	**flag**	**age**	**p_Control lever**	**Bad condition**	**Corrosion**	**Cracks**
IACS	white	young	0.00003	0.00001	0.00001	0.00001
IACS	white	old	0.00004	0.00001	0.00001	0.00002
IACS	grey	young	0.00003	0.00001	0.00001	0.00001
IACS	grey	old	0.00005	0.00002	0.00002	0.00001
IACS	black	young	0.00003	0.00001	0.00001	0.00001
IACS	black	old	0.00005	0.00002	0.00002	0.00001
Non_IACS	white	young	0.00003	0.00001	0.00001	0.00001
Non_IACS	white	old	0.00005	0.00002	0.00001	0.00002
Non_IACS	grey	young	0.00003	0.00001	0.00001	0.00001
Non_IACS	grey	old	0.00006	0.00002	0.00002	0.00002
Non_IACS	black	young	0.00003	0.00001	0.00001	0.00001
Non_IACS	black	old	0.00008	0.00004	0.00002	0.00002

Table 40: Probability of failure of davit structure for free-fall lifeboats

key	key	key	Total value	Nature of defect		
class	flag	age	**p_davit structure**	Bad condition	Corrosion	Cracks
IACS	white	young	0.00004	0.00001	0.00002	0.00001
IACS	white	old	0.00035	0.00011	0.00022	0.00002
IACS	grey	young	0.00004	0.00001	0.00002	0.00001
IACS	grey	old	0.00037	0.00012	0.00025	0.00001
IACS	black	young	0.00004	0.00001	0.00002	0.00001
IACS	black	old	0.00041	0.00013	0.00027	0.00001
Non_IACS	white	young	0.00004	0.00001	0.00002	0.00001
Non_IACS	white	old	0.00038	0.00012	0.00025	0.00002
Non_IACS	grey	young	0.00004	0.00001	0.00002	0.00001
Non_IACS	grey	old	0.00042	0.00013	0.00027	0.00002
Non_IACS	black	young	0.00005	0.00001	0.00003	0.00001
Non_IACS	black	old	0.00044	0.00014	0.00030	0.00002

Table 41: Probability of failure of limit switch for free-fall lifeboat

key	key	key	Total value	Nature of defect		
class	flag	age	**p_limit switch**	Bad condition	Corrosion	Cracks
IACS	white	young	0.00003	0.00001	0.00001	0.00001
IACS	white	old	0.00006	0.00003	0.00001	0.00002
IACS	grey	young	0.00003	0.00001	0.00001	0.00001
IACS	grey	old	0.00007	0.00003	0.00002	0.00002
IACS	black	young	0.00003	0.00001	0.00001	0.00001
IACS	black	old	0.00007	0.00003	0.00002	0.00002
Non_IACS	white	young	0.00003	0.00001	0.00001	0.00001
Non_IACS	white	old	0.00006	0.00003	0.00001	0.00002
Non_IACS	grey	young	0.00003	0.00001	0.00001	0.00001
Non_IACS	grey	old	0.00008	0.00004	0.00002	0.00002
Non_IACS	black	young	0.00003	0.00001	0.00001	0.00001
Non_IACS	black	old	0.00009	0.00005	0.00002	0.00002

Table 42: Probability of failure of winch general subcomponent (everything apart from brake and gear system) for free-fall lifeboats

key	key	key	Total value	Nature of defect		
class	flag	age	**p_winch general**	**Bad condition**	**Corrosion**	**Cracks**
IACS	white	young	0.00008	0.00004	0.00003	0.00001
IACS	white	old	0.00079	0.00043	0.00035	0.00001
IACS	grey	young	0.00008	0.00004	0.00003	0.00001
IACS	grey	old	0.00089	0.00047	0.00039	0.00002
IACS	black	young	0.00009	0.00004	0.00004	0.00001
IACS	black	old	0.00097	0.00052	0.00043	0.00002
Non_IACS	white	young	0.00008	0.00004	0.00003	0.00001
Non_IACS	white	old	0.00087	0.00047	0.00039	0.00001
Non_IACS	grey	young	0.00009	0.00004	0.00004	0.00001
Non_IACS	grey	old	0.00098	0.00052	0.00044	0.00002
Non_IACS	black	young	0.00010	0.00005	0.00004	0.00001
Non_IACS	black	old	0.00108	0.00058	0.00048	0.00002

Table 43: Probability of failure of winch gear system for free-fall lifeboats

key	key	key	Total value	Nature of defect		
class	flag	age	**p_winch gear system**	**Bad condition**	**Corrosion**	**Cracks**
IACS	white	young	0.00003	0.00001	0.00001	0.00001
IACS	white	old	0.00004	0.00001	0.00002	0.00001
IACS	grey	young	0.00003	0.00001	0.00001	0.00001
IACS	grey	old	0.00004	0.00001	0.00001	0.00002
IACS	black	young	0.00003	0.00001	0.00001	0.00001
IACS	black	old	0.00004	0.00001	0.00001	0.00002
Non_IACS	white	young	0.00003	0.00001	0.00001	0.00001
Non_IACS	white	old	0.00004	0.00001	0.00002	0.00001
Non_IACS	grey	young	0.00003	0.00001	0.00001	0.00001
Non_IACS	grey	old	0.00005	0.00001	0.00002	0.00002
Non_IACS	black	young	0.00003	0.00001	0.00001	0.00001
Non_IACS	black	old	0.00006	0.00002	0.00002	0.00002

Table 44: Probability of failure of winch brake for free-fall lifeboats

key	key	key	Total value	Nature of defect		
class	**flag**	**age**	**p_winch brake**	**Bad condition**	**Corrosion**	**Cracks**
IACS	white	young	0.00003	0.00001	0.00001	0.00001
IACS	white	old	0.00004	0.00002	0.00001	0.00001
IACS	grey	young	0.00003	0.00001	0.00001	0.00001
IACS	grey	old	0.00004	0.00001	0.00002	0.00001
IACS	black	young	0.00003	0.00001	0.00001	0.00001
IACS	black	old	0.00004	0.00001	0.00002	0.00001
Non_IACS	white	young	0.00003	0.00001	0.00001	0.00001
Non_IACS	white	old	0.00004	0.00002	0.00001	0.00001
Non_IACS	grey	young	0.00003	0.00001	0.00001	0.00001
Non_IACS	grey	old	0.00005	0.00002	0.00002	0.00001
Non_IACS	black	young	0.00003	0.00001	0.00001	0.00001
Non_IACS	black	old	0.00006	0.00002	0.00002	0.00002

Table 45: Probability of failure of lifeboat for free-fall lifeboats

key	key	key	Total value	Nature of defect		
class	**flag**	**age**	**P_Boat**	**Bad condition**	**Corrosion**	**Cracks**
IACS	white	young	0.00012	0.00006	0.00001	0.00005
IACS	white	old	0.00129	0.00075	0.00001	0.00053
IACS	grey	young	0.00013	0.00007	0.00001	0.00005
IACS	grey	old	0.00143	0.00084	0.00001	0.00058
IACS	black	young	0.00014	0.00008	0.00001	0.00006
IACS	black	old	0.00157	0.00092	0.00001	0.00064
Non_IACS	white	young	0.00013	0.00007	0.00001	0.00005
Non_IACS	white	old	0.00142	0.00083	0.00001	0.00058
Non_IACS	grey	young	0.00014	0.00008	0.00001	0.00006
Non_IACS	grey	old	0.00158	0.00092	0.00001	0.00065
Non_IACS	black	young	0.00016	0.00009	0.00001	0.00006
Non_IACS	black	old	0.00174	0.00102	0.00001	0.00071

Table 46: Probability of failure of falls, sheaves & blocks for free-fall lifeboat

key	key	key	Total value	Nature of defect		
class	flag	age	P_Falls_sheaves & blocks	Bad condition	Corrosion	Cracks
IACS	white	young	0.00009	0.00005	0.00003	0.00001
IACS	white	old	0.00104	0.00062	0.00034	0.00009
IACS	grey	young	0.00010	0.00006	0.00003	0.00001
IACS	grey	old	0.00116	0.00069	0.00038	0.00009
IACS	black	young	0.00011	0.00006	0.00004	0.00001
IACS	black	old	0.00128	0.00076	0.00042	0.00010
Non_IACS	white	young	0.00010	0.00006	0.00003	0.00001
Non_IACS	white	old	0.00115	0.00068	0.00038	0.00009
Non_IACS	grey	young	0.00011	0.00007	0.00004	0.00001
Non_IACS	grey	old	0.00128	0.00076	0.00042	0.00010
Non_IACS	black	young	0.00012	0.00007	0.00004	0.00001
Non_IACS	black	old	0.00141	0.00084	0.00046	0.00012

Table 47: Probability of failure of fall wires for free-fall lifeboats

key	key	key	Total value	Nature of defect		
class	flag	age	P_Wires	Bad condition	Corrosion	Cracks
IACS	white	young	0.00005	0.00001	0.00003	0.00001
IACS	white	old	0.00045	0.00001	0.00030	0.00015
IACS	grey	young	0.00005	0.00001	0.00003	0.00001
IACS	grey	old	0.00050	0.00001	0.00033	0.00016
IACS	black	young	0.00006	0.00001	0.00003	0.00002
IACS	black	old	0.00055	0.00001	0.00036	0.00018
Non_IACS	white	young	0.00005	0.00001	0.00003	0.00001
Non_IACS	white	old	0.00050	0.00001	0.00033	0.00016
Non_IACS	grey	young	0.00006	0.00001	0.00003	0.00002
Non_IACS	grey	old	0.00056	0.00001	0.00036	0.00018
Non_IACS	black	young	0.00006	0.00001	0.00003	0.00002
Non_IACS	black	old	0.00061	0.00001	0.00040	0.00020

Davit launched liferafts

Table 48: Probability of failure of hooks for davit launched liferafts

key	key	key	Total value	Nature of defect		
class	**flag**	**age**	**p_Hook mechanism**	**Bad condition**	**Corrosion**	**Cracks**
IACS	white	young	0.00030	0.00010	0.00015	0.00005
IACS	white	old	0.00297	0.00119	0.00122	0.00056
IACS	grey	young	0.00040	0.00011	0.00023	0.00005
IACS	grey	old	0.00347	0.00132	0.00153	0.00062
IACS	black	young	0.00044	0.00012	0.00026	0.00006
IACS	black	old	0.00383	0.00145	0.00169	0.00069
Non_IACS	white	young	0.00040	0.00011	0.00023	0.00005
Non_IACS	white	old	0.00394	0.00131	0.00201	0.00062
Non_IACS	grey	young	0.00044	0.00012	0.00026	0.00006
Non_IACS	grey	old	0.00430	0.00146	0.00215	0.00069
Non_IACS	black	young	0.00050	0.00014	0.00029	0.00007
Non_IACS	black	old	0.00484	0.00180	0.00228	0.00076

Table 49: Probability of failure of operating cables for davit launched liferafts

key	key	key	Total value	Nature of defect		
class	**flag**	**age**	**p_Operating cables**	**Bad condition**	**Corrosion**	**Cracks**
IACS	white	young	0.00008	0.00002	0.00000	0.00005
IACS	white	old	0.00086	0.00022	0.00000	0.00064
IACS	grey	young	0.00009	0.00002	0.00001	0.00006
IACS	grey	old	0.00096	0.00024	0.00000	0.00071
IACS	black	young	0.00009	0.00002	0.00000	0.00007
IACS	black	old	0.00106	0.00027	0.00001	0.00078
Non_IACS	white	young	0.00008	0.00002	0.00000	0.00006
Non_IACS	white	old	0.00096	0.00024	0.00001	0.00071
Non_IACS	grey	young	0.00009	0.00002	0.00000	0.00007
Non_IACS	grey	old	0.00106	0.00027	0.00001	0.00079
Non_IACS	black	young	0.00010	0.00003	0.00000	0.00007
Non_IACS	black	old	0.00117	0.00030	0.00001	0.00087

Table 50: Probability of failure of control lever for davit launched liferafts

key	key	key	Total value	Nature of defect		
class	**flag**	**age**	**p_Control lever**	**Bad condition**	**Corrosion**	**Cracks**
IACS	white	young	0.00003	0.00001	0.00001	0.00001
IACS	white	old	0.00009	0.00006	0.00002	0.00001
IACS	grey	young	0.00005	0.00001	0.00002	0.00002
IACS	grey	old	0.00009	0.00007	0.00001	0.00001
IACS	black	young	0.00003	0.00001	0.00001	0.00001
IACS	black	old	0.00012	0.00008	0.00002	0.00002
Non_IACS	white	young	0.00003	0.00001	0.00001	0.00001
Non_IACS	white	old	0.00013	0.00007	0.00003	0.00003
Non_IACS	grey	young	0.00003	0.00001	0.00001	0.00001
Non_IACS	grey	old	0.00015	0.00008	0.00004	0.00003
Non_IACS	black	young	0.00003	0.00001	0.00001	0.00001
Non_IACS	black	old	0.00018	0.00009	0.00005	0.00004

Table 51: Probability of failure of falls, sheaves & blocks for davit launched liferafts

key	key	key	Total value	Nature of defect		
class	**flag**	**age**	**p_falls_sheaves_& blocks**	**Bad condition**	**Corrosion**	**Cracks**
IACS	white	young	0.00005	0.00002	0.00001	0.00001
IACS	white	old	0.00046	0.00028	0.00015	0.00004
IACS	grey	young	0.00005	0.00003	0.00001	0.00001
IACS	grey	old	0.00051	0.00031	0.00017	0.00004
IACS	black	young	0.00005	0.00003	0.00002	0.00001
IACS	black	old	0.00056	0.00034	0.00018	0.00005
Non_IACS	white	young	0.00005	0.00003	0.00001	0.00001
Non_IACS	white	old	0.00051	0.00030	0.00016	0.00004
Non_IACS	grey	young	0.00005	0.00003	0.00002	0.00001
Non_IACS	grey	old	0.00057	0.00034	0.00018	0.00005
Non_IACS	black	young	0.00006	0.00003	0.00002	0.00001
Non_IACS	black	old	0.00062	0.00037	0.00020	0.00005

Table 52: Probability of failure of fall wires for davit launched liferafts

key	key	key	Total value	Nature of defect		
class	flag	age	P_Wires	Bad condition	Corrosion	Cracks
IACS	white	young	0.00006	0.00002	0.00002	0.00002
IACS	white	old	0.00069	0.00022	0.00018	0.00029
IACS	grey	young	0.00007	0.00002	0.00002	0.00003
IACS	grey	old	0.00077	0.00024	0.00020	0.00032
IACS	black	young	0.00007	0.00002	0.00002	0.00003
IACS	black	old	0.00084	0.00027	0.00022	0.00035
Non_IACS	white	young	0.00007	0.00002	0.00002	0.00003
Non_IACS	white	old	0.00076	0.00024	0.00020	0.00032
Non_IACS	grey	young	0.00007	0.00002	0.00002	0.00003
Non_IACS	grey	old	0.00085	0.00027	0.00023	0.00036
Non_IACS	black	young	0.00008	0.00003	0.00002	0.00003
Non_IACS	black	old	0.00093	0.00029	0.00025	0.00039

Table 53: Probability of failure of davit structure for davit launched liferafts

key	key	key	Total value	Nature of defect		
class	flag	age	P_Davit structure	Bad condition	Corrosion	Cracks
IACS	white	young	0.00003	0.00001	0.00001	0.00001
IACS	white	old	0.00012	0.00008	0.00003	0.00001
IACS	grey	young	0.00003	0.00001	0.00001	0.00001
IACS	grey	old	0.00013	0.00009	0.00003	0.00001
IACS	black	young	0.00003	0.00001	0.00001	0.00001
IACS	black	old	0.00014	0.00010	0.00003	0.00001
Non_IACS	white	young	0.00003	0.00001	0.00001	0.00001
Non_IACS	white	old	0.00013	0.00009	0.00003	0.00001
Non_IACS	grey	young	0.00003	0.00001	0.00001	0.00001
Non_IACS	grey	old	0.00014	0.00010	0.00003	0.00001
Non_IACS	black	young	0.00003	0.00001	0.00001	0.00001
Non_IACS	black	old	0.00015	0.00011	0.00004	0.00001

Table 54: Probability of failure of limit switch for davit launched liferafts

key	key	key	Total value	Nature of defect		
class	**flag**	**age**	**P_Limit switch**	**Bad condition**	**Corrosion**	**Cracks**
IACS	white	young	0.00004	0.00002	0.00001	0.00001
IACS	white	old	0.00033	0.00021	0.00001	0.00011
IACS	grey	young	0.00004	0.00002	0.00001	0.00001
IACS	grey	old	0.00037	0.00023	0.00001	0.00013
IACS	black	young	0.00004	0.00002	0.00001	0.00001
IACS	black	old	0.00040	0.00025	0.00001	0.00014
Non_IACS	white	young	0.00004	0.00002	0.00001	0.00001
Non_IACS	white	old	0.00036	0.00023	0.00001	0.00012
Non_IACS	grey	young	0.00004	0.00002	0.00001	0.00001
Non_IACS	grey	old	0.00040	0.00025	0.00001	0.00014
Non_IACS	black	young	0.00005	0.00002	0.00001	0.00001
Non_IACS	black	old	0.00044	0.00028	0.00001	0.00015

Probability of failure of winch general subcomponent (everything apart from brake and gear system) for davit launched liferafts

key	key	key	Total value	Nature of defect		
class	**flag**	**age**	**P_Winch general**	**Bad condition**	**Corrosion**	**Cracks**
IACS	white	young	0.00005	0.00002	0.00003	0.00001
IACS	white	old	0.00051	0.00019	0.00031	0.00001
IACS	grey	young	0.00006	0.00002	0.00003	0.00001
IACS	grey	old	0.00057	0.00021	0.00035	0.00001
IACS	black	young	0.00006	0.00002	0.00003	0.00001
IACS	black	old	0.00063	0.00024	0.00038	0.00001
Non_IACS	white	young	0.00006	0.00002	0.00003	0.00001
Non_IACS	white	old	0.00057	0.00021	0.00034	0.00001
Non_IACS	grey	young	0.00006	0.00002	0.00003	0.00001
Non_IACS	grey	old	0.00064	0.00024	0.00038	0.00002
Non_IACS	black	young	0.00007	0.00002	0.00004	0.00001
Non_IACS	black	old	0.00071	0.00026	0.00042	0.00003

Table 56: Probability of failure of winch gear system for davit launched liferafts

key	key	key	Total value	Nature of defect		
class	**flag**	**age**	**p_winch gear system**	**Bad condition**	**Corrosion**	**Cracks**
IACS	white	young	0.00005	0.00001	0.00001	0.00003
IACS	white	old	0.00005	0.00001	0.00001	0.00003
IACS	grey	young	0.00003	0.00001	0.00001	0.00001
IACS	grey	old	0.00005	0.00001	0.00001	0.00003
IACS	black	young	0.00003	0.00001	0.00001	0.00001
IACS	black	old	0.00005	0.00001	0.00001	0.00003
Non_IACS	white	young	0.00003	0.00001	0.00001	0.00001
Non_IACS	white	old	0.00005	0.00001	0.00001	0.00003
Non_IACS	grey	young	0.00003	0.00001	0.00001	0.00001
Non_IACS	grey	old	0.00005	0.00001	0.00001	0.00003
Non_IACS	black	young	0.00003	0.00001	0.00001	0.00001
Non_IACS	black	old	0.00006	0.00001	0.00001	0.00004

Table 57: Probability of failure of winch brake for davit launched liferafts

key	key	key	Total value	Nature of defect		
class	**flag**	**age**	**p_winch brake**	**Bad condition**	**Corrosion**	**Deformation**
IACS	white	young	0.00003	0.00001	0.00001	0.00001
IACS	white	old	0.00029	0.00027	0.00001	0.00001
IACS	grey	young	0.00003	0.00001	0.00001	0.00001
IACS	grey	old	0.00050	0.00048	0.00001	0.00001
IACS	black	young	0.00003	0.00001	0.00001	0.00001
IACS	black	old	0.00062	0.00059	0.00002	0.00001
Non_IACS	white	young	0.00003	0.00001	0.00001	0.00001
Non_IACS	white	old	0.00052	0.00049	0.00001	0.00002
Non_IACS	grey	young	0.00003	0.00001	0.00001	0.00001
Non_IACS	grey	old	0.00063	0.00061	0.00001	0.00002
Non_IACS	black	young	0.00003	0.00001	0.00001	0.00001
Non_IACS	black	old	0.00103	0.00100	0.00002	0.00002