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Code Development for Capturing Ship Inspections Capabilities

Diploma Thesis

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Abbreviations

ABS	American Bureau of Shipping
ALARP	As Low As Reasonably Practicable
AMSB	Australian Maritime Service Board
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
BN	Bayesian Network
BRS	Bulgarian Register of Shipping
BV	Bureau Veritas
CCS	China Classification Society
CLC	Civil Liability for Oil Pollution Damage
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
FSC	Flag State Control
FTA	Fault Tree Analysis
GCAF	Gross Cost of Averting a Fatality
HAZID	Hazard Identification
HAZOP	Hazard Operability
HRS	Hellenic Register of Shipping
HRS	High Risk Ships
HSC	Health and Safety Commission
IACS	International Association of Classification Societies
IBC Code	International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk
ICC	Impressed Current Cathodic Protection
ICS	International Chamber of Shipping
IGC Code	Code for Cons Construction and Equipment of Ships Carrying Liquefied Gases in Bulk
IMO	International Maritime Organization
IMR	Inspection, Maintenance, and Repair
IRS	Indian Register of Shipping

ISM	International Safety Management
KR	Korean Register of Shipping
LL	Load Lines
LR	Lloyd's Register
LRS	Low Risk Ships
LSA	Life Saving Appliances
MAIB	Marine Accident Investigation Branch
MSC	Maritime Safety Committee
NCAF	Net Cost of Averting a Fatality
NIR	New Inspection Regime
NK	Nippon Kaiji Kyokai
NPD	Norwegian Petroleum Directorate
NPV	Non-Priority Vessel
OCIMF	Oil Companies International Marine Forum
OMCS	Overseas Marine Certification Services
PI	Priority I Vessel
PII	Priority II Vessel
PoU	Paris Memorandum of Understanding
PRS	Polish Register of Shipping
PSC	Port State Control
PSCC	Port State Control Committee
PSCO	Port State Control Officer
Q	Qualitative
QRA	Quantitative
RBI	Risk Based Inspection
RCM	Reliability Centered Maintenance
RINA	Registro Italiano Navale
RINA VE	Registro Internacional Naval
RS	Russian Maritime Register of Shipping
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
UNCTAD	United Nations Conference on Trade
USCG	Port State Control in The United States

Περίληψη

Σκοποί της παρούσας διπλωματικής εργασίας είναι ο υπολογισμός του βάθους διάβρωσης σε διάφορα κατασκευαστικά στοιχεία του πλοίου, καθώς επίσης και ο υπολογισμός της πιθανότητας αστοχίας τριών διαφορετικών σωστικών μέσων, με βασικό γνώμονα τις επιθεωρήσεις των πλοίων με βάση το ρίσκο. Οι υπολογισμοί και των δύο προαναφερθέντων μοντέλων πραγματοποιήθηκαν με την ανάπτυξη κώδικα σε περιβάλλον Matlab και Octave.

Αρχικά, η παρούσα εργασία μελετά εκτενώς τις διαδικασίες των παραδοσιακών επιθεωρήσεων πλοίων, αναλύοντας τα είδη τους αλλά και το από ποιους πραγματοποιούνται. Στη συνέχεια, αφού ορίζονται τα βασικά μεγέθη που απαρτίζουν τις επιθεωρήσεις των πλοίων με βάση το ρίσκο, περιγράφεται αναλυτικά η διαδικασία εκτέλεσης του Formal Safety Assessment (FSA), μέσω των πέντε βημάτων που το αποτελούν, την αναγνώριση του κινδύνου, την εκτίμηση του ρίσκου, τα μέτρα ασφαλείας για τη μείωση του ρίσκου, την ανάλυση των ωφελειών μέσω της εφαρμογής των μέτρων και την λήψη αποφάσεων. Επιπλέον, γίνεται εκτενής αναφορά στον ρόλο των επιθεωρήσεων με βάση το ρίσκο στην ναυτιλία, σχετικά με την προσφορά και τα οφέλη τους. Έπειτα, περιγράφεται το φαινόμενο της διάβρωσης και η κρισιμότητα του στον χώρο της ναυτιλίας, μέσα από την εκτενή αναφορά στα είδη διάβρωσης και στους τρόπους αποφυγής του φαινομένου. Την περιγραφή του φαινομένου της διάβρωσης ακολουθεί η ανάλυση του μοντέλου που εφαρμόστηκε προκειμένου να υπολογιστεί το βάθος διάβρωσης στα διάφορα κατασκευαστικά στοιχεία του πλοίου. Ακολούθως, γίνεται αναφορά στην ανάγκη ύπαρξης σωστικών μέσων στα πλοία, στη σημασία της σωστής συντήρησής τους, στα είδη τους που εμφανίζονται στα πλοία, καθώς και στον εξοπλισμό των πλοίων με αυτές με βάση τους κανονισμούς. Στη συνέχεια γίνεται θεωρητική ανάλυση του μοντέλου που εφαρμόστηκε στον υπολογισμό πιθανής αστοχίας των σωστικών μέσων. Έπειτα, για κάθε μοντέλο γίνεται η παρουσίαση και ο σχολιασμός των αποτελεσμάτων για τις διάφορες εφαρμογές που πραγματοποιήθηκαν. Τέλος, παραθέτονται τα συμπεράσματα για το σύνολο των αποτελεσμάτων.

Στο 1^ο κεφάλαιο, μέσω βιβλιογραφικής επισκόπησης, δίνεται ο ορισμός των επιθεωρήσεων με βάση το ρίσκο, καθώς επίσης και τα οφέλη που προσδίδει η εφαρμογή τους. Επιπλέον, γίνονται αναφορές σχετικά με την εφαρμογή αυτού του τύπου επιθεωρήσεων στην ναυτιλία, στις πλατφόρμες εξαγωγής πετρελαίου και στην αεροναυπηγική.

Στο 2^ο κεφάλαιο, γίνεται περιγραφή του ρόλου των νηογνομόνων που είναι υπεύθυνοι για την επίβλεψη της επιχείρησης των πλοίων. Επίσης, αναφέρονται και αναλύονται τα διάφορα είδη των υποχρεωτικών κλασικών επιθεωρήσεων με ιδιαίτερη έμφαση στο Port State Control (PSC).

Στο 3^ο κεφάλαιο, αρχικά ορίζονται τα μεγέθη που αφορούν τις επιθεωρήσεις των πλοίων με βάση το ρίσκο. Εν συνεχεία, γίνεται περιγραφή του FSA, αλλά και ανάλυση των πέντε βημάτων από τα οποία αποτελείται. Στο τέλος του κεφαλαίου καθορίζεται η διαδικασία των βημάτων των επιθεωρήσεων με βάση ρίσκο, που αποτελεί μέρος του FSA.

Στο 4^ο κεφάλαιο, παρατίθεται το θεωρητικό υπόβαθρο του φαινομένου της διάβρωσης, μέσω της σημασίας της στη ναυτιλία, των ειδών της και των τρόπων αντιμετώπισης. Αντίστοιχα, συμβαίνει και για τα σωστικά μέσα με την περιγραφή των ειδών τους και των εξαρτημάτων αλλά και των αυστηρών κανονισμών αναφορικά με τον εξοπλισμό των πλοίων με αυτά. Τέλος, περιγράφονται τα μοντέλα με βάση τα οποία αναπτύχθηκαν οι κώδικες σε Matlab και Octave.

Στο 5^ο και στο 6^ο κεφάλαιο, παρουσιάζονται τα αποτελέσματα όπως αυτά προέκυψαν από την Matlab και την Octave. Τα μοντέλα εφαρμόστηκαν σε πλοία διαφορετικού τύπου και νηογνώμονα, αλλά και διαφορετικής ηλικίας. Σκοπός αυτής της σύγκρισης ήταν η αξιολόγηση της βαρύτητας των διαφόρων παραμέτρων που επηρεάζουν το βάθος διάβρωσης των κατασκευαστικών στοιχείων και την πιθανότητα αστοχίας των σωστικών μέσων του πλοίου

Στο 7^ο κεφάλαιο, παρατίθενται τα συμπεράσματα της παρούσας διπλωματικής εργασίας, καθώς επίσης και προτάσεις για μελλοντική έρευνα.

Λέξεις κλειδιά: <<επιθεώρηση με βάση το ρίσκο, μοντέλο διάβρωσης, μοντέλο σωστικών μέσων, επιθεώρηση πλοίων>>

Abstract

The aims of the present thesis is the evaluation of the depth of corrosion on several structural elements of a ship, as well as the calculation of the probability of failure of three different Life Saving Appliances (LSA), both based on Risk Based Inspection (RBI). The estimation of both above-mentioned models has been accomplished by developing codes in Matlab and Octave programs.

Initially, the present study investigates the procedures of traditional inspections of a ship, elaborating their types and defining the organizations which operate them. After the determination of the basic parameters that constitute the RBI, the procedures of Formal Safety Assessment (FSA) are described, by the gradual application of five steps; hazard identification, risk analysis (assessment), risk control options, cost benefits analysis, and decision making. Additionally, according to the FSA, the steps which are needed to be followed are described for the implementation of an RBI procedure. Then, the phenomenon of corrosion is approached, with detailed information associated with corrosion types and preventing measures, as well as corrosion's significance in maritime. Following the theoretical framework of corrosion, the applied model of the depth of corrosion is described. Afterwards, the thesis mentions the necessity of existence of LSA on vessels, the significance of appropriate maintenance, the several types of LSA on ships, as well as the equipment of ships with LSA according to the regulations. Subsequently, the applied theoretical model for the evaluation of the probability of failure is described, for the several types of LSA. Afterwards, the thesis presents and annotates the results of the various applications, as they have eventuated for each model. Finally, conclusions and proposals for further study are mentioned.

Chapter 1 includes the literature review, through which the definition of RBI is given, as well as the significance and the benefits of implementing RBI methods. Additionally, applications in maritime, offshore, and aerospace industries are referred.

Chapter 2 describes the role of Classification Societies which are responsible for the supervision of ship's operations. Moreover, the several types of mandatory surveys are analyzed, emphasizing to the procedures of Port State Control (PSC).

Chapter 3 defines the parameters which constitute the RBI methods. Afterwards, FSA procedure is described by the analysis of its five steps approach. At the end of this chapter, the steps of implementing RBI are defined, as the latter composes a part of FSA.

Chapter 4 includes the theoretical framework of the phenomenon of corrosion, as well as its significance in maritime, its types, and methods to prevent it. Accordingly, the theoretical framework of LSA is stated, describing their types and their components, as well as the strict regulations which are associated with the

equipment of ships with them. Finally, the implementing models are described in detail, through which the codes of Matlab and Octave have been developed.

Chapter 5 and 6 present the results of Matlab and Octave, as they have eventuated for each model. The models are applied on ships of different age, type, and classification society. The purpose of this comparison was the evaluation of the importance of each of the several parameters, which influence the depth of corrosion on structural elements and the probability of failure of LSA on ships.

Chapter 7 contains the conclusions of the present thesis, as well as proposals for further studies.

Keywords: <<risk based inspection, corrosion model, life saving appliances model, ship inspection>>

1 LITERATURE REVIEW

Risk based inspection planning (RBI) for constructions is an implementation of the Bayesian decision analysis, intending to devise the optimal inspection strategy for degrading constructions (Straub and Faber, 2005). RBI methodology had been developed by the American Society of Mechanical Engineers (ASME) since 1941 but it became common during the 90's (Tan et al., 2011). The earliest application of risk based inspection appeared in the nuclear industry in the 1970's and by the years it have been implemented into other industries, such as the downstream petrochemical industry in the 1980's and 1990's, and subsequently it extended to rails, aircraft and shipping industries (Serratella et al., 2007). RBI planning aims to the optimization of inspection frequency in order to avoid possible unacceptable risks from under inspections of structural components or from over inspections to functional items; basically, the main object of RBI methodology is to identify items which have the highest potential of failure and to organize a plan from which, the risk levels will be controlled at reasonable cost (Chang et al., 2005). However, there are savings which are not easy to quantify, as it happens with risk and cost; examples of such savings may be the avoidance of failure of equipment of high safety consequence (human loss, environmental, etc.), avoidance of losing production, punctually warning of planning repairs, timely identification of procedure upsets (accelerated corrosion, unusual temperatures, etc.) and the optimal investment to material, design, and structures by taking into consideration the risk and the inspection data (Patel, 2005). By considering risk based approach, inspections become more substantive and the operational constraints better managed; because risk based inspection's aim, is to assure that all resources will be distributed in the most profitable way, in terms of risk and cost (Conachey et al., 2008). A risk based inspection analysis can be carried out at several levels (i.e. qualitatively, semi-quantitatively, and quantitatively) and the selection of the approach is based on various variables, such as the target of the study, the available resources and time, the complexity of facilities, the complexity of process, as well as the nature and validity of the available data (Vianello et al., 2016). Regardless of the chosen approach (qualitative, semi-quantitative, and qualitative), risk is estimated by combining the likelihood of failure and the consequence of failure as a function of time (API 581, 2008). It is worth mentioning that for the same likelihood (probability) of a specific type of degradation occurring, the value of risk may vary according to the range of consequence of failure (Perumal, 2014). To sum up, RBI is a practical framework to the assess failure probabilities and consequences for systems, to organize a targeted inspection program, to estimate the condition of structural components, realization of defects and to evolve design, structure, operation, as well as maintenance processes (Tammer and Kaminski, 2013).

Inspection procedures of marine vessels containing of structural systems, which are composed of subsystems and components, can be enhanced by implementing risk based approaches. In a highly complex environment as being the sea, the integrity of the above-mentioned systems constitutes a significant role, in both their design and

operation. Consequences of a possible failure of a ship may contain human injuries, as well as losses, economic damages, and environmental pollution (Ayyub et al., 2002). International Maritime Organization (IMO) has produced International Safety Management Code (ISM Code) (2014) as a tool of identification and assessment of risk to ship, seafarers and environment. According to ISM, shipping companies should recognize emergency situations due to the failure of a technical system into the vessel and prepare the necessary procedures to cope with this undesirable event. Hence, ISM Code composes a risk based approach but without defining the type of the assessment that it should be considered in order to confront unpredictable events. Additionally, the Maritime Safety Committee (MSC) had approved guidelines for Formal Safety Assessment (FSA) for utilize in the IMO rule-making process in 2002. FSA constitutes a rational procedure for estimating the risk associated with the maritime safety and the protection of environment, as well as the evaluation of costs and benefits by decreasing these risks. According to MSC, the FSA methodology should be composed of the following steps: identification of hazards, risk analysis, risk control options, cost benefit assessment, and recommendations for decision-making. Furthermore, on 1 January 2011, the Port State Control Committee (PSCC) of Paris Memorandum (Paris MoU) adopted the New Inspection Regime (NIR). The major target of the NIR was to insert the risk based approach to selecting vessels for inspection. In other words, NIR reward the well maintained ships by reducing aimless inspections, while ships of high risk profile are inspected more frequent and detailed. Moreover, the statistical analysis of Knapp and van de Velden (2011) on the investigation of ship risk profiles, as well as the susceptible areas to general safety, conclude that older general cargo ships are highly prone to risk and two regions, the Caribbean and the Gulf of Mexico, verify the need of port state control inspection because their international legislations does not include smaller ships. Heij and Knapp (2012), provide suggestions for estimating risk at an individual ship by rating various risk factors, such as the type of ship, the nature of companies and managers, historical information on previous accidents, inspections, detentions, etc..With regards to the seawater ballast tank structures for ships, Paik et al. (2004) attempted to estimate the depth of corrosion as a function of time by using a mathematician model which provided the appropriate statistical characteristics. Their study focused on the prediction of corrosion wastage on low alloy carbon steel plates into seawater ballast tank structures of vessels. A study for the calculation of corrosion wastage in ballast tanks of a ship was also considered by Gudze and Melchers (2008). Their model had taken into consideration the operational profile of the examining vessel, as well as the several temperatures of the geographical areas where the ship used to operate. Soares et al. (2009), examined further the influence of temperature and marine environment to the corrosion rate on vessels. They demonstrated that corrosion is mainly influenced by moisture in marine environments, and subsequently by the period of exposure to wetness.

In offshore industry several studies have been applied associated with risk based approaches. Offshore platforms are steel structures responsible for drilling well in

order to extract oil and natural gas. Due to the hazardous nature of the extracting products, offshore platforms are considered of high risk procedures. The attention of risk management is relied on the safety of the crew, the integrity of structure, the prevention of environmental pollution and the regularity of production (Brandsæter, 2002). It is indispensable to secure that regardless of the harsh environment, the platform will maintain its integrity by means of Inspection, Maintenance and Repair (IMR) plans. The optimization of these plans is to inspect by using the right tool, at the right place, at the right time, and at the lowest cost (Rouhan and Schoefs, 2003). In 1976, the Norwegian Petroleum Directorate (NPD) published the “Regulations Concerning Safety Related to Production and Installation”. The Regulations demanded the conduction of risk assessment in case that the living quarters were placed on the offshore platform; basically, these estimations were qualitative. The first official conducted regulations for offshore quantitative risk assessment were published from NPD in 1981 and entitled as “Guidelines for Safety Evaluation of Platform Conceptual Design”. In 1996, the U.K. Offshore Operators Association (UKOOA) produced the risk based decision making framework providing guidance to decision making. The framework supports the determination of risks As Low As Reasonably Practicable (ALARP). In the 21st century, the risk based approaches in offshore industry are more targeted to components which may cause disastrous consequences. Specifically, Goyet et al. (2002) applied a risk based inspection plan for a welded joint in the hull structure of a Floating Production, Storage and Offloading facilities. Furthermore, Straub et al. (2006) focused on the economical benefits of adapting risk based inspection planning to offshore platforms. Their study compared the costs of risk based inspection strategy with the traditional fixed inspection intervals for all possible critical elements. In 2010, DNV distributed a detailed description of risk based inspection on offshore platforms. The recommended practice of DNV refers to topside mechanical equipment including similar characteristics to formal safety assessment. The study of Kawsar et al. (2015) was based on the subsea pipeline systems of offshore platforms. The proposed probabilistic model was applied to several accidental scenarios to confirm the safety of subsea pipelines under different environmental conditions.

In aerospace industries, airlines are focused on prolonging the service life of aircrafts with reasonable costs. For identifying the optimal inspection intervals for aircrafts risk based approaches have been applied which are known in aerospace as Reliability Centered Maintenance (RCM). RCM approach was adapted for the first time by the United Airlines for military aircrafts in 1978. However, recent years, more innovative approaches are presented by academics. Gobbato et al. (2012), produced a reliability-based methodology for evaluating the remaining service life of aircraft structure by emphasizing on wings structures. Additionally, Regattieri et al. (2015) developed an innovative mathematical model in an airline carrier in order to determine an optimal maintenance policy relied on preventive and corrective approaches.

2 VESSELS INSPECTION

2.1 Introduction

The growth of the world economy is closely related with the shipping industry (Bijwaard and Knapp, 2009). According to the United Nations Conference on Trade and Development (UNCTAD) total world seaborne trade reached 8.75 billion ton of goods in 2011, which is an increase of 235% compared with 1970 when the world seaborne trade was counted 2.61 billion ton, as it is presented on Figure 1.

<i>Year</i>	<i>Oil and gas</i>	<i>Main bulks^a</i>	<i>Other dry cargo</i>	<i>Total (all cargoes)</i>
1970	1 440	448	717	2 605
1980	1 871	608	1 225	3 704
1990	1 755	988	1 265	4 008
2000	2 163	1 295	2 526	5 984
2005	2 422	1 709	2 978	7 109
2006	2 698	1 814	3 188	7 700
2007	2 747	1 953	3 334	8 034
2008	2 742	2 065	3 422	8 229
2009	2 642	2 085	3 131	7 858
2010	2 772	2 335	3 302	8 409
2011	2 796	2 477	3 475	8 748

Figure 1: Developments in international seaborne trade, selected years (Millions of tons loaded) (UNCTAD, 2012)

One of the major concerns of ship managers and ship owners is the safety of vessels. There are vast penalties for insufficiency of safety for every shipping company, in terms of personnel losses, environmental pollution and structural damages. Apparently, all maritime companies try hard to obey the rules in order to avoid these penalties.

Moreover, excluding the issue of penalties, shipping companies make efforts to protect their reputation for social reasons. Societies are very sensitive about accidents, which include lives lost and massive pollution, leading to the application of more strict laws. A characteristic example is the Liberian tanker *Torrey Canyon* which crashed into rocks near the coast of Cornwall, England, in 1967 and spilled 100,000 tons of oil (Rothblum, 2000). As a result, the implement of the International Convention Relating to Intervention on the High Seas in Cases of Oil Pollution Casualties (INTERVENTION), the International Convention on Civil Liability for Oil Pollution Damage (CLC) and the International Convention on the Establishment of an

International Fund for Compensation for Oil Pollution Damage (FUND) have adopted (Rogowska and Namieśnik, 2010). Another example is the accident of the Maltese tanker *Erika* south of the coast of Brittany. The tanker broke in two and polluted 400 km of coastline with 5,000 to 7,000 tons of oil (Hingson et al., 2008). Therefore, the composition of the three *Erika* packages had been occurred; the target of which contained the enhancement of safety at sea by setting up a system of identifying and monitoring ships (Directive 2002/59/EC), monitoring the activity of classification societies (Directive 2001/105/EC), survey of foreign ships entering European Union ports (known as Port State Control), the removal of single-hull tankers (Regulation (EC) 417/2002) and the establishment of a European Maritime Safety Agency (Rogowska and Namieśnik, 2010).

For all these reasons, shipping companies try hard to ensure the strength structure and the equipment systems remain operational in a satisfactory condition. Inspections, as a process, help these companies to reach this goal by recognizing degrading systems or equipments and improving them. However, surveys do not secure the safety of passengers and the integrity of the structure. Thus, the possibility of undesirable events is not be minimized by the frequency of inspections but by their quality (Boon et al., 2009). Although inspections are useful to expand the lifetime of a vessel, it should be noted that that they are also essential for every ship in order to navigate. The authorization of navigation for ships is formalized by classification societies.

2.2 Classification Societies

A classification society is a nongovernmental organization which defines the technical standards of a ship building or an offshore structure and supervises their operation. The society is responsible for setting the technical rules, for the above-mentioned constructions, monitoring the process in order to confirm that the design meets these rules, subsequently rendering the essential certificates and documents to the ship in order to formalize its operation. In addition, the organization should survey these constructions to ensure that they proceed in meeting the rules. On account of this, societies organize inspections to make sure that these structures can still operate efficiently.

In 1760, the first classification society was formed in Lloyd's Coffee House, which was a coffee shop in London. This classification took its name by this shop and it is known as Lloyd's Register. In 1834, the society published the first rules related to surveys and classification of vessels. In 1968, the International Association of Classification Societies (IACS) was founded and, today, it consists of 12 classification societies:

- American Bureau of Shipping (ABS)
- Bureau Veritas (BV)
- China Classification Society (CCS)
- Croatian Register of Shipping (CRS)
- Det Norske Veritas/ Germanischer Lloyd (DNV/GL)
- Indian Register of Shipping (IRS)
- Korean Register of Shipping (KR)
- Lloyd’s Register (LR)
- Nippon Kaiji Kyokai (NK)
- Polish Register of Shipping (PRS)
- Registro Italiano Navale (RINA)
- Russian Maritime Register of Shipping (RS)

However, except from the 12 IACS’s members classification societies, more than 50 societies exist which are not member of the party. In Table 1 there are presented some of the most popular non IACS classification societies around the world.

Table 1: Non IACS classification societies

Name	Founded	Head Office
Shipping Register of Ukraine	1998	Kyiv, Ukraine
Registro Internacional Naval (RINAVE)	1973	Lisbon, Portugal
International Register of Shipping (IRS)	1993	Miami, U.S.
Overseas Marine Cerification Services (OMCS CLASS)	2004	Panama City, Republic of Panama
Hellenic Register of Shipping (HRS)	1919	Piraeus, Greece
Bulgarian Register of Shipping (BRS)	1950	Varna, Bulgaria

2.3 Harmonized System

In 2000, the IMO adopted a harmonized system of survey and certification which includes international shipping regulation. In fact, many societies had already operated a form of harmonized survey and certification. The system is based on the International Convention for the Safety of the Life at Sea (SOLAS) 1974, the International Convention for Load Lines (LL) 1966, the International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk (IBC Code) and Code for Cons Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code).

Shipping companies should prove the functionality of their ships and meet the quality requirements, of the above-mentioned Conventions, through specific surveys. However, ship's operation can be inactivated by these obligatory surveys for a long period. The harmonized system helps to reduce these inactivated days. First of all, surveys should provide an interval of a year between them. These surveys can be initial, intermediate, periodical or renewal. In addition, the renewal survey can be completed within three months before the termination of the existing certificate. Moreover, for every cargo ship, the maximum period of validity is five years, while for the passenger ships the equivalent interval is 12 months. Last but not least, a period of extension is given for ships which have not completed their voyages and their existing certification has expired. This extension is three months for ships which are engaged on long voyages and one month on short ones. Finally, when an extension has been agreed, the new certificate starts before the termination day of the existing certification.

2.4 Mandatory Inspections

Mandatory inspections vary, in terms of the ship type. These surveys are carried out by Classification societies according to the statutory requirements. The various types of surveys have been categorized by the IMO and they are separated in two subcategories: the periodical and the non-periodical inspections (DNV, 2008, IACS, 2011).

2.4.1 Periodical Surveys

The periodical surveys should be executed at specific interval and may be divided into segregated parts within given time windows but it is obligatory to be completed before the expiration of these spaces. The periodical surveys are detailed below.

A – Annual

The annual survey, as its name reveals, is executed annually in the anniversary date of the class certification. The time window of this survey should be 3 months and it must be carried out within 6 months. It includes a general examination of the hull, equipment, machinery and systems in order to verify that the ship complies with the regulations. It must be mentioned that for chemical and liquefied tankers this type of survey is preferably to take place during a loading or a discharging operation.

I – Intermediate

In general, the intermediate inspection shall be carried out between the second or the third year of the annual survey. This type of inspection has a time window of 9 months. This survey contains a more detailed visual examination of the hull,

equipment, machinery and systems than the annual survey, for the purpose of confirming that the ships can operate under the required regulations.

C – Complete

The intervals of the complete survey are 2.5 years, 5 years and 15 years. It must be carried out within 9 months before and 6 months after the due date. It must be noted that complete survey should be executed either at the same time with the renewal survey or before of its termination.

R – Renewal

The renewal survey concurs to the expiry date of the classification certificate and it should be carried out at 5 years. Therefore, it must start between the fourth and the fifth annual surveys without exceeding the last annual survey. There is a time window of three months before the due date when the survey should have been completed. This survey is considered as the most significant because it includes the most detailed examination, measurements and testing of the whole ship components in order to verify that the vessel maintains in a satisfactory condition and can operate efficiently. Any indicated repairs must be completed before the termination of renewal survey.

Table 2: Summary of Harmonized System of Survey and Certification (Knapp and Franses, 2006)

Years	1			2			3			4			5	
Months	9	12	15	21	24	27	33	36	39	45	48	51	57	60
Certificates/Inspection areas														
Passenger Ship Safety Cert.	R			R			R			R			R	
CS Safety Equipment Cert.	A			A or I			I or A			A			R	
SC Safety Construction Cert.	A			A or I			I or A			A			R	
CF GAS (IGC/GC)	A			A or I			I or A			A			R	
CF Chemical (IBC/BCH)	A			A or I			I or A			A			R	
Load Line Certificate	A			A			A			A			R	
IOPP (MARPOL Annex I)	A			A or I			I or A			A			R	
IPP (MARPOL Annex II)	A			A or I			I or A			A			R	

In Table 2 is presented the correlation between the several surveys and the time intervals. Specifically, it can be seen that the time interval of annual and periodical inspection is one year, while intermediate inspections take place between the second and the third year of the certification for cargo ships. It is noticeable that every 5 years

a renewal inspection is indispensable for these ship types. In contrast, it should be noted that the harmonized approach is intensively stricter for passenger ships. Due to the sensitivity of their operation, as they account a vast number of passengers throughout a year, they should carry out a renewal survey every 12 months.

Bottom

Bottom shall be inspected twice throughout the five-year classification certificate. However, this interval should not exceed a 36 months period. Each of these two surveys should take place before the due date and no time window have been allowed.

Propeller shaft

This survey is set every 5 years in accordance with the complete survey. In general, the condition of propeller shaft should be examined concurrently with the bottom survey in dry dock.

Propeller Connection

The propeller connection survey is scheduled every 5 or 15 years at the same time with the complete survey. On the 5th year, the survey aims to the keyless propeller connections, whereas flanged propeller connections are added on these while at 15 years.

Boiler

The schedule of boiler surveys includes two surveys in the five year period of the classification certificate, while the interval between these two inspections should not exceed 36 months. It must be noted that one boiler survey should take place concurrently with the renewal survey.

2.4.2 Non Periodical Surveys

The non periodical surveys refer to unscheduled and unpredictable inspections. Such surveys may be (IACS, 2011):

- The upgrade of classification documents. For example, the change of ship owner, ship name or flag.
- The handling of any failure or suspected failure either in any component or a system of the ship.
- The repair of any damage which has been indicated on the ship.
- The modification or postponement of survey.
- Any unexpected inspection during the Port State Control.

In every unpredictable event which can compromise either the personnel or the environmental safety due to structural damage, a non periodical survey must take place. The ship owner is responsible for informing the classification society promptly, without any delay, especially if the damage can endanger the class of the ship. . Then, a survey is scheduled by a surveyor of the society who, subsequently, composes the survey report and indicates the essential assignments that must take place. When the shipping company finishes the outstanding work, the surveyor re-surveys the ship in order to identify if it meet the regulations.

2.4.3 Port State Control

Port state control (PSC) is the power of any port or coastal state to perform safety surveys and to obligate ships, which visit these ports, to implement the international shipping requirements (Heij et al., 2011). Any ship that does not accomplish to qualify the requirements of the coastal control is immobilized, until extra measures have been taken into consideration. Then, the port re-examines the ship in order to confirm that the vessel meet the rules and release it. Rarely, a ship, which has been detained several times, can be banned from re-entering to ports. Ship owners strive to respect the rules in order to avoid any detention which would cause the economic harms. These harms are the delays on voyages and the further inspections which are obligatory. The major deficiencies which may cause a detention are in Table 3:

In 1982, the Paris Memorandum of Understanding (PoU) was signed by 14 West European Nations. The details of PSC inspections are captured in the computer centre which is located in Saint-Malo, France (Alderton and Saieva, 2013).

Several countries have signed and confirmed similar MoUs to Paris MoU all over the world. At this moment, nine parties of MoU exist and they will be described below (ClassNK, 2015).

Paris MoU

Paris MoU was established in 1982 and it consists of 27 maritime Administrations. Specifically, Belgium, Bulgaria, Canada, Croatia, Cyprus, Denmark, Estonia, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Latvia, Lithuania, Malta, Netherlands, Norway, Poland, Portugal, Romania, Russian Federation, Slovenia, Spain, Sweden and United Kingdom are the members of the party. Paris MoU includes the European coastal States and the North Atlantic basin from Europe to North America.

Table 3: Categories of deficiencies (Randić et al., 2015)

<i>Number of Category</i>	<i>Category of deficiencies</i>
01	Certificates & Documentation
02	Structural condition of the hull
03	Water / Weather condition
04	Emergency systems
05	Radio communication appliances
06	Cargo operations including equipment
07	Fire safety
08	Different alarms
09	Working and living conditions
10	Safety of navigation appliances
11	Life saving appliances
12	Dangerous goods appliances
13	Propulsion and auxiliary machinery
14	Sea pollution prevention appliances
15	ISM Code - International Safety Management Code for the safe management and operation of ships and for pollution prevention
16	ISPS Code – The International Ship and Port Facility Security Code
17	Other
18	MLC Code – Regulations and Code of the Maritime Labour Convention

Paris MoU categorizes the ships to Low Risk Ships (LRS), Standard Risk Ships (SRS) and High Risk Ships (HRS). The maximum interval after the last inspection is set in accordance with the ship risk profile; this interval is, for HRS 5 to 6 months, for SRS 10-12 months and for LRS 24-36 months after the last inspection. The criteria of the first and the second ban are categorized depending on ship's flag. A black flag ship shall be banned after more than 3 detentions in a period of 36 months. A grey flag ship shall be banned after more than 3 detentions in a period of 24 months. Any detention after the second ban leads to a new ban. In addition, ships with a HRS profile, as well as, chemical tankers, oil tankers, gas carriers, bulk carriers and passenger ships aged 12 years or older shall apply the ETA72 (a 72 hour pre-arrival) notification requirement.

Asia-Pacific region (Tokyo MoU)

Tokyo MoU was established in 1993 and 18 maritime Administrations participate on it. Australia, Canada, Chile, China, Fiji, Hong Kong, Indonesia, Japan, Republic of Korea, Malaysia, New Zealand, Papua New Guinea, Philippines, Russian Federation, Singapore, Thailand, Vanuatu and Vietnam. The time windows after the last

inspection are set according to the Ships Risk Profile. This interval is set for LRS between 9 and 18 months, for SRS between 5 and 8 months and for HRS from 2 to 4 months.

Latin America region (Vina del Mar)

Vina del Mar was established in 1996. The participant members are Argentina, Bolivia, Brazil, Chile, Colombia, Cuba, Dominica, Ecuador, Guatemala, Honduras, Mexico, Panama, Peru, Uruguay and Venezuela.

Caribbean region (Caribbean MoU)

In 1997, Caribbean MoU was established and its members are Antigua and Barbuda, Aruba, Bahamas, Barbados, Belize, Cayman Islands, Cuba, Curacao, Grenada, Guyana, Jamaica, Netherlands Antilles, St. Kitts and Nevis, Suriname and Trinidad & Tobago.

Mediterranean region (Mediterranean MoU)

This party was established in 1996. The members of Mediterranean MoU are Algeria, Cyprus, Egypt, Israel, Jordan, Lebanon, Malta, Morocco, Tunisia and Turkey.

Indian Ocean region (Indian Ocean MoU)

Indian Ocean region was established in 1998. It includes Australia, Bangladesh, Djibouti, Eritrea, France (La Reunion Island), India, Iran, Kenya, Maldives, Mauritius, Mozambique, Seychelles, South Africa, Sri Lanka, Sudan, Sultanate of Oman, Tanzania, Union of Comoros and Yemen. It should be noted that a total of 6,059 inspections were exercised and 379 vessels were detained in 2014 by the Indian Ocean MoU.

Black Sea region (Black Sea MoU)

This region was established in 2000 and includes Georgia, Romania, Russian Federation, Turkey and Ukraine. A total of 5,080 ships were inspected and 151 vessels were detained in 2014.

West and Central Africa region (Abuja MoU)

It was established in 1999 including Angola, Benin, Cote d'Ivoire, Gabon, Ghana, Nigeria, Republic of Congo, Republic of Guinea, Sao Tome & Principe, Senegal, Sierra Leone, South Africa, The Gambia and Togo.

Arab States of the Gulf (Riyadh MoU)

Riyadh MoU is the newest MoU party which was established in 2004. Members of Arab States of the Gulf are The Kingdom of Bahrain, Kuwait, Qatar, The Kingdom of Saudi Arabia, The Sultanate of Oman and United Arab Emirates.

Port State Control in The United States (USCG)

Even though the United States Coast Guard (USCG) is not participating in any MoU, it functions as a supervisor at a number of MoUs and exercises effective PSC in cooperation with other MoUs. In 1994, USCG performed innovative risk management programs in PSC for the purpose of identifying ships, ship owners, classification societies and flag Administrations which possibly violated the law. In 2001, USCG applied a new program, known as Qualship 21 which focused on recognizing high quality ships. This program is used until today and is considered as a very useful tool in the identification of well operated and maintained vessels.

Port State Control and Environmental Protection Compliance Targeting Matrix is a system introduced by USCG. According to the USCG Port State Control website states that the “The Safety Targeting Matrix enables the Coast Guard to rationally and systematically determine the probable risk posed by non-U.S. ships calling at U.S. ports. The Matrix is used to decide which ships Port State Control Officers should board on any given day, in any given port.” This system of evaluating ships has increased the number of inspections exercised by USCG because the Coastal Guard is allowed to inspect any vessel at any time without prior notice (Compliance Systems Inc., 2007). The process of assessment is shown in Figure 2.

- Priority I Vessel (PI) refers to ships scored 17 or more points on the Matrix. Basically, port entry is denied until the accomplishment of a Port State Control safety control exercised at anchor outside the port limits. Any vessel involved in a marine casualty influencing its seaworthiness shall also be classified as PI, as well as ships whose classification society has a detention ratio equal to or greater than 2%.
- Priority II Vessel (PII) includes ships which reach the total of 7 and 16 points on the Matrix. Additionally, it contains any ship that enters for first time to U.S. or has not been controlled by PSC within the last 12 months. Any cargo operation is denied for the ship until the Sector Officer states that the ship does not constitute a safety or environmental hazard to the port.
- Non-Priority Vessel (NPV) contains ships which scores 6 or fewer points on the Matrix. These vessels are considered sufficiently safe for humans and environment. However, CS may choose and exercise a random inspection by using PSC at any time.



Figure 2: Port State Control Safety and Environmental Protection Compliance Targeting Matrix (United States Coast Guard, 2015)

Inspection of all foreign ships by a port state is reasonably unreachable for matters of time and because not all ships have deficiencies. Therefore, port states have set a general approach in order to prioritize the selection of ships. Central databases, such as SIRENAC and APCIS, collect the essential data including port arrivals, shipping schedules and ship position reports; by that way, port states are capable to identify which ships need to be examined. Basically, ships to take in consideration for priority inspections are (Rosso, 2010):

- Ships which have been reported by any port authority of having deficiencies.
- Any ship transferring hazardous or polluting cargo and having failed to report the necessary information to port states.
- Ships which have been reported by another Authority.
- Ships which have been reported by any worker of the ship, due to safety matters, shipboard living and working conditions or the environmental issues.
- Any ship which has been suspended by their Classification society in an interval of six months.
- Any ship that has been maneuvered in an unsafe way.
- Ships which are reported a collision on their way to the coastal state.

The procedures of PSC are specific and shall be executed strictly (IMO, 2011). Generally, according to the regulations of implemented conventions, parties may organize inspection of foreign ships in their ports and these surveys can be based on three different reasons. The first reason constitutes initiative of the party. Secondly, an inspection may be requested by another party based on information related to ship's integrity. The third reason is based on possible complaints by a crew member, an association, an international body or any other individual. The port state can contract the survey out to recognized organizations or to inspectors nominated for this purpose. Normally, port states shall inspect very carefully the vessels in order to avoid overly detentions or delays because in these occasions they should compensate ship owners for any loss. The first step of the survey is known as initial inspection. The Port State Control Officer (PSCO) may observe the condition of the vessel, in general, before boarding. Afterwards, we should examine all the essential certificates and documents, as well as their validity and completeness. These certificates include the general condition of the vessel, containing its equipment, navigational bridge, decks, cargo areas, engine room and pilot transfer arrangements. If PSCO has any clear objection that the vessel does not meet the rules, he should proceed to the second step of inspection which is a more detailed inspection. PSCO should examine further any equipment which does not demonstrate valid certificates or does not persuade the PSCO for its operability and safety. If the detailed inspections lead to the identification of significant hazards and deficiencies related to safety and environment matters, PSCO is obliged to detain the ship in the port. Port state should ensure that every identified hazard is eliminated to before allowing the ship to travel. Therefore, actions should be taken for the eradication of hazards either in the port or in the nearest recognized repair yard.

2.4.4 Flag State Control

At sea, the use of flag from every ship which ventured out of home waters was essential. Flag, as a symbol, presents the origins of the ship and demonstrates its political allegiance. Normally, ships without flag are recognized as pirate by the international law. However, the necessity of registering ships under international law was first codified by Health and Safety Commission (HSC) through the article 5 (Mansell, 2009):

“Each State shall fix the conditions for the grant of its nationality to ships, for the registration of ships in its territory, and for the right to fly its flag. Ships have the nationality of the state whose flag they are entitled to fly. There must exist, a genuine link between the State and the ship; in particular, the State must effectively exercise its jurisdiction and control in administrative, technical and social matters over ships flying its flag.”

Flag State must exercise jurisdictions and controls to ships flying under its flag related to the enforcement of regulations considering inspections, certifications, safety matters and pollution preventions. Each government is responsible for having skillful maritime experts to apply the laws; however, it has the ability to assign a recognized organization to execute the surveys. In addition, Flag State has the authority to organize surveys in order to confirm that the ships meet the rules and respect the regulations of the State. The nature of these surveys is similar to this of PSC. Inspections of flags state aim to the insurance that the vessels, which fly under its flag, possess all the essential certificates and document related to the personnel safety and the prevention of pollution.

2.4.5 Port State Control vs. Flag State Control

Ship-owners have the legal right to register their ship in the State of their desire and they may change the Flag registration in case of transfer of ownership or any other reason. In the 1990s, concerns increased because many ship-owners transferred easily their flags in order to avoid detentions and bans (Mansell, 2009). Therefore, the Port State Control is considered as the second line of defense of identifying substandard ships. States have the right to exercise surveys to foreign ships and immobilize them if they do not respect the legislations. The formation of PSC is a result of the existence of flag of conveniences. By the term “flag of conveniences” is described any State which has flexible legislation and as a result attracts foreign ship-owners. Ships are registered under these States to minimize the costs and avoid the regulations of the ship-owners country. In an ideal world, any Flag State would be deeply sensitive trying to identify the deficiencies of the ships which are under its flag for the purpose of protecting ship’s personnel and environmental pollution. However, the existence of PSC is vital due to the malpractices of Flag States.

3 RISK-BASED INSPECTION

3.1 Definitions

3.1.1 Risk

Risk, as an object of concern, is used in different occasions on a daily basis. In fact, many times during the day, people make their decisions based on risk unconsciously. These decisions diverge, depending on their significance. There is a simple group of decisions, such as choosing to watch a movie at home or going to the cinema and another group which is characterized by complexity: for instance, the decision of investing money in a new car or in a new house. These examples prove that almost every decision contains risk on a daily basis.

Risk is a combination of two parameters, the likelihood and the consequences of an event. An event could be a car accident or the failure of a pipeline due to corrosion. At mathematical terms, risk is defined as:

$$\text{Risk} = \text{Likelihood} \times \text{Consequences}$$

3.1.2 Likelihood

Likelihood is the probability of an event to happen. In maritime, the term of likelihood is expressed by the possibility of degradation. For example, the likelihood of a piping system to fail or a hull structure to deteriorate. The estimation of likelihood is separated into two different categories; qualitative and quantitative. Table 4 presents the ranking scale for both types, as it is proposed by (DNV, 2009).

3.1.3 Consequences

Consequence has been defined as the outcome of an event. This result could have either a positive or a negative effect. However, in matters of safety, consequences have always a negative meaning. Usually, in maritime, consequences refer to three different categories: personnel safety, environmental or economic consequences.

- *Personnel safety* is described by the potential loss of a human life.
- *Environmental consequences* refer to the pollution of the environment by an oil spill or to the financial cost of cleaning it up.
- *Economic consequences* are expressed by the units of money which are needed because of failure.

Generally, consequences should be estimated and presented separately depending on their type. The evaluation of consequences could be quantitative or qualitative and they can be represented as in Table 5.

Table 4: Probability of failure description (DNV, 2009)

Cat.	Annual failure probability		Description
	Quantitative	Qualitative	
5	$>10^{-2}$	Failure expected	In a small population*, one or more failures can be expected annually.
			Failure has occurred several times a year in location.
4	10^{-3} to 10^{-2}	High	In a large population**, one or more failures can be expected annually.
			Failure has occurred several times a year in operating company.
3	10^{-4} to 10^{-3}	Medium	Several failures may occur during the life of the installation for a system comprising a small number of components.
			Failure has occurred in operating company.
2	10^{-5} to 10^{-4}	Low	Several failures may occur during the life of the installation for a system comprising a large number of components.
			Failure has occurred in industry.
1	$<10^{-5}$	Negligible	Failure is not expected.
			Failure has not occurred in industry.
Notes:			
*Small population= 20 to 50 components			
**Large population= More than 50 components			

Table 5: Consequence of failure description (DNV, 2009)

Types	Safety	No Injury	Minor Injury Absence < 2 days	Major Injury Absence > 2 days	Single Fatality	Multiple Fatalities
	Environment	No pollution	Minor local effect. Can be cleaned up easily	Significant local effect. Will take more than 1 man work to remove.	Pollution has significant effect upon the surrounding ecosystem.	Pollution than can cause massive and irreparable damage to ecosystem.
	Business	No downtime or asset damage	<€10.000 damage or downtime < 1 shift	<€100.000 damage or downtime < 4 shift	<€1.000.000 damage or downtime < 1 month	<€10.000.000 damage or downtime one year
	Ranking	A	B	C	D	E

3.1.4 Hazard

Hazard is a situation or a phenomenon which can potentially cause an undesirable event. Such an event can lead to physical injury, damage property or environmental disaster. It must be noted that the term “hazard” is not relative to the possibility of the event occurrence but only to the potential of injury.

3.1.5 Risk Estimation

In maritime, risk estimation refers to a negative incident. As above-mentioned, risk equals to the product of the likelihood and the consequences of a failure. The risk can be computed by a qualitative or a quantitative method or a combination of both, as it exactly happens with the probability and the consequences.

Usually, risk is presented by a matrix, known as a “risk matrix” which enables to contribute the two parameters, likelihood and consequences. As it is proposed by DNV at 2002, for achieving sufficiently a result, a 5x5 matrix is recommended. An adequate example of a qualitative matrix is presented on Figure 3. The likelihood of failure is expressed on the vertical axis of the matrix and the consequences of failure on the horizontal one. The ranking scale of each factor can be presented by using numbers from 1 to 5. Every number corresponds to a linking word which demonstrates either the probability of an event or the severity of the consequence. The level of risk can be recognized by the three colors; green, yellow (orange) and red.

- Green color refers to a region where the risk is characterized as acceptable and it is “low”. All extra measures which are needed to be taken are for keeping the risk levels in this zone.
- Yellow (Orange) color presents an area of an acceptable risk but it is known as “medium (medium-high) risk”. There is a need of taking extra safety measures for keeping the risk levels in this region and ensuring that they will not rise above this zone.
- Red color describes a high risk level area where the risk is unacceptable and it is indispensable of taking extra measures to reduce either the likelihood or the consequences of the event, or both, thus the risk level decreases in the acceptable region.

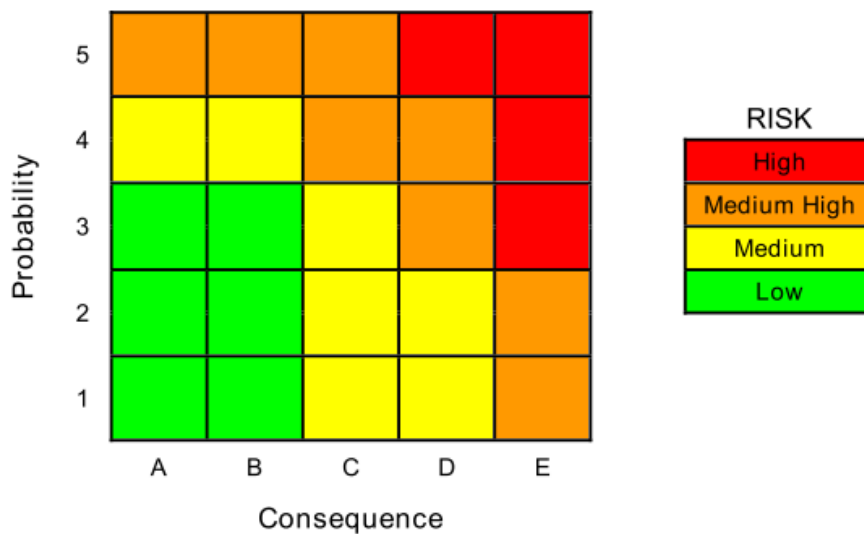


Figure 3: Risk Matrix (API 581, 2008)

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). In fact, FSA is a significantly helpful tool in the assessment of innovative regulations for maritime safety and prevention of environmental pollution, as well as the comparison between the current and the potential new regulations. FSA scopes to the efficient correlation between any operational matter and technical issues, which may be either a component or human element, and between the maritime safety or environmental protection and costs. The FSA methodology can be implemented by a Member Government or a consultative organization in order to propose modifications which can improve the maritime safety and environmental protection. The application of FSA contains 5 different steps which are presented in a diagram in Figure 4:

- Step 1 – Hazard Identification (HAZID)
- Step 2 – Risk Assessment
- Step 3 – Risk Control Options
- Step 4 – Cost Benefit Analysis
- Step 5 – Decision Making

FSA Methodology

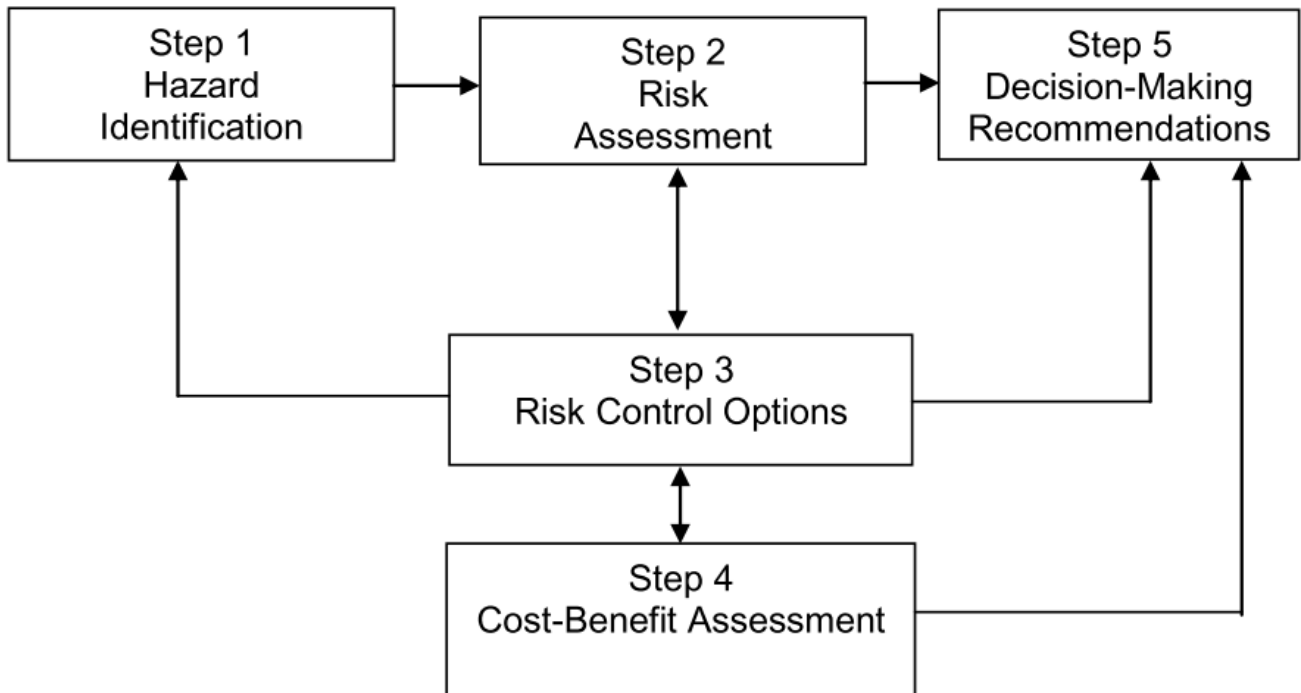


Figure 4: FSA methodology (IMO, 2013)

3.2.2 Step 1 – Hazard Identification

The first step of FSA methodology contains the Hazard Identification (HAZID) and it is probably the most crucial part of this process. This point of view relies on the fact that every hazard which will be identified, will not be assessed, and subsequently will not be moderated. Therefore, the main object is to identify and rank all potential threats which can lead to undesirable results, e.g. personnel, environmental and property safety.

Most of times, HAZID composes a qualitative approach based on the judgment of experts. Many methods have been developed in HAZID and a number of them have been standardized for specific applications. However, experience has proved that it is not required to use an exact technique in particular cases. In fact, after breaking the interested system down, so that it is easier to recognize the several hazards, a group of experts chooses the suitable HAZID technique or its modification or a combination of different techniques to evaluate the danger.

Although there are no boundaries in choosing the optimal HAZID technique, there are some essential conditions on which will be implemented (HSE, 2001). The HAZID needs to be creative, in order to contribute to the identification of hazards that have not been considered previously. Furthermore, it is significant having a distinct structure, for the purpose of obtaining comprehensive of relevant dangers without

overlooking less obvious problem areas. Last but not least, the exploitation of previous accidents by experienced work force should be taken into account, securing that past mistakes will not be repeated. Finally, the HAZID's scope should be clearly defined by clarifying which hazards have been included and which not. There are five different techniques which can be implemented for the identification of a hazard:

- Hazard Review
- Hazard Checklists
- Hazard Operability (HAZOP)
- Failure modes, effects and criticality analysis (FMECA)
- Structured what-if checklist (SWIFT)

Hazard Review

In general, the hazard review can be easily understood and characterized as a qualitative approach. It is based on previous assessments, accidents, experience and on a number of guidelines. It must be noted that this technique can be implemented by one person and it is not necessary more experts to be included. Although it cannot be used to quantitative approaches, it does not require a large amount of information and it is performed at low cost.

Hazard Checklists

Hazard checklists are composed by a list of questions and they cover a range of safety issues. The aim of these questionnaires is to receive the substantial information and helping the risk assessment. However, these checklists include a list of specific hazards for the several industries. Even though it is not support the brainstorming because the questionnaire is a very strict and a narrow process, it can help to prevent previous accidents due to the fact that it is well developed in specific categories of hazards.

HAZOP

This technique aims to identify the possible hazards that might compromise safety and operability and relies on the use of guidelines. It is executed by a number of experts under the supervision of a leader and they attempt to notice every possible deviation of each subsystem from its initial design. Subsequently, they try to predict every potential consequence considering if extra safety measures are required. Unfortunately, it is based on standard hazards and it is deeply depends on the abilities of the leader. However, the fact that the final decisions are considered by a group of experts, as a result of a thorough discussion, it makes it a significant HAZID technique.

FMECA

FMECA is a technique which identifies the failure modes. Generally, a couple of analysts evaluate the consequences and the criticality of a failure. The format of this technique can be characterized as a straight forward process which aims to rank the critical components. In fact, it does not include the parameter of human error which is vital in industries. Although it is performed at low cost, it is widespread and well-understood.

SWIFT

This technique is a hazard identification method relied on the brainstorming. A group of experts under the supervision of a specialist, as well as in HAZOP, discusses about the system on which they are interested in. The beginning of the conversation include some basic questions such as “What-if” or “How could?” helping the brainstorming evolve. As it happens in HAZOP, it is powerfully depended on leader’s abilities and many hazards may be excluded unconsciously. However, the discussion about the operative process can be really useful an adjusted on the circumstances.

3.2.3 Step 2 – Risk Assessment

Risk assessment constitutes the second step of the FSA. Practically, at this point, the detailed analysis of the hazards, which have been identified in step 1, is occurred. These hazards help to define the risk, which is the combination of the frequency of an event and the probable consequences. Specifically, risk is the product of the frequency of an incident and the associated consequences (IMO, 2008).

The Qualitative (Q), the Semi-Quantitative (SQ) and the Quantitative (QRA), consist the three different approach types of this step, in order to calculate the value of risk. Although these three methods follow the same procedure, they diverge in their need of inputs and outputs. As above-mentioned, risk is the combination of the likelihood and the consequences, hence RBI, as a risk approach, is also depended on these two parameters. Therefore, the nature of these two parameters determines the type of the RBI assessment method. The correlation of these methods with the risk assessment process is presented in (HSE, 2006).

The selection of the most suitable type for a case study is influenced by the risk levels and the complexity of the problem. Usually, for a low risk and simple problem a Qualitative approach is recommended, whereas a Quantitative approach is needed for more risky and difficult ones (Figure 6) (HSE, 2006).

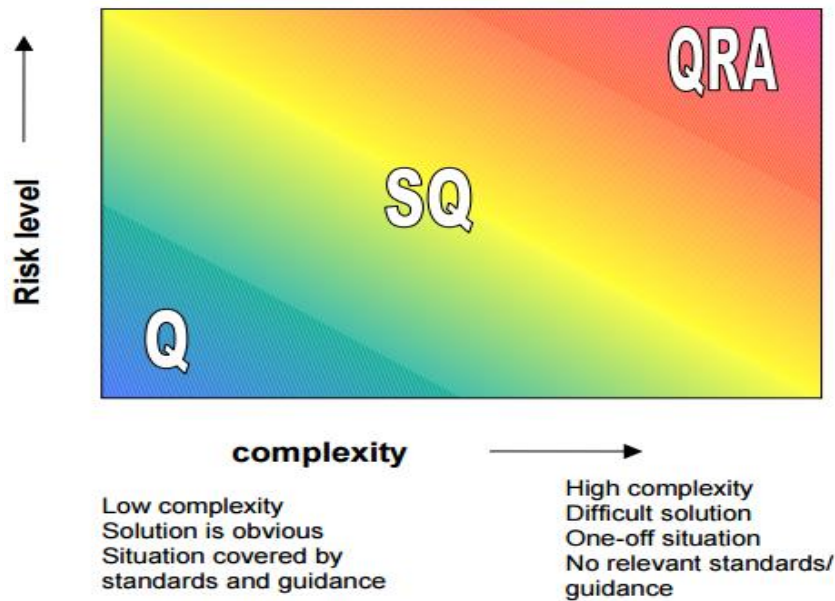


Figure 6: Risk assessment as a function of risk level and complexity

Qualitative method

An approximate estimation of the failure likelihood is needed for this type of assessment. The estimation can be calculated in a numeric or a non-numeric form and it can be expressed as the lifetime failure likelihood, the annual failure likelihood or the failure rate (Ayyub et al., 2000). An example of a numeric estimation can be “10 years” which defines the mean time of lifetime, while a non-numeric form for the annual failure likelihood can be “medium”.

Moreover, the types of consequences which should be taken into consideration in a case study need to be determined. Human loss, environmental damage, and materialistic damage, consist the types of consequences. The estimation of consequences is approximate and separated in numeric and non-numeric, as well as for the probability. For instance, a numeric form for fatalities can be “100 human losses”, whereas a non-numeric form can be “very large”.

The selection of form for both parameters, the likelihood and the consequences, should be rely on the available information and database, the skill of the experienced work force to provide the essential information in the form which is needed, and the significance of collecting numeric versus non-numeric information (Ayyub et al., 2002). Consequently, the result of risk qualitative method can be expressed figuratively or numerically and this value is not absolute but relative. Qualitative risk assessment methods are various (Segudovic, 2006).

- Risk Matrix. As have been mentioned in section 3.1.5, risk matrix is one of the major calculative tools in qualitative approach. It is based on the combination of two parameters, likelihood of an event and its consequences. Both parameters may be assessed either by a number relatively or by color. The numerical approach is considered from 1 (low value) to 5 (high value), while

the color approach uses green, yellow, orange and red, from low to high values respectively.

- Failure Modes and Effects Analysis (FMEA). This method is suitable for well-defined electrical and mechanical systems. It is common knowledge that every ship is full of such equipments and this technique may be extremely helpful. The basic steps of FMEA are to identify the probable failure of a component and, then, to recognize the effects of this failure on the system. In Table 6 an example of a section of FMEA technique is formed on a compressed air system onboard a vessel (ABS, 2000).

Table 6: FMEA evaluation example (ABS, 2000)

<i>Failure Mode</i>	<i>Effects</i>			<i>Causes</i>	<i>Indications</i>	<i>Safeguards</i>	<i>Recommendations/Remarks</i>
	<i>Local</i>	<i>Higher Level</i>	<i>End</i>				
No start signal when the system pressure is low	Open control circuit	Low pressure and air flow in the system	Interruption of the systems supported by compressed air	Sensor failure or miscalibrated Controller failure or set incorrectly Wiring fault Control circuit relay failure Loss of power for the control circuit	Low pressure indicated on air receiver pressure gauge Compressor not operating (but has power and no other obvious failure)	Rapid detection because of quick interruption of the supported systems	Consider a redundant compressor with separate controls Calibrate sensors periodically in accordance with written procedure

- Predefined value matrix. This approach includes three different parameters, resource value (AV), vulnerability (V) and threats (T). All the parameters are estimated relatively to the probable threats, whereas the threats are considered relatively to vulnerabilities. Each value, is quantified randomly.

Specifically, an example of this method is presented in Table 7 In this example, the resource value is assessed randomly the range of values is from 0 (low value) to 3 (high value), while the vulnerability and threats numerical range is from 0 (low level) to 2 (high level). The value of risk eventuates from the sum of these 3 parameters. Therefore, the low risk is equal to 0 ($AV_{min} + V_{min} + T_{min} = 0 + 0 + 0 = 0$),

whereas the high risk is 8 ($AVmax + Vmax + Tmax = 4 + 2 + 2 = 8$). As a result, the range of risk is considered to be between 0 and 8 (Segudovic, 2006).

Table 7: 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

The main object of this method is to estimate in a quantitative form the probability of failure for different components or areas with high risk profile and needs to be grounded on the identified failure modes. The final form of the failure likelihood should be in a lifetime or an annual failure probability.

As regard the failure consequences, it is essential that their estimation should be based on all consequence types and be determined in detail. The impact of any failure should be analyzed specifically by giving a numerical result.

As it has been mentioned the likelihood and the consequences of failure should be detailed. As regards the likelihood, it can be determine by several approaches (HSE, 2001):

Historical accident frequency data. This method exploits the experience of past accidents. It is about a very simple and easily to understand method but it can only be adjusted in existing technology for specific and recorded incidents.

Fault Tree Analysis (FTA). This method contains the disintegration of the incident into separate causes, including human error. All this process aims to the complete understanding of the accident and comes from human experience as well as from historical data. An example of this technique is presented on Figure 8.

Simulation. The likelihood of many accidents can be projected by using simulation models.

Event Tree Analysis (ETA). An initiating event is developed as a tree where the branches of this tree involve the possible outcomes of this event as it shown in Figure 7.

Human reliability analysis. This is a way of modeling the influence of human error to accidents which can be used to create inputs either fault tree analysis or event tree analysis.

Judgmental evaluation. This method is based on the judgment of experienced work force. This process might contain simple assessments either for usual events or for events where no better approach is available.

Bayesian Network (BN). A BN methodology is implemented by a graphical technique in order to present the correlation between variables. This method is used to predict the probability of an unknown variable, as well as to update the probability value of a known variable. The risk is calculated through the Bayes' theorem (Khakzad et al., 2011).

$$P(A|B) = \frac{P(B|A)P(A)}{P(B)}$$

- A and B are the possible events.
- P(A) and P(B) are the probabilities of A and B without related to each other.
- P(A|B) is the conditional probability of A given the fact that B is true.
- P(B|A) is the conditional probability of B given the fact that A is true.

Generally, the best way of deploying these methods is to combine them so that the quantitative approach becomes more effective.

An assessment of the consequences is essential to estimate the total risk of a failure. It is significant to comprehend the value of any loss and evaluate it accordingly. This estimation can be done by judgments of experienced work force, fault tree analysis, event tree analysis or simulation.

Taking into consideration past accidents or failures can compose a very helpful tool so that the failure likelihood and consequences can be determined explicitly. The concept of this method is to use the above-mentioned source list for matching a case study with an event which had been occurred. The experience of past accidents can help to improve the treatment of hazardous situations as well as the personnel and the environmental safety. Moreover, the correlation of case studies with past incidents can be really effective for a proactive attitude which is the main concept of FSA.

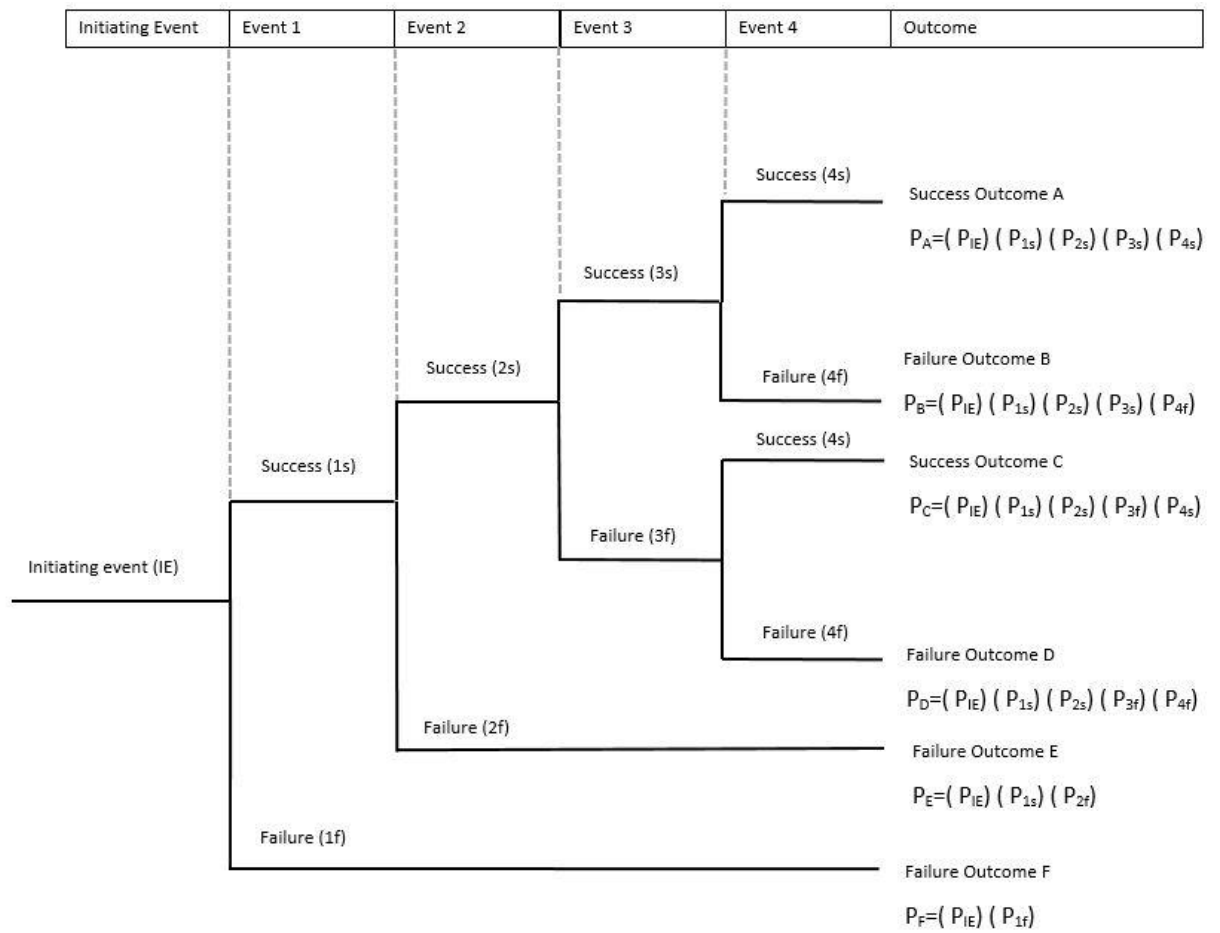


Figure 7: Event Tree Analysis

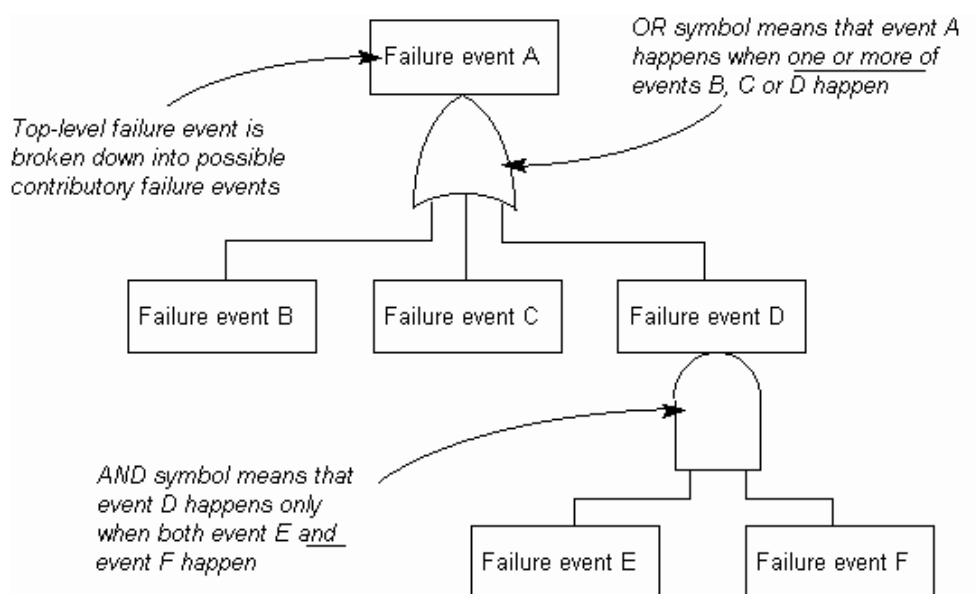


Figure 8: Fault Tree Analysis

3.2.4 Step 3 – Risk Control Options

On this step the main target is to receive extra safety measures to limit the estimated risk in step 2. Normally, the procedures are focused on the areas of high risk profile (Lois et al., 2004). One method of avoiding or reducing the effect of probable hazards is the countermeasures which can increase the safety levels of an operation. For any possible hazard, there is a need of taking into consideration countermeasures relied on people, procedure, or equipment solution. An optimal way to follow this process is by breaking the subjected hazard into pieces, which is known as the casual chain of events. This chain includes everything that might lead to an accident. As a result, the main idea of this procedure is to implement countermeasures in order to break that casual chain and prevent its completion. After taking countermeasures, a re-evaluation of risk shall be considered by repeating the step 2 for the purpose of checking if the risk has been reduced. An example of a casual chain is presented in Figure 9 (U.S. Coast Guard).

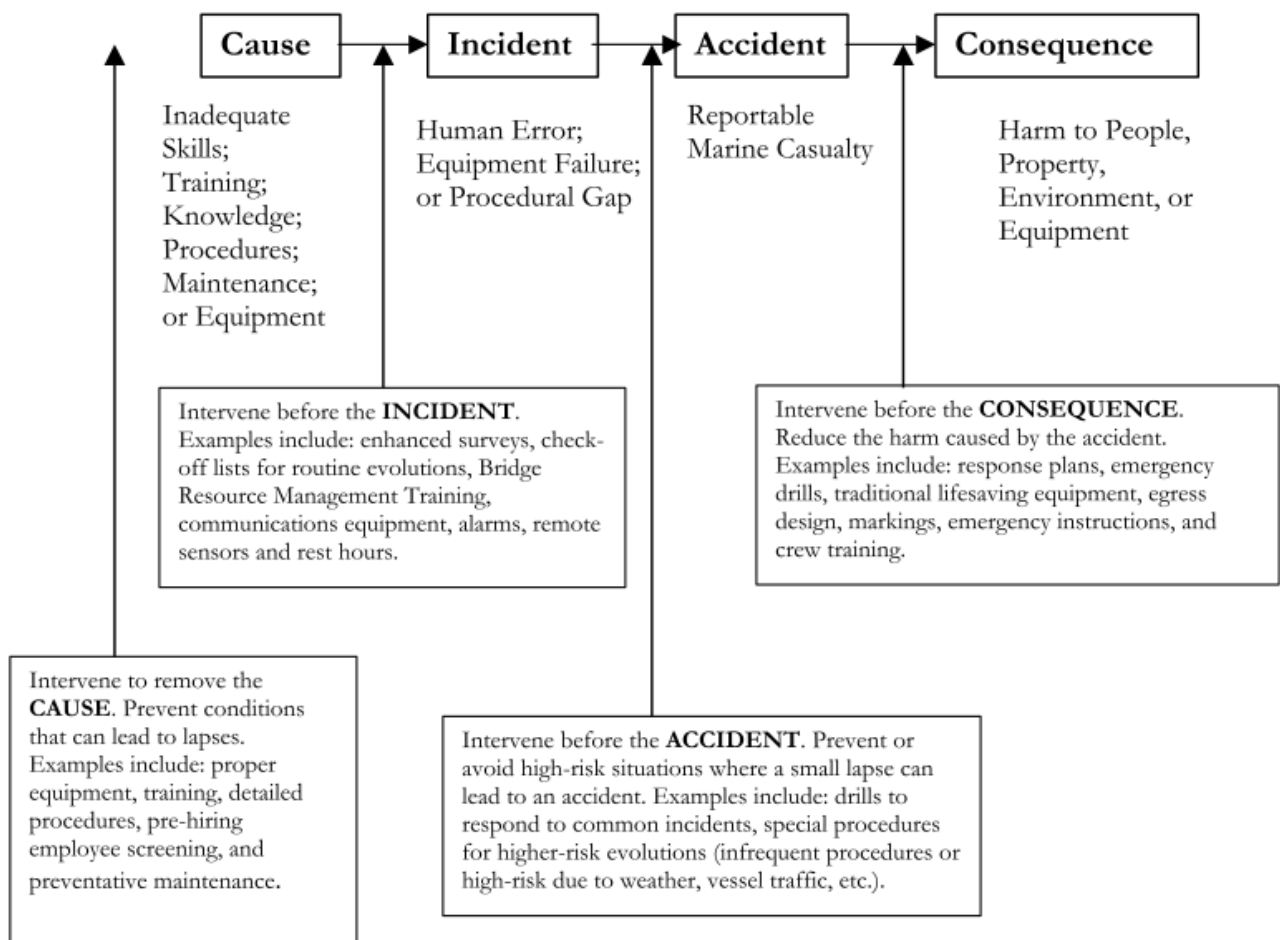


Figure 9: Example of casual chain (U.S. Coast Guard)

3.2.5 Step 4 – Cost Benefit Analysis

This step includes the detection of costs and benefits related to the risk control options of step 3, and subsequently compare them. The term “costs” refers to the total potential life cycle costs containing initial, operating, inspection, certification etc, while “benefits” might include the limitation of human losses, injuries, and prevention of environmental pollution and the increase of the total life of ships (IMO, 2013). This step contains several different indices of estimating the cost-effectiveness on safety:

Gross Cost of Averting a Fatality (GCAF). This index is a cost-effectiveness ratio of the supplementary cost of the risk control option to the restriction of risk to personnel fatalities averted.

Net Cost of Averting a Fatality (NCAF). It is a ratio of the difference between the additional cost and the economic benefits, to the restriction of risk to personnel fatalities averted.

Usually, the GCAF index is used because it does not consider the economic benefits. By using NCAF index, it is possible to overestimate certain risk control options due to the enlarged economic benefits. However, as above-mentioned, the main idea of this step is to conclude to the optimal correlation between the costs and benefits.

3.2.6 Step 5 – Decision Making

When the likelihood and the consequences have been evaluated, the final risk can be finally estimated (if a Qualitative approach has been chosen) or calculated (if a Quantitative approach has been chosen). Subsequently, it is essential that some decisions should be taken.

First of all, it is needed to examine whether the risk levels fulfill the terms. If the value of risk exceeds the risk criteria then extra measures should be considered. Therefore, the choice of the suitable extra safety measures should take into account the best combination between the type of measures and the money which are needed to be invest.

It must be noted that the decision making of a company, specifically in a shipping company, is not only based on safety manners but also on operational, social, economic, environmental and political reasons too (HSE, 2001). Hence, it is important to produce a risk assessment with respect to these issues.

As above-mentioned, the risk should be compared with some criteria. These criteria can be either qualitative or quantitative. However, the whole criteria may be separated according to what they refer to. For example, one group of criteria may be addressed to the individual risk. Specifically, it describes the acceptable annually time

when a worker can be exposed to huge risks. Another one criteria may be the group risk which refers to the total acceptable risk of serious accidents including a large number of deaths. Moreover, there is the impairment criterion which describes the acceptable risk of personnel deterioration and it does not involve fatalities. Another notable criterion is the cost. The importance of this criterion is the comparison between the costs and the advantages of a case study. To be more specific, using the cost criteria helps to evaluate whether a project is worthy.

In conclusion, the decision making process can be useful because it follows, and finally considers the risk evaluation, aiming to the most suitable and efficient solution to reduce the total risk of a hazardous component/event.

3.3 RBI Methodology

There are two extreme types of inspections which can be both considered as objectionable. The first one is to inspect components only few times and replace them only when they fail; this method of inspection is unacceptable because it is “reactive” and the replacement of equipment occurs after the failure. On the other hand, the second type is a short interval method and as result the huge number of inspections is regarded as uneconomic for a shipping company.

A number of organizations, such as American Petroleum Institute (API), have recommended several ways of maximizing the inspection intervals. These methods could be more economic and substantial for any shipping company.

Risk base inspection (RBI) calculates the risk as a base for prioritizing and formatting the inspection program. RBI is focused on the improvement of the inspection intervals on the high-risk equipment but without overlooking on the lower risk components. In maritime, the hazardous components, which should be prioritized, can be the main hull, the fuel and ballast tanks, the superstructures, and the engine room. RBI, as a risk approach, contributes to the improvement of both the inspecting method and its frequency. Risk Based Inspection is an inspection optimization technique (Patel, 2005).

In maritime, RBI is a risk assessment method, containing the fully understanding of the possible deterioration mechanisms and consequence of failures in the ship's structure (Conachey et al., 2008). In fact, RBI is a specialized application of FSA, including step 2 (risk assessment), step 3 (risk control options), step 4 (cost benefit analysis) and step 5 (decision making). When a classical survey fails to deal with the regulations, it is required to identify and apply risk control options in order to limit the risk and this is the role of RBI. RBI is considered as a risk control options because intervenes to the inefficient classical surveys. A risk model of inspection is developed accounting all the possible variables and parameters, and subsequently it is performed in order to recalculate the risk. If the re-assessment of risk remains unacceptable then it is required to redefine the applicable model. When the value of risk falls to the

acceptable zone, the methodology proceeds to the step 4. At this stage of the assessment, costs and benefits are considered after the implement of the RBI model. As a result of the risk reduction, costs have been limited. Costs refer to inspections, repairs, operating, cleaning-up environmental damages and. Furthermore, RBI intends to maximize the inspection interval in an optimal way, therefore the inspections are reduced as well as the repairs and the unpredictable damages. However, in step 2 where the risk has been limited due to the implement of RBI model, costs have been reduced because they correspond to consequences which are a parameter of risk. As the survey intervals have been maximized, the operating costs are reduced and shipping companies present economic benefits. The final step of decision making includes the comparison of the proposed methods, the classical survey and the application of an RBI model. Taking into consideration all the involved aspect, risk value, cost, benefits, feasibility, a shipping company shall select the optimal inspection program.

It must be noted that mandatory classical surveys cannot be neglected; either they are exercised by Classification societies or PSC and FSC. However, shipping companies can apply the preferable and optimal inspection program between these obligatory inspections in order to maintain ship's operability and safety in high levels.

4 SIMULATIONS

4.1 Corrosion Model

4.1.1 Corrosion

“Corrosion is the gradual deterioration of a material or its properties through a chemical reaction with its environment.” (Tezdogan and Demirel, 2014). In maritime, corrosion may influence negatively and extremely the operability of ships because of the aquatic environment, affecting the functioning equipment, as well as the ship’s structural integrity. Therefore, corrosion consists one of the most important parameters which may limit the service life of a ship by reducing its strength ability and long-term structural integrity (Saad-Eldeen et al., 2011). That chemical phenomenon may lead to thickness penetration, fatigue cracks and unpredictable failures and as result to disastrous consequences, including human losses, environmental pollution as well as huge costs for a shipping company.

Throughout the design stage, the selection of constructive materials is characterized as a significant and detailed process in order to keep the corrosion resistance in the highest levels. Subsequently, ship design shall take into consideration the mechanical and physical aspects of the component, costs, availability, economics etc (Perumal, 2014). Usually, additional corrosion measures are taken into consideration to increase the net thickness of hull and expand the life cycle of the ship. Afterwards, when the surveys take place, surveyors examine the structural components of the ship to identify the material losses due to corrosion, in order to replace them according to the safety requirements. It is not unusual ship-owners demand ships on which the wall thickness is larger; hence, the survey intervals become longer and the costs of shipping company are reduced (Soares et al., 2009).

Considering the possible disastrous consequences, the sensitivity of shipping industry on this chemical phenomenon is huge. Thus far, a numerous of studies have been performed relevant to corrosion evaluation in offshore structures (Guedes Soares et al., 2008). Basically, the development of a corrosion wastage model is not a straightforward process entirely based on theory because corrosion is naturally a very complex electrochemical reaction which is influenced by several independent variables, such as types of corrosion protection system, cargo types, temperature (Paik et al., 2004). Consequently, the corrosion may differ in accordance with the type of vessel or the interested structural locations. According to the (DNV, 2012), the hazardous structural location are the following.

Splash Zone

Splash zone is located 5 meters above and 4 meters below the draft. This zone is considered one of the most riotous marine environments because of “exposure to fully aerated seawater, UV radiation, repeated wetting and drying and possibly salt built up” where corrosion rate may be extremely high with disastrous consequences, such as intensive corrosion and wall loss. Therefore, the exercised inspection shall be over careful and detailed. An example of an extensive corrosion located in splash zone is shown on Figure 10.



Figure 10: Outboard Splash Zone (DNV, 2012)

Topside

Top side corrosion can be identified everywhere above the splash zone. Because of the intricacy of the topside, the above part of the structure can be separated to four categories including primary structures, secondary structures, process equipment and piping, safety and emergency equipment. A more detailed description of these parts is presented in Table 8.

Tanks and Internals Structures

Cargo oil tanks, ballast tanks, pump rooms, chain lockers and void tanks are in danger of excessive corrosion. Due to the difficult accessibility and the corrosive environment which involve into these areas, the phenomenon of corrosion constitutes a great threat for the internal surfaces. Ballast tanks record the highest rates of corrosion because of the high humidity and the difficult access into them in order to survey, and subsequently maintain this location (Gudze and Melchers, 2008). Cargo oil tanks are also offended by corrosion because of the existence of the element S, as well as the use of seawater in the cleaning process of the tanks (Sakashita et al., 2007).

Table 8: Structure elements divided of over the different main topside areas

<i>Primary structures</i>	<i>Secondary structures</i>	<i>Process equipment and piping</i>	<i>Safety and emergency equipment</i>
<ul style="list-style-type: none"> - Top side section of the columns and braces; ship hull - Structural topside braces - Main deck and helicopter deck - Control room and control room structures - Drill rig - Cranes 	<ul style="list-style-type: none"> - Control room and accommodations - Walkways and stairs - Communication systems 	<ul style="list-style-type: none"> - Pressure vessels and piping - Storage tanks and vessels - Sump systems 	<ul style="list-style-type: none"> - Firefighting systems including waterlines and pumps - Escape systems (life boats/ escape modules as well as the launch system) - Gas monitoring systems - Alarm systems

4.1.2 Types of corrosion

Normally, corrosion is recognized according to its type relied on the nature of corroded material, the environmental circumstances or the morphology of the corrosion. In accordance with the morphology of damage on the corroded metal, corrosion can be fragmented in 14 categories (Ricker et al.) (Παντελής, 2012):

- *General Corrosion / Uniform Corrosion.* In general corrosion, the whole exposed surface is attacked uniformly from electrochemical or chemical reactions. As a result, due to corrosion the metal becomes thinner and its shape of surface alters. Usually, locations with low temperature and low humidity suffer from general corrosion, such as ballast tanks.
- *Galvanic Corrosion / Bimetallic Corrosion / Contact Corrosion.* It is an electrochemical reaction between two different metals which come into electrical contact in presence of an electrolyte. The corrosion rate increases to the more active metal, whereas it decreases to the nobler one. The nature, the humidity and the conductivity of the environment are significant parameters for galvanic corrosion. In addition, the correlation between the surfaces of the active and noble metal determines the corrosion rate. Also, the presence of electrolyte is crucial because in a dry environment, galvanic corrosion cannot occur.
- *Pitting Corrosion.* Pitting corrosion is a high rate localized corrosion which causes small holes in the surface of the metal. The reduction of pH, the presence of Cu^{2+} and Fe^{3+} ions, high temperatures and the increase of the Cl^- concentration are parameters which lead to pitting corrosion. Moreover, a metal with sleek surface may be attacked from few and big pits, while a metal with a more abrasive surface may present numerous and small pits. Usually, pitting corrosion is identified in tankers and specifically in the internal of main deck.

- *Crevice Corrosion.* Crevice corrosion is recognized in metals with gaps, on their surfaces, where the entrance of the liquid of the environment is restricted. These gaps are called crevices. Crevice corrosion is identified in passive or easily passivised metals and alloys which are exposed to aqueous environment with high levels of chloride. If two metals coexist in the same environment, then galvanic corrosion occurs, also. The factors influencing the crevice corrosive are the nature of the metal, the environment, the geometry of metal's surface and the initial gap of the crevice. Usually, this phenomenon is presented in bolts, flanges, nails and joints of pipes.
- *Intergranular Corrosion.* Intergranular corrosion attacks to the boundaries of crystals. That localized corrosion leads to the separation of crystals and as result, of the metal. It bronze, the existence of diluted Zn at high levels on the boundaries of crystals, as well as the low concentration of Cr on the boundaries of crystals in stainless steel can lead to intergranular corrosion.
- *Selective Attack – Leaching / Dealloying.* Dealloying is identified to alloys of two or more metals in a solid form. The less noble metal is selectively removed from the surface. Although the remaining part of the alloy maintains its solid form, its mechanical strength is reduced.
- *Cavitation Corrosion.* Cavitation corrosion is caused by the creation and the collapse of water bubbles which are, usually, produced by a high speed impeller. Cavitation is identified with the form of big pits which cause an abrasive surface and it occurs in aqueous environment with great levels of salinity. This type of corrosion is presented in propellers of ships and hydraulic turbines.
- *Erosion corrosion.* Erosion corrosion is the accelerated loss of metallic component due to the flow of a liquid on the surface of this component. Dilutes of high velocity remove the protective film of the metal and subsequently the phenomenon of erosion corrosion occurs. Solid particles in the liquid may cause damage on the surface, as well as two-phase flows. Erosion can be detected in pump impellers, propellers, turbines and pipes with changes in the directions of the flow.
- *Fretting Corrosion.* The oscillatory tangential movement of two metals which are in contact and highly loaded may induce fretting corrosion. The parameters influencing the significance of this phenomenon are the load (as friction and load increase relatively), greater frequencies produce greater fretting corrosion and the temperature which influences metals according to their oxidation characteristics. If the nature of the metal encourages the creation of a protective film from oxides which prevents the contact of the metals, then the rate of vibration is reduced. Fretting corrosion can be identified to bearings, threads and parts of car engines.
- *Corrosion Fatigue.* The combination of a cycling stress and a corrosive environment cause the corrosion fatigue. If a metal is exposed in a highly corrosive environment under cyclic loading, the service life of this metal

becomes shorter due to the harmful circumstances. As stress increases, the demanded number of cycles to induce failure is decreased. Corrosion fatigue is directly influenced by loading, environmental and metallurgical parameters.

- *Stress Corrosion Cracking*. The combination of tensile stress and the existence of corrosive environment lead to stress corrosion cracking. Tensile stress may be caused from external loads, temperature variations or residual stresses. The most influential factors are mechanical (applied stresses), environmental (temperature and chemical composition of dilute), and metallurgical (composition of metal).

4.1.3 Safety measures

Marine corrosion damage may lead to disastrous consequences for personnel and environment. Therefore, ships shall take prevention measures in order to control this unpredictable phenomenon. The control measures of corrosion can be segregated to five categories (Chandler, 2014) (Παντελής, 2012).

- *The selection of materials* which can resist at the operational environment. This method is the most usual, as a preventing measure of corrosion, and aims to the selection of an alloy which presents the optimal combination of aqueous environment – alloy. The resistance of metals from corrosion can be increased by inclusions or heat treatments which improve the mechanical behavior of the alloy.
- *Design*. The factor of design may be characterized as significant as the selection of materials is. At the initial stage of construction, designers make efforts to create an operative, aesthetic and stable structure. However, it is also important to take into account the impact of the corrosive environment which influences ship's performance. Therefore, the design of a ship or equipment shall avoid the creation of areas where water might be trapped, crevices, and residual stresses, as well as the necessary depth of the shears and the easy access for maintenance.
- *Coatings*. One of the most common methods of preventing corrosion is coatings. This method is based on the application of layers on the metallic surface in order to isolate that surface from the corrosive environment. Coatings can be grouped in three categories: metallic, inorganic and organic. Metallic layers can be identified as the “more noble” and the “less noble”. More noble layers isolate the metal and function as sacrificial coatings while less noble protect the metal via galvanic reaction. Inorganic layers may be created from chemical action. Heat treatments change the surface of metal into a film of metallic oxide or compound (chromate, phosphate, nitride, passive films) which provide better corrosive resistance. Organic layers function as obstructions between metallic surface and corrosive environment. They

consist of three levels: primers, it is considered as the most significant part of the coating, undercoats, they are added only when a minimum depth of coating is required, and top coats, which compose the external surface of the layer and the first defensive level against corrosion. If the organic coating fails, the protection of the metallic surface ends.

- *Cathodic Protection.* Probably, cathodic protection is the most effective and significant method for preventing corrosion in ships. When two dissimilar metals or alloys come into contact in the same aqueous environment, one of them corrodes (anodes) at a higher rate whereas the other (cathodes) is protected. The corrosion rate of steel may be reduced or zeroed if blocks of aluminum, magnesium, and zinc are attached on steel. There are two different applicable methods of cathodic protection. The first one is known as Impressed Current Cathodic Protection (ICCP) and it is based on the connection between the metal and an external DC electrical power source. The external source functions as a sacrificial anode and provides current in a higher rate than the metal loses respectively. The second method is relied on the galvanic protection and it requires the direct contact of an anode above the surface of protected metal. This method is known as Sacrificial Anode method.
- *Inhibitors.* Inhibitors are substances which are used for the deceleration or the postponement of corrosion. They can be deployed only to enclosed atmospheric spaces. This method of protection includes the addition of inhibitors at low concentrations in a corrosive environment. The inhibitors of sorption constitute the most common category of inhibitors. They are organic substances which are absorbed from the active areas of metal surface, and subsequently postponed the failure of metal. Other categories of inhibitors are scavengers, oxidizers, vapor phase. The application of inhibitors shall take into consideration the nature of metal, the temperature, the environment and the concentration.

The model aims to the prediction of the depth of corrosion based on time dependent parameters. For evaluating time dependent corrosion, one of the many models which had been developed is the two parameter power approximation (Yamamoto, 1997).

$$z(\tau) = a \cdot \tau^b$$

z : the loss of plate thickness in mm.

a : constant which determines the corrosion growth.

b : constant characterizing the slope of function z .

τ : age of the vessel minus the coating life.

The calculation of corrosion wastage (z) requires the estimation of the variable τ :

$$\tau = \text{Ship Age} - \text{Coating Lifetime}$$

As the age of a ship is defined from databases, the evaluation of coating lifetime shall be determined according to the influential factors. Coating lifetime is governed from several parameters which can be grouped in 6 categories and had been quantified by Classification Societies and experts. The parameters are presented in Table 9. The mean and the standard deviation of theoretical coating lifetime diverge depending on ship structural area and they are expressed in terms of years.

Table 9: Parameters of coating lifetime

Category	Parameters
Quality of initial coating	<ul style="list-style-type: none"> - Country of yard - Building class
Maintenance	<ul style="list-style-type: none"> - No of owner changes - Flag - Class - Time at sea - Lay days in port
Operational Profile	<ul style="list-style-type: none"> - Operation in tropics/subtropics
Cargo type and handling	<ul style="list-style-type: none"> - Cargo frequency - Abrasivity of cargo - Cargo handling
Survey	<ul style="list-style-type: none"> - No of deficiencies - No of detentions - Time to next docking survey
Theoretical coating life	<ul style="list-style-type: none"> - Mean value - Standard deviation

Corrosion model parameter a refers to the corrosion rate depending on several variables which are presented in Table 10, analytically. The possible values of a_{corr} were evaluated by taking into consideration information provided by (Harada et al., 2001) and (Sone et al., 2003).

Table 10: Parameters influencing factor a

Category	Parameters
Operational Profile	- Operation in tropics/subtropics - Ballast ratio
Cargo type and handling	- Cargo temperature - Corrosivity of cargo
Theoretical value of a (a_{corr})	- Ship type - Structural area

Concerning the constraint b, as it is proposed by Guo et.al. (2008), it is quantified to 2/3 for mean corrosion rate.

The developed code requires from the user to give as an input the IMO number of a ship (Figure 12), on which he is interested in calculating the depth of corrosion.

The screenshot shows the Matlab editor interface with the following code in the script editor:

```

1 - clear all
2 - close all
3 - clc
4
5 - [~, ~, ex] = xlsread('C:\Users\Admin\Desktop\sxoli\THESIS\MATLAB\Corrosion Model.xlsx','φύλλο1');
6 - IMO_NUMBER = input('give IMO number= ');
7
8

```

Figure 12: IMO number is required as an input (Matlab)

As regards the Matlab script, after the given input of the user, an excel file is loaded and the including data are placed on a matrix. The excel file contains necessary information, related to ship's variables which are provided by databases (IHS fairplay, AIS data and Paris MoU) and quantified by experiences surveyors and researchers. Then, the Matlab code searches the created matrix in order to match the IMO number, which has been given as an input, with the existed IMO number of the loaded excel file. Subsequently, a new matrix is created with the essential variables of the ship. These variables are named below:

- ❖ Ship type. Depending on the cargo a vessel carries several ship types can be identified. According to the cargo of a ship the corrosion can differ in cargo holds.
- ❖ Ship age. Coating condition can be determined by the age of the ship. On a young ship the coating may be in better condition than on an old one.

- ❖ Owner changes. Generally, ships that do not change owners for a long time are in better technical condition than those which are often sold. The quantification of this variable is presented in Table 11.

Table 11: Factors for owner changes

No of owner changes	Factor for coating lifetime	Factor for corrosion rate
0	1.2	1.0
1-2	1.0	1.0
>2	0.9	1.0
unknown	0.9	1.0

- ❖ Class. The classification society of a ship can define its technical condition. Ships have been separated to those which have been classed by an IACS class and those which have not. The members of IACS are:
 - American Bureau of Shipping (ABS),
 - Bureau Veritas (BV),
 - DNV GL (DNV, GL and DNV GL)
 - Lloyd’s Register (LR),
 - Nippon Kaiji Kyokai (NK),
 - China Classification Society (CCS),
 - Croatian register of shipping (CRS)
 - Indian Register of Shipping (IRS)
 - Korean Register (KR)
 - Polish Register of shipping (PRS)
 - Registro Italiano Navale (RINA)
 - Russian Maritime Register of Shipping (RS)

The quantification of this parameter is presented in Table 12.

Table 12: Factors for class

Class	Factor for coating lifetime	Factor for corrosion rate
IACS	1.1	1.0
Non IACS	0.9	1.0
unknown	0.9	1.0

The quantification of each variable can be seen in ANNEX A. Corrosion Influencing Factors

- ❖ Building class. Every ship is design and built in accordance with the rules of a classification society. The rules of societies diverge, thus the building quality depends on the class which surveyed the building process.
- ❖ Country of yard. This variable refers to the country where the ship was build. The quality of workmanship and materials, as well as the climatic conditions of the country may determine the coating life.
- ❖ Flag. According to Paris MoU and PSC findings, corrosion is related to the flag of the ship, as the flag can indicate the technical condition of the vessel. In this model, flags of 72 countries have been considered.
- ❖ Time at sea (in days). Ships that sail long distances between ports are in better technical condition because crew has more time to maintain the ship effectively than those that travels short time.
- ❖ Time at port (in hours). On ships staying long time to ports the crew has more time to for maintenance work.
- ❖ Detentions. An indicator of the technical condition of a ship may be its detentions. Numerous detentions for a ship, indicates that it is not well maintained and safe.
- ❖ Deficiencies. An indicator of the technical condition of a ship may be its deficiencies. Numerous deficiencies for a ship, indicates that it is not well maintained and safe.
- ❖ Cargo corrosivity. Cargoes that contain sulphur may have increasing corrosion rates. Principally, sulphur in bulk, copper concentrate, coal, petroleum coke and iron ore are parameters which increase the corrosion rate.
- ❖ Cargo abrasivity. Ships that load abrasive bulk cargo or its shift during the voyage may damage the cargo hold coating.
- ❖ Cargo temperature. High cargo temperature leads to an increase in corrosion, thus the temperature in the cargo hold shall be considered.
- ❖ Operating in tropics/subtropics
- ❖ Cargo handling. Coating in cargo holds may be damaged by mechanical cargo methods.
- ❖ Cargo frequency. Changes in cargo frequency can be estimated from the draught of the ship and influence the coating life.
- ❖ Time with ballast (Ballast ratio). Corrosion in ballast tanks depends on the time a ship is in ballast condition. Although in ballast condition the ballast tank surfaces are exposed seawater, the corrosion degrades the tanks when they are deballasted because of the high levels of humidity in the enclosed area (Gardiner and Melchers, 2003).
- ❖ Time to next docking (in years). Docking surveys are exercised every 5 years. During the survey the condition of coating is examines. Therefore, a ship that has been surveyed a short time ago it can be considered that its coating is at an acceptable level.

The above-mentioned characteristics may be string or numeric. The value of each variable, regardless of its type, is matched to a numeric value and all these values are used for the computation of the corrosion depth. The correlation between the variables of the ship and the matched variables of the Matlab code is presented below:

- Ship age → Ship_Age
- Owner changes → Factor_OwnerChanges
- Class → Factor_Class
- Building class → Factor_Building_Class
- Country of yard → Factor_Yard
- Flag → Factor_Flag
- Time at sea (in days) → Factor_Haul
- Time at port (in hours) → Factor_Days_In_Port
- Detentions → Factor_Detentions
- Deficiencies → Factor_Deficiencies
- Cargo corrosivity → Factor_Corrosive_Cargo
- Cargo abrasivity → Factor_Abrasive
- Cargo temperature → Factor_Cargo_Temperature
- Operating in tropics/subtropics → Factor_Tropics_Subtropics (for coating life)
- Operating in tropics/subtropics → F_Rate_Tropics_Subtropics (for corrosion rate)
- Abrasive cargo handling → Factor_Handling
- Cargo frequency → Factor_Frequency
- Time with ballast (Ballast ratio) → Factor_Ballast_Ratio
- Time to next docking (in years) → Factor_Next_Survey

Firstly, the code calculated the coating life. The above-named factors are grouped in 5 categories according to their contribution to ship's functions. They can be identified on those which influence the corrosion levels via cargo, building quality, operational area, maintenance, and surveys. The multiplication of factors leads to the evaluation of these 4 parameters which are called nodes. Nodes are presented below, as they have been named in the code and considering the factors which influence them:

- Factor_Abrasive, Factor_Handling, Factor_Frequency → ***Node_Cargo***
- Factor_Yard, Factor_Building_Class → ***Node_Building_Quality***
- Factor_Tropics_Subtropics → ***Node_Operational_Area***
- Factor_OwnerChanges, Factor_Class, Factor_Flag, Factor_Haul, Factor_Days_In_Port → ***Node_Maintenance***
- Factor_Next_Survey, Factor_Detentions, Factor_Deficiencies → ***Node_Survey***

Afterwards, the theoretical coating life has to be defined in order to estimate the coating life. The mean value and the standard deviation depend on the ship type and the interesting structural area. Table 13 presents the possible values, as they had been

determined by experienced researchers. Subsequently, the parameter τ is calculated, as the ship age is known and the coating life has been assessed.

Then, the parameter a is calculated and results from the product of Factor_Ballast_Ratio, Factor_Cargo_Temperature, Factor_Corrosive_Cargo, F_Rate_Tropics_Subtropics, and a_{corr} . The value of theoretical correction of a depends on the structural area that is examined and the ship type as it is shown in Table 14.

Table 13: Mean value and Standard deviations

Locations	Tanker		Bulkер		General Cargo	
	Mean	Stdv.	Mean	Stdv.	Mean	Stdv.
Living Space	10	2	10	2	10	2
Interior deck	10	2	9	1.8	9	1.8
Exterior deck	9	1.8	10	2	10	2
Bottom	10	3	10	3	10	3
<i>Cargo Space</i>						
- Interior deck	9	2.7	10	3.9	10	3.9
- Bulkhead	9	2.7	7	2.8	7	2.8
- Sideshell	10	4	10	4	10	4
- Inner bottom	7	2.1	3	0.9	3	0.9
- Floor	8	2.4	10	3	10	3
<i>Water ballast tanks</i>						
- Bulkhead	8	3.2	8	3.2	8	3.2
- Inner bottom	11	3.3	11	3.3	11	3.3

Table 14: Corrosion model parameter a for different locations in ship and ship types

Locations	Tanker	Bulkер	General Cargo
Living Space	0.61	0.61	0.61
Interior deck	0.21	0.61	0.61
Exterior deck	0.61	0.21	0.21
Bottom	0.20	0.20	0.20
<i>Cargo Space</i>			
- Interior deck	0.30	0.21	0.21
- Bulkhead	0.40	0.28	0.58
- Sideshell	0.28	0.28	0.28

- Inner bottom	0.30	0.57	0.57
- Floor	0.31	0.31	0.31
<i>Water ballast tanks</i>			
- Bulkhead	0.52	0.52	0.52
- Inner bottom	0.38	0.38	0.38

As the parameters of the model have been defined, the depth of corrosion can be estimated according to the mathematic formula below:

$$depth = a \times \tau^b$$

As regards the code which has been developed in Octave, although the computational procedure is the same to this of Matlab, the most significant difference is the procedure of loading the ship's database from the excel file. The most noticeable difficulty in developing the Octave code was the use of command which loads an excel file which includes both strings and numbers. For that reason, two different procedures were followed. The first is that the essential characteristics of the ships are typed by the user as inputs in Octave environment. However, this procedure is certainly time consuming and of course not optimal. Therefore, the second approach is that the correspondence of ship's characteristics and the relative variables results in the excel file and not in Octave, as it happens in Matlab code. As a result, Octave file loads only numerical values, and subsequently the procedure of calculation eventuates in Octave.

At both environments, Matlab and Octave, three matrices are created after the completion of essential calculations which lead to the depth of corrosion,. The first matrix contains the characteristics of ship which was studied analytically. The second matrix includes the final values of mean, standard deviation and constraint a , for each location of the ship. Finally, the third matrix presents the value of every factor or node which participates in the computational procedure. All three matrices, are exported to an excel file, using the appropriate command of Matlab (Figure 13).

```

2382
2383 -   xlswrite('Corrosion Model - Data for Bulk Carrier - Ballast Tanks.xlsx',input_data,1)
2384 -   xlswrite('Corrosion Model - Data for Bulk Carrier - Ballast Tanks.xlsx',Nodes,3)
2385 -   xlswrite('Corrosion Model - Data for Bulk Carrier - Ballast Tanks.xlsx',Mean_Std_a,2)
2386 -   end
2387 -   end

```

Figure 13: Creation of excel file with the appropriate input data and results

4.2 LSA model

4.2.1 LSA

Human fatalities and severe injuries continue to appear due to the ineffective function of life saving appliances even though huge efforts have been made in order to solve that problem by the maritime industry. Usually, the exercising drills for the purpose of training the crew of the vessel lead to contrary results instead of preparing efficiently its members to deal with unpredictable situations.

In 1994, the numerous accidents involving different types of saving appliances prompted Oil Companies International Marine Forum (OCIMF) to research additionally the causes. A questionnaire have been formed and handed out to the International Chamber of Shipping (ICS), ship operators, Flag State administrators and national authorities. Their publication included reports of 92 accidents which had been analyzed, as well as detailed information about the type of activity taking place when the accident occurred (drill, survey, maintenance etc.), the source of accident (human fault, equipment failure, poor designing etc.), key component failure and the range of consequences. Expanding the investigation of 1994, OCIMF published a new research associated with the extensive control of LSA. The latter research was based in a questionnaire handed out to members of OCIMF, INTERTANKO, and Society of International Gas Tanker and Terminal Operators (SIGTTO). Davit launched lifeboats was contained in the majority of the 89 reports because of the complexity of their design. The principal cause of accidents was equipment failure in spite of the reported LSA type, followed by insufficient maintenance, and design errors. A short number of human errors during the operation were recorded, as well as inadequate training and wrong communication.

In 1999, the Australian Maritime Service Board (AMSB) distributed a summary of LSA incidents containing a period of seven years to the IMO. The research considered 9 accidents associated with lifeboats and concluded that the major causes of incidents were inadequacies in design, equipment and training.

In 2001, Marine Accident Investigation Branch (MAIB) published a research on accidents associated with lifeboats in the UK in a period of 10 years, from 1989 to 1999. The investigation was based on design, maintenance, and training of crew members correlated with key components of lifeboat launch system, such as winches, falls, davits, hooks etc., which were involved in the incidents. The MAIB pointed out that it was necessary to take suitable measures for mitigating the occurrence of accidents because of the remarkable number of human losses and consequences.

Ross (2006), conducted a study with regards to life saving appliances accidents in 2006. Insufficient design and maintenance of equipment, as well as lack of training and errors during the operation, were associated with lifeboat launching mechanisms issues according to Ross. The research was focused on the not completed

comprehension of crewmembers equivalent to the operational procedures and requirements of the davit launches subsystems. In addition, Ross recognized that a significant extension of incidents resulted by equipment deficiencies.

4.2.2 Types of LSA

The obligatory existence of life saving appliances aims to the decrease of possible injuries and fatalities of seafarers or passengers, which might be caused by any unpredictable incident. The social sensitivity on human losses has led to the improvement of lifeboats design, as a result of severe maritime accidents which had caused numerous fatalities (e.g. Titanic in 1912, S.S. Eastland in 1915 etc.). This thesis focuses on and elaborates the function of three different types of life saving appliances.

- Davit launched lifeboats.
- Davit launched liferafts.
- Free-fall lifeboats.

Each LSA type is divided into main components. The deficiency of each main component results the total failure of the LSA. The analysis of each LSA and its main components will be described below.

Davit launched lifeboats & life rafts

Davit launched lifeboats and davit launched life rafts are composed by seven main components and the majority of them consists of subcomponents.

- *Davits.* The responsibility of davits is to bring either the lifeboat or the life raft from a stowed position to the embarkation and to the launching position. The subcomponents of davits are a limit switch, davit arms, the fall wires and the winch. The majority of lifeboats include two davit arms on their installation, whereas life rafts contain one. The existence of limit switch ensures the quick restoration of the fall wire.
- *Release mechanism.* Release mechanism is responsible for releasing the embarked LSA. A remarkable number of accidents derive from the failure of release mechanism. The hooks, the operating cables, and the control lever compose the subcomponents of release mechanism. Davit launched lifeboats have two hooks, while the life rafts have one hook. Most of accidents are observed in lifeboats installations. The principal cause is the unintentional release of hooks which may be degraded by corrosion.
- *Winch.* Winches consist of winch brakes, motors, and their back-up mechanisms, as well as winch clutches. Winches can be attacked by corrosion or insufficient maintenance. A possible failure of winch brakes or clutch may cause restrictions in controlling the LSA safely either during the procedure of embarkation or the launch's.

- *Falls, sheaves & blocks.* In every davit installation, components such as falls, sheaves and block can be identified. They compose the smallest parts of the installation and their deficiency might cause the general failure of davit.
- *Tricing & bowsing.* Usually, while the davit launched lifeboat is in stowed position, seafarers or passengers are not capable to board and the lifeboat should be lowered to an embarkation platform. Tricing pennants are responsible for pulling the lifeboat to the preferable position in order to contribute to a safety boarding. When the lifeboat reaches the required position, the bowsing tackles help the blocks to be constrained, and subsequently the tricing pennants are released. Tricing pennants and bowsing tackles are correlated directly. A possible malfunction of tricing pennants forbid the procedure of boarding, while in case of lack of bowsing tackles, load is transferred partially to tricing pennants which are not constructed for this goal.
- *Lifeboat.* In some cases the LSA has not been maintained in good condition and as a result it is not capable to operate safely. The appropriate maintenance is indispensable in order to secure the integrity of LSA.
- *Fall wires.* Fall wires have to cope with the most harsh loads and environmental conditions. Their function includes the transfer of the LSA load to the davit. LSA loads may be reinforced due to bad weather conditions, and simultaneously fall wires are offended by the highly corrosive environment.

Free-fall lifeboats

Free-fall lifeboats consist of several main components which functionality secures the safe operation of LSA. The main components are analyzed below.

- *Davits.* The most noticeable contrast between davit launched lifeboats and those of free fall, is that the latter's function is based on the sliding of lifeboat, since the hooks are released, on two rails which constitute part of the davit. Davit arms provide the safe retrieve of the lifeboat from the sea and they might be used as a davit launched backup system.
- *Release mechanism.* Release mechanisms on free-fall installation are almost the same to those of davit launched and both installations are composed by the same subcomponents. Accidents in free-fall lifeboats are not as usual as in davit launched installations due to release mechanism failure; because of the existence of davit's rails the lifeboat can be hold on the correct direction even if an unintentional release occurs.
- *Winch.* Winches are useful for recovering the lifeboat from water in cases when the davits are not able to operate, and a davit launched backup system is placed on the free-fall installation.

Main components, such as falls, sheaves & blocks, lifeboat, and fall wires illustrated similar characteristics to those of davit launched installations.

4.2.3 Regulations

The principal requirements related to saving appliances on a ship are defined briefly in SOLAS regulations in Chapter III. Concerning the number and the capacity of a vessel in combination with its type, there are specific requirements which should be followed.

Cargo ships

Generally, cargo ships must carry at least one enclosed lifeboat conforming to the requirements of such aggregate capacity on each side of the ship in order to provide space for the total number of seafarers on board. Additionally, all cargo ships must carry at least one inflatable or rigid life rafts, conforming to the requirements of a mass of less than 185 kg and stowed in a position which provides an easy side to side transfer at a single open deck level, as well as of such aggregate capacity on each side of the ship in order to provide space for the total number of seafarers on board. If the liferafts do not meet the requirements of a mass of 185 kg and are not stowed in a position which provides an easy side to side transfer at a single open deck level, the total capacity on each side must be sufficient in order to accommodate the number of people on board, in total.

Additional lifeboats installations are on the discretion of shipping management. Cargo ships may carry on or more free fall lifeboats which shall be capable of being free fall launched over the stern of the ship; providing space for the total number of seafarers on board. Moreover, one or more inflatable or rigid life rafts which are placed on each side of the ship, of such aggregate capacity providing space for the total number of seafarers on board.

Concerning cargo ships of less than 85m length excluding oil tanker, chemical tankers, and gas carriers, may conform to the below regulations. They must carry at least one or more inflatable or rigid life rafts of such aggregate capacity providing space for the total number of seafarers on board. If the life rafts do not meet the requirements of a mass of 185 kg and are not stowed in a position which provides an easy side to side transfer at a single open deck level, the total capacity on each side must be 150% of the total number of people on board. If the lifeboat is totally enclosed, it may be included in the aggregate capacity, on condition that the total capacity on either side of the ship is at least 150% of the total number of people on board. In any case that a lifeboat have been lost or rendered unserviceable, there must be sufficient survival craft available for use on each side, containing any that are of a mass of less than 185 kg and stowed in position which provides easy transfer from side to side at a single open deck level, to accommodate the number of people on board, in total.

Passenger ships

Passenger ships engaged on long international voyages must carry partially or totally enclosed lifeboats on each side of such an aggregate capacity providing more than 50% of the total number of people on board. The Administration may allow the replacement of lifeboats by life rafts of relative total capacity on condition that there shall be never less than sufficient lifeboats on each side of the passenger ship to provide space for 37.5% of the total number of people on board. The inflatable or rigid life rafts shall be served by launching appliances divided equally on each side of the ship. Additionally, the above mentioned passenger ships shall carry inflatable or rigid life rafts of such aggregate capacity providing accommodation for more than 25% of the total number of people on board. These life rafts must be served by at least one launching appliance on each side or relative confirmed appliances capable of being used on both sides.

With regards to passenger ships engaged on short voyages, they must carry partially or totally enclosed lifeboats on each side of such an aggregate capacity providing more than 30% of the total number of people on board. The lifeboats shall be divided equally on each side of the ship, as far as possible. Additionally, inflatable or rigid life rafts shall be carried of such an aggregate capacity that together with the lifeboat capacity, the survival craft will be capable to provide space for the number of people on board, in total. The inflatable or rigid life rafts shall be served by launching appliances divided equally on each side of the ship. Moreover, passenger ships of that type shall carry inflatable or rigid life rafts of such aggregate capacity providing accommodation for more than 25% of the total number of people on board. These life rafts must be served by at least one launching appliance on each side or relative confirmed appliances capable of being used on both sides.

4.2.4 Model

This thesis calculates the probability of failure of different LSA types. The study focuses on the possible deficiency of davit launched lifeboats, davit launched life rafts, and free fall lifeboats which are installed into general cargo ships and passenger ships. The approach of this model is relied on Fault Trees (Figure 14), considering the malfunction of a subcomponent which leads to the general failure of the installation. A fault tree presents all the parameters (subcomponents and main components) which influence the function of the equipment, which is the LSA installation on the study. Practically, the parameters compose the causes, and as a result the different scenarios of a possible general failure. The collection of approximately 25,000 reports from Paris MoU and Norsafe Water craft Hellas A.E, has lead to the definition of the probability of failure of each subcomponent. The above-mentioned reports included information about detentions regarding LSA, with further details about the flag, the class and the age of the detained vessels. In addition, they provide information about the nature of defects on the several components. The deficiency of the equipment may

be resulted by different combinations of main and sub components failure. These combinations are define by the gates “AND” and “OR”. Gate “AND’ requires the occurrence of all causes in order to lead to the event, whereas the gate “OR” demands the happening of only one cause.

There are several factors which influence the safe operation of life saving appliances, such as the functional design, human errors, and appropriate maintenance. However, the literature review defines the latter parameter as the most significant. The organizing and appropriate maintenance of the subparts of any LSA type can reduce the involuntary accidents substantially. Concerning the maintenance of davit launched lifeboats, davit launched life rafts, and free-fall lifeboats, it is directly connected to the flag and the class of the ship, as well as to its age. A ship can fly under a white, black or grey flag and be classified by an IACS or a non IACS classification. With regards to the parameter of age, ships are divided to those which are less than 5 years old and those which are older. The parameters are presented in detail in Table 15.

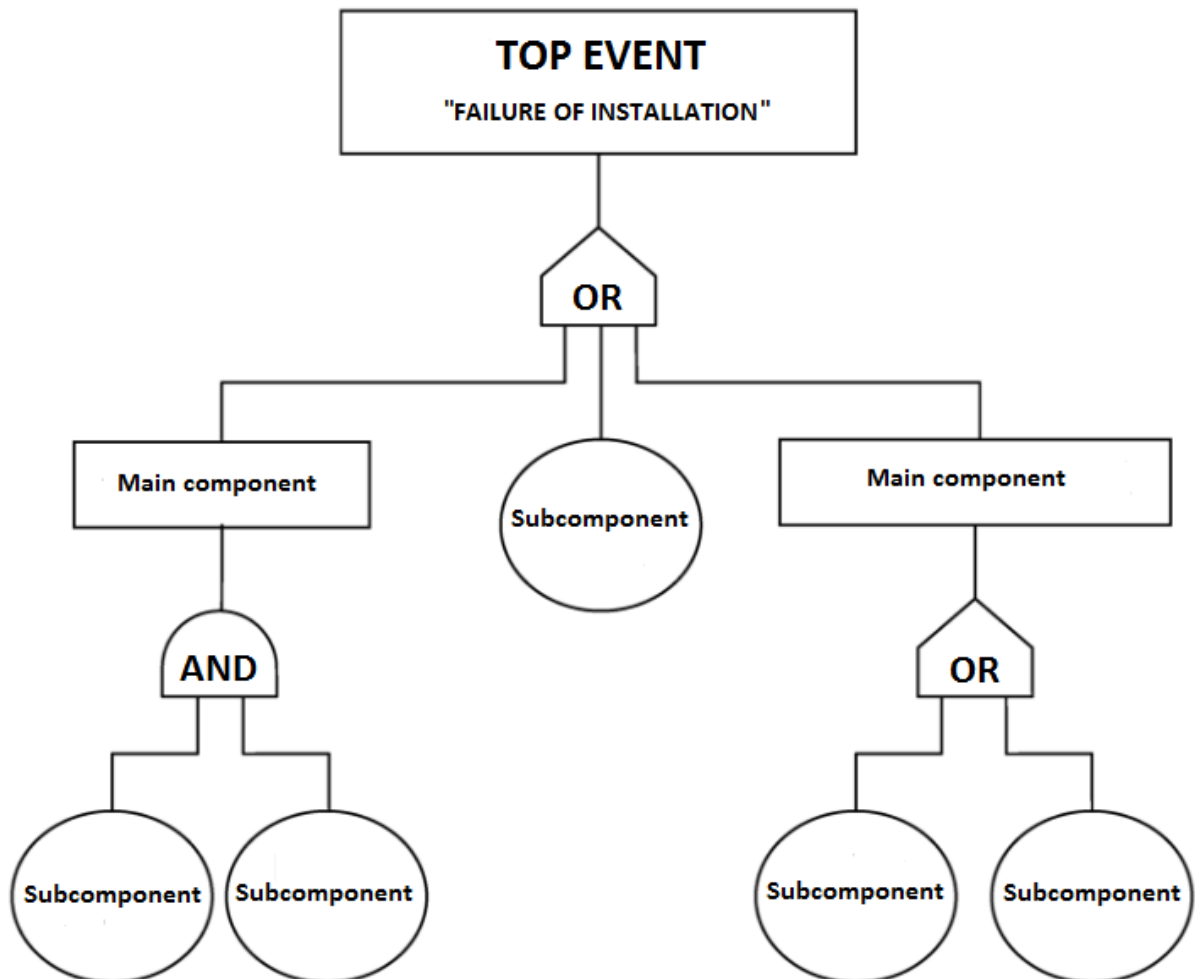


Figure 14: Fault tree diagram

Table 15: Parameters of maintenance

Parameters of Maintenance	Qualitative Values
CLASS	IACS
	Non IACS
SHIP AGE	≤ 5
	> 5
FLAG	White
	Grey
	Black

DAVIT LAUNCHED LIFEBOATS

Figure 15 presents the developed model which calculates the probability of failure of davit launched lifeboats.

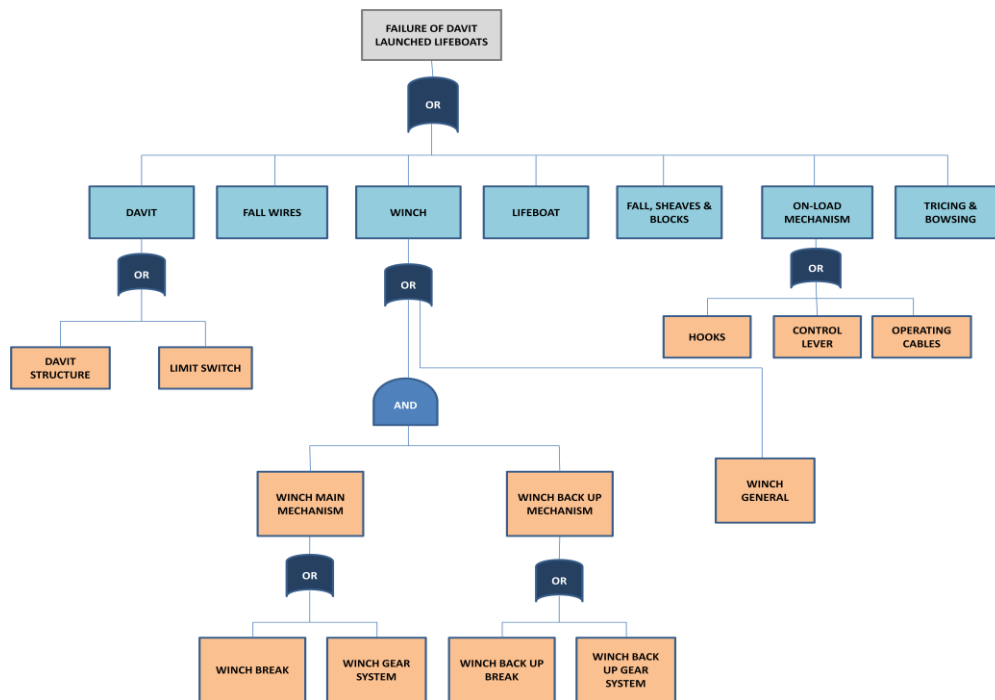


Figure 15: Developed model for the estimation of probability of failure davit launched lifeboats

The value of the probability of the malfunction of davit launched liferafts is a result of the following calculations:

- $$P_{FAILURE\ OF\ DAVIT\ LAUNCHED\ LIFEBOATS} = P_{DAVIT\ FAILURE} + P_{FALL\ WIRES\ FAILURE} + P_{WINCH\ FAILURE} + P_{FALL,\ SHEAVES\ \&\ BLOCKS\ FAILURE} + P_{ON-LOAD\ RELEASE\ MECHANISM\ FAILURE} + P_{LIFEBOAT\ FAILURE} + P_{TRICING\ \&\ BOWSING\ FAILURE}$$

- $P_{DAVIT\ FAILURE} = P_{DAVIT} + P_{LIMIT\ SWITCH}$
- $P_{WINCH\ FAILURE} = P_{WINCH\ BREAK\ FAILURE} + P_{WINCH\ GENERAL\ FAILURE}$
- $P_{ON-LOAD\ RELEASE\ MECHANISM\ FAILURE} = P_{HOOKS\ FAILURE} + P_{CONTROL\ LEVER\ FAILURE} + P_{OPERATING\ CABLES\ FAILURE}$

DAVIT LAUNCHED LIFERAFTS

Figure 16 presents the developed model which calculates the probability of failure of davit launched liferafts.

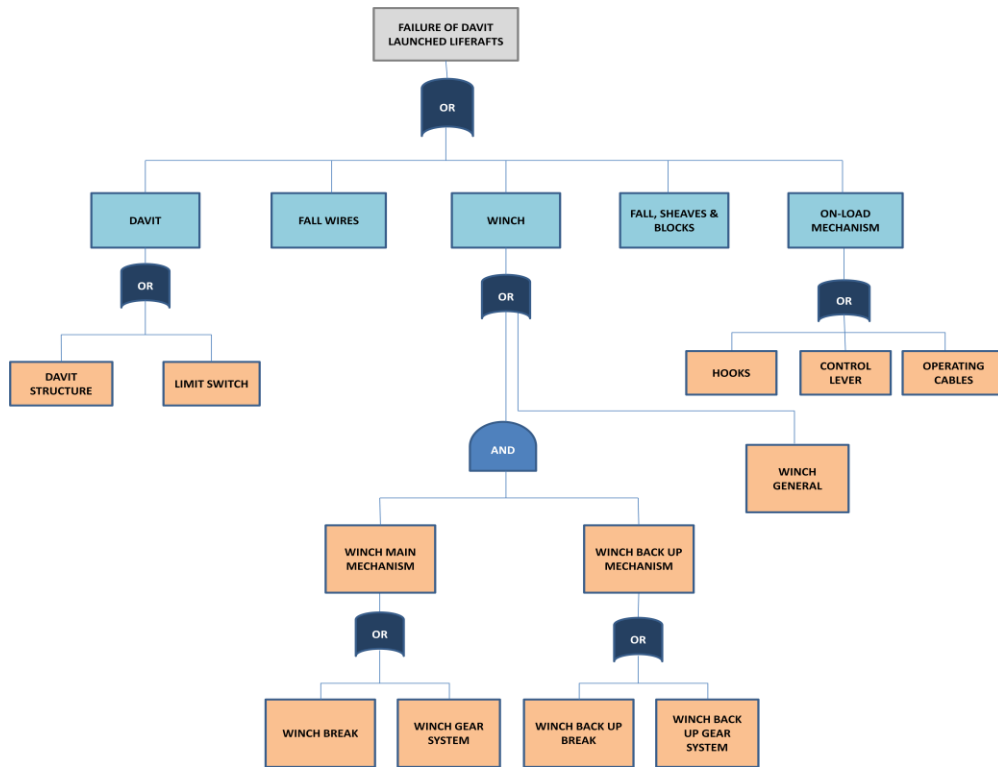


Figure 16: Developed model for the estimation of probability of failure davit launched liferafts

The value of the probability of the malfunction of davit launched liferafts is a result of the following calculations:

- $P_{FAILURE\ OF\ DAVIT\ LAUNCHED\ LIFERAFTS} = P_{DAVIT\ FAILURE} + P_{FALL\ WIRES\ FAILURE} + P_{WINCH\ FAILURE} + P_{FALL,\ SHEAVES\ \&\ BLOCKS\ FAILURE} + P_{ON-LOAD\ RELEASE\ MECHANISM\ FAILURE}$
- $P_{DAVIT\ FAILURE} = P_{DAVIT} + P_{LIMIT\ SWITCH}$
- $P_{WINCH\ FAILURE} = P_{WINCH\ BREAK\ FAILURE} + P_{WINCH\ GENERAL\ FAILURE}$

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

FREE FALL LIFEBOATS

Figure 17 presents the developed model which calculates the probability of failure of free fall lifeboats. The failure of this LSA is divided to the failure of the main mechanism and the failure of the backup mechanism.

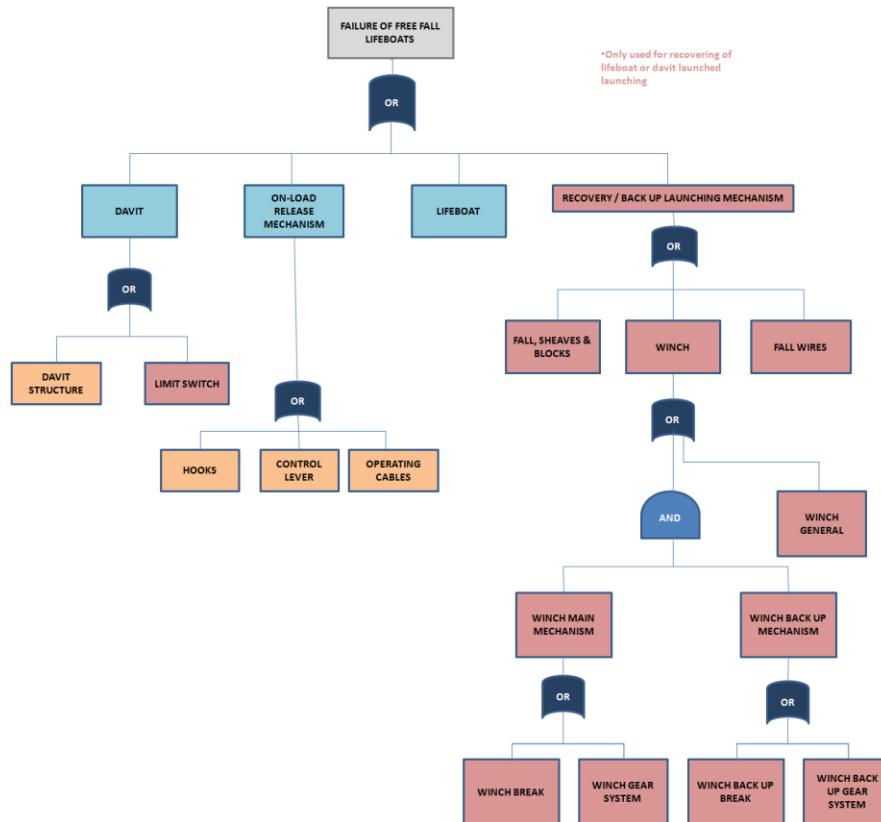


Figure 17: Developed model for the estimation of probability of failure of main mechanism of free fall lifeboats

- $P_{FAILURE OF FREE FALL LIFEBOATS} = P_{DAVIT FAILURE} + P_{FALL WIRES FAILURE} + P_{WINCH FAILURE} + P_{FALL, SHEAVES & BLOCKS FAILURE} + P_{ON-LOAD RELEASE MECHANISM FAILURE} + P_{LIFEBOAT FAILURE}$
- $P_{DAVIT FAILURE} = P_{DAVIT} + P_{LIMIT SWITCH}$
- $P_{WINCH FAILURE} = P_{WINCH BRAKE FAILURE} + P_{WINCH GENERAL FAILURE}$
- $P_{ON-LOAD RELEASE MECHANISM FAILURE} = P_{HOOKS FAILURE} + P_{CONTROL LEVER FAILURE} + P_{OPERATING CABLES FAILURE}$

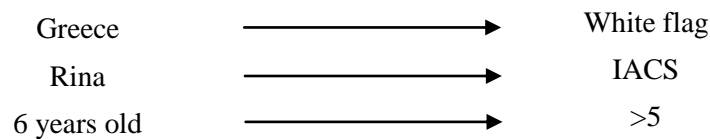
The developed code loads an excel file including data which are useful for calculating the probability of failure of life saving appliances at several ships. Afterwards, it requires from the user to give as an input the IMO number of a ship in order to search and match in with the relative of the loaded file. That matrix contains all the essential information which will lead to the estimation of the required probability. Such information are the number and exact type of life saving appliances for every ship which are identified by Matlab script, and as a result the appropriate calculations are based on the recognized LSA type. Moreover, the country flag, the class, and the ship age, which influence the maintenance of LSA, are included in the excel file and define According to the values of those three parameters different scenarios of deficiencies are conducted and the initial probabilities of failure of subcomponents are defined. The function and the procedure of code's calculations can be totally accessible by the following example.

Step 1: Recognize the appropriate data

Table 16: Ship parameters

TYPE OF LSA	Free-fall lifeboat
COYNTRY	GREECE
CLASS	RINA
AGE	6

Step 2: Correlation between data and their qualitative value



Step 3: Quantification of data

Probability of failure of subcomponent	FREE FALL LIFEBOATS											
	IACS						NO IACS					
	BLACK		GREY		WHITE		BLACK		GREY		WHITE	
	5+	5-	5+	5-	5+	5-	5+	5-	5+	5-	5+	5-
Wires	0.0413	0.4463	0.0223	0.1517	0.3794	0.4347	0.2049	0.2347	0.0582	0.0798	0.1017	0.0549
Davit	0.0827	0.1157	0.0116	0.0393	0.0984	0.1127	0.0138	0.0158	0.0003	0.0054	0.0264	0.0037

Figure 18: Quantification of data

Table 16 constitutes an example of data which may characterize a vessel. Step 1 includes the loading of those parameters by the Matlab code. In step 2, the script of Matlab and Octave relates the data to qualitative values. In step 3, codes in accordance with the qualitative values, quantifies the data and defines the probabilities of subcomponents (Figure 18). In Matlab and Octave, the control of conditions is occurred by the command “if” .Finally, the calculation of the appropriate model may begin in order to estimate the probability of failure of the LSA.

```
460 -     if Type_1=='FFALL' %FREE FALL LIFEBOAT
461 -         if Node_Class=='IACS' %IACS
462 -             if Node_Flag=='BL' %BLACK
463 -                 if Ship_Age>=5 %>=5
464 -                     Subcomponent_Wires_FFALL=ex{52,2};
465 -                     Subcomponent_Davit_FFALL=ex{53,2};
```

Figure 19: Control of conditions (Matlab)

5 CORROSION MODEL RESULTS

5.1 Introduction

After the completion of coding, three different case studies were selected to be taken into account in order to test the effectiveness of the algorithm, as well as to check the results of these studies. The first case study includes the probable corrosion wastage of a bulk carrier on different structural areas which are the cargo holds, ballast tanks and some general areas in the ship. The second case contains an examination of two different ship types, the examined bulk carrier of the first case's and a tanker which is characterized from the same parameters, as the bulker's, excluding the cargo that it carries. The third study calculates and compares the corrosion wastage of two different ship types and ages. The quantification of the parameters has been defined from information taken by AIS, FHS and PSC data bases.

The structural areas which have been chosen to taken into account are divided to three categories; the cargo holds, ballast tanks and some general areas. The three different categories of areas consist of various structural elements. Interior deck, side shell, bulkhead, inner bottom, and floor can be identified on cargo holds. The general areas include living space, external deck, interior deck, and bottom, while the bulkhead and the inner bottom are contained in ballast tanks.

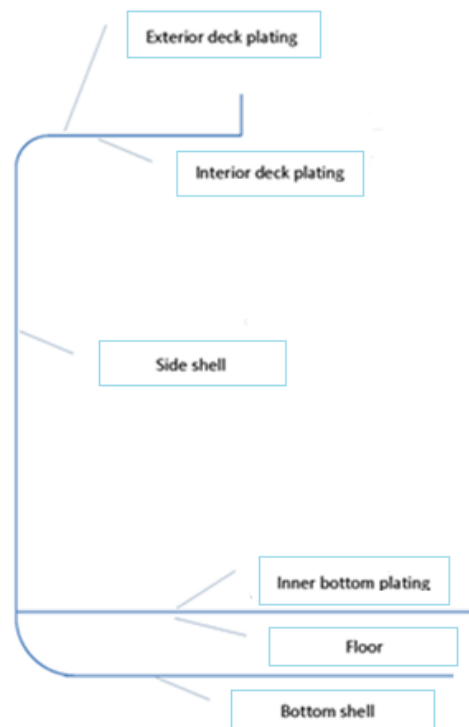


Figure 20: Identified structural elements at midship section

The presentation of results in first study case contains the figures of both Matlab and Octave programs, as they have resulted for each structural area. With regards to the second study case, the results of model include, for each area, one figure, which presents the distribution of corrosion wastage of the two studied ships in order to identify the different consequences of the cargo to the structural elements. The figures of the second study case are produce from Matlab. The presentation of results of the third study is similar to the second's.

5.2 Bulk Carrier

In the first case, the type of ship which has been taken into consideration is a bulk carrier. The examination has included all the structural areas that have been mentioned above. Table 17 presents the parameters of the vessel, as well as the relative empirical factor of each parameter.

Table 17: Parameters and factors of bulk carrier (case 1)

	Parameters	Factor for coating lifetime	Factor for corrosion rate
Ship type	Bulk Carrier		
Year built	2011		
Flag	Marshall Islands	1.1	1
Country of yard	China	0.67	1
Class	IACS	1.1	1
No of owner changes	None	1.2	1
Time at sea (in days)	9.36 (long)	1.2	1
Time at port (in days)	3.03 (long)	1.1	1
Corrosivity of cargo	Regularly	1	1.5
Abrasivity of cargo	Regularly	0.9	1
Temperature of cargo	Low	1	1
Operation in tropics/subtropics	Mostly	0.9	1.11
Time with ballast (Ballast ratio)	High	1	1.1
Building class	Non IACS	0.9	1
Abrasive cargo handling	Regularly	0.9	1
Frequency of cargo	Often	0.9	1
Detentions	None	1	1
Deficiencies	None	1	1
Time to next docking survey	Overdue	0.9	1

5.2.1 Cargo Holds

The grouped areas of cargo holds are the interior deck, the side shell, the bulkhead, the inner bottom, and the floor. The distribution and the mean values of corrosion wastage on these areas will be presented below, as they have been calculated in Matlab and Octave.

5.2.1.1 Interior deck

The figure of distribution of depth of corrosion concerning the interior deck of cargo spaces contains 100% of the cases for both Matlab and Octave figures. It can be seen in Figure 21 and Figure 22 that they are quite similar. The point of convergence of mean value of each code can be shown in Table 18. A Weibull distribution fits best and its parameters are described in Table 19. Approximately, 20% of cases approach the mean value.

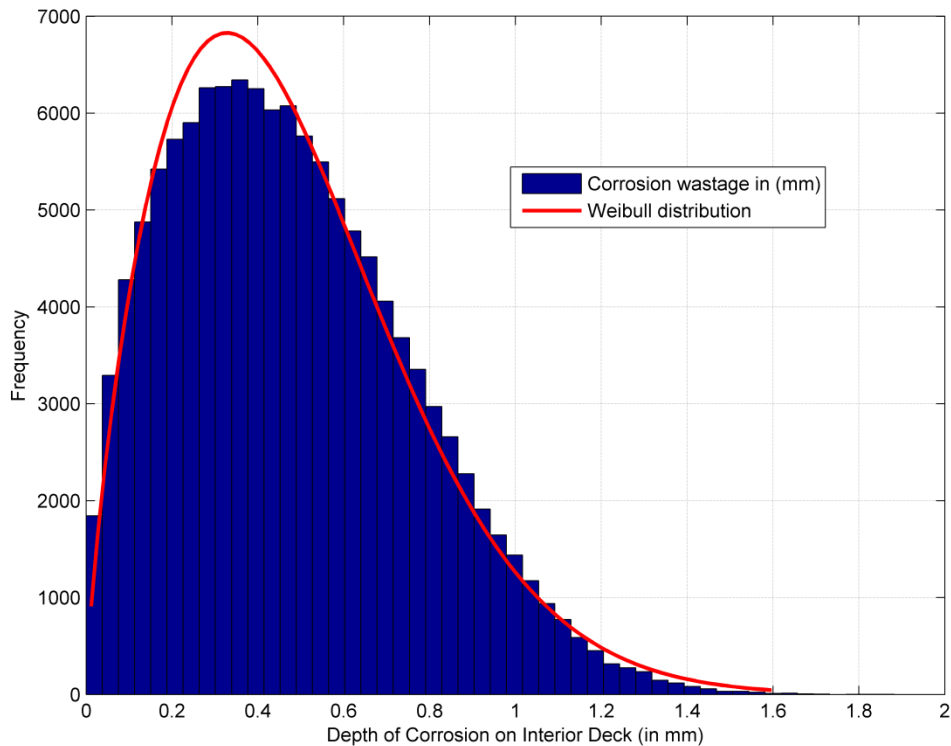


Figure 21: Depth of corrosion (in mm) on interior deck of cargo hold by Matlab

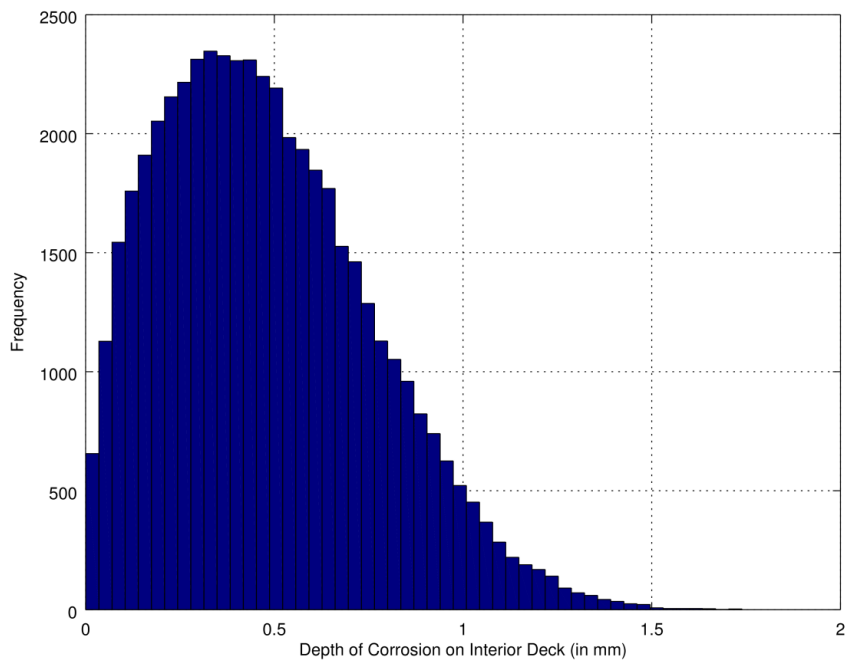


Figure 22: Depth of corrosion (in mm) on interior deck of cargo hold by Octave

Table 18: Mean values of corrosion wastage on interior deck by Matlab and Octave

	Mean Value (in mm)
Matlab	0.480
Octave	0.480

Table 19: Parameters of best fitted distribution for interior deck

	Weibull
a	0.5378
b	1.7357

5.2.1.2 Side shell

With regards to the structural element of side shell in cargo spaces, in Figure 23 and Figure 24 it can be seen that the estimation of both, Matlab and Octave, is almost the same. The mean values of each code are presented in Table 21. A Weibull distribution fits best and its parameters are described in Table 20. Approximately, 19% of cases approach the mean value.

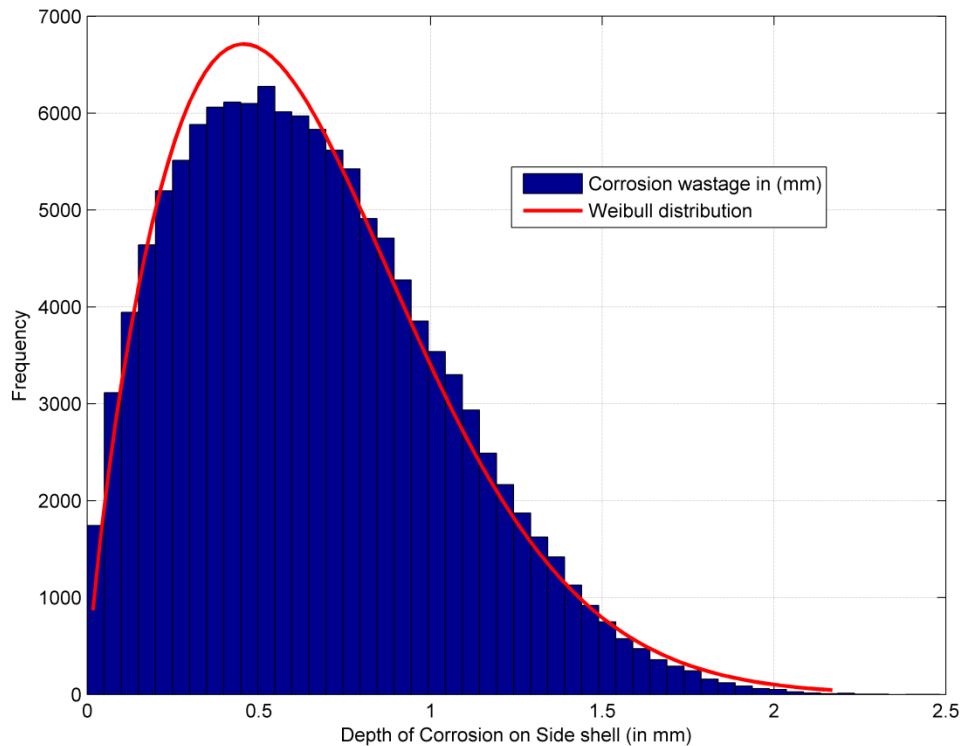


Figure 23: Depth of corrosion (in mm) on side shell of cargo hold by Matlab

Table 20: Parameters of best fitted distribution for side shell

	Weibull
a	0.7382
b	1.7517

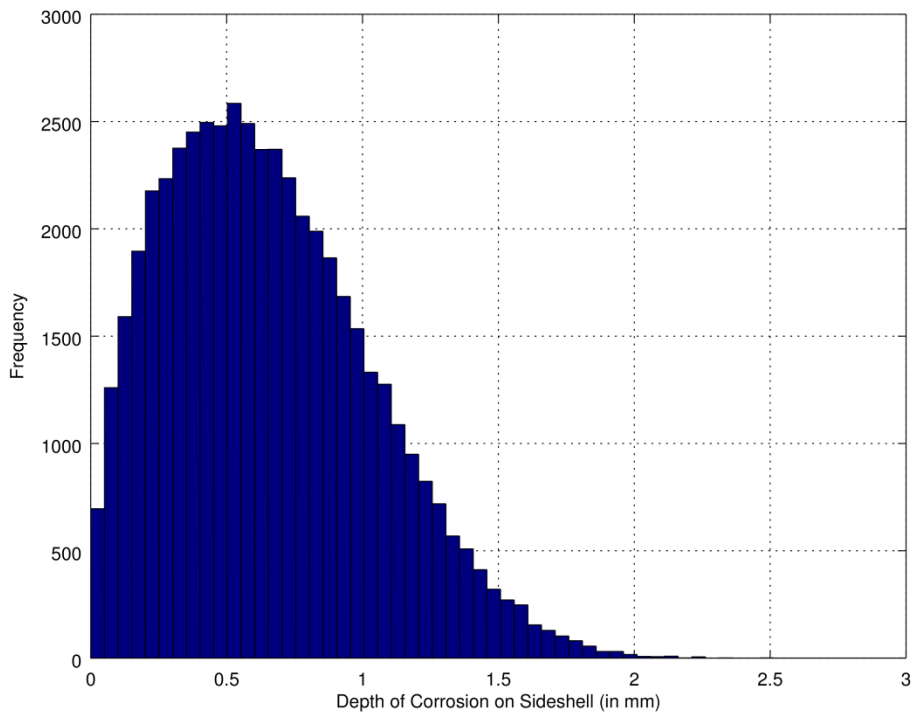


Figure 24: Depth of corrosion (in mm) on side shell of cargo hold by Octave

Table 21: Mean values of corrosion wastage on side shell by Matlab and Octave

	Mean Value (in mm)
Matlab	0.659
Octave	0.654

5.2.1.3 Bulkhead

Concerning the bulkhead of cargo areas, it can be noted that both codes produce almost similar distributions as it can be seen in Figure 25 and Figure 26. Table 22 presents the mean values of the developed codes. A Weibull distribution fits best and its parameters are described in Table 23. Approximately, 19% of cases approach the mean value.

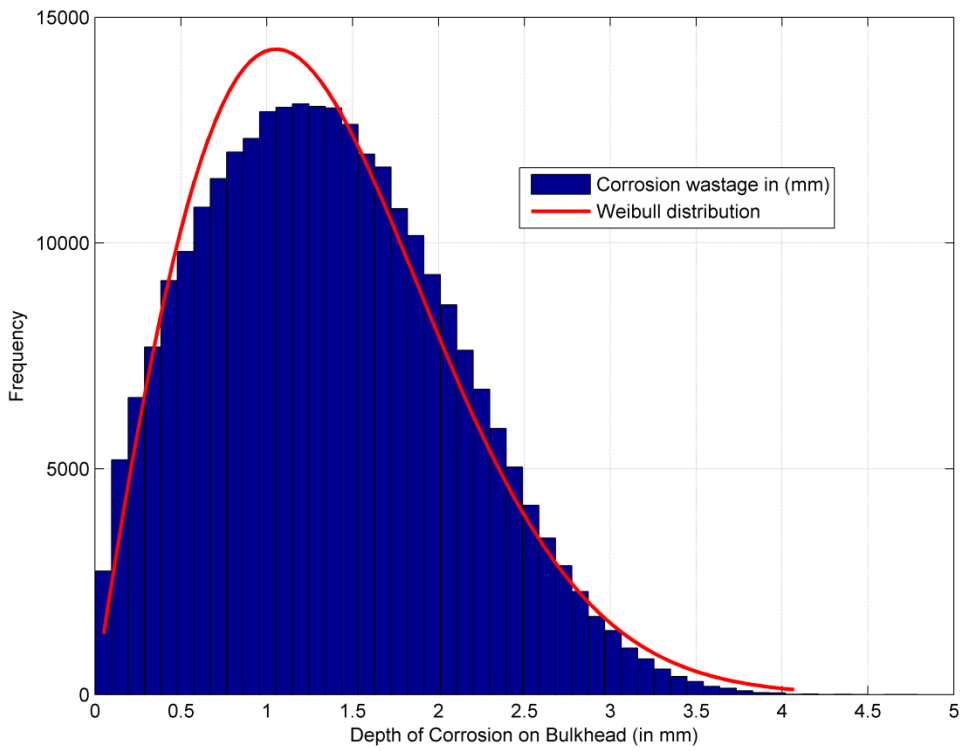


Figure 25: Depth of corrosion (in mm) on bulkhead of cargo hold by Matlab

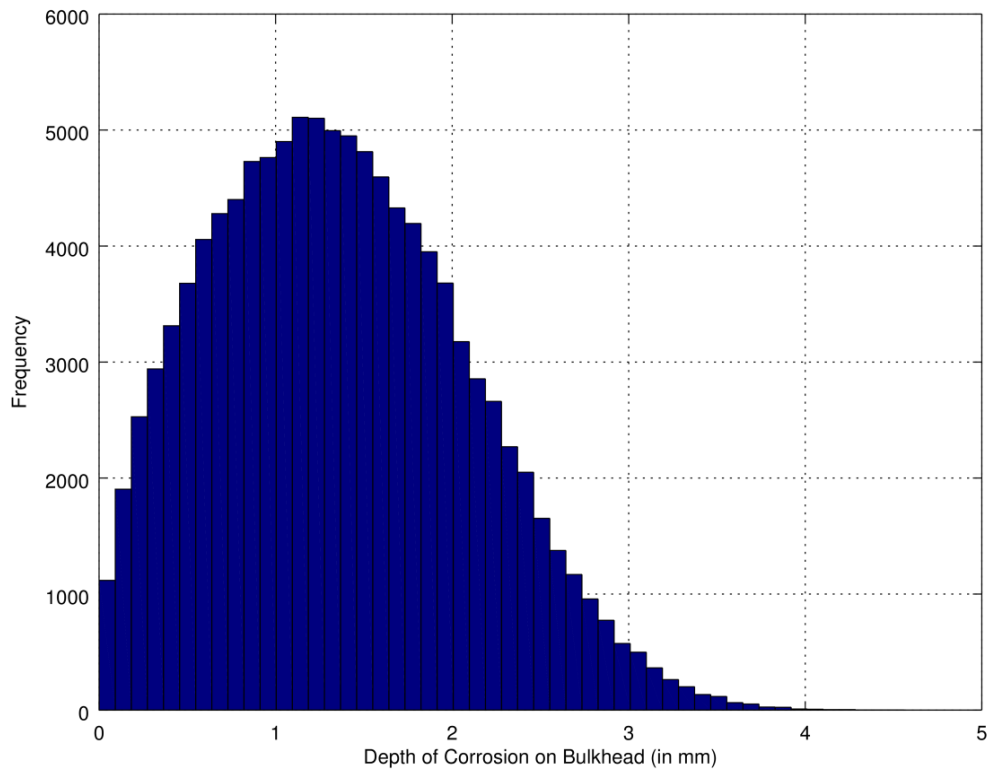


Figure 26: Depth of corrosion (in mm) on bulkhead of cargo hold by Octave

Table 22: Mean values of corrosion wastage on bulkhead by Matlab and Octave

	Mean Value (in mm)
Matlab	1.365
Octave	1.361

Table 23: Parameters of best fitted distribution for bulkhead

	Weibull
a	1.5338
b	1.9349

5.2.1.4 Inner bottom

As regards the inner bottom, the depth of corrosion is presented in Figure 27 and Figure 28. Table 24 shows the mean values as they resulted from Matlab and Octave. Both figures perform the similar distribution. A Normal distribution fits best and its parameters are described in Table 24 and Table 25. Approximately, 31% of cases approach the mean value.

Table 24: Mean values of corrosion wastage on inner bottom by Matlab and Octave

	Mean Value (in mm)
Matlab	2.137
Octave	2.139

Table 25: Parameters of best fitted distribution for inner bottom

	Normal
mu	2.1371
sigma	0.3020

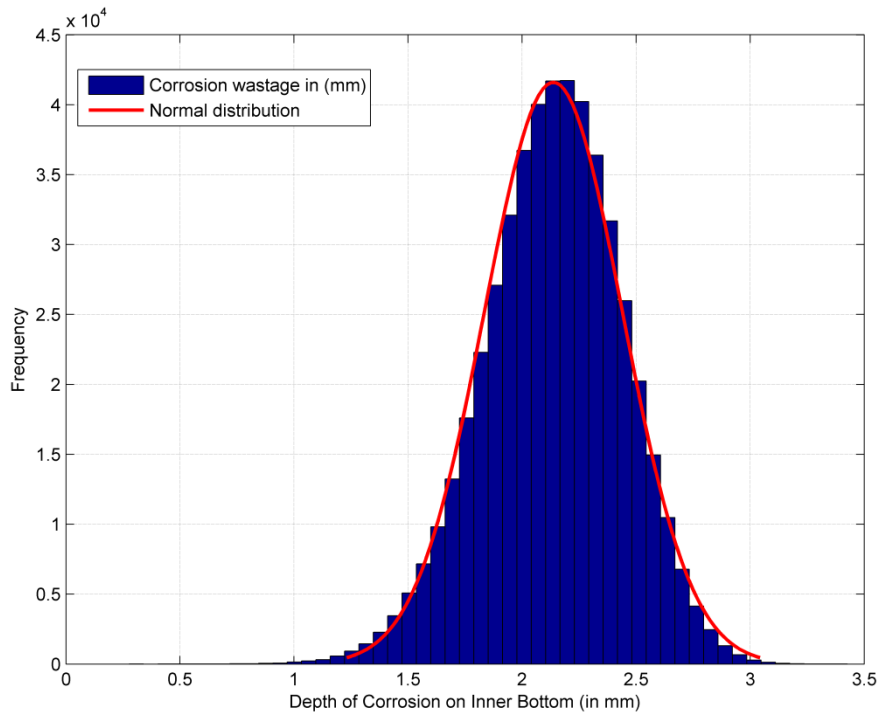


Figure 27: Depth of corrosion (in mm) on inner bottom of cargo hold by Matlab

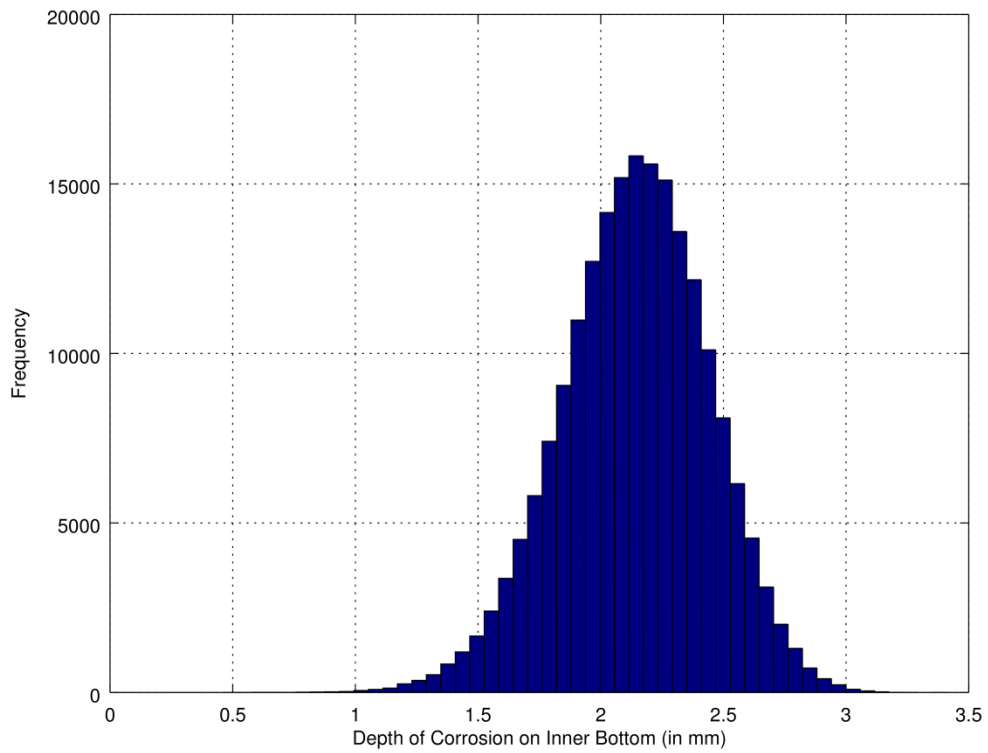


Figure 28: Depth of corrosion (in mm) on inner bottom of cargo hold by Octave

5.2.1.5 Floor

Regarding the corrosion wastage on floor of cargo areas, Matlab and Octave produced Figure 29 and Figure 30, respectively. The mean values are presented in Table 27. A Weibull distribution fits best and its parameters are described in Table 26. Approximately, 20% of cases approach the mean value.

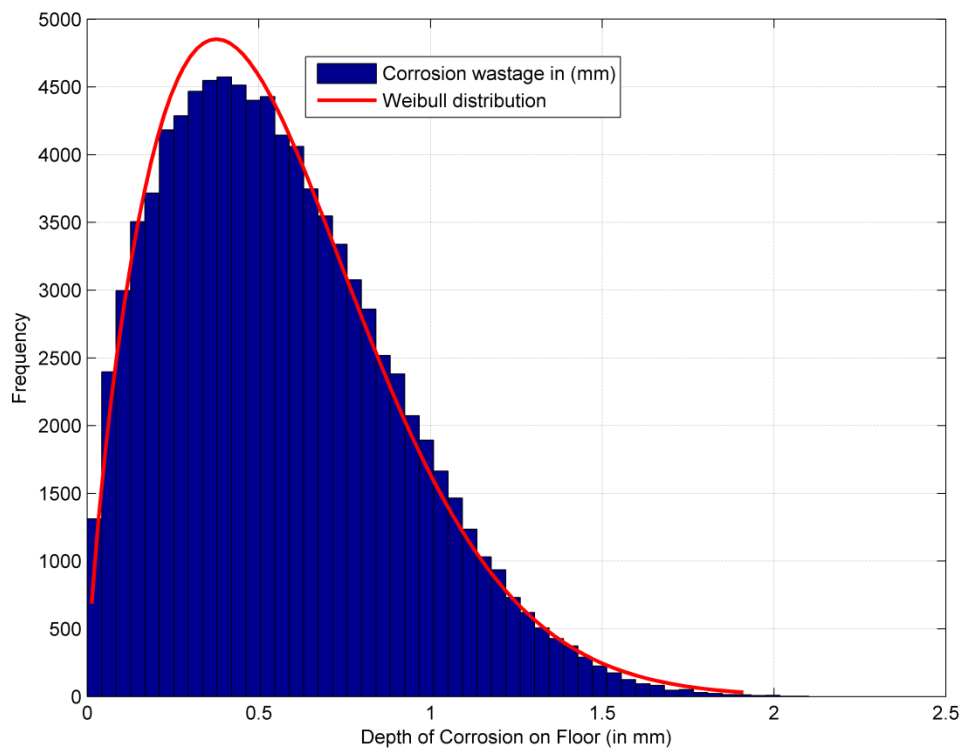


Figure 29: Depth of corrosion (in mm) on floor of cargo hold by Matlab

Table 26: Parameters of best fitted distribution for floor

	Weibull
a	0.6314
b	1.7057

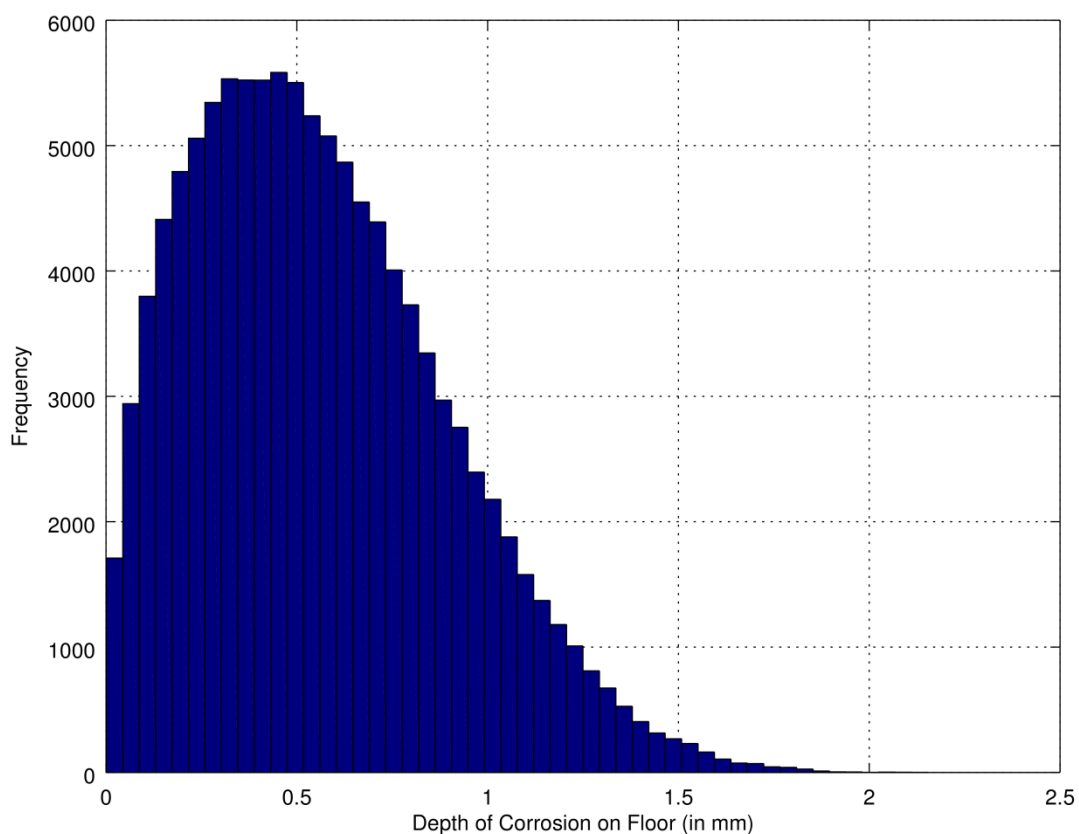


Figure 30: Depth of corrosion (in mm) on floor of cargo hold by Octave

Table 27: Mean values of corrosion wastage on floor by Matlab and Octave

	Mean Value (in mm)
Matlab	0.564
Octave	0.564

5.2.2 General Areas

The general areas include spaces outside the cargo hold, such as the living space, exterior deck, interior deck, and bottom shell.

5.2.2.1 Living space

The living space refers to the structural elements of superstructures. The depth of corrosion is presented in Figure 31 for Matlab and Figure 32 for Octave, while the mean values are shown in Table 28. A Weibull distribution fits best and its parameters are described in Table 29. Approximately, 20% of cases approach the mean value.

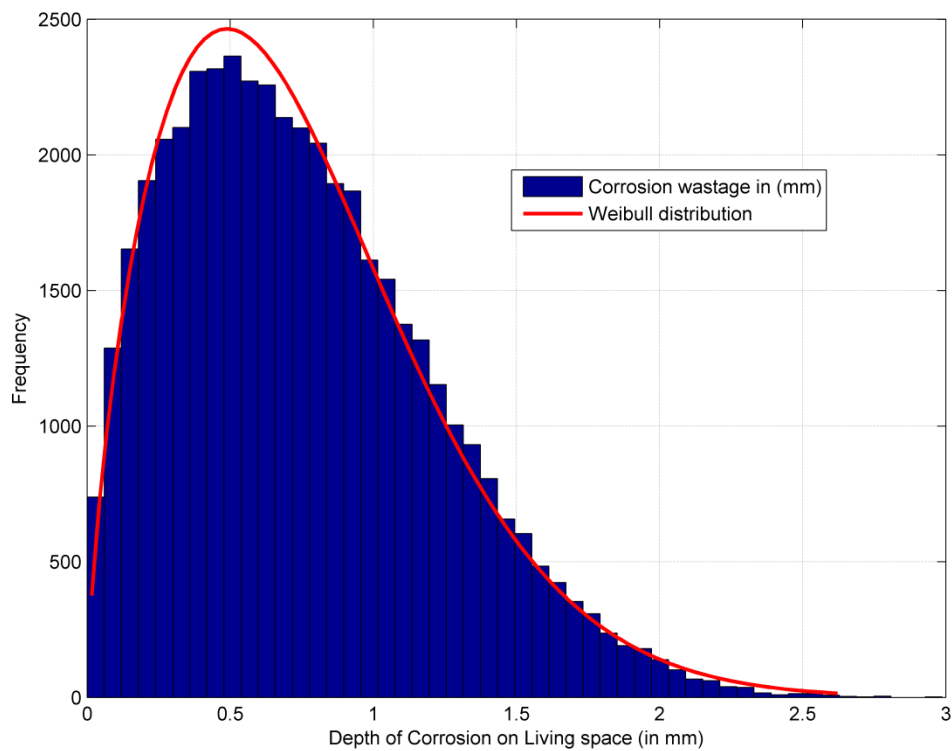


Figure 31: Depth of corrosion (in mm) on living space of general areas by Matlab

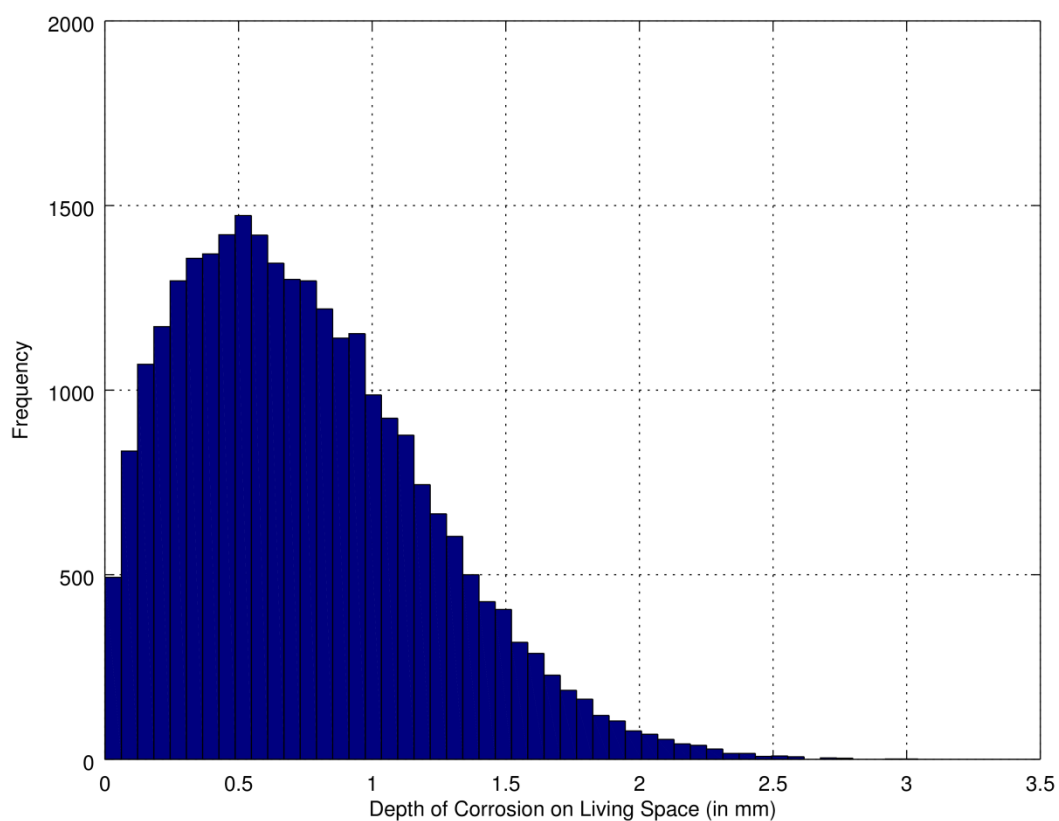


Figure 32: Depth of corrosion (in mm) on floor of general areas by Octave

Table 28: Mean values of corrosion wastage on living space by Matlab and Octave

	Mean Value (in mm)
Matlab	0.757
Octave	0.753

Table 29: Parameters of best fitted distribution for living space

	Weibull
a	0.8451
b	1.6680

5.2.2.2 Exterior deck

The depth of corrosion on exterior deck refers to the external decks of the vessel. The corrosion wastage is shown in Figure 33 and Figure 34 as it has been calculated in Matlab and Octave. The mean values of depth are presented in Table 31. A Weibull distribution fits best and its parameters are described in Table 30. Approximately, 20% of cases approach the mean value.

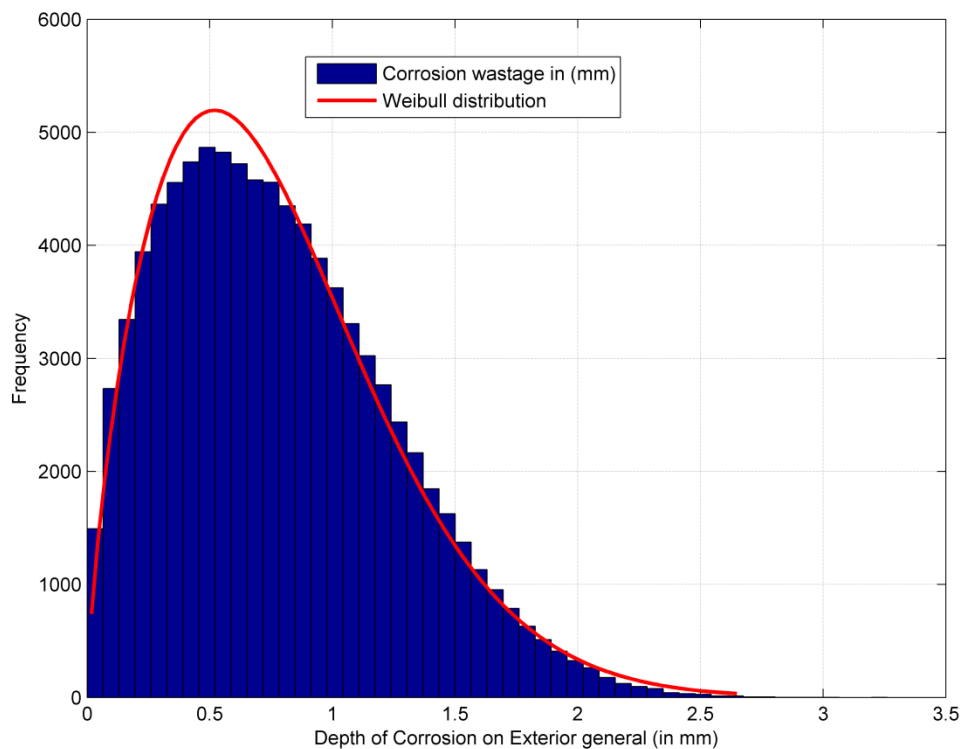


Figure 33: Depth of corrosion (in mm) on exterior deck of general areas by Matlab

Table 30: Parameters of best fitted distribution for exterior deck of general areas

	Weibull
a	0.8735
b	1.7025

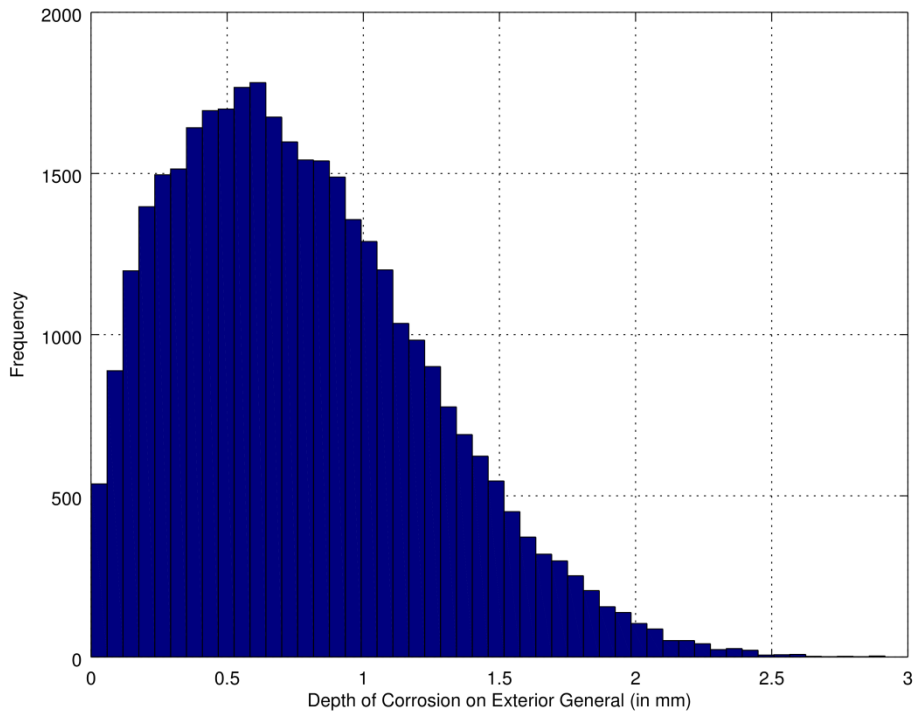


Figure 34: Depth of corrosion (in mm) on exterior deck of general areas by Octave

Table 31: Mean values of corrosion wastage on exterior deck by Matlab and Octave

	Mean Value (in mm)
Matlab	0.781
Octave	0.778

5.2.2.3 Interior Deck

The interior deck of general areas refers to the internal decks of the ship excluding those on cargo spaces. The distribution of the corrosion wastage is presented in Figure 35 and Figure 36, while the mean values in Table 32. A Weibull distribution fits best and its parameters are shown in Table 33. Approximately, 20% of cases approach the mean value.

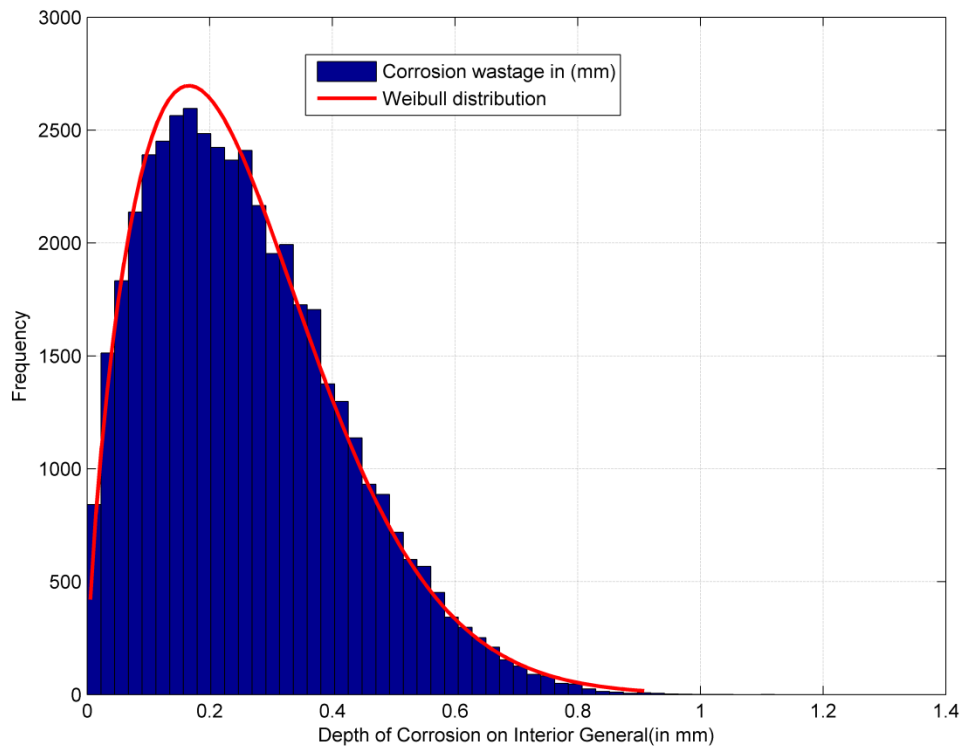


Figure 35: Depth of corrosion (in mm) on interior deck of general areas by Matlab

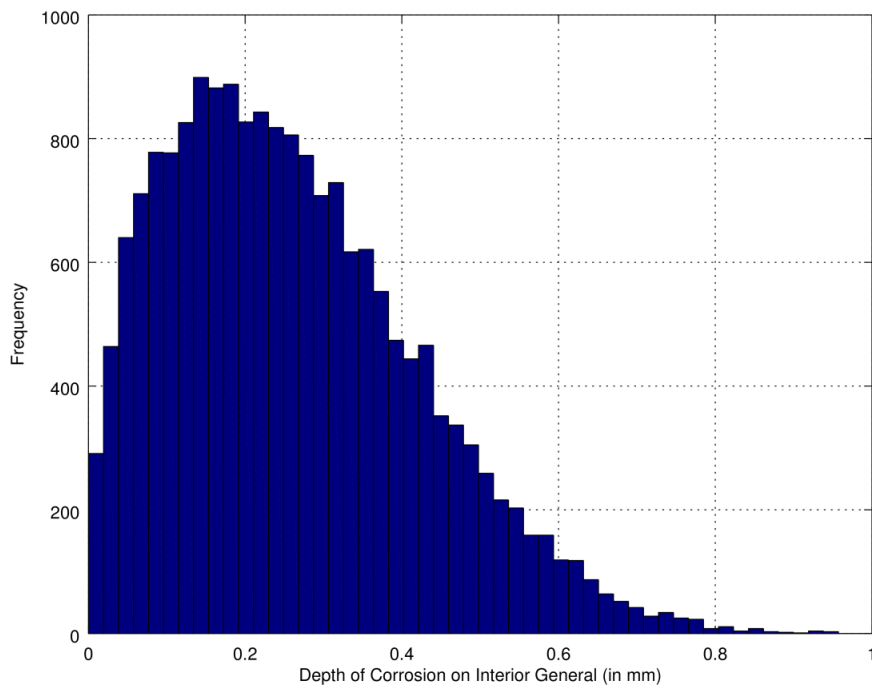


Figure 36: Depth of corrosion (in mm) on interior deck of general areas by Octave

Table 32: Mean values of corrosion wastage on interior deck of general areas by Matlab and Octave

	Mean Value (in mm)
Matlab	0.260
Octave	0.261

Table 33: Parameters of best fitted distribution for interior deck of general areas

	Weibull
a	0.2904
b	1.6562

5.2.2.4 Bottom

Corrosion wastage of bottom shell area is shown in Figure 37 and Figure 38, and the mean values can be seen in Table 34, as they have been calculated in Matlab and Octave. A Weibull distribution fits best and its parameters are described in Table 35. Approximately, 38% of cases approach the mean value.

Table 34: Mean values of corrosion wastage on bottom by Matlab and Octave

	Mean Value (in mm)
Matlab	0.363
Octave	0.365

Table 35: Parameters of best fitted distribution for bottom of general areas

	Weibull
a	0.4065
b	1.7043

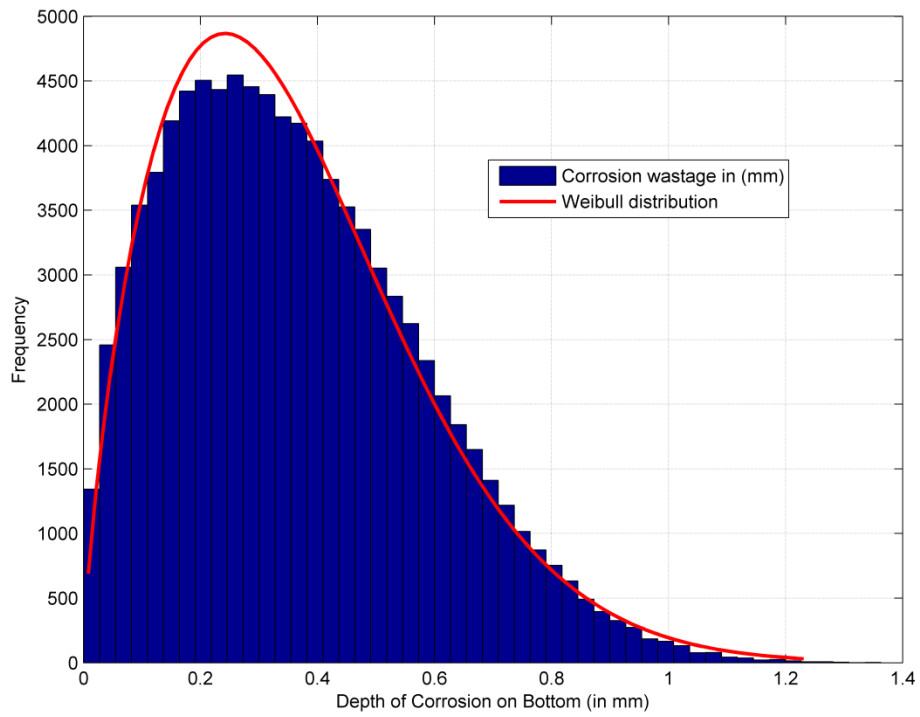


Figure 37: Depth of corrosion (in mm) on bottom of general areas by Matlab

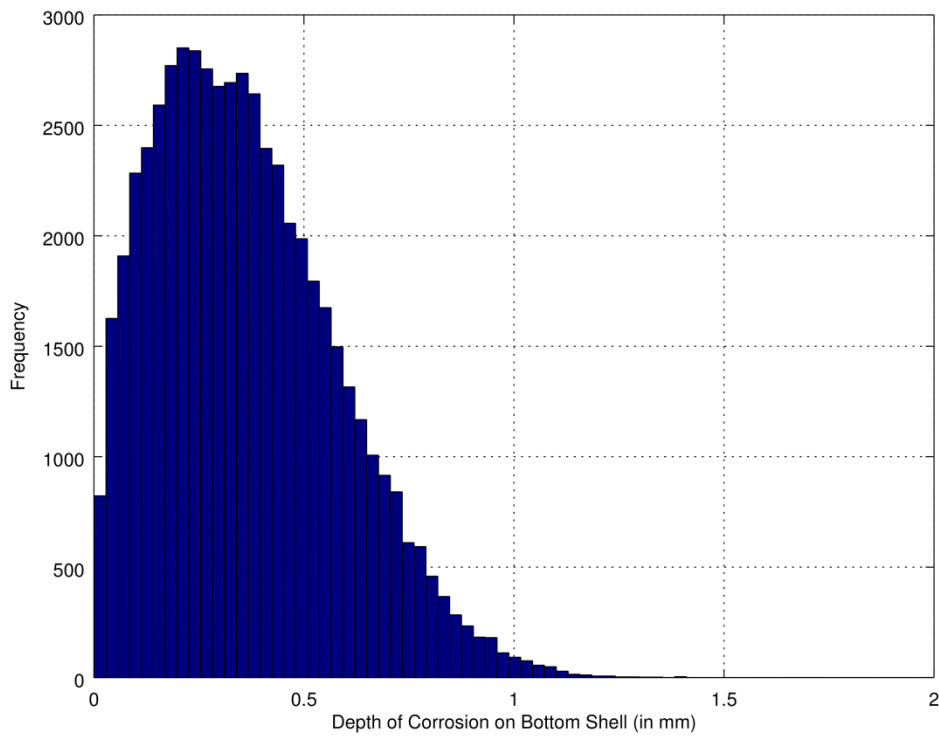


Figure 38: Depth of corrosion (in mm) on bottom of general areas by Octave

5.2.3 Ballast Tanks

The structural areas of inner bottom and bulkhead of ballast tanks have been taken into consideration for the calculation of corrosion wastage.

5.2.3.1 Inner bottom

The estimated distribution of depth of corrosion on the inner bottom of ballast tanks is presented in Figure 39 and Figure 40. The calculated mean values are shown in Table 36, as they have been calculated in Matlab and Octave. A Weibull distribution fits best and its parameters are described in Table 37. Approximately, 20% of cases approach the mean value.

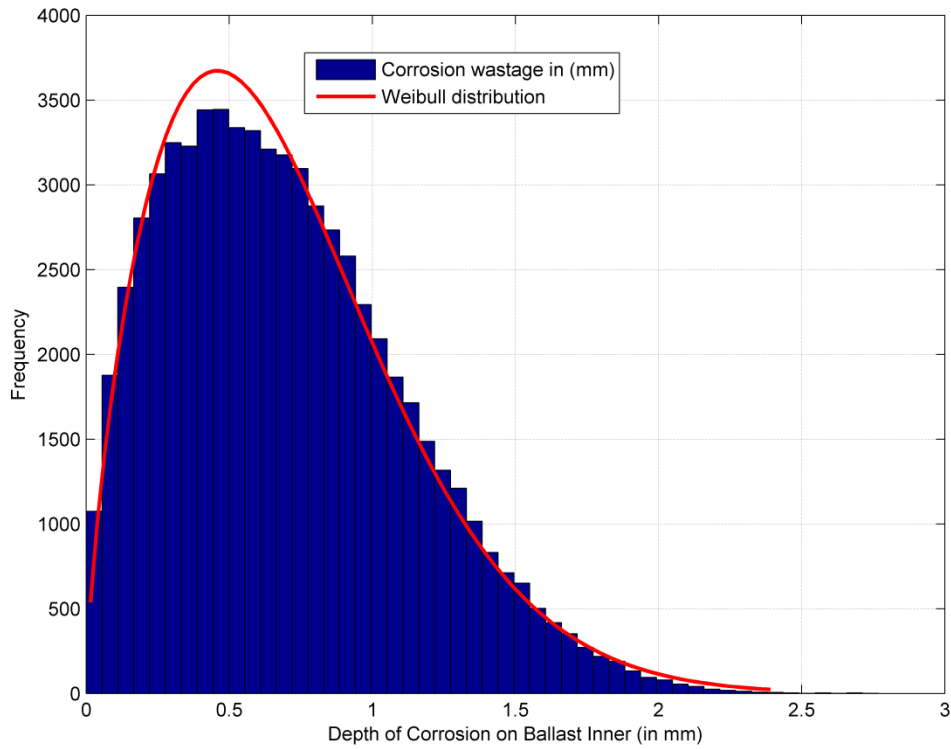


Figure 39: Depth of corrosion (in mm) on inner bottom of ballast tanks by Matlab

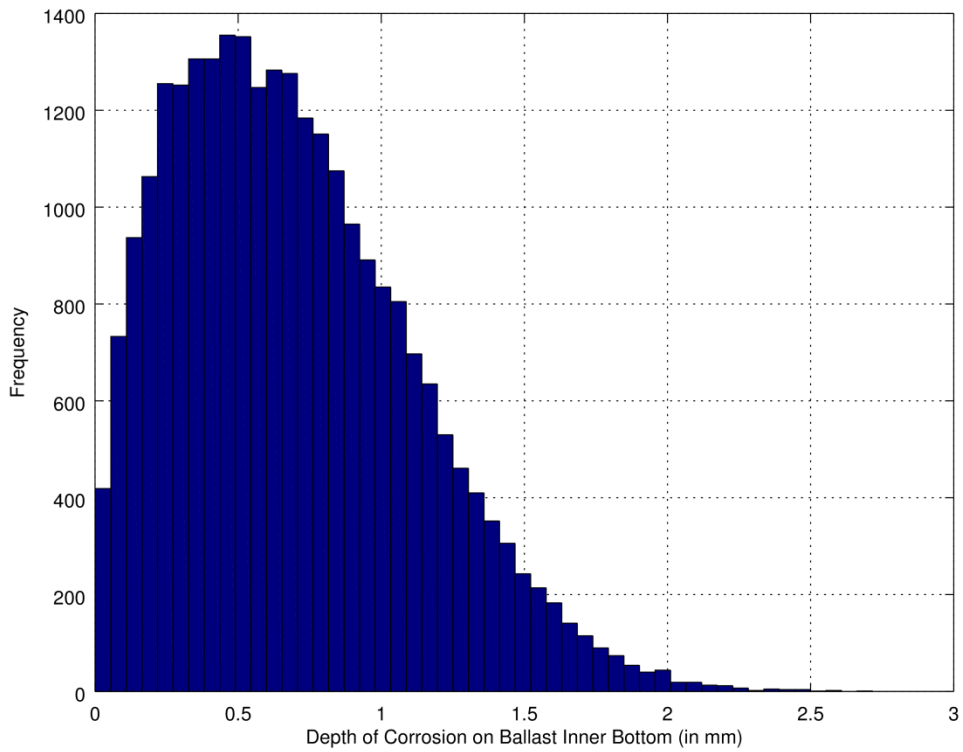


Figure 40: Depth of corrosion (in mm) on inner bottom of ballast tanks by Octave

Table 36: Mean values of corrosion wastage on inner bottom of ballast tanks by Matlab and Octave

	Mean Value (in mm)
Matlab	0.699
Octave	0.694

Table 37: Parameters of best fitted distribution for inner bottom of ballast tanks

	Weibull
a	0.7808
b	1.6875

5.2.3.2 Bulkhead

The corrosion wastage on bulkhead in ballast tank can be seen in Figure 41 and Figure 42 which have been produced from Matlab and Octave, respectively. The relative mean values of depth of corrosion are presented in Table 39. A Weibull distribution fits best and its parameters are described in Table 38. Approximately, 19% of cases approach the mean value.

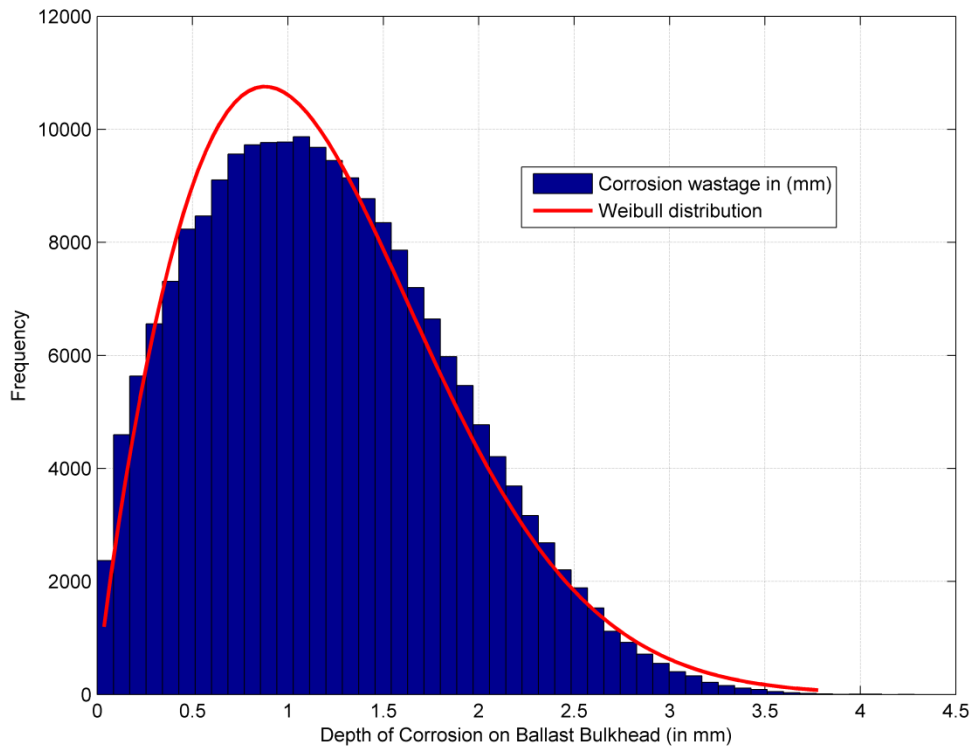


Figure 41: Depth of corrosion (in mm) on bulkhead of ballast tanks by Matlab

Table 38: Parameters of best fitted distribution for bulkhead of ballast tanks

	Weibull
a	1.3501
b	1.8351

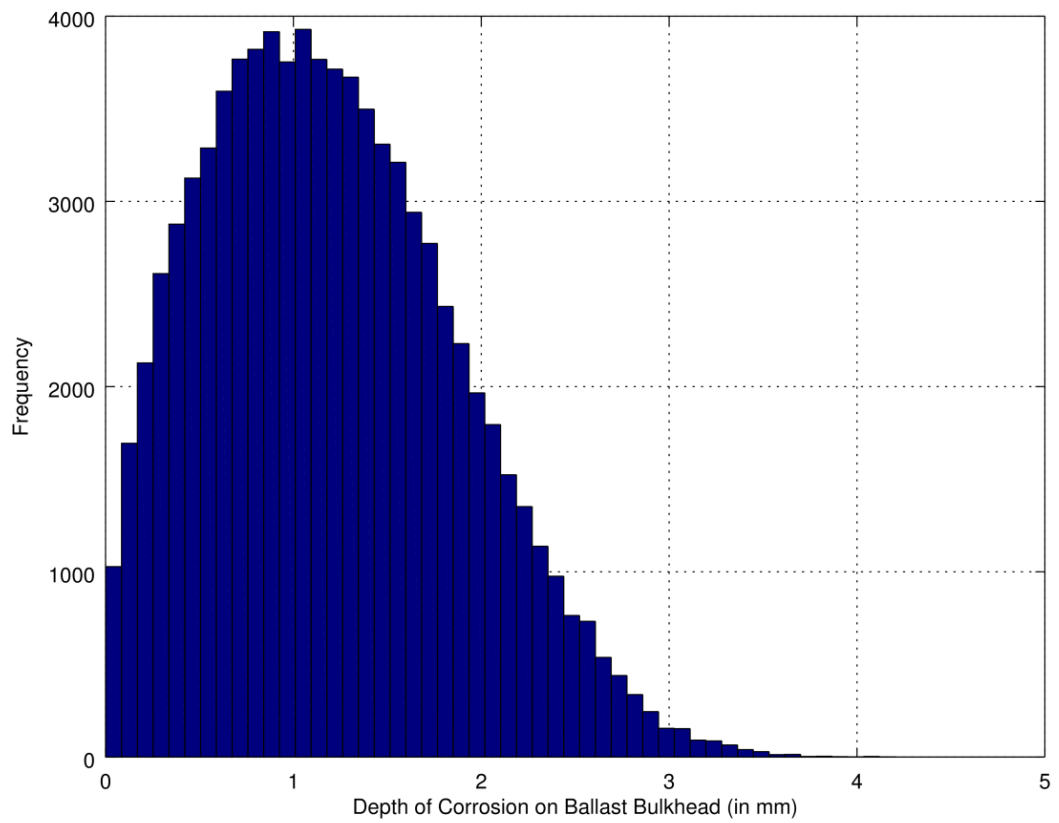


Figure 42: Depth of corrosion (in mm) on bulkhead of ballast tanks by Octave

Table 39: Mean values of corrosion wastage on bulkhead of ballast tanks by Matlab and Octave

	Mean Value (in mm)
Matlab	1.203
Octave	1.205

5.2.4 Comparison between different structural areas

With regards to cargo hold's areas, it can be noted that when the mean theoretical coating life is reduced, then the depth of corrosion increases. On the inner bottom where the coating life is supposed to be only 3 years, the estimated wastage is 2.137 mm which is the largest depth of corrosion between the elements of cargo space. This result can be considered logical because the goods, and the materials, which are carried and which can be corrosive, corrode the whole area of inner bottom. The next larger depth of corrosion is observed in bulkheads which are also in directly contact with the transferred cargo. Concerning the codes of Matlab and Octave, their results are significantly similar. However, it shall be noted that the run time of Matlab is almost 3 to 4 times shorter than the equivalent of Octave.

Table 40: Estimated corrosion wastage and theoretical coating life

		Mean of estimated corrosion wastage(mm)	Mean of theoretical coating life (years)
Cargo Hold	Interior deck	0.482	10
	Side shell	0.657	10
	Bulkhead	1.363	7
	Inner bottom	2.137	3
	Floor	0.565	10
General Areas	Living space	0.756	10
	Exterior deck	0.780	9
	Interior deck	0.262	10
	Bottom shell	0.366	10
Ballast Tanks	Inner bottom	0.699	11
	Bulkhead	1.200	8

5.3 Relative ships carrying different cargo type

This case study is based on the comparison of two ships characterized by almost same parameters excluding the cargo type. Therefore, the bulker of the first case study has been compared to a tanker of equal parameters. Table 41 and

Table 42 presents in detail the parameters of the two examined vessels, as well as the relative factors of coating lifetime and corrosion rate. The major diversities are observed in the abrasivity, the temperature, and the handling of cargo which resulted due to the different cargo types.

Table 41: Parameters and factors of bulk carrier (case 2)

	Parameters	Factor for coating lifetime	Factor for corrosion rate
Ship type	Bulk Carrier		
Year built	2011		
Flag	Marshall Islands	1.1	1
Country of yard	China	0.67	1
Class	IACS	1.1	1
No of owner changes	None	1.2	1
Time at sea (in days)	9.36 (long)	1.2	1
Time at port (in days)	3.03 (long)	1.1	1
Corrosivity of cargo	Regularly	1	1.5
Abrasivity of cargo	Regularly	0.9	1
Temperature of cargo	Low	1	1
Operation in tropics/subtropics	Mostly	0.9	1.11
Time with ballast (Ballast ratio)	High	1	1.1
Building class	Non IACS	0.9	1
Abrasive cargo handling	Regularly	0.9	1
Frequency of cargo	Often	0.9	1
Detentions	None	1	1
Deficiencies	None	1	1
Time to next docking survey	Overdue	0.9	1

Table 42: Parameters and factors of tanker (case 2)

	Parameters	Factor for coating lifetime	Factor for corrosion rate
Ship type	Tanker		
Year built	2011		
Flag	Marshall Islands	1.1	1
Country of yard	China	0.67	1
Class	IACS	1.1	1
No of owner changes	0	1.2	1
Time at sea (in days)	Long (>=3)	1.2	1
Time at port (in days)	Long (>=1)	1.1	1
Corrosivity of cargo	Regularly	1	1.5
Abrasivity of cargo	Never	1	1
Temperature of cargo	High	1	1.5
Operation in tropics/subtropics	Mostly	0.9	1.11
Time with ballast (Ballast ratio)	High	1	1.1
Building class	Non IACS	0.9	1
Abrasive cargo handling	Never	1	1
Frequency of cargo	Often	0.9	1
Detentions	None	1	1
Deficiencies	None	1	1
Time to next docking survey	Overdue	0.9	1

5.3.1 Cargo holds

5.3.1.1 Interior deck

The distribution of corrosion wastage of the bulk carrier and the tanker is presented in Figure 43. The mean values of depth of corrosion of these ships are shown in Table 43. The theoretical coating life on this area for a tanker is 9, whereas for a bulker is 10. Therefore, the corrosion wastage of the tanker is larger than the

bulker's. Approximately, with regards to bulk carrier, 20% of cases approach the mean value, while the equivalent proportion of tanker's is 19%.

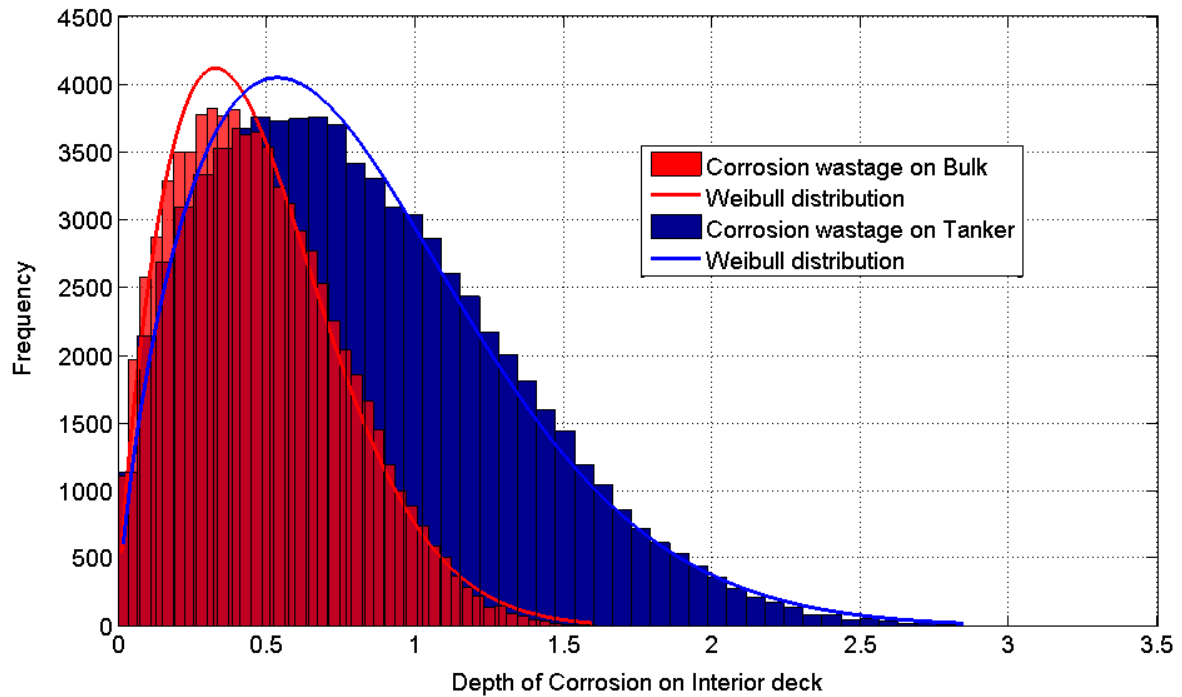


Figure 43: Depth of wastage (in mm) on interior deck for two different ship types

Table 43: Mean values of corrosion wastage on interior deck for two different ship types

	Mean Value (in mm)
Bulk carrier	0.480
Tanker	0.825

5.3.1.2 Side shell

The distribution of depth of corrosion for a bulk carrier and a tanker is different, as it can be seen in Figure 44. The theoretical coating life of the two ship types is 10 years but the estimated mean values diverge as the Table 44 shows. Probably, the higher cargo temperature of tanker which increases the corrosion rate causes larger corrosion wastage than the estimated depth of corrosion of bulker. Approximately, with regards to bulk carrier, the 19% of cases approaches the mean value, while the equivalent proportion of tanker's is 20%.

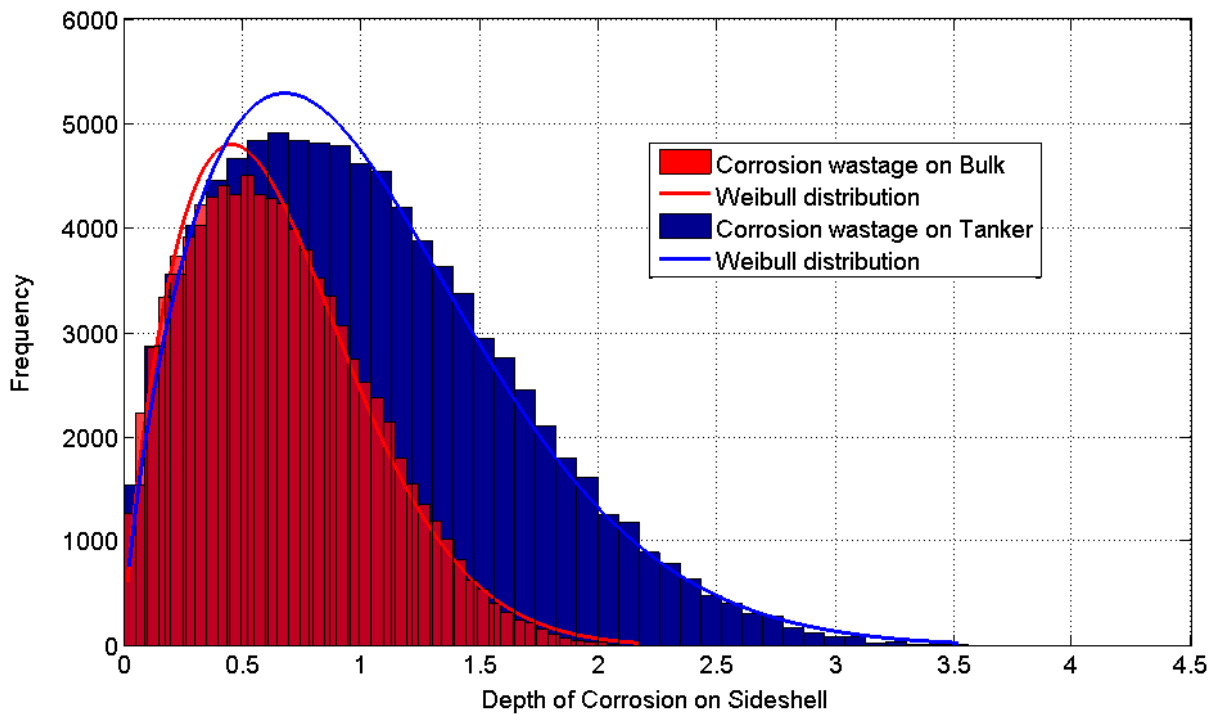


Figure 44 Depth of wastage (in mm) on side shell for two different ship types

Table 44: Mean values of corrosion wastage on side shell for two different ship types

	Mean Value (in mm)
Bulk carrier	0.659
Tanker	1.031

5.3.1.3 Bulkhead

The estimated distribution of depth of corrosion can be seen in Figure 45. As Table 45 shows, the mean value of corrosion wastage in bulker is larger than the tanker's. This result can be characterized as logical because the theoretical coating life of tanker is 9 years, while the relative number of bulk carrier is 7. Approximately, with regards to bulk carrier, 20% of cases approach the mean value, while the equivalent proportion of tanker's is 18%.

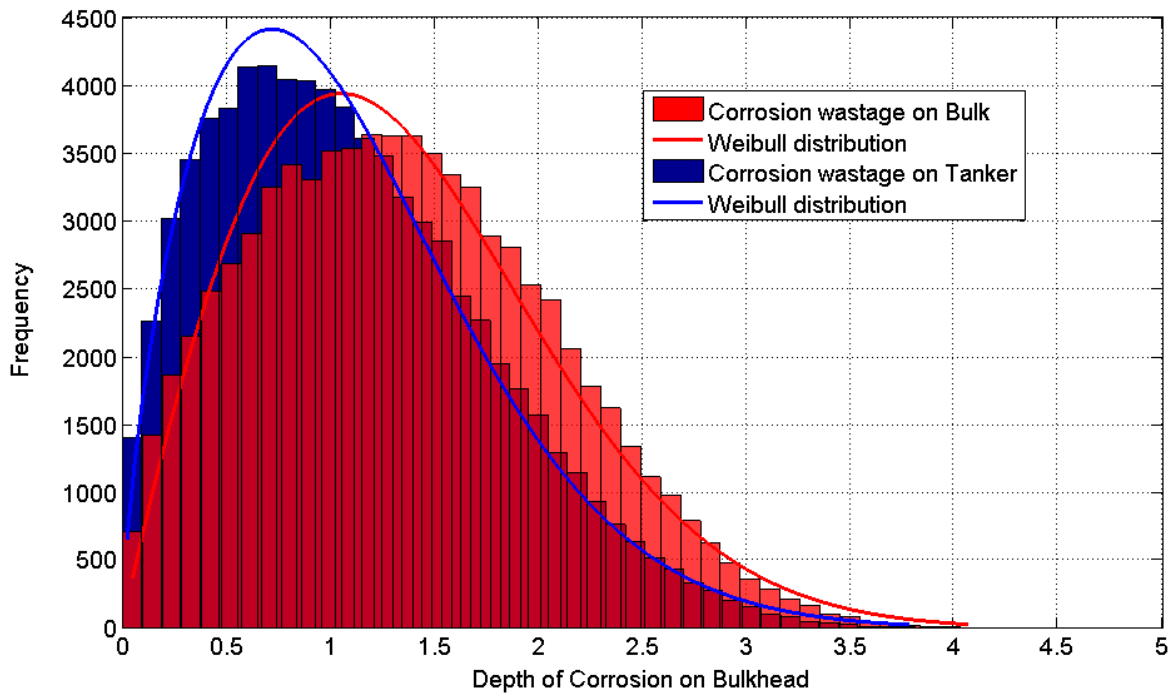


Figure 45: Depth of wastage (in mm) on bulkhead for two different ship types

Table 45: Mean values of corrosion wastage on bulkhead for two different ship types

	Mean Value (in mm)
Bulk carrier	1.365
Tanker	1.099

5.3.1.4 Inner bottom

Concerning the inner bottom of cargo space, Figure 46 show that the estimate corrosion wastage differs according to the ship type. The mean values in Table 46 are justified by the difference between the theoretical values of the coating life. The assessed coating life for a bulk carrier is 3 years, whereas for a tanker is 7. The explanation might be that the cargo of a tanker most of times is extremely hazardous; therefore the coating on inner bottom in tankers should be more durable than the coating of a bulk carrier. Approximately, with regards to bulk carrier, 38% of cases approach the mean value, while the equivalent proportion of tanker's is 21%.

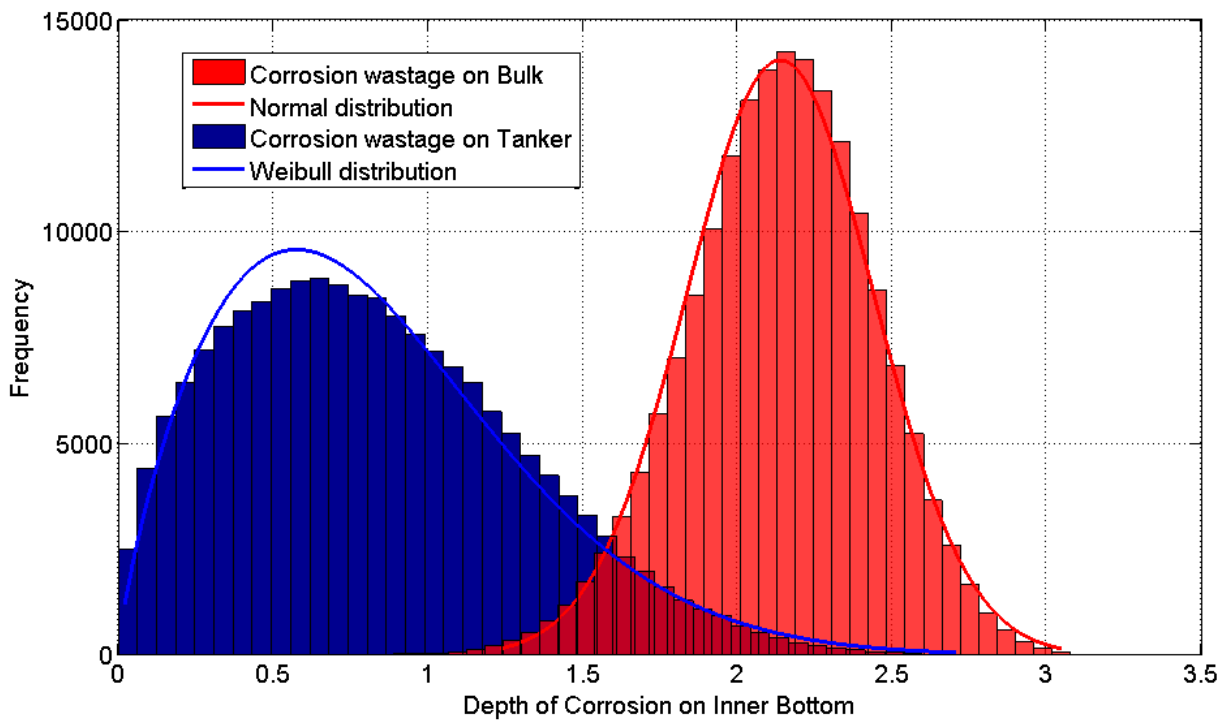


Figure 46: Depth of wastage (in mm) on inner bottom for two different ship types

Table 46: Mean values of corrosion wastage on inner bottom for two different ship types

	Mean Value (in mm)
Bulk carrier	2.137
Tanker	0.827

5.3.1.5 Floor

The estimated distribution of depth of corrosion on floor for two different ship types can be shown in Figure 47. Table 47 demonstrates that the calculated mean values of the two different ship types correspond to the theoretical coating life. Approximately, with regards to bulk carrier, 19% of cases approach the mean value, while the equivalent proportion of tanker's is 22%.

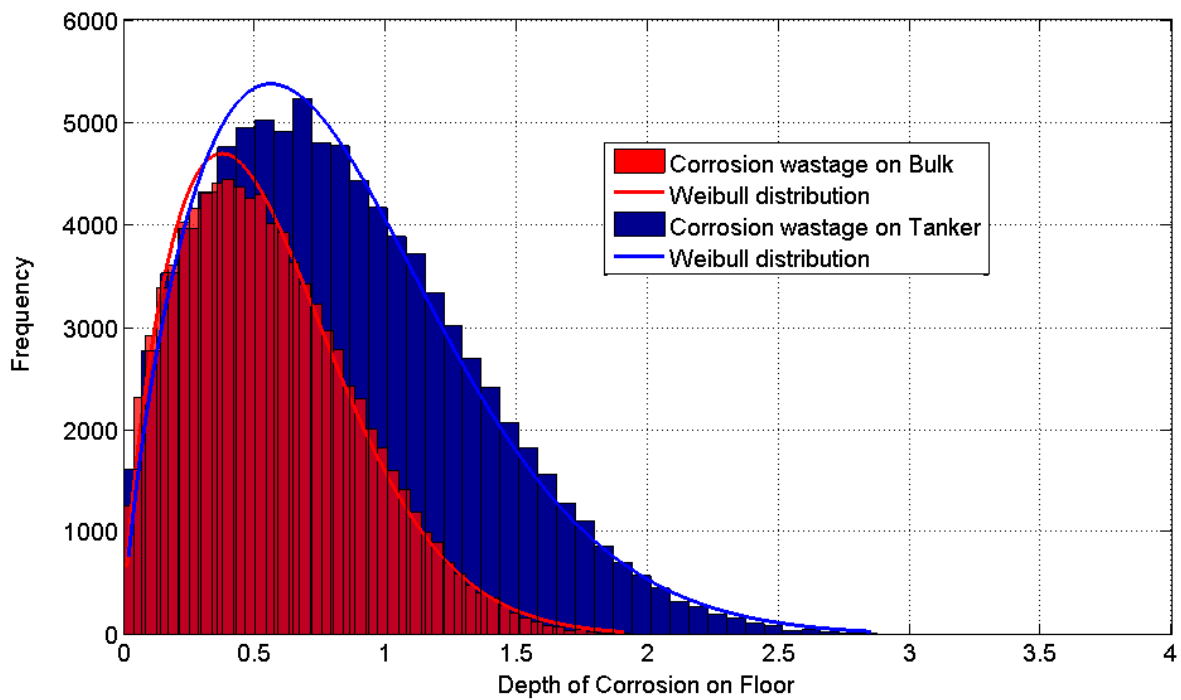


Figure 47: Depth of wastage (in mm) on floor for two different ship types

Table 47: Mean values of corrosion wastage on floor for two different ship types

	Mean Value (in mm)
Bulk carrier	0.564
Tanker	0.848

5.3.2 Comparison between different ship types

The estimated mean values of depth of corrosion between two different ship types differ on each structural area of the cargo hold, as Table 48 shows. These results are influenced by the type of cargo and its parameters. The cargo temperature may lead to dissimilar distribution forms of corrosion wastage. It can be seen that the corrosion wastages are directly connected to the theoretical coating lifetime. When the coating life of a structural area is short, the protected metal surface corrodes sooner than an element whose coating life is larger. As a result, in bulkers, inner bottom and bulkhead, whose coatings have the shortest life, presents a larger depth of corrosion in contrast with the relative structural areas of tanker.

Table 48: Estimated corrosion wastage and theoretical coating life in two different ship types

		Mean of estimated corrosion wastage(mm)		Mean of theoretical coating life (years)	
		Bulk Carrier	Tanker	Bulk Carrier	Tanker
Cargo Hold	Interior deck	0.482	0.823	10	9
	Side shell	0.657	1.037	10	10
	Bulkhead	1.363	1.097	7	9
	Inner bottom	2.137	0.829	3	7
	Floor	0.565	0.844	10	8

5.4 Comparing ships of different type and age

This case study has been developed in accord with the study of paragraph above. However, this study is characterized by the change of tanker's age which is 10 years instead of five. The aim of this study is to observe the evolvement of corrosion wastage in the tanker during a period of five years and make a comparison between that ship and a younger bulk carrier. The examination of depth of corrosion has been focused on the cargo areas in order to observe when the depth of corrosion on inner bottom and bulkhead into the cargo holds will be equal between the tanker and the bulk carrier; because these structural areas are the most significant into a cargo hold, considering the fact that they are in contact directly with the cargoes. The parameters and the factors of the two vessels are presented in Table 49 and Table 50.

Table 49: Parameters and factors of bulk carrier (case 3)

	Parameters	Factor for coating lifetime	Factor for corrosion rate
Ship type	Bulk Carrier		
Year built	2011		
Flag	Marshall Islands	1.1	1
Country of yard	China	0.67	1
Class	IACS	1.1	1
No of owner changes	None	1.2	1
Time at sea (in days)	9.36 (long)	1.2	1
Time at port (in days)	3.03 (long)	1.1	1
Corrosivity of cargo	Regularly	1	1.5
Abrasivity of cargo	Regularly	0.9	1
Temperature of cargo	Low	1	1
Operation in tropics/subtropics	Mostly	0.9	1.11
Time with ballast (Ballast ratio)	High	1	1.1
Building class	Non IACS	0.9	1
Abrasive cargo handling	Regularly	0.9	1
Frequency of cargo	Often	0.9	1
Detentions	None	1	1
Deficiencies	None	1	1
Time to next docking survey	Overdue	0.9	1

Table 50: Parameters and factors of tanker (case 3)

	Parameters	Factor for coating lifetime	Factor for corrosion rate
Ship type	Tanker		
Year built	2006		
Flag	Marshall Islands	1.1	1
Country of yard	China	0.67	1
Class	IACS	1.1	1
No of owner changes	0	1.2	1
Time at sea (in days)	Long (>=3)	1.2	1
Time at port (in days)	Long (>=1)	1.1	1
Corrosivity of cargo	Regularly	1	1.5
Abrasivity of cargo	Never	1	1
Temperature of cargo	High	1	1.5
Operation in tropics/subtropics	Mostly	0.9	1.11
Time with ballast (Ballast ratio)	High	1	1.1
Building class	Non IACS	0.9	1
Abrasive cargo handling	Never	1	1
Frequency of cargo	Often	0.9	1
Detentions	None	1	1
Deficiencies	None	1	1
Time to next docking survey	Overdue	0.9	1

5.4.1 Cargo holds

5.4.1.1 Interior deck

With regards to corrosion wastage of interior deck, it can be seen that it has been increased in a period of five years. The life of coating on interior deck for tankers is 9 years, consequently, probably the coating has been destroyed and the corrosion degrades the metal surface directly. The correlation of corrosion wastage is shown of Figure 48. Table 51 presents the mean values of corrosion depth of each ship. Approximately, with regards to bulk carrier, 20% of cases approach the mean value, while the equivalent proportion of tanker's is 19%.

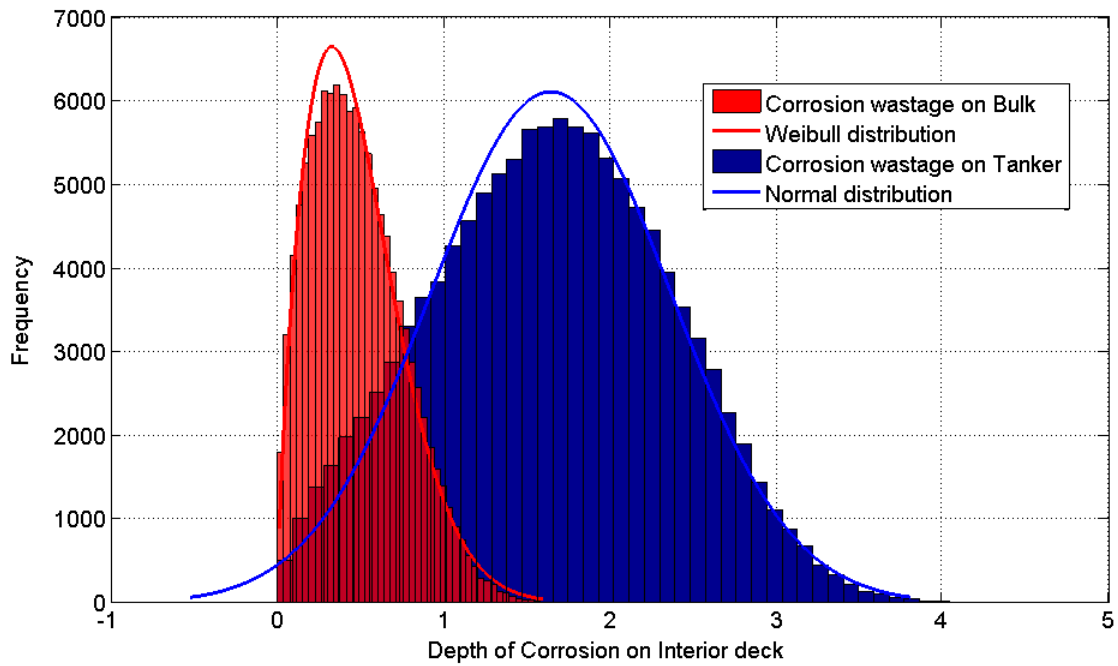


Figure 48: Depth of wastage (in mm) on interior deck for two ships of different age and type

Table 51: Mean values of corrosion wastage on interior deck for two ships of different age and type

	Mean Value (in mm)
Bulk carrier	0.480
Tanker	1.645

5.4.1.2 Side shell

The correlation of depths of corrosion between the defined bulk carrier and the 5 years older tanker is presented in Figure 49. Table 52 shows the mean values of the calculated distributions. It should be noted that although the theoretical coating life of both ships is 10 years, the corrosion wastage on the tanker's side shell is estimated to be threefold than the relative of the bulker's.

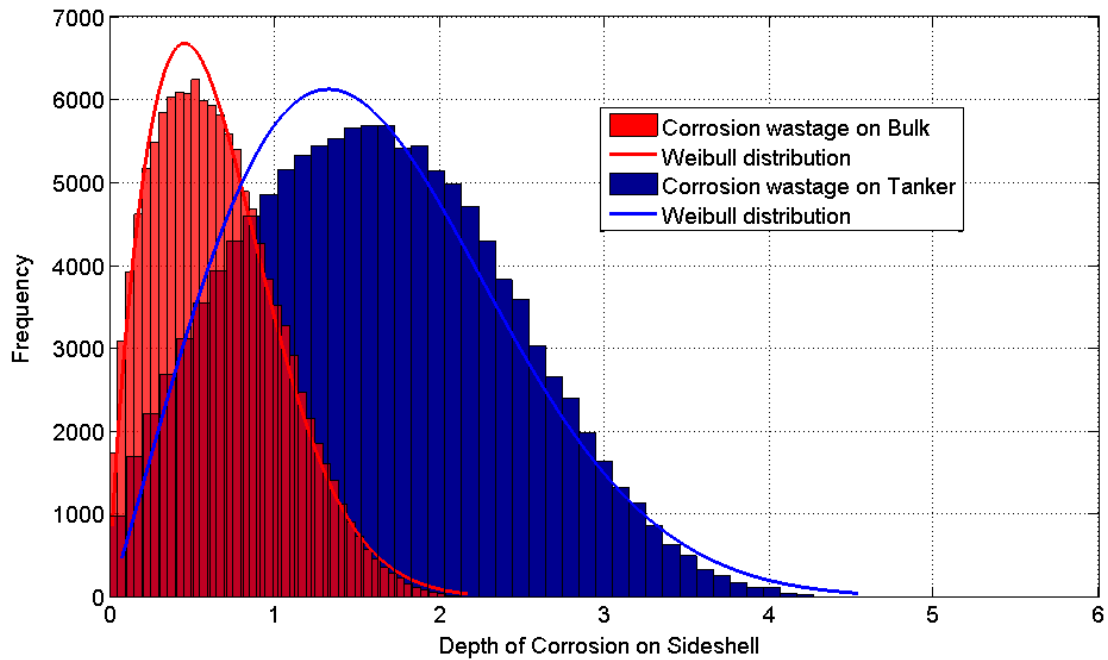


Figure 49: Depth of wastage (in mm) on side shell for two ships of different age and type

Table 52: Mean values of corrosion wastage on side sell for two ships of different age and type

	Mean Value (in mm)
Bulk carrier	0.659
Tanker	1.622

5.4.1.3 Bulkhead

Concerning the structural area of the bulkhead, the comparing Figure 50 shows the correlation of the depth of corrosion between the two ships. The theoretical coating lifetime for the bulk carrier is 7 years, while for the tanker is 9 years; which means that the metallic surface of the bulkhead in tanker is unprotected during the 10th year. Table 53 shows that the corrosion wastage of the tanker is larger; which is an expected result. Approximately, with regards to bulk carrier, 22% of cases approach the mean value, while the equivalent proportion of tanker's is 21%.

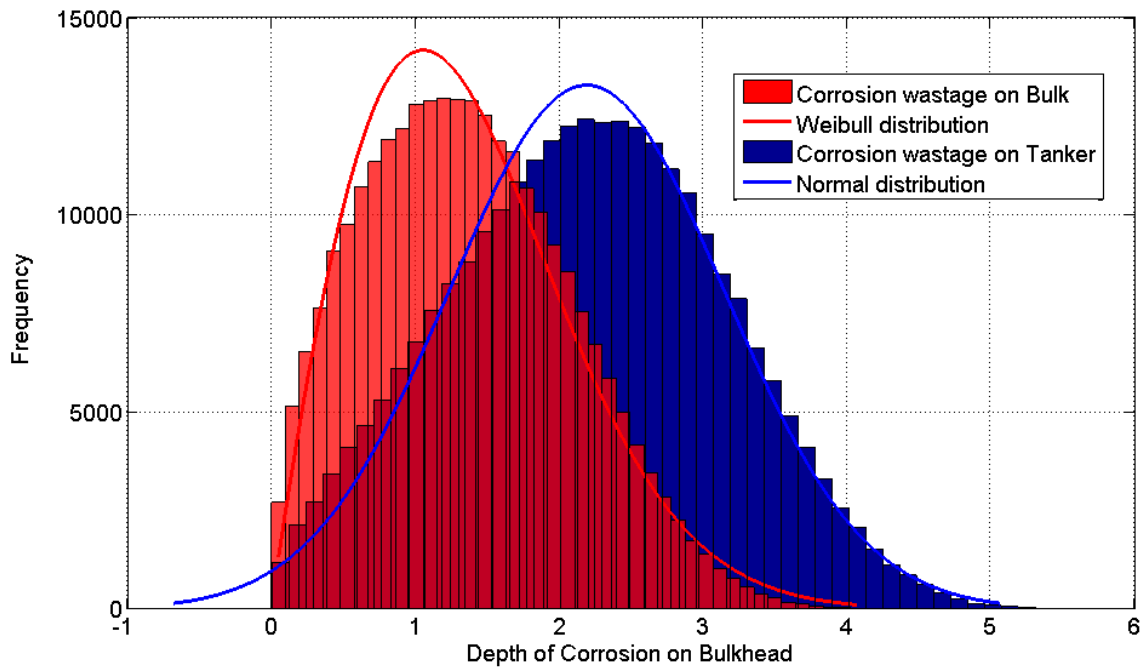


Figure 50: Depth of wastage (in mm) on bulkhead for two ships of different age and type

Table 53: Mean values of corrosion wastage on bulkhead for two ships of different age and type

	Mean Value (in mm)
Bulk carrier	1.365
Tanker	2.190

At this point, it is worth to mention that the depth of corrosion on the structural element of bulkhead in cargo hold, for the bulk carrier and the tanker, will be approximately equal if the tanker was 7 years old as Figure 51 and Table 54 demonstrate. The coating life of bulk carrier's bulkhead is estimated to 7 years, whereas for the tanker to 9 years. In view of the fact that the bulk carrier is 5 years old and the tanker 7, it might be considered that both bulkheads have similar behavior against corrosion. Approximately, with regards to bulk carrier, 18% of cases approach the mean value, while the equivalent proportion of tanker's is 19%.

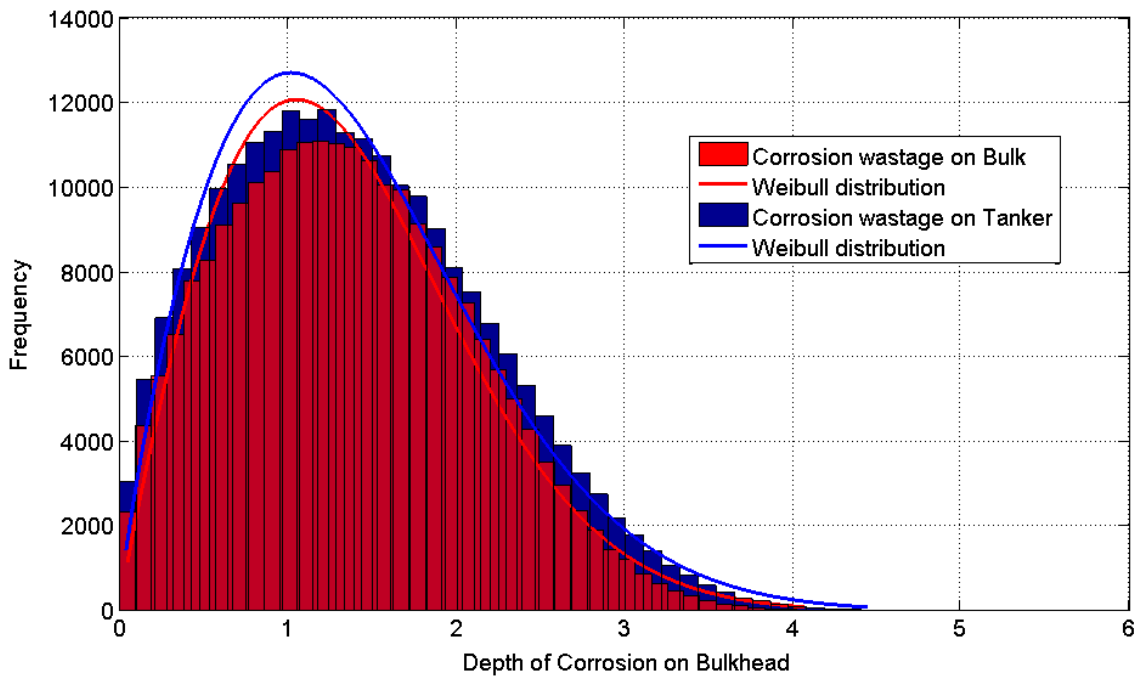


Figure 51: Depth of wastage (in mm) on bulkhead for two ships of different age (2 years) and type

Table 54: Mean values of corrosion wastage on bulkhead for two ships of different age (2 years) and type

	Mean Value (in mm)
Bulk carrier	1.363
Tanker	1.408

5.4.1.4 Inner bottom

Inner bottom composes the most interesting structural area of the cargo hold. Figure 52 and Table 55: Mean values of corrosion wastage on inner bottom for two ships of different age and type present the estimated distribution of corrosion wastage on the inner bottom of the 5 years old bulk carrier and the 10 years old tanker. It is shown that the calculated mean values are equal, approximately. The theoretical coating life of bulk carrier is 3 years which means that for 2 years the metallic surface is unprotected, while the inner bottom of the tanker is not protected during a period of 3 years because the coating life is assessed to 7 years. However, the estimated mean

value of depth of corrosion is almost equal; despite the fact that the cargo of tanker is considered more corrosive and hazardous than this of bulker's. A reasonable explanation might be that the coating on tanker is more durable, due to the stricter legislations for that ship types. As a result, as long as the coating protects the surface of inner bottom, the latter is not attacked as much the equivalent of bulker's. Approximately, with regards to bulk carrier, 33% of cases approach the mean value, while the equivalent proportion of tanker's is 23%.

Table 55: Mean values of corrosion wastage on inner bottom for two ships of different age and type

	Mean Value (in mm)
Bulk carrier	2.137
Tanker	2.083

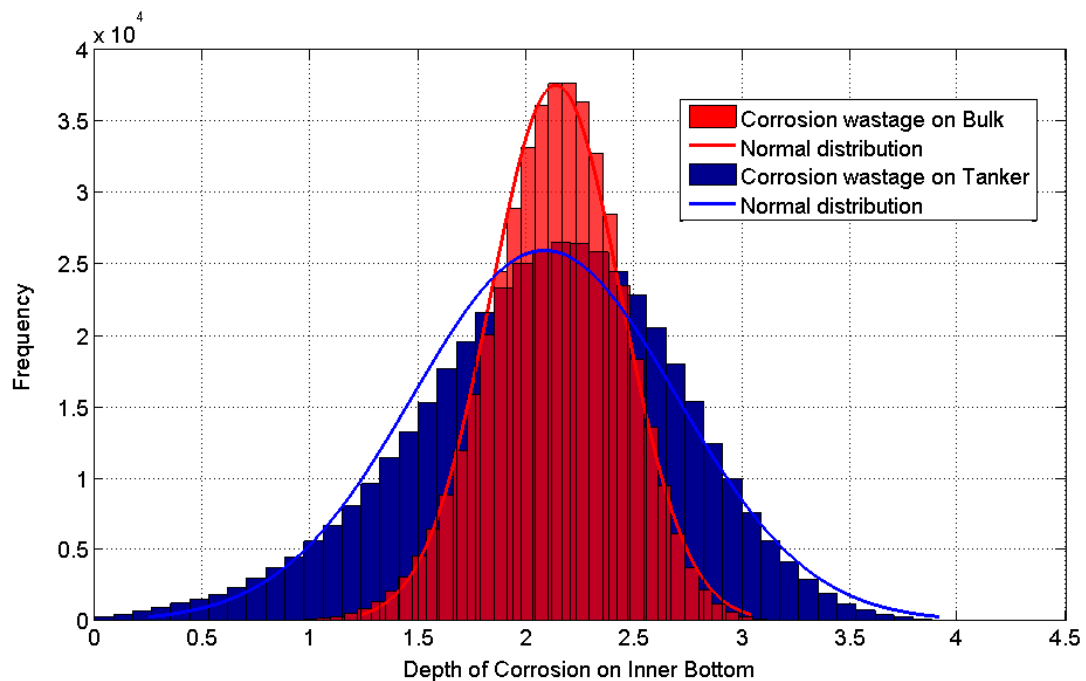


Figure 52: Depth of wastage (in mm) on inner bottom for two ships of different age and type

5.4.1.5 Floor

The estimated mean values and distribution are presented in Table 56 and in Figure 53. The theoretical coating life of floor for the tanker is assessed at 8 years, and as a result the metallic surface is unprotected for 2 years. Approximately, with regards to bulk carrier, 19% of cases approach the mean value, while the equivalent proportion of tanker's is 18%.

Table 56: Mean values of corrosion wastage on floor for two ships of different age and type

	Mean Value (in mm)
Bulk carrier	0.564
Tanker	1.895

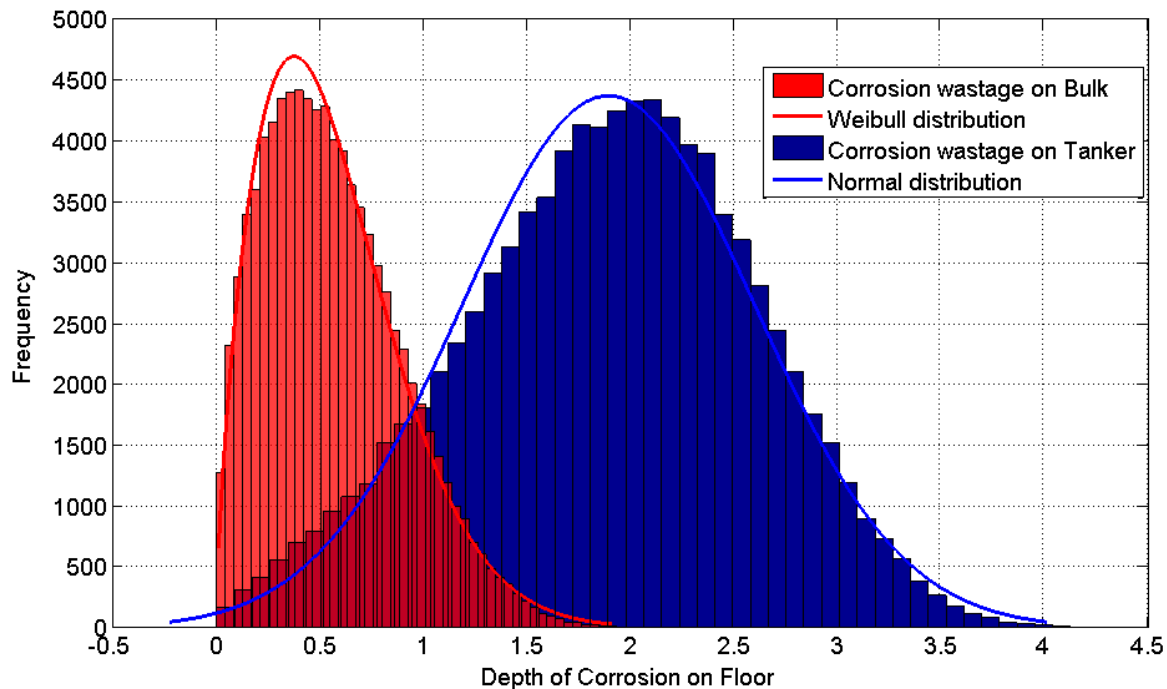


Figure 53 Depth of wastage (in mm) on floor for two ships of different age and type

5.4.2 Comparison between ships of different age and type

Usually, the protecting system of coating functions as a shield for the metallic surface by reducing the corrosion rate. However, it is extremely difficult to prevent completely the degradation of the metal, even if it has not been destroyed.

Table 57 presents the total results of the estimated corrosion wastage on cargo holds, as they have been mentioned above. Concerning the structural elements of cargo hold which are not in contact directly with the carrying cargo (interior deck, side shell, floor), it seems that they are degraded faster in a tanker than in a bulk carrier. Specifically, for two different ship types of approximately same age, the depth of corrosion on the interior deck is estimated twofold than the equivalent of bulk carrier; on the side shell it is calculated 1.037 mm in a tanker, while in a bulk carrier is about 0.657 mm; and on floor is assessed 0.844 m and 0.565 mm, in a tanker and in a bulk carrier, respectively. With regards to the locations which are in contact directly with the carrying cargo (bulkhead and inner bottom), the estimated corrosion wastage is shorter in bulk carrier than the corresponding of tanker. As regards the bulkhead, the results which refer to the ships of the same age establish the assessment of expert about the theoretical coating life. They considered that the theoretical coating life is approximately 7 years for a bulk carrier and 9 for a tanker. Therefore, the degradation of bulkhead in tanker is shorter because the coating is on the half of its life, comparing with the relative in bulk carrier which has 2 more years of living. As regard the inner bottom, it is estimated that a 10 years old tanker with same characteristics as those of the 5 years old bulk carrier, records comparable depth of corrosion; which can be considered logical because the coating life of tanker is larger than the relative of bulk carriers’.

Table 57: Estimated depth of corrosion (in mm)

Locations	Bulk Carrier (5 years old)	Tanker (5 years old)	Tanker (10 years old)
Interior deck	0.482	0.823	1.643
Side shell	0.657	1.037	1.617
Bulkhead	1.363	1.097	2.186
Inner bottom	2.137	0.829	2.081
Floor	0.565	0.844	1.893

Table 58: Percentage adjustment of corrosion wastage between tankers

Locations	Percentage adjustment (%)
Interior deck	99.6
Side shell	55.9
Bulkhead	99.3
Inner bottom	151.0
Floor	124.3

6 LSA MODEL RESULTS

6.1 Introduction

After the completion of the code in Matlab and Octave, the probability of failure of davit launched lifeboat due to corrosion was calculated. In order to examine deeply the importance of variables, all possible combinations of parameters was taken into account. At this moment, it is important to mention the two different types of failure, the critical failure and the non-critical failure. As critical failure is defined the damage of a component which can extremely harsh the total system by making it non-functional. On the other hand, a failure of a component that degrades performance or operational capability of a system but which can be tolerated for a brief period before correction, is called non-critical (Zheng et al., 2012). This study investigates non-critical possible failure.

6.1.1 Modifying parameters of davit launched lifeboat

6.1.1.1 Case 1

The first case examines a davit launched lifeboat by which the bulk carrier of corrosion model in chapter 5 is equipped. The procedure of the evaluation of the probability will be described extensively. Firstly, the program code identifies the appropriate data which influence the maintenance of the davit launched lifeboat on the vessel (Table 59).

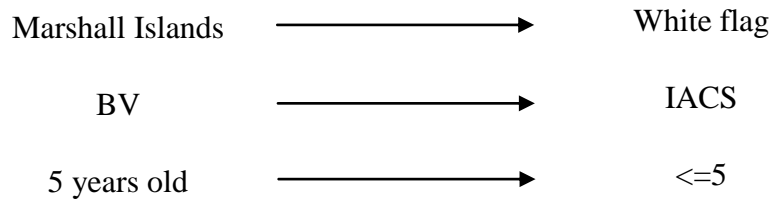
Step 1: Recognize the appropriate data

Table 59: Identification of bulk carrier's ship parameters

IMO	9437098
TYPE OF LSA	Davit Launched Lifeboat
COYNTRY	Marshall Islands
CLASS	BV
AGE	5

Following the procedure of identifying the appropriate data, the program code relates the data to the qualitative values of the model.

Step 2: Correlation between data and their qualitative value



Considering the qualitative values, the program code matches them with the equivalent quantified value of each subcomponent (Figure 54).

Step 3: Quantification of data

Non-critical probability of failure	DAVIT LAUNCHED LIFEBOATS											
	IACS						NO IACS					
	BLACK		GREY		WHITE		BLACK		GREY		WHITE	
	5+	5-	5+	5-	5+	5-	5+	5-	5+	5-	5+	5-
Davit structure	0.00036	0.00003	0.00032	0.00003	0.00029	0.00003	0.00039	0.00003	0.00036	0.00003	0.00032	0.00003
Limit switch	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Winch Brake	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Winch General	0.00052	0.00004	0.00480	0.00004	0.00043	0.00004	0.00058	0.00005	0.00053	0.00005	0.00047	0.00004
Hooks	0.00298	0.00026	0.00271	0.00023	0.00244	0.00021	0.00330	0.00028	0.00300	0.00026	0.00270	0.00023
Control Lever	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Operating cables	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Fall wires	0.00080	0.00007	0.00073	0.00006	0.00065	0.00006	0.00088	0.00008	0.00080	0.00007	0.00072	0.00006
Falls, Sheaves, Blocks	0.00055	0.00005	0.00050	0.00004	0.00045	0.00004	0.00061	0.00005	0.00055	0.00005	0.00050	0.00004
Lifeboat	0.00025	0.00002	0.00023	0.00002	0.00020	0.00002	0.00027	0.00002	0.00025	0.00002	0.00022	0.00002
Tricing & bowising	0.00006	0.00001	0.00006	0.00000	0.00005	0.00000	0.00007	0.00001	0.00006	0.00001	0.00006	0.00000

Figure 54: Quantification of bulk carrier's data

After the quantification of the basic subcomponents, the program code calculated gradually the probability of failure of davit launched lifeboat due to corrosion, using the equations of sector 4.2.4. Table 60 presents the results in detail for each main component or subcomponent, as well as the probability of failure of the davit launched lifeboat. Figure 55 presents the exact location of main components on the davit launched lifeboat, as well as their probabilities of failure and the equivalent of the total system.

Table 60: Probability of each component

Subcomponent	Probability
Davit structure	0.00003
Limit switch	0
Winch brake	0
Winch general	0.00004
Hooks	0.00021
Control lever	0
Operating cable	0
Main Component	
Davit	0.00003
Fall wires	0.00006
Winch	0.00004
Lifeboat	0.00002
Falls, sheaves & blocks	0.00004
On-load release mechanism	0.00021
Tracing & bowsing	0
Failure of davit launched lifeboat	0.0004

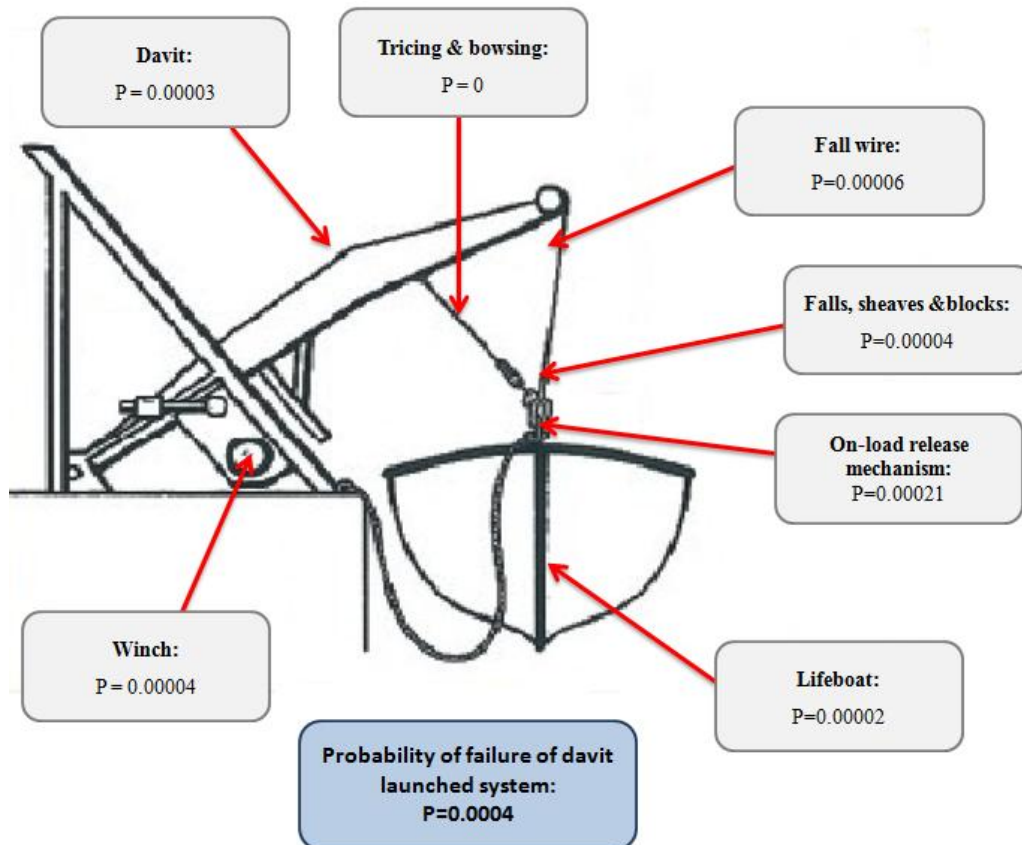


Figure 55: Depiction of davit launched system

6.1.1.2 Case 2

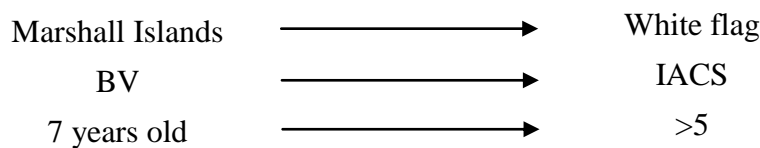
On this case the parameters of bulk carrier remain constant, except the ship age. The alternation of the age by considering the ship older than 5 years old will influence the possibility of failure of davit launched lifeboat. The possibility is calculating by following the same procedure as case 1.

Step 1: Recognize the appropriate data

Table 61: Ship parameters (modifying initial age)

TYPE OF LSA	Davit Launched Lifeboat
COYNTRY	Marshall Islands
CLASS	BV
AGE	7

Step 2: Correlation between data and their qualitative value



Step 3: Quantification of data

Non-critical probability of failure	DAVIT LAUNCHED LIFEBOATS											
	IACS						NO IACS					
	BLACK		GREY		WHITE		BLACK		GREY		WHITE	
	5+	5-	5+	5-	5+	5-	5+	5-	5+	5-	5+	5-
Davit structure	0.00036	0.00003	0.00032	0.00003	0.00029	0.00003	0.00039	0.00003	0.00036	0.00003	0.00032	0.00003
Limit switch	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Winch Brake	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Winch General	0.00052	0.00004	0.00480	0.00004	0.00043	0.00004	0.00058	0.00005	0.00053	0.00005	0.00047	0.00004
Hooks	0.00298	0.00026	0.00271	0.00023	0.00244	0.00021	0.00330	0.00028	0.00300	0.00026	0.00270	0.00023
Control Lever	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Operating cables	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Fall wires	0.00080	0.00007	0.00073	0.00006	0.00065	0.00006	0.00088	0.00008	0.00080	0.00007	0.00072	0.00006
Falls, Sheaves, Blocks	0.00055	0.00005	0.00050	0.00004	0.00045	0.00004	0.00061	0.00005	0.00055	0.00005	0.00050	0.00004
Lifeboat	0.00025	0.00002	0.00023	0.00002	0.00020	0.00002	0.00027	0.00002	0.00025	0.00002	0.00022	0.00002
Tricing & bowising	0.00006	0.00001	0.00006	0.00000	0.00005	0.00000	0.00007	0.00001	0.00006	0.00001	0.00006	0.00000

Figure 56: Quantification of bulk carrier's data (modifying initial age)

Table 62 presents the results in detail for each main component or subcomponent, as well as the probability of failure of the davit launched lifeboat after modifying the ship age. Figure 57 presents the exact location of main components on the davit launched lifeboat, as well as their probabilities of failure and the equivalent of the total system.

Table 62: Probability of each component (modifying initial age)

Subcomponent	Probability
Davit structure	0.00029
Limit switch	0
Winch brake	0
Winch general	0.00043
Hooks	0.00244
Control lever	0
Operating cable	0
Main Component	
Davit	0.00029
Fall wires	0.00065
Winch	0.00043
Lifeboat	0.00020
Falls, sheaves & blocks	0.00045
On-load release mechanism	0.00244
Tracing & bowsing	0.00005
Failure of davit launched lifeboat	0.00451

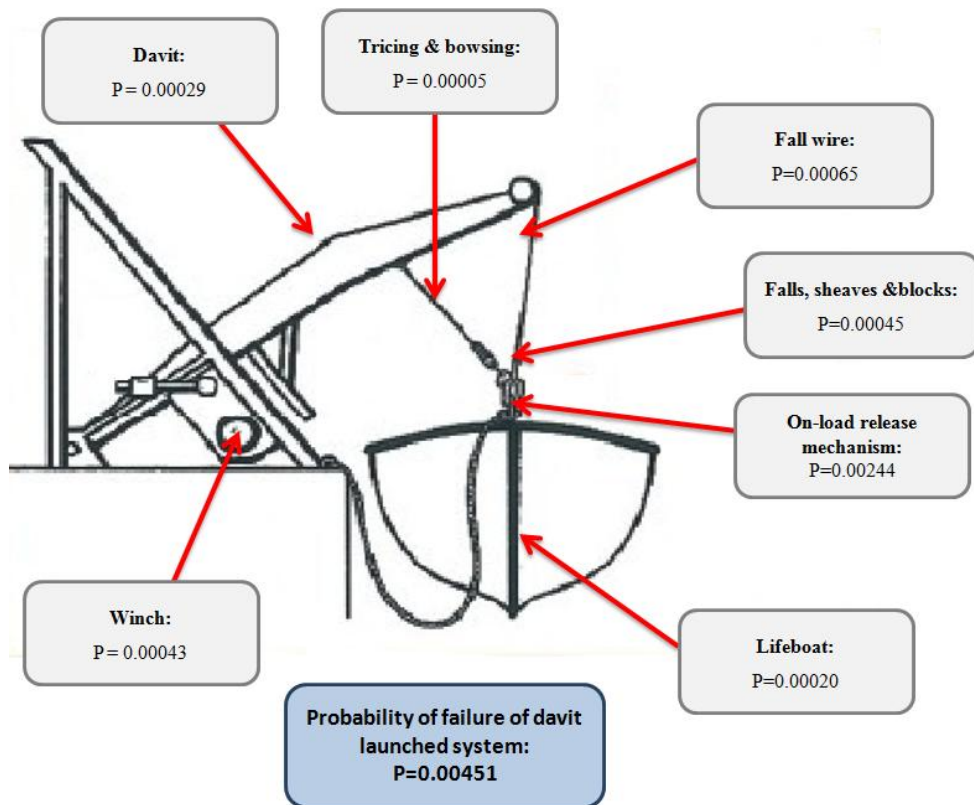


Figure 57: Depiction of davit launched system (modifying initial age)

6.1.1.3 Case 3

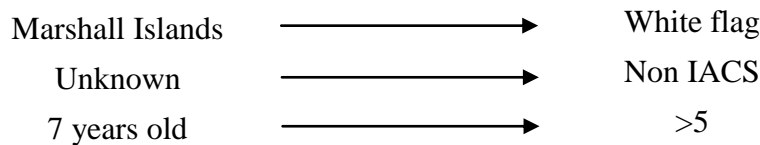
On this case only the parameter of flag remains constant. For the purpose of the study, the class is considered unknown (Non IACS). The alternation of both age and class will influence the possibility of failure of davit launched lifeboat. The possibility is calculating by following the same procedure as case 1.

Step 1: Recognize the appropriate data

Table 63: Ship parameters (modifying initial age & class)

TYPE OF LSA	Davit Launched Lifeboat
COYNTRY	Marshall Islands
CLASS	Unknown
AGE	7

Step 2: Correlation between data and their qualitative value



Step 3: Quantification of data

Non-critical probability of failure	DAVIT LAUNCHED LIFEBOATS											
	IACS						NO IACS					
	BLACK		GREY		WHITE		BLACK		GREY		WHITE	
	5+	5-	5+	5-	5+	5-	5+	5-	5+	5-	5+	5-
Davit structure	0.00036	0.00003	0.00032	0.00003	0.00029	0.00003	0.00039	0.00003	0.00036	0.00003	0.00032	0.00003
Limit switch	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Winch Brake	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Winch General	0.00052	0.00004	0.00480	0.00004	0.00043	0.00004	0.00058	0.00005	0.00053	0.00005	0.00047	0.00004
Hooks	0.00298	0.00026	0.00271	0.00023	0.00244	0.00021	0.00330	0.00028	0.00300	0.00026	0.00270	0.00023
Control Lever	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Operating cables	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Fall wires	0.00080	0.00007	0.00073	0.00006	0.00065	0.00006	0.00088	0.00008	0.00080	0.00007	0.00072	0.00006
Falls, Sheaves, Blocks	0.00055	0.00005	0.00050	0.00004	0.00045	0.00004	0.00061	0.00005	0.00055	0.00005	0.00050	0.00004
Lifeboat	0.00025	0.00002	0.00023	0.00002	0.00020	0.00002	0.00027	0.00002	0.00025	0.00002	0.00022	0.00002
Tricing & bousing	0.00006	0.00001	0.00006	0.00000	0.00005	0.00000	0.00007	0.00001	0.00006	0.00001	0.00006	0.00000

Figure 58: Quantification of bulk carrier's data (modifying initial age & class)

Table 64 presents the results in detail for each main component or subcomponent, as well as the probability of failure of the davit launched lifeboat after modifying the ship age and the class. Figure 59 presents the exact location of main components on the davit launched lifeboat, as well as their probabilities of failure and the equivalent of the total system.

Table 64: Probability of each component (modifying initial age & class)

Subcomponent	Probability
Davit structure	0.00032
Limit switch	0
Winch brake	0
Winch general	0.00047
Hooks	0.00270
Control lever	0
Operating cable	0
Main Component	
Davit	0.00032
Fall wires	0.00072
Winch	0.00047
Lifeboat	0.00022
Falls, sheaves & blocks	0.00050
On-load release mechanism	0.00270
Tracing & bowsing	0.00006
Failure of davit launched lifeboat	0.005

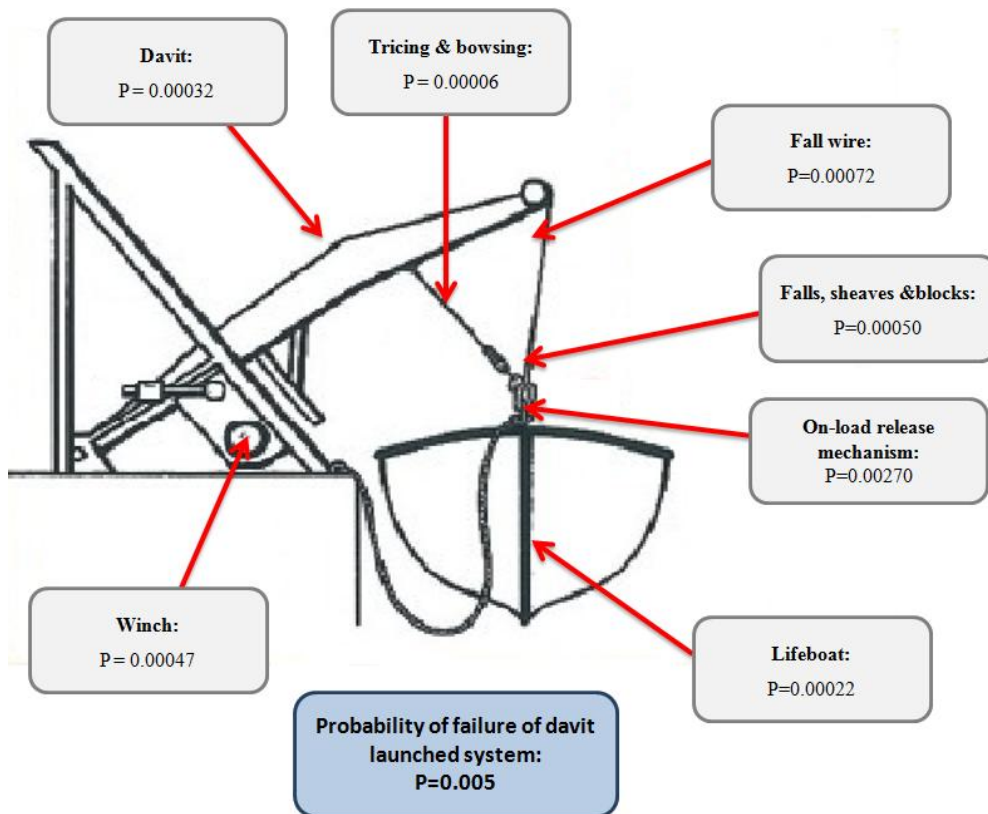


Figure 59: Depiction of davit launched system (modifying initial age & class)

6.1.1.4 Case 4

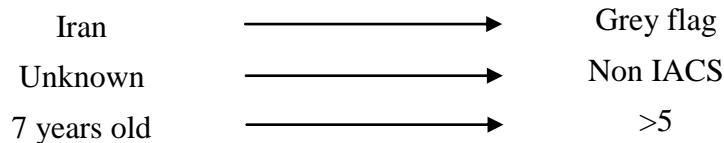
On this case none of the parameters remain constant. For the purpose of the study, the class is considered unknown (Non IACS), as on case 2, and the country flag from Iran (grey). The alternation of all parameters will influence the possibility of failure of davit launched lifeboat. The possibility is calculating by following the same procedure as case 1.

Step 1: Recognize the appropriate data

Table 65: Ship parameters (modifying initial age, class & flag)

TYPE OF LSA	Davit Launched Lifeboat
COYNTRY	Iran
CLASS	Unknown
AGE	7

Step 2: Correlation between data and their qualitative value



Step 3: Quantification of data

Non-critical probability of failure	DAVIT LAUNCHED LIFEBOATS											
	IACS						NO IACS					
	BLACK		GREY		WHITE		BLACK		GREY		WHITE	
	5+	5-	5+	5-	5+	5-	5+	5-	5+	5-	5+	5-
Davit structure	0.00036	0.00003	0.00032	0.00003	0.00029	0.00003	0.00039	0.00003	0.00036	0.00003	0.00032	0.00003
Limit switch	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Winch Brake	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Winch General	0.00052	0.00004	0.00480	0.00004	0.00043	0.00004	0.00058	0.00005	0.00053	0.00005	0.00047	0.00004
Hooks	0.00298	0.00026	0.00271	0.00023	0.00244	0.00021	0.00330	0.00028	0.00300	0.00026	0.00270	0.00023
Control Lever	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Operating cables	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Fall wires	0.00080	0.00007	0.00073	0.00006	0.00065	0.00006	0.00088	0.00008	0.00080	0.00007	0.00072	0.00006
Falls, Sheaves, Blocks	0.00055	0.00005	0.00050	0.00004	0.00045	0.00004	0.00061	0.00005	0.00055	0.00005	0.00050	0.00004
Lifeboat	0.00025	0.00002	0.00023	0.00002	0.00020	0.00002	0.00027	0.00002	0.00025	0.00002	0.00022	0.00002
Tricing & bowsing	0.00006	0.00001	0.00006	0.00000	0.00005	0.00000	0.00007	0.00001	0.00006	0.00001	0.00006	0.00000

Figure 60: Quantification of bulk carrier's data (modifying initial age, class & flag)

Table 66 presents the results in detail for each main component or subcomponent, as well as the probability of failure of the davit launched lifeboat after modifying the ship age, the class and flag. Figure 61 presents the exact location of main components on the davit launched lifeboat, as well as their probabilities of failure and the equivalent of the total system.

Table 66: Probability of each component (modifying initial age, class & flag)

Subcomponent	Probability
Davit structure	0.00036
Limit switch	0
Winch brake	0
Winch general	0.00053
Hooks	0.00300
Control lever	0
Operating cable	0
Main Component	
Davit	0.00036
Fall wires	0.00080
Winch	0.00053
Lifeboat	0.00025
Falls, sheaves & blocks	0.00055
On-load release mechanism	0.00300
Tracing & bousing	0.00006
Failure of davit launched lifeboat	0.0056

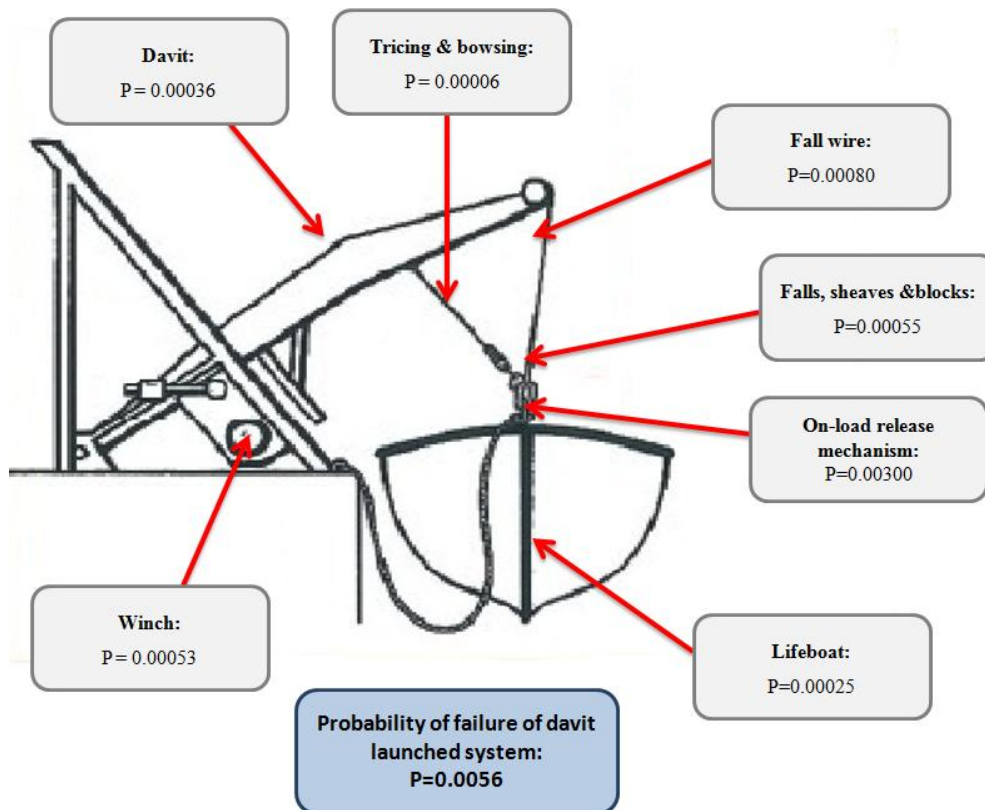


Figure 61: Depiction of davit launched system (modifying initial age, class & flag)

6.1.1.5 Case 5

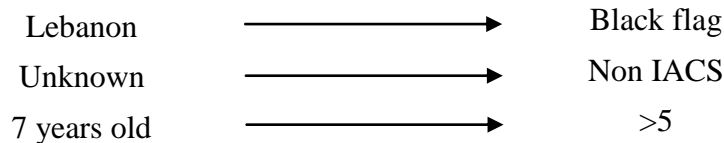
On this case the parameters remain constant, as those of case 3 except the parameter of flag. The country flag is considered to be from Lebanon (black). The alternation of the parameter of flag will influence the possibility of failure of davit launched lifeboat. The possibility is calculating by following the same procedure as case 1.

Step 1: Recognize the appropriate data

Table 67: Ship parameters (modifying flag)

TYPE OF LSA	Davit Launched Lifeboat
COYNTRY	Lebanon
CLASS	Unknown
AGE	7

Step 2: Correlation between data and their qualitative value



Step 3: Quantification of data

Non-critical probability of failure	DAVIT LAUNCHED LIFEBOATS											
	IACS						NO IACS					
	BLACK		GREY		WHITE		BLACK		GREY		WHITE	
	5+	5-	5+	5-	5+	5-	5+	5-	5+	5-	5+	5-
Davit structure	0.00036	0.00003	0.00032	0.00003	0.00029	0.00003	0.00039	0.00003	0.00036	0.00003	0.00032	0.00003
Limit switch	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Winch Brake	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Winch General	0.00052	0.00004	0.00480	0.00004	0.00043	0.00004	0.00058	0.00005	0.00053	0.00005	0.00047	0.00004
Hooks	0.00298	0.00026	0.00271	0.00023	0.00244	0.00021	0.00330	0.00028	0.00300	0.00026	0.00270	0.00023
Control Lever	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Operating cables	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Fall wires	0.00080	0.00007	0.00073	0.00006	0.00065	0.00006	0.00088	0.00008	0.00080	0.00007	0.00072	0.00006
Falls, Sheaves, Blocks	0.00055	0.00005	0.00050	0.00004	0.00045	0.00004	0.00061	0.00005	0.00055	0.00005	0.00050	0.00004
Lifeboat	0.00025	0.00002	0.00023	0.00002	0.00020	0.00002	0.00027	0.00002	0.00025	0.00002	0.00022	0.00002
Tricing & bousing	0.00006	0.00001	0.00006	0.00000	0.00005	0.00000	0.00007	0.00001	0.00006	0.00001	0.00006	0.00000

Figure 62: Quantification of bulk carrier's data (modifying flag)

Table 68 presents the results in detail for each main component or subcomponent, as well as the probability of failure of the davit launched lifeboat after modifying the ship age, the class and flag. Figure 63 presents the exact location of main components on the davit launched lifeboat, as well as their probabilities of failure and the equivalent of the total system.

Table 68: Probability of each component (modifying flag)

Subcomponent	Probability
Davit structure	0.00039
Limit switch	0
Winch brake	0
Winch general	0.00058
Hooks	0.00330
Control lever	0
Operating cable	0
Main Component	
Davit	0.00039
Fall wires	0.00088
Winch	0.00058
Lifeboat	0.00027
Falls, sheaves & blocks	0.00061
On-load release mechanism	0.00330
Tracing & bowsing	0.00007
Failure of davit launched lifeboat	0.0061

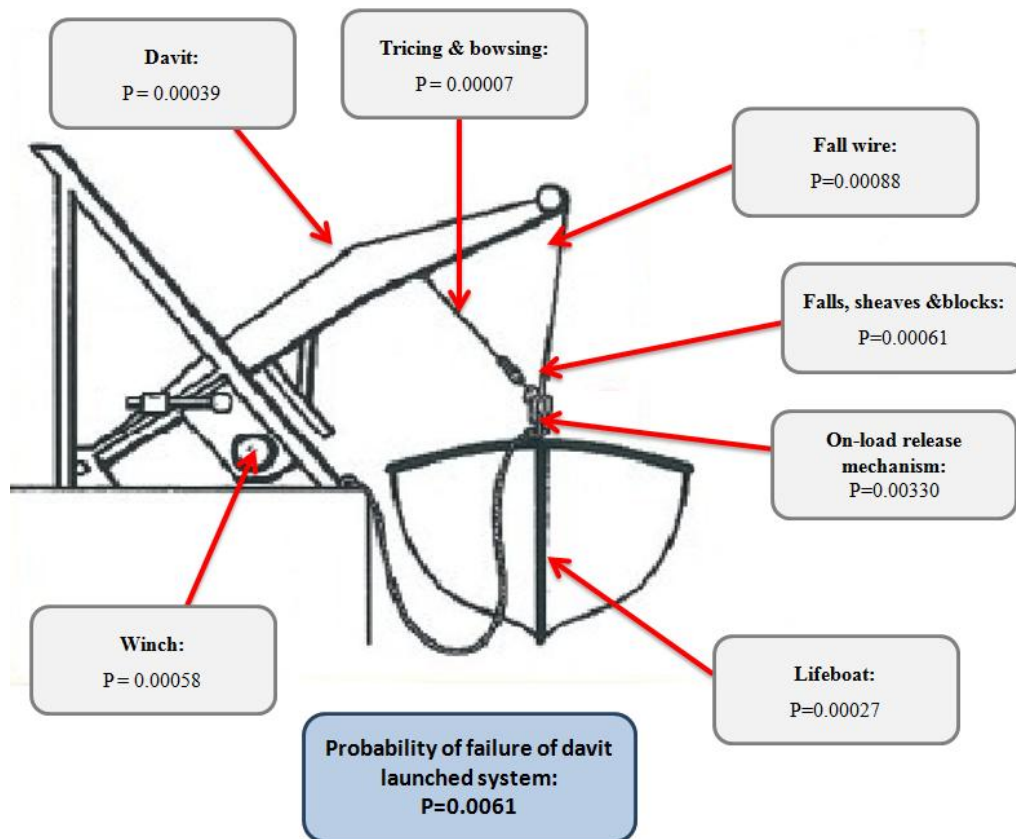


Figure 63: Depiction of davit launched system (modifying flag)

Table 69: Summary table of various combinations of parameters for davit launched

Case		1	2	3	4	5
Parameters	<i>Flag</i>	White	White	White	Grey	Black
	<i>IACS</i>	Yes	Yes	No	No	No
	<i>AGE</i>	5	7	7	7	7
Probability of failure of davit launched life boat		0.0004	0.0045	0.0050	0.0056	0.0061

6.1.2 Examining LSA types on bulk carrier

6.1.2.1 Case 6

On this case, the probabilities of failure of a davit launched lifeboat, a davit launched liferaft, and a free-fall lifeboat, existing on the same vessel, are examined. For the purpose of this case the ship which had been taken into account, is the bulk carrier of case 1, where the probability of failure of davit launched due to corrosion had been calculated. Therefore, the evaluation of failure of davit launched liferaft and free-fall lifeboat comes next.

Step 1: Recognize the appropriate data

Table 70: Ship parameters for davit launched liferaft

TYPE OF LSA	Davit Launched Liferaft
COYNTRY	Marshall Island
CLASS	BV
AGE	5

Step 2: Correlation between data and their qualitative value

Marshall Islands	—————→	White flag
BV	—————→	IACS
5 years old	—————→	≤5

Step 3: Quantification of data for davit launched liferaft and free fall lifeboat

Non-critical probability of failure	DAVIT LAUNCHED LIFERAFTS											
	IACS						NO IACS					
	BLACK		GREY		WHITE		BLACK		GREY		WHITE	
	5+	5-	5+	5-	5+	5-	5+	5-	5+	5-	5+	5-
Davit structure	0.00003	0.00000	0.00003	0.00000	0.00003	0.00000	0.00004	0.00000	0.00003	0.00000	0.00003	0.00000
Limit Switch	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Winch brake	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Winch General	0.00024	0.00002	0.00022	0.00002	0.00020	0.00002	0.00027	0.00002	0.00025	0.00002	0.00022	0.00002
Hooks	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Control Lever	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Operating Cables	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Fall wires	0.00022	0.00002	0.00020	0.00002	0.00018	0.00002	0.00025	0.00002	0.00023	0.00002	0.00020	0.00002
Falls, Sheaves,Blocks	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

Figure 64: Quantification of davit launched liferaft

	FREE FALL LIFEBOATS											
	IACS						NO IACS					
	BLACK		GREY		WHITE		BLACK		GREY		WHITE	
	5+	5-	5+	5-	5+	5-	5+	5-	5+	5-	5+	5-
Fall wires	0.00036	0.00003	0.00033	0.00003	0.00030	0.00003	0.00040	0.00003	0.00036	0.00003	0.00033	0.00003
Davit structure	0.00027	0.00002	0.00025	0.00002	0.00022	0.00002	0.00030	0.00003	0.00027	0.00000	0.00025	0.00002
Limit Switch	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Winch Brake	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Falls, Sheaves,Blocks	0.00042	0.00004	0.00038	0.00003	0.00034	0.00003	0.00046	0.00004	0.00042	0.00004	0.00038	0.00003
Hooks	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Control Lever	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Operating cables	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Lifeboat	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Winch General	0.00043	0.00004	0.00039	0.00003	0.00035	0.00003	0.00048	0.00004	0.00044	0.00004	0.00039	0.00003

Figure 65: Quantification of free fall lifeboat

Table 71 presents the results in detail for each main component or subcomponent of davit launched liferaft, as well as the probability of failure of the total system. Figure 66 presents the exact location of main components on the davit launched lifeboat, as well as their probabilities of failure and the equivalent of the total system.

Table 72 presents the results in detail for each main component or subcomponent of free fall lifeboat, as well as the probability of failure of the total system. Figure 67 presents the exact location of main components on the free fall lifeboat, as well as their probabilities of failure and the equivalent of the total system.

Table 71: Probability of each component for davit launched liferaft

Subcomponent	Probability
Davit structure	0
Limit switch	0
Winch brake	0
Winch general	0.00058
Hooks	0
Control lever	0
Operating cable	0
Main Component	
Davit	0
Fall wires	0.00002
Winch	0.00002
Falls, sheaves & blocks	0
On-load release mechanism	0
Failure of davit launched liferaft	0.00004

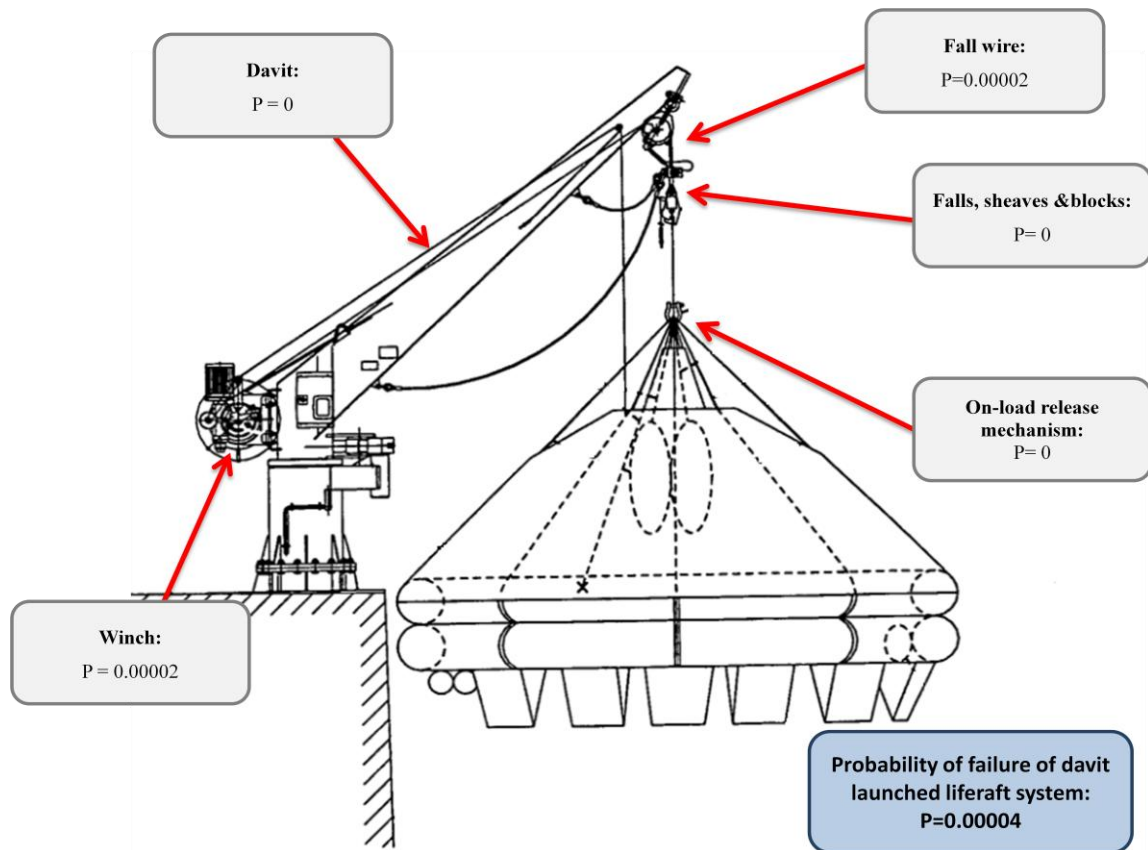


Figure 66: Depiction of davit launched liferaft system

Table 72: Probability of each component for free fall lifeboat

Subcomponent	Probability
Davit structure	0.00002
Limit switch	0
Winch brake	0
Winch general	0.00003
Hooks	0
Control lever	0
Operating cable	0
Main Component	
Davit	0.00002
Fall wires	0.00003
Winch	0.00003
Lifeboat	0
Falls, sheaves & blocks	0.00003
On-load release mechanism	0
Failure of davit launched lifeboat	0.00011

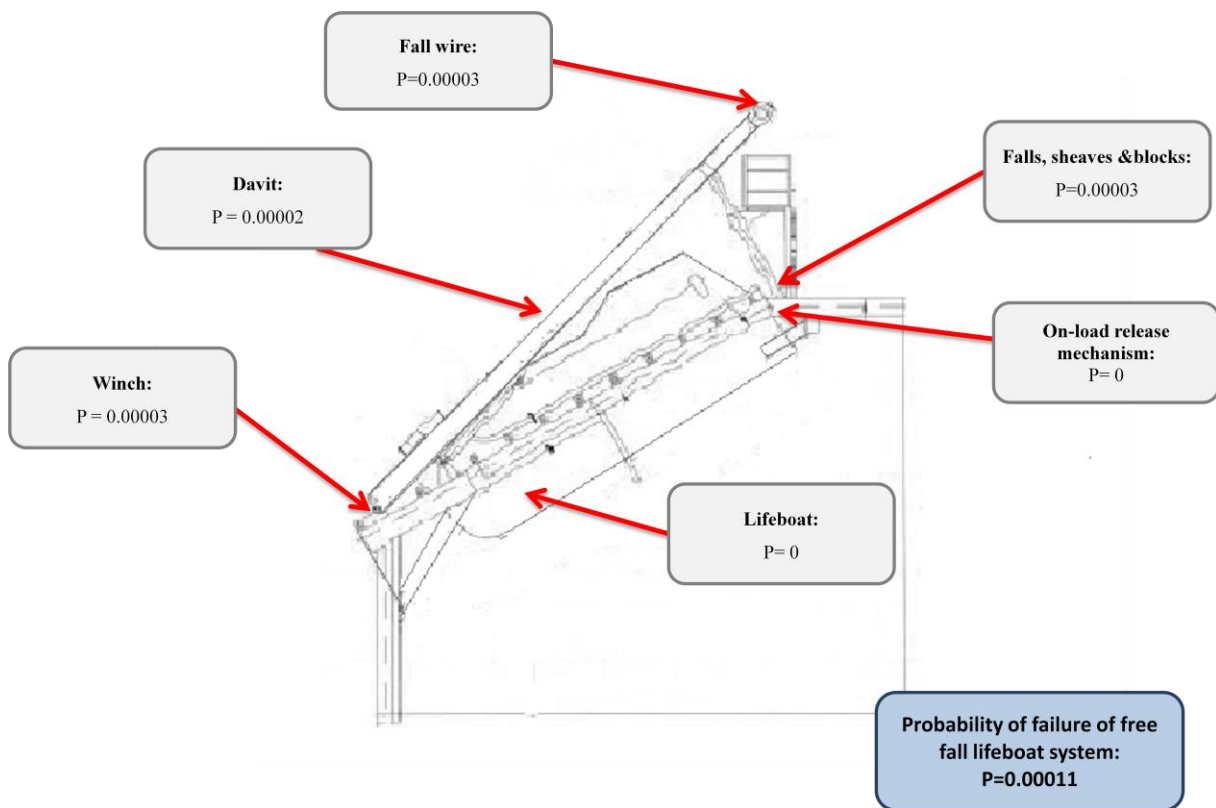


Figure 67: Depiction of free fall lifeboat system

Table 73: Summary table of probabilities of LSA types

LSA type	Probability of failure
Davit launched lifeboat	0.00040
Davit launched liferaft	0.00004
Free fall lifeboat	0.00010

Table 73 presents the final evaluating probabilities of failure of davit launched lifeboat, davit launched liferaft, and free fall lifeboat, due to corrosion. It can be seen that davit launched lifeboat is considered as the most hazardous type to fail between the life saving appliances, as its estimated probability is the highest. Second in order is the free fall lifeboat which probability calculated 0.00010. Finally, the less dangerous of failing LSA type is the davit launched liferaft which is calculated 0.00004; that means 10 times lower than the equivalent of davit launched lifeboat.

7 CONCLUSIONS

The purpose of this study is to investigate the implementation of Risk Based Inspection in maritime. Specifically, two RBI models was applied in order to evaluate the depth of corrosion in several structural areas of ship and to estimate the probability of failure of different LSA types. The general capture of RBI is to indicate the most hazardous areas on a vessel which shall be prioritized in a survey.

With regards to the implemented model of corrosion, it shall be noted that the results of model, for each structural element, approach the mean values adequately. In general, regardless of the examining structural area, the proportion of samples approaching the mean value is not less than 15% and in some cases it reaches the 31%. The most noticeable contrast of two programs (Matlab and Octave) is the required run time. The run time of Matlab can be estimated 3 to 4 times shorter than the equivalent of Octave. In addition, Matlab can be considered more practicable and easier to use because of the variety of its library, while the relative of Octave is more limited. Concerning the nature of results, it shall be noted that they demonstrate the danger of tanker's cargoes. The structural elements of cargo hold, such as inner bottom and bulkhead, where the cargo comes in contact directly, are affected more than other areas and present higher durability in tankers than in bulk carriers. The depth of corrosion on inner bottom is evaluated approximately equal for a 10 years old tanker and a 5 years old bulk carrier, both of similar variables, and that fact proves the durability of the selected coating in tankers, generally.

As regards the LSA model, the exercised cases included a comparison between different combinations of parameters on davit launched lifeboat system, as well as the probabilities of failure of three different types of LSA which exist on the same vessel. The major factor influencing the probability of failure of LSA is the maintenance whose parameters are the age, the class, and the flag of the ship. The various combination of these parameters influence significantly the probability of failure on davit launched lifeboat. In fact, LSA existing on an old ship which is classified by a non IACS classification society with grey or black flag is considered to be most hazardous than other combinations. The examination of different LSA types on a specific vessel illustrates that the most dangerous type of LSA to fail is the davit launched lifeboat, contrary to free fall lifeboat and davit launched liferaft.

Although the implemented models approach the two case studies sufficiently, further optimization of models can lead to a general and more effective application in maritime; in order to minimize failures, and as a result involuntary accidents. Further studies for improving the implementation of RBI models can be:

- Further research of factors which might influence the robustness operation of vessel.
- The extension of model to other dangerous location of the ship, such as the engine room, the propeller, the fuel oil tanks.

- The implementation of RBI model in passenger ships by defining the appropriate influential factors.
- Optimization of existing factors of corrosion model and LSA model
- Utilize parallel computing model such as OpenMP to parallelize the developed code.

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ANNEX A. Corrosion Influencing Factors

The quantification of the parameters are defined by experienced surveyors and researchers who evaluated available data from IHS Fairplay and AIS.

1. Changes of owner.

Table A-1: Factors for owner changes

No of owner changes	Factor for coating lifetime	Factor for corrosion rate
0	1.2	1.0
1-2	1.0	1.0
>2	0.9	1.0
unknown	0.9	1.0

2. Class.

The quantification of this parameter resulted from the assumption that ships which are classified by an IACS class considered to be better maintained than other ships. The members of IACS are:

- American Bureau of Shipping (ABS)
- Bureau Veritas (BV)
- China Classification Society (CCS)
- Croatian Register of Shipping (CRS)
- Det Norske Veritas/ Germanischer Lloyd (DNV/GL)
- Indian Register of Shipping (IRS)
- Korean Register of Shipping (KR)
- Lloyd's Register (LR)
- Nippon Kaiji Kyokai (NK)
- Polish Register of Shipping (PRS)
- Registro Italiano Navale (RINA)
- Russian Maritime Register of Shipping (RS)

Table A-2: Factors for class

Class	Factor for coating lifetime	Factor for corrosion rate
IACS	1.1	1.0
Non IACS	0.9	1.0
unknown	0.9	1.0

3. Building class

Table A-3: Factors for building class

Class	Factor for coating lifetime	Factor for corrosion rate
IACS	1.0	1.0
Non IACS	0.9	1.0
unknown	0.9	1.0

4. Country of yard

Table A-4: Factors for country of yard

Country	Workmanship (points out of 5)	Factor for corrosion lifetime (Points/average points)	Factor for corrosion rate
China	2.4	0.67	1.00
Europe	3.8	1.06	1.00
Japan	4.2	1.17	1.00
South Korea	4.0	1.11	1.00
Average	3.6	1.00	1.00
Other /unknown		0.67	1.00

5. Flag

This study had considered 72 different flags according to Paris MoU and PSC findings. Depending on the total number of deficiencies for each flag, they categorized to white, black, and grey flags. The color of the flag quantifies the factor of flag.

Table A- 5: Color of flags according to deficiencies

Flag	Corrosion deficiencies per inspection		Flag	Corrosion deficiencies per inspection	
Cambodia	0,142	black	Panama	0,020	white
Tanzania	0,147	black	UK	0,005	white
Sierra Leone	0,136	black	Antigua Barbuda	0,008	white
Comoros	0,152	black	France	0,008	white
Dominica	0,098	black	Hongkong	0,001	white
Togo	0,079	black	Bahamas	0,007	white
Moldovia	0,096	black	Sweden	0,000	white
Bulgaria	0,179	black	Isle of Man	0,001	white
Algeria	0,097	black	Denmark	0,001	white
Ukraine	0,138	black	USA	0,014	white
Lebanon	0,119	black	Italy	0,011	white
Albania	0,092	black	Singapore	0,006	white
Tuvalu	0,069	black	China	0,018	white
St Vincent /Grena	0,045	grey	Greece	0,002	white
Belize	0,064	grey	Finland	0,002	white
Cook Islands	0,051	grey	Liberia	0,013	white
Thailand	0,053	grey	Netherlands	0,001	white
Morocco	0,053	grey	Bermuda	0,009	white
St Kitts/Nevis	0,041	grey	Malta	0,012	white
Belgium	0,042	grey	Cayman Islands	0,000	white
Iran	0,048	grey	Gibraltar	0,005	white
Russian Fed	0,047	grey	Croatia	0,008	white
Switzerland	0,034	grey	Cyprus	0,009	white
Portugal	0,010	white	Faroe Islands	0,000	white
Malaysia	0,000	white	India	0,014	white
Spain	0,005	white	Saudi Arabia	0,000	white
Lithuania	0,020	white	Kazakhstan	0,000	white
Poland	0,000	white	Barbados	0,023	white
Libya	0,000	white	Turkey	0,029	white
Egypt	0,019	white	Estonia	0,000	white
Tunisia	0,000	white	Japan	0,000	white
Curacao	0,005	white	Latvia	0,000	white
Vanuatu	0,028	white	Ireland	0,000	white
Germany	0,007	white	Philippines	0,014	white
Marshall Islands	0,011	white	Luxembourg	0,000	white
Norway	0,005	white	Korea, Rep of	0,031	white

Table A- 6: Factors for flag

Flag	Factor for coating lifetime	Factor for corrosion rate
White	1.1	1.0
grey	1.0	1.0
Black	0.9	1.0
unknown	0.9	1.0

6. Time at sea**Table A- 7: Factors for time at sea**

Time at sea	Average sailing time between two ports	Factor for coating lifetime	Factor for corrosion rate
Long	≥ 3 days	1.2	1.0
Short	< 3 days	1.0	1.0
unknown	unknown	1.0	1.0

7. Time at port**Table A- 8: Factors for time in port**

Time in port	Average time in port	Factor for coating lifetime	Factor for corrosion rate
Long	≥ 1 day	1.1	1.0
Short	< 24 day	1.0	1.0
unknown	unknown	1.0	1.0

8. Detentions

Table A- 9: Factors for detentions

No of detentions in last 36 months by Paris MoU		Factor for coating lifetime	Factor for corrosion rate
Many	>2	0.90	1.00
Some	1 or 2	0.95	1.00
None	0	1.00	1.00
unknown	unknown	0.90	1.00

9. Deficiencies

Table A- 10: Factors for deficiencies

No of deficiencies in last 36 months by Paris MoU		Factor for coating lifetime	Factor for corrosion rate
Many	>5	0.90	1.00
Some	=<5	0.95	1.00
None	0	1.00	1.00
unknown	unknown	0.90	1.00

10. Corrosivity of cargo

Table A- 11: Factors for corrosivity

Transport of corrosive cargos	Factor for coating lifetime	Factor for corrosion rate
Never	1.00	1.00
Occasionally	1.00	1.20
Regularly	1.00	1.50
No information	1.00	1.50

11. Abrasivity of cargo

Liquid cargoes are not considered as abrasive, hence all tankers are not affected by this factor.

Table A- 12: Factors for abrasivity

Transport of abrasive cargo	Factor for coating lifetime	Factor for corrosion rate
Never	1.00	1.00
Occasionally	0.95	1.00
Regularly	0.90	1.00
No information	0.90	1.00

12. Temperature of cargo

It is considered that bulkers transport no heated cargoes.

Table A- 13: Factors for temperature

Temperature	Temperature in Celsius	Factor for coating lifetime	Factor for corrosion rate
High	>45°C	1.00	1.50
Medium	25...45°C	1.00	1.20
Low	<25°C	1.00	1.00
unknown	unknown	1.00	1.50

13. Operation in tropics and subtropics

Table A- 14: Factors for operational area

Operation in tropics or subtropics	% of time	Factor for coating lifetime	Factor for corrosion rate
Mostly	≥ 75	0.90	$1/0.90=1.11$
Occasionally	$25 < \dots < 75$	0.95	$1/0.95=1.05$
Seldom	≤ 25	1.00	1.00
unknown	unknown	0.90	$1/0.90=1.11$

14. Abrasive cargo handling

It is considered that tankers and containerships are not affected by this factor.

Table A- 15: Factors for abrasive cargo handling

Abrasive cargo handling	Factor for coating lifetime	Factor for corrosion rate
Never	1.00	1.00
Occasionally	0.95	1.00
Regularly	0.90	1.00
No information	0.90	1.00

15. Frequency of cargo

Table A- 16: Factors for the frequency of cargo

Cargo changes	Cargo changes per day	Factor for coating lifetime	Factor for corrosion rate
Often	>0.143 (More than once per week)	0.90	1.00
Medium	0.07...0.143 (at least once per 14 days)	0.95	1.00
Rarely	<0.07 (Less than once per 14 days)	1.00	1.00
unknown	unknown	0.90	1.00

16. Time with ballast (Ballast ratio)

The ballast ratio is calculated by the draught of the vessel, which is given by AIS data. If the given draught by AIS is <80% of the given draught by IHS Fairplay, then the ship is considered to be in ballast.

The ballast ratio is determined by the equation below:

$$\text{Ballast ratio} = \frac{\text{time in ballast}}{\text{time period available in AIS}}$$

Ballast ratio		Factor for coating lifetime	Factor for corrosion rate
High	> 50%	1.00	1.10
Medium	10...50%	1.00	1.05
low	< 10%	1.00	1.00
unknown		1.00	1.10

17. Time to next dry dock survey

Table A- 17: Factors for next dry docking survey

Time to next survey	Factor for coating lifetime	Factor for corrosion rate
< 1 year	0.90	1.00
1-3 years	0.95	1.00
>3 years	1.00	1.00
Unknown or overdue	0.90	1.00