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ΣΧΟΛΗ ΝΑΥΠΗΓΩΝ ΜΗΧΑΝΟΛΟΓΩΝ ΜΗΧΑΝΙΚΩΝ

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«RISK BASED INSPECTION: THEORY AND AN APPLICATION ON THREE DIFFERENT SHIP TYPES»

ΔΙΠΛΩΜΑΤΙΚΗ ΕΡΓΑΣΙΑ

της

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Επιβλέπων : ΝΙΚΟΛΑΟΣ Π. ΒΕΝΤΙΚΟΣ
Καθηγητής Ε.Μ.Π.

Αθήνα, Ιούλιος 2016

Η σελίδα αυτή είναι σκόπιμα λευκή

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Εγκρίθηκε από την τριμελή εξεταστική επιτροπή την __η Ιουλίου 2016.

Νικόλαος Βεντίκος	*Απόστολος Παπανικολάου*	*Αλέξανδρος Γκίνης*
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Καθηγητής Ε.Μ.Π.	Καθηγητής Ε.Μ.Π.	Καθηγητής Ε.Μ.Π.

Αθήνα, Ιούλιος 2016

(Υπογραφή)

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ΤΣΕΛΕΠΗ ΕΥΑΝΘΙΑ

Διπλωματούχος Ναυπηγός Μηχανολόγος Μηχανικός Ε.Μ.Π.

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Περίληψη

Ο σκοπός της διπλωματικής εργασίας ήταν η ανάπτυξη ενός μοντέλου πρόβλεψης του βάθους διάβρωσης σε διάφορα σημεία του πλοίου.

Αρχικά, μελετήθηκε η διαδικασία της διάβρωσης, οι μηχανισμοί της, οι παράγοντες που την επηρεάζουν καθώς επίσης και οι συνέπειες της διάβρωσης. Έγινε πιο λεπτομερής αναφορά στη θαλάσσια διάβρωση, τόσο στα πλοία όσο και στις πλωτές κατασκευές καθώς και στους τρόπους προστασίας αυτών από τη διάβρωση. Στη συνέχεια, μελετήθηκαν τα αντιδιαβρωτικά χρώματα καθώς και οι απαραίτητες ενέργειες προετοιμασίας των επιφανειών για την εφαρμογή τους.

Ακολούθως, μελετήθηκε εκτενώς ο λιμενικός έλεγχος και οι διεθνείς συνθήκες που διέπουν τις επιθεωρήσεις στα πλοία. Αναφέρθηκαν οι μεγάλοι τοπικοί συνεταιρισμοί που δημιουργήθηκαν με σκοπό να ενοποιηθούν οι λιμενικοί έλεγχοι. Ακόμα, παρουσιάζονται κάποια γενικά στοιχεία σχετικά με τις διάφορες επιθεωρήσεις που υποβάλλονται τα πλοία καθώς και οι μεγαλύτερες βάσεις δεδομένων στις οποίες καταχωρούνται τα στοιχεία των επιθεωρήσεων ώστε οι πληροφορίες αυτές να είναι προσβάσιμες από τα ενδιαφερόμενα μέρη.

Για την ανάπτυξη του μοντέλου μελετήθηκαν διάφοροι παράγοντες που επηρεάζουν τόσο τη διάρκεια ζωής της βαφής όσο και το βάθος της διάβρωσης. Το βάθος διάβρωσης επηρεάζεται από την ηλικία του πλοίου, τη διάρκεια ζωής της βαφής του καθώς επίσης και από κάποιους άλλους παράγοντες όπως το φορτίο που μεταφέρει και οι περιοχές που ταξιδεύει. Η διάρκεια ζωής της βαφής του πλοίου επηρεάζεται από παράγοντες όπως η συντήρησή του, το φορτίο που μεταφέρει, η ποιότητα κατασκευής του και από το ιστορικό επιθεωρήσεων που έχει περάσει. Αφού αναπτύχθηκε το μοντέλο, επιλέχθηκαν τρία πλοία, ένα φορτηγό πλοίο, ένα δεξαμενόπλοιο και ένα πλοίο γενικού φορτίου ώστε να έχουμε αποτελέσματα από το μοντέλο μας. Πιο συγκεκριμένα, μελετήθηκαν συγκεκριμένες περιοχές στους χώρους φορτίου και στις δεξαμενές έρματος και για τους τρεις διαφορετικούς τύπους πλοίων.

Τέλος, έγινε μια ανάλυση ευαισθησίας για να δειχθεί ποιοι παράγοντες επηρεάζουν περισσότερο το τελικό αποτέλεσμα. Η διαδικασία αυτή πραγματοποιήθηκε για ένα τύπο πλοίου και συγκεκριμένα για δεξαμενόπλοιο για τις διάφορες δομικές περιοχές τόσο στους χώρους φορτίου όσο και στις δεξαμενές έρματος.

Λέξεις Κλειδιά: << επιθεώρηση με βάση το ρίσκο, μοντέλο διάβρωσης >>

Η σελίδα αυτή είναι σκόπιμα λευκή.

Abstract

The scope of this thesis was the development of a predictive model for the depth of corrosion at various structural points of the ship.

Initially, the corrosion process was studied, as well as its mechanisms and its consequences. A more detailed reference was made to marine corrosion, both at vessels and at floating structures. Furthermore, the anticorrosive paints set into consideration and all the necessary steps of surface preparation for their implementation.

Subsequently, the port state control was extensively studied and the international conventions governing inspections on ships. Moreover, the local agreements between neighbor countries were mentioned. These local cooperatives were created in order to consolidate the port state control inspections within specific areas. Some general elements regarding inspections on board were presented and the largest databases on which are recorded the data of inspections so that this information can be accessed by all parties concerned.

For the model development various factors affecting coating lifetime and the depth of corrosion were studied. The depth of corrosion is affected by the age of the ship, the coating lifetime as well as some other factors such as the cargo carrying and operational area. The coating lifetime is influenced by some other factors such as the maintenance, the cargo carried, the building quality of the vessel and the survey records. After the model was developed, three vessels were selected, a bulk carrier, a tanker and a general cargo ship in order to get results from the model. More specifically, some structural areas in cargo spaces and in ballast tanks were studied for these three different ship types.

Ultimately, a sensitivity analysis was performed in order to demonstrate which of the above mentioned factors affect the most the final results. This procedure was carried out for a type of vessel namely tanker for all the different structural points both in cargo spaces and in ballast tanks.

Keywords: << risk based inspection, corrosion model >>

Η σελίδα αυτή είναι σκόπιμα λευκή

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Abreviations

RBI	Risk-based Inspection
PoF	Probability of Failure
CoF	Consequence of Failure
ISO	International Organization for Standardization
ASME	*American society of mechanical engineers*
API	American Petroleum Institute
RIMAP	Risk Management Professionals
CEN	European Committee for Standardization
FSIS	*Food Safety and Inspection Service*
WSAA	*Water Services Association of Australia*
DNV	*Det Norske Veritas*
GL	*Germanischer Lloyd*
DAG	*Directed Acyclic Graph*
IMO	International Maritime Organisation
ILO	International Labour Organization
UN	United Nations
SAR	Search and Rescue
MCA	Marine Coastguard Agency
EU	European Union
MOU	Memorandum of Understanding
PSC	Port State Control
SOLAS	International Convention for the Safety of Life At Sea
MARPOL	International Convention for the Prevention of Pollution from Ships
STCW	International Convention on Standards of Training, Certification and watch keeping for Seafarers
UNCLO	United Nations Convention on the Law of the Sea
ISM	International Safety Management
COLREG	Collision Prevention Regulations
ISPS	International Ship and Port Facility Security
WT	Wall Thickness
NB	New Building
BC	Bulk Carrier
GCS	General Cargo Ship
BT	Ballast Tank
CH	Cargo Hold

1 Literature Review

1.1 RISK-BASED INSPECTION

This literature review aims to examine published reports and researches related to Risk-based Inspection (RBI) procedure. Risk-based inspection is methodology which involves the probability of failure (PoF) and the consequence of failure (CoF) in contrast to condition-based inspection. Each industry gives different definition for risk, although according to International Risk Management Institute risk is defined as "Uncertainty arising from the possible occurrence of given events." Another definition is given by the International Organization for Standardization (ISO) who defines risk as "the effect of uncertainty on objectives." A financial publication defines risk as "the variability of returns from an investment" when another financial definition for investment risk is "deviation from an expected outcome." There are even more definitions for risk than the ones already presented and this variation proves that there are a lot of different approaches, some dealing with uncertainty, some with threats, some others with events which are either predictable or unpredictable. (Gordon D. Proctor, 2012)

Generally, risk is a mathematical expression that depends on the probability to happen an incident and the consequences of this incident.

Risk = Likelihood (Probability) x Consequence (Severity)

According to risk-based inspection items with high probability to occur and followed by important consequences are given priority during inspection, although if some items have low probability but in case of failure high consequences are also inspected with priority. A result of this method is the optimal distribution of the provided resources for the inspection and a relative reduction of the time of the inspection, with multiple advantages of all parties concerned. The risk-based inspection procedures have been developed in two different directions: the qualitative approach is used for general issues and the quantitative one is used for more detailed issues.

“The first idea of Risk Based Inspections (RBI) has been introduced in 1991 by American society of mechanical engineers ASME to plan equipment inspections, aiming to reduce risk without affecting costs.” (Paolo Bragatto, 2012) Basically, the idea of risk-based inspection is to optimize the intervals between the inspections, which are affected by the assessment of failure risk instead of the methods used by that time where the inspection modes and times were defined by law, based on a deterministic model. There are several codes regarding RBI although the most popular ones are: the API 581 code by the American Petroleum Institute (API, 2008), the RIMAP by the European Committee for Standardization (CEN, 2008) and the code by the American Society of Mechanical Engineers (ASME, 2008). (Paolo Bragatto, 2012)

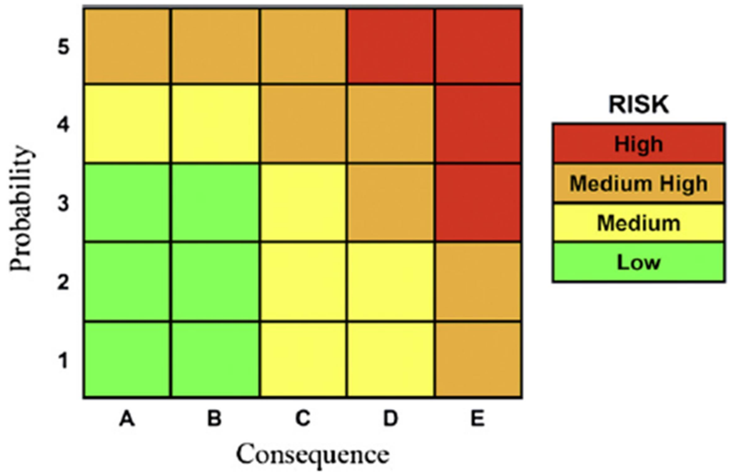


Figure 1: Ranking Criteria for likelihood and Consequence

"Risks are classified by the distribution of likelihood and consequence as shown in Fig. 1. More specifically categories 1, 2, 3, 4 and 5 represent the likelihood of failure from 1 to 5 in an increasing order. The consequence category A, B, C, D and E represents the consequence of failure from A to E in an increasing order for clearly taking hold of the distribution of the risks." (Tien, Hwang, & Tsai, 2007)

Then according to the findings the inspectors have to form a risk matrix in order to be able to decide the risk level of equipment inspected. A risk matrix is presented in Fig. 2. (Shuai, Han, & Xu, 2012)

Likelihood category

Likelihood factor	Likelihood category
1–15	1
16–25	2
26–35	3
36–50	4
51–75	5

Consequence category

Consequence factor	Consequence category
0–19	A
20–34	B
35–49	C
50–70	D
> 70	E

Figure 2: Matrix indicating risk levels

According to risk-based inspection methodology it is possible to achieve lower levels of risk with simultaneous increase of the levels of safety without increasing the costs. In the beginning because of the method's many degrees of freedom many national Legislation approach the risk-based inspection method with precaution and its implementation must be authorized every time demonstrating its deterministic equivalence. However for more than a decade risk-based inspection implementations have been demonstrated successful by many different operators leading a few countries to recognize officially risk-based inspection methods as an adequate alternative to time based methods and at the same time many other countries are still facing them cautiously. *"The strengths of the RBI methods are more effective inspections and optimized costs. The weaknesses are the definition of the assessment method and the level of tolerable risk."* (Paolo Bragatto, 2012)

1.1.1 CROSS-COUNTRY PETROLEUM PIPELINE

Petroleum is necessary for the countries for multiple purposes such as transportation, heating and industries operation. The first crude oil pipeline was built in 19^{th} century and since then this project is constantly evolving. "*Oil pipelines are made from steel or plastic tubes with inner diameter typically from 4 to 48 inches (100 to 1,220 mm). Most pipelines are typically buried at a depth of about 3 to 6 feet (0.91 to 1.83 m). To protect pipes from impact, abrasion, and corrosion, a variety of methods are used. These can include wood lagging (wood slats), concrete coating, rock-shield, high-density polyethylene, imported sand padding, and padding machines." (Tien et al., 2007)*

Pipelines are used for the transition of various goods like gas, petroleum and finished products through underground or aboveground infrastructure for long distances either inside a country's boundary or between different countries and even continents. The usage of pipelines has been proved probably the energy-efficient, safe, environmentally friendly, and economic way to ship these products. Although for pipelines the possibility of failure is much lower than this of the railway or highway transportation, it still exists and in case of failure the consequences can be disastrous. "*In 1993, in Venezuela, 51 people were burnt to death when a gas pipeline failed and the escaping gas ignited. Again in 1994, a 36-inch (914 mm) pipeline in New Jersey failed, resulting in the death of one person and more than 50 injuries. Similar failures also have occurred in the UK, Russia, Canada, Pakistan, and India (Hopkins, 1994).*" (Dey, 2001)

It is obvious that the failure rate of pipeline must be as low as possible and for that reason various techniques are used to achieve this goal. "*Traditionally, most pipeline operators ensure that during the design stage, safety provisions are created to provide a theoretical minimum failure rate for the life of the pipeline. Safety provisions are considered when selecting pipes and other fittings. To prevent corrosion, a pipeline is electrically isolated by providing high resistance external coating materials. As a secondary protective measure, a low-voltage direct current is impressed in the pipe at a pre-calculated distance to transfer any corrosion that occurs due to breaks in the coating caused by a heap of buried iron junk, rails, etc. This is called impressed current cathodic* *protection."* (Dey, 2001) In modern methodologies the structural integrity of pipeline can be ensured while the pipeline is in service.

Even nowadays the inspections and the maintenance practices are mostly based on experience. A cross-country pipeline has to face different conditions depending on the diversity of the soil and the temperature difference between the places crossed by the pipeline, which affect the behavior of the pipeline along its length and throughout its life-cycle. A technique that will give guidance to the operators of the pipeline system, who are also decision makers for the inspection, to choose among other inspection techniques the most appropriate one. In order to define the risks, a hierarchy procedure is necessary where the element of subjectivity and individual assessment, especially in decision-making procedure, is limited. *"The procedure for building an Risk-based inspection model for piping in the petrochemical industries includes collecting and analyzing the related domestic and international data, as well as confirming the standard for verification." (Tien et al., 2007)*

The methodology used for pipeline inspections is «divide and conquer»: the pipeline is divided into sections along the length, all the information concerning this section should be collected and finally the risk level is identified. The more often reasons for which the pipelines fail are: corrosion, construction and materials defects, external interference and human or operational error. Some of the advantages are that subjectivity is reduced and is more achievable to identify the right section of the pipeline which has to be inspected.

"The technique does have limitations, because subjectivity is not totally eliminated. For instance, the weightage against each of the failure factors is based upon experience and available data. Despite these limitations, a cross-country petroleum pipeline inspection and maintenance policy formed on the basis of our methodology is an effective tool to mitigate risk. It is cost effective and environmentally friendly." (Dey, 2001)

1.1.2 LARGE-SCALE CRUDE OIL TANKS

Technological development and the increase in living standards have led to an increased demand for products, and therefore the requirements for petroleum from industries in order to respond to the new reality were also enlarged. So the Crude Oil Companies were asked to manage larger orders and therefore larger storage was necessary. Therefore conventional petroleum tanks no longer meet current needs and thus large-scale oil tanks were built. This kind of tanks is more convenient for the industries since they require less amount of iron in their manufacture, less space for their placement as well as lower maintenance costs, due to the replacement of the multiple pump systems for many small tanks by less for the larger tanks. However a potential failure to a large-scale oil tank, in addition to the environmental pollution due to leakage could provoke even fire or explosion.

The inspection plan for these tanks is critical in order to avoid unpleasant situations. The tanks should empty and clean to be inspected which takes time and it is also possible to delay the production of the industry. By following a periodic inspection plan some tanks with low failure risk will be inspected raising the cost of the inspection while causing losses due to business interruption and some other tanks with high failure risk will be inspected with delay and severe problems, mainly caused by corrosion in the tanks, may occur. "*Therefore, the determination of a reasonable inspection interval not only can reduce inspection costs and financial loss for business interruption, but also avoid environmental cost, component damage caused by the leak of tank.*" (Shuai et al., 2012)

A risk-based inspection plan, which can deal with these problems and provide a plan with optimum frequencies of inspection and appropriate methods, is necessary. Risk-based inspection is able to identify the tanks with high corrosion risk and those with low risk, so the resources of the inspection are focused on the high risk tanks. "*One of the purposes of risk analysis based on RBI is to rank the relative risks of facilities, units, systems, equipment or components in a plant. So inspection and maintenance activities can be concentrated and more cost-effective.*" (Shuai et al., 2012) The advantages for the industry are less time and lower cost for the inspection while less interruption for its production.

The level of the acceptable risk, for example the acceptable thickness of the tank's bottom, should be identified by the industry. The reason why the risk is connected with the bottom of the tank is because the bottom is more vulnerable at corrosion than the shells of the tank. When the bottom is thinner than the acceptable values should be repaired or removed. "*The determination of the acceptable risk for crude oil tank should not be allowed to deteriorate to a point where the minimum acceptable thickness or fitness-for-service could be threatened. In order to ensure safe operation of all tanks, an identical acceptable risk for the whole oil depot should be lower than the minimum value*" (Shuai et al., 2012) This may cause a little higher cost for the repairs but it is accepted considering the consequences of a possible leakage.

1.1.3 CHEMICAL PROCESS INDUSTRY

One of the industries which are using risk-based inspection is Chemical Process Industry mainly for equipment as pipelines transferring oil and gas under pressure. Such items is very likely to face corrosion problems and in case of failure there will be severe consequences such as release of toxic gases, fire, injury to operating personnel and damage to the surrounding environment. The steps of a typically risk-based inspection procedure are the following (Perumal, 2014):

- Categorize all operating equipment as high, medium or low risk item;
- For items classified as high and/or medium risk carry out detailed assessment while taking into consideration the possible consequences due to the corrosion leakage;
- Based on the results of criticality appraisal to each item should be given the appropriate priority according to their risk rating;

- Design an appropriate Risk Based Inspection Program (RBI) to monitor corrosion more actively in high and medium risk units.

To proceed with the Risk-based Inspection procedure the industry has to collect various essential data in order to create a significant database. Many times an industry uses data "borrowed" from industries with similar experience and generally as much information as possible should be obtained in order to identify better the damage mechanism. After the identification of the mechanism the industry has to proceed to the probability determination and to the severity determination so finally to get the equipment's risk ranking. "*The probability of leakage due to general corrosion is determined from system parameters like thickness of the wall of the equipment/piping, flow velocity, corrosion allowance. These consequences are basically loss of containment, quantity based on hold up volumes, and hazardous nature of the process fluid." (Perumal, 2014)*

The combination of the above mentioned probability of an incident to happen with its consequences determinates the risk level. Depending on the risk level which each industry can afford the inspection plan should be reconsidered and some improvements to be added. *"Risk-based inspection is highly effective in improving plant safety, compared to conventional code-based inspection programs. RBI can reduce risk considerably, even before any corrosion mitigation methods are put into practice." (Perumal, 2014)*

It is obvious that risk-based inspection is a dynamic procedure, which includes lots of different parameters and it is also continuously updating and improving. Furthermore, it is possible that the equipment and the processes used for risk-based inspection should be updated at as short as necessary intervals so that the inspection's result to be trustworthy. *"When RBI identifies potential equipment flaws, the equipment must be evaluated using appropriate engineering analysis to evaluate its suitability for continued operation (fitness for service) and decisions taken on repair, replacement, maintenance or for continued operation." (Perumal, 2014)*

1.1.4 PUBLIC HEALTH

"*The Food Safety and Inspection Service (FSIS) is proposing a Public Health Risk-Based Inspection System the purpose of which is to focus FSIS inspection resources on the areas of greatest food safety risk and improve the Agency's ability to protect public health while maintaining the levels of inspection required*." (*Public Health Risk-Based Inspection System for Processing and Slaughter* 2008) The bacteria of Campylobacter, Salmonella, and Escherichia coli (E. coli) are most often responsible for foodborne infections. It is estimated by the FSIS that approximately 60 percent of these infections originate from Salmonella and 34 percent from E. coli.

The FSIS inspector should check the sanitary conditions in the various facilities and companies associated with foodservice and sale of food, like restaurants and supermarkets, in order to prevent epidemics due to such causes. The Public Health Risk-

Based Inspection System is supposed to assist the inspectors to focus on the critical points of the system but also to certify that certain measures will be taken for those who don't comply, in order to protect public health from foodborne infections and epidemics.

"*Observations at vulnerable points may reveal the establishment is failing to maintain sanitary conditions or failing to implement sanitation standard operating procedures and consequently might be yielding product that is injurious to health.*" (*Public Health Risk-Based Inspection System for Processing and Slaughter* 2008)

Public Health is very important and affects almost all the people of a society so the inspections should be carried out with attention and mostly at these points which are most possible to cause huge problems. It is also necessary that if at a routine inspection something odd is observed, inspectors are required to look in depth and a repetitive inspection to take place shortly. In public health circumstances the acceptable risk levels should be extremely low, due to the severe consequences of a possible foodborne infection or epidemic which is going to affect many people, and for some of them, in extreme situations, can be fatal.

1.1.5 TRANSPORTATION

Transportation management is a wide field where risk-based inspection is possible to be applied, mainly in occasions where possible failure will have severe consequences such as the destruction of a part of a highway or a collapse of bridge. In such situations the incident can be fatal for some people and for more others to get injured. The World Road Association has defined risk as "The combination of the probability of a hazard and its consequences" although it notes that risk could be more broadly defined as "the possibility of a negative deviation from whatever is the desire of any human being." The Risk Management Process Manual of the New Zealand transportation agency defines risk as "The chance of something happening that will have an impact on objectives. It is measured in terms of a combination of the likelihood of an event and its consequence." (Gordon D. Proctor, 2012)

It is more than obvious that in such public infrastructures which are used by many people every day, there should be high standards during their construction and additionally a very effective inspection plan. As already mentioned a risk-based inspection plan can provide an inspection plan with less time needed during the inspection and with lower cost comparatively to a condition-based inspection. Based on this method an industry and/or a government are able to locate the weaknesses of the construction and to define the acceptable risk levels. Concerning the highways "The methodology enables the filtering and assessment of assets for maintenance while addressing the potential for extreme events. The methodology balances the costs, benefits, and risks of maintenance and inspection policies as applied to various types of assets. Three objective functions are used in evaluating options and strategies: minimizing short-term cost, minimizing long-term cost, and maximizing the remaining service life of highway assets." (Gordon D. Proctor, 2012)

1.1.6 WATER SECTOR VALVES

“*Water utilities are today faced with the challenge of delivering required levels of service with limited funds in the face of an ageing asset stock and increasingly stringent standards and customer expectations.” (Marlow, Beale, & Mashford, 2012)* The water can cause serious deteriorations and damages to almost all the component which operate in the aquatic environment, and more specifically to valves. Due to these damages the possibility of a valve to fail is raising and in that case it is possible the whole network to face serious problems. Water utilities have to follow a well-designed inspection plan in order to prevent unpleasant situations. *“In 2006, the Water Services Association of Australia (WSAA) held a workshop to formulate a program of research to address gaps in asset management capacity. One priority identified was the need to develop specific guidance on condition assessment and inspection processes for water main valves.” (Marlow et al., 2012)*

So a risk-based inspection plan can provide a balance between the cost of an inspection and the cost that may occur in case of a failure. Employees with significant knowledge of the aquatic environment and its implications as well as of the whole network and its weakness can contribute significantly in the hierarchy of the components to be inspected in cases where data from industries/utilities with similar experience are not available. “*Once the inspection program has commenced, data will become available that can then be used to schedule and prioritize on-going inspections. In this case, the lowest risk valves were monitored opportunistically (with systems put in place to ensure relevant data was captured), whereas higher risk valves were placed on a program of routine inspections, with immediate corrective action being required for the highest risk valves.” (Marlow et al., 2012)*

1.1.7 OFFSHORE PLATFORMS

Offshore platforms, first used in the late 19th century, are large structures made of concrete or steel which are used to drill wells and extract oil and natural gas, at sea and/or lake areas of great depth. However, as the years pass and the standards rise, these platforms are becoming more complex and their operating systems are becoming more innovative. Furthermore these platforms have facilitated for accommodation of the working personnel. The three main types of offshore platforms are these which are anchored to the seabed, these which are floating and these which are consisted of an artificial island. Offshore production platforms, also called oil rings, are built on a nearby coast and the transferred to the drilling point. (http://en.wikipedia.org; Robert)

Almost all oil rings have permanent staff, from geologists and engineers to doctors, drivers and cooks, to achieve optimum operation. These people are facing everyday difficult situations and potentially fatal condition. “*The business of an oil rig boils down to drawing extremely flammable fluids out of the Earth, burning some of it off in a giant jet of flame and separating highly poisonous hydrogen sulfide gas from the extracted petroleum. On top of this, workers have to deal with all the typical dangers* *associated with operating dangerous machinery and working at tall heights in windy, stormy conditions." (Robert)* So, all these operators of marine structured have to make sure that these constructions are safe and stable during the life cycle of the platform and to assure that an Inspection, Maintenance and Repair plan is adopted and used. "*For very large structures in harsh environment as offshore platforms, there is a need to optimize inspections planning and to model data both in terms of decision on the actual structural integrity and impact on the global cost." (A. Rouhan & Schoefs, 2003)*

Offshore platforms face various difficulties, from finding the correct installation point to their smooth operation. These structures are placed at deep and hostile waters with any problems arising from these difficult physical conditions: "t*he deep-water environment is cold, dark, distant and under high pressures and the oil and gas reservoirs, when found deep in the Earth, exist at even higher pressures (thousands of pounds per square inch)." (Aryee, 2012)* The construction materials, the installation point, the suitable equipment, the accommodation facilities and everything else placed on an offshore platform should be checked and inspected very carefully and detailed.

The previous years the rapid development of these structures create new requirements and safety criteria which lead to new and improved inspection methods with the objective of better management of time and resources available. Traditional methods of inspection didn't provide the required flexibility so new methods of inspection were needed. Risk-based inspection planning is one of these methods, providing a framework which enables operators and inspectors to be more focused and effective with their jobs. "*Risk-based inspection (RBI) is an indispensable methodology, which identify the structure inspection intervals based on both the structure failure consequence and probability.*" (Huilong Ren, 2014) RBI methods combine data based on experience with various techniques in order to provide a plan of inspections which determine the frequency and purpose of each inspection. ("Hydrocarbon Engineering: A Calculated Risk," 2012)

According to ABS classification society in order to identify the risk the three following questions should be answered:

i) What can go wrong?

ii) How likely is it?

iii) What are the consequences?

Based on the above answers a risk based inspection plan can be compiled and followed by the staff of an offshore platform. It is obvious that an area with very low risk level will require little or no inspection which gives the opportunity to the person in charge to redirect the available resources to high risk areas. Furthermore, a risk based inspection plan can ensure that according to the various risks facing at different areas, the correct inspection method is selected and will be held by appropriately trained people with the necessary equipment.

"With respect to the RBI program, likelihood is considered to be the most important factor in the risk equation since it most directly affects the selection of inspection frequency." (ABS, 2003, December)

The development of a risk based inspection model can be based on various methodologies. However the typical procedural steps for the development on an RBI program, supported by ABS, are the following:

i. RBI Team Setup
ii. Component Grouping and Baselining
iii. Risk-Based Prioritization
iv. Inspection Plan Development
v. Inspection Execution and Analysis of Inspection Results
vi. RBI Program Updating

Operational experiences can provide valuable data during the process of creating a Risk-based inspection model. The development of a reliability-based management of inspection, monitoring, maintenance and repair of such platforms is strongly related to the design criteria prior to the construction of offshore marine platforms. (Moan, 2005)

The most serious problems of the offshore platforms are fatigue and corrosion, and by using a risk-based inspection plan the inspectors are able to design a plan of inspection which will give greater priority to these structural components that have a greater risk of failure. (A. Ku, 2012) "The methodology facilitates a generic modeling of fatigue and corrosion degradation for both structural and process type components." (Michael Havbro Faber, 2003) A «corrosion handbook» should be kept updated with the result of the latest inspection in order these result to be used by a risk-based inspection method to operate properly and give qualitative results on the degree corrosion and lifecycle of the inspected object.

Non-destructive underwater inspections are a method for inspected off shore platforms and it is mainly use for cracking incidents. However these inspections are pretty expensive and the areas these platforms are placed not very friendly, so the inspections are not carried out as often as they should. There are often recorded false alarms so "The basic policy 'repair when crack is detected' and 'do nothing when no crack is detected' is shown to be not optimal" (Antoine Rouhan, 2002) In order an off shore platform to avoid the loss of its structural integrity, a maintenance and inspection plan is necessary. Risk based inspection models are influenced by false alarms so a risk based inspection model cannot be form using a deterministic approach. The most valuable results occur by taking into consideration both the probability of detention and of false alarms, which lead to an optimal inspection and maintenance plan.

To design a risk-based inspection plan, experienced staff and people with specialized knowledge are necessary and nowadays technology plays an important role in the whole process. After the merge of classification societies, DNV and GL in 2013, the combination of their technical know-how as well as their expertise staff manage to create new software used by offshore platform's operators worldwide, the Synergi Plant. "*This brings together GL's Galiom product for managing asset integrity risk with DNV's legacy software*" (http://www.energyglobal.com) "*The software is based on the extensively used risk-based inspection methodology.*" (https://www.dnvgl.com) There is an exclusive edition of the Synergy Plant Risk-based Inspection for the offshore platforms. More specifically this software includes (https://www.dnvgl.com):

- *Includes methods for qualitative, semi-quantitative and quantitative RBI*
- *Enables you to evaluate and justify inspection budgets and set inspection targets*
- *Helps you demonstrate effective return on investment*

- *Qualitative analysis can start at a high level and gain detail as more data becomes available*
- *Detailed calculation of consequence of failure, probability of failure, financial risk, cost benefit, and optimization in quantitative modules.*

Risk-based inspection method in an offshore platform can assist the people on it, to save time and to prevent unpleasant situation by performing focused inspections in compartments with higher risk of failure and with severe consequences. The technology and the software mentioned above, is an advantage for the operators and the inspectors of the offshore platforms. “Risk-based Inspection methods provide a better linkage between the mechanisms that lead to equipment failure and the inspection approaches that will effectively reduce the associated risks.” ("Hydrocarbon Engineering: A Calculated Risk," 2012) By this point of view RBI methods provide better support to the inspectors to perform more accurate inspections whose result are even more trust worthy.

Except for the risk faced by the offshore platform itself there are other kind of “risks” such as risks faced by the personnel of the platform, risks faced by the environment near the platform and of course economical risks. So, for the overall facility the level of the accepted risk should be defined considering the risk acceptance criteria of each individual subsection. The necessary inspection and maintenance plan used by offshore structures should take into consideration “all aspects of traditional risk analysis and methods of structural reliability theory.” (Goyet, Straub, & Faber, 2002)

In conclusion, it is more than obvious that Risk-based inspection methods goal isn’t to relax inspection practices. Their goal is to focus on areas with higher risk to fail or higher consequences by redirecting the available resources to these difficult areas, while on the same time less dangerous areas are inspected but not in the same frequency. Risk-based inspection model is a dynamic model and it should be updated and revised as soon as new information and results arise.

1.2 BAYESIAN NETWORKS

In recent years, networks of Bayes are more and more often used and expanding their scope particularly in shipping and maritime transportations. The Bayesian networks represent the relationship between the data given on the model and the results that count on possible manifestations.

“A Bayesian network, Bayes network, belief network, Bayes(ian) model or probabilistic directed acyclic graphical model is a probabilistic graphical model (a type of statistical model) that represents a set of random variables and their conditional dependencies via a directed acyclic graph (DAG).” (https://en.wikipedia.org)

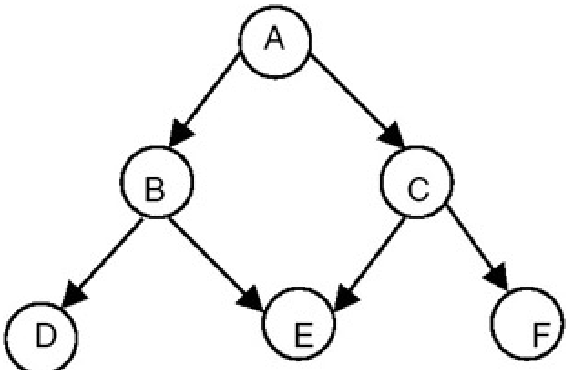


Figure 3: Bayesian Networks Directed Acyclic Graph (DAG)

The networks of Bayes are becoming more popular due to some specific characteristics that make them more manageable. Bayesian networks (Heckerman, 1995, March):

- Can readily handle incomplete data sets
- Allow one to learn about causal relationships
- In conjunction with Bayesian statistical techniques facilitate the combination of domain knowledge and data
- In conjunction with Bayesian networks and other types of models offers an efficient and principled approach for avoiding the over fitting of data.

Bayesian networks have a wide range of applications in the maritime industry, like maritime piracy, search and rescue, ship grounding and collision accidents.

Oil exploitation and shipping is growing rapidly and one of the major threats they face is the pirate attacks. An innovative solution to these attacks could be a network that takes into account the various parameters of a potential threat: the characteristics of the threat, available tools for protection, the environmental parameters etc. and define the appropriate reaction ways and response measures to deal with that threat. "*The creation of the Bayesian network used for response planning relied on the coupling of quantitative information from the IMO's "Piracy and Armed Robbery" database and qualitative knowledge offered by experts in the maritime domain. Development was divided into two stages. The first step was to construct a Bayesian network from database records of attacks against shipping and oil installations across the globe, while the second step was to exploit the knowledge of experts in order to refine the results and to add counter-measures.*" (Amal Bouejala, 2014) However, this model do not take into consideration all the related values, but it can be used to help the crew to define the principal steps which must be done in order to protect themselves.

An intention of the English government is to improve the operations of the Search and Rescue (SAR) in cooperation with the Maritime and Coastguard Agency (MCA) centers. "An earlier study highlighted the importance of explanatory variables such as the size or scale of incidents, staff workload and the length of coastline monitored by each coordination center." (Norrington, Quigley, Russell, & Van der Meer, 2008) So the aim is to create a Bayesian model that takes into consideration all the key factors that affect the proper functioning of Search and Rescue operation. The basic problem is that many factors needed by the Bayesian network are not measure officially and in the next stage more data and details should be collected and measured. However, the Bayesian network provides some for procedure improvement while the validity of the model's results is matter of further research.

Modern ships are equipped with passive protection systems but accidents still happen in the maritime transportation and it is generally accepted that it is the human factor which plays a significant role in most accidents. "Grounding (32%), striking (24%) and collision (16%) are the most frequent occurrences and they have the highest rate of casualties." (Trucco, Cagno, Ruggeri, & Grande, 2008) A good estimation of the probability of a ship-to-ship collision is a step closer to make maritime transportation safer. "The number of collisions N within a certain ship traffic area and time is calculated as a product of a number of geometrical collision candidates N_A and a causation probability P_C" (Hänninen & Kujala, 2012)

$$N = N_A \cdot P_C$$

In the Gulf of Finland a Bayesian network model is used in order to study the parameters of the weather, human factor and extra vigilance which influence the probability of a collision accident during the passage of a vessel from this particular area. "The results show that the probability of collisions is very sensitive to the causation probability value and it should be modelled with great care to obtain reliable results." (Kujala)

The operation of a vessel, especially an oil tanker entails many risks. The collision accidents are one of the most important danger ships face with immediate results to material damages on the vessel itself and the environment from potential leakage of the cargo. Although there are various systems installed onboard for the protection of the vessel the human factor still plays an important role during the operation of the ship. There is a methodology proposed in order to analyze the human factor and its reliability, based on Bayesian network model which can be applied to the oil tanker performance focusing on the possibility of a collision accident to occur. The above mention model is focused on defining the order of activities and random events that can lead to a collision accident and the actions that can be done to limit these risks. (Martins & Maturana, 2013)

2 CORROSION

2.1 HISTORICAL EVOLUTION

The man, from the beginning of its existence, making his effort for survival and in order to promote human life, invents and manufactures things and situations and then uses whatever is necessary to implement all of the above. In this effort, he began to use tools and weapons. For the manufacture of such tools and weapons, originally used, materials found in nature. Such materials, which were abundant in the environment where he lived, were the stones, wood and clay. Later, when demands increased, and he had already learned to utilize and tames fire, sought materials harder and more resistant which he could found in its natural environment and in addition could be formulated relatively easily. So man discovered and used metals.

The first metals discovered and used by man was gold and copper. Then he learned to mix copper with tin and makes so the brass, compound which is far more solid and more durable. The era of metals mainly starts with the use of brass. The use of metals has been undoubtedly one of the highlights of a creative course of man from the very dark cradle until today. The discovery and the use of metals was so important, that is considered a station in the history, and was able to characterize entire seasons, depending on which metal was used. At the same time, following the use of metals and their alloys began to employ him and the problem of wear of metal objects and tools he used to use in his everyday life. The damage was not only due to everyday use but mainly to the phenomenon of corrosion since the metal as we will see below have a natural erosion predisposition.

But indeed what is corrosion? For most people corrosion means "rust". But rust only describes the alteration of a single metal, and specifically iron, while corrosion is a destructive phenomenon observed at almost all metals. Generally, we could say that corrosion is the destructive deterioration of the metal surface.

The phenomenon of corrosion, like many other natural phenomena, was first observed in Greece, during the Minoan period. However several centuries passed from the Minoan period until we found again observations on the phenomenon of corrosion. Specifically, Plutarch, who was studying in details the superficial defects and corrosion of brass statues in Delphi, made so acute observations about the phenomenon of corrosion and went so deep while trying to interpret the phenomenon, that he managed to understand the actual mechanism, which only in 1958 was proved theoretically and experimentally.

The universal deployment and use of iron which withstands less corrosion compared to copper, made the study of the corrosion phenomenon more necessary than before. Despite this, the phenomenon of corrosion has been studied extensively since 1900, when we have the formulation of quantum theory by Plank. So in order a phenomenon takes place (such as the corrosion) we are not interested in the form (thermal, electrical, electromagnetic, etc.) of the energy available, but for the size of its quantum.

The man never stopped to use metals. Even today metals and their alloys are the main structural materials used in each artificial construction made by men. This is due to their excellent properties, physical and mechanical (strength, toughness, easy processing, etc.), and which they have been found long ago. At the same time, despite all the above mentioned good qualities they have, they still have several drawbacks. One of these disadvantages is their stability toward the environment that is not unlimited. As known, the environment in which a metal or alloy is exposed, can affect it significantly by causing damage or even total destruction. For this reason the engineer must be able to anticipate adverse conditions and prevent the destruction of the material. In most cases, this destruction of the material is due to corrosion.

It should be noted that there is no metal or alloy that does not corrode. This is due to the natural tendency metals have to be joined with various other components and forming compounds, which as shown to be most stable. For this reason, few metals are found in nature unedited in pure metallic, i.e., without other impurities. Metals which are found in nature in pure metallic form called noble (gold, platinum, silver and copper) and do not require special protection, remain stable and preserve their properties in most corrosive environments. In contrast, almost all other metals are found in nature in the form of compounds, mainly in oxides, and constitute the minerals. However, metals standardized in their metallic form, is typically energy upgraded materials in comparison to their raw materials, so they tend to return to their natural and stable oxidized form, which is lower energy level than the pure metals.

Since corrosion is a phenomenon that tends to restore metals or alloys in the original form of the natural compounds, of which the man spent energy to obtain them, the aim must be the restriction of the phenomenon, as the elimination of this is almost impossible. So our efforts should be focused on how to eliminate and slowdown this phenomenon. Prevention or reduction of the corrosion are essential and constitute both a technical and economic problem confrontation of a specific corrosion problem depends on the properties of the metal and the properties of the corrosive environment in which the metal will operate.

2.2 DEFINITION OF CORROSION

Confusion prevails in the literature as far as the definition of corrosion is concerned. This is because from time to time various definitions are given by different organizations, not necessarily perfectly coincident with each other. Some of these definitions are not complete and others are used for various practical purposes.

So the DIN 50900 (PART 1, 10) defines corrosion as the reaction (chemical or electrochemical) of a metallic material with the environment, which produces a measurable change in the material and can lead to its failure.

The definition of corrosion by ISO as given by the ISO 8084, of the year 1986 is the following: "Corrosion is the physicochemical interaction between a metal and its environment that results in changes in the properties of the metal, and which may lead to significant impairment of the function of the metal, the environment, or the technical system, of which these form a part"

A more comprehensive definition is the one emerged from discussions in the International Commission on Marine Corrosion and fouling and Construction International Congresses and is below. Corrosion is called every spontaneous, thus constrained, thus electrochemical, thus chemically, thus mechanical, hence biological nature deterioration of the metal and alloys surface, which leads to a loss of material.

The same definition applies, except for metals and alloys, and for any other material, with the observation that in these excels the alteration of the physical or chemical nature as the electrochemical (e.g. polymers) and grows the alteration of biological nature (e.g. wood, stone). Then the concepts mentioned in the definition will be explained separately.

- *Spontaneous alteration*: The phenomenon of corrosion is spontaneous and occurs from a higher energy level to a lower, since it is required by the second thermodynamic law. Spontaneous alteration contains the concept of the corrosion to be realized in natural corrosive environment.

- *Constrained alteration*: In this case, the phenomenon of corrosion is thermodynamically spontaneous but performed with acceleration because there is intense artificial corrosive environment. As intense artificial can be regarded chemicals, high temperature, radiation, increasing electrical charge etc. Therefore, the main difference from the first case (spontaneous corrosion) lies in the speed of corrosion and the possible change type (when she is compelled).

- *Distinction between electrochemical and chemical nature of deterioration*: It is known that during the electrochemical action takes place electrical current which is not seems to happen during chemical alterations. However in all chemical actions there is a redox step while an electron exchange is happening. Thus in a chemical reaction electricity enters spontaneously with electron transfer form. So the distinction between electrochemical and chemical alterations is not easy.

- *Mechanical alteration*: Mechanical alteration is considered any on-surface engineering injury, caused by friction, shock and flow effect of the fluid or sublimation (due to vacuum generation).

- *Biological alteration*: It is caused by microorganisms (natural or animal) that causing corrosion of metals in stationary (Piers) and mobile (ship) building, using their secretions. The problem is particularly intense on the hulls of the ships during their stay in ports.

- *Deterioration of the surface*: By this is meant the alteration of the actual surface. Actual surface is not only the geometric one, but the effective surface, i.e. the geometrical surface containing the irregularities and resources and the active sites as well as active streets of mischief structure. It is emphasized that only such a surface is base of phenomena such as corrosion.

- *Material loss*: Loss is understood as loss of material compared to the original form (Metal oxide) material, not necessarily the loss of mass of the material.

2.3 TYPES OF CORROSION

The types of corrosion are divided into various categories. They are divided according to the causes of corrosion, according to the results and according to the environmental characteristics

2.3.1 DISTINCTION ACCORDING TO THE CAUSES OF CORROSION

According to the definition, a case of corrosion can be classified in terms of the causes in the following categories:

- **Electrochemical corrosion**: Is the type of corrosion encountered most often. It is characterized by the presence of potential between the metal and the environment and various positions on the metal surface with different potential (local galvanic cells). The first (potential difference) is due to the disposition of the metal to deteriorate energy. The second (local galvanic cells) can come from mischief structure, lattice defects, etc. Characteristic of electrochemical corrosion course is the transfer of charges (ions and electrons) through the boundary surface of the metal to the corrosive environment and the generated potential difference and power flow.

- **Chemical corrosion**: Damage of the metal surface from chemical compound and deterioration of the surface due to chemical reactions. The main characteristic of this type of corrosion is that the redox action is performed in a closed chemical system and the electrons do not travel through the metal. As mentioned above, this type of corrosion, looks like the electrochemical and sometimes, depending on the conditions, can evolve into electrochemical corrosion and therefore the distinction is difficult. The result of the chemical corrosion is usually a uniform dissolution of the metal surface.

- **Mechanical (physical) Corrosion**: The friction causes deterioration to the metal surface by removing parts of the surface mechanically.

- **Biological corrosion**: With effect of microorganisms that adhere to the metal and corrode it with their secretions.

2.3.2 DISTINCTION ACCORDING TO THE FORM AND/OR THE RESULTS

According to the definition, a case of corrosion can be classified in terms of the form and/or the result in the following categories:

- **Uniform or general corrosion:** So called the corrosion, when on the surface of the metal or alloy, is observed the creation of a uniform, approximately equal thickness, corrosion product layer, or when an approximately uniform dissolution of the surface is taking place.

- **Pitting Corrosion, macroscopic local corrosion**: To this kind of corrosion, eclectic local formation of corrosion's product is observed. It is formed even if the metal or alloy is covered with the products of corrosion or protective paint or plated or selective dissolution of surface.

- **Stress Corrosion Cracking**: When from pitting corrosion or mechanical damage, a recess is created on the surface of a part of a machine or an installation which is stressed mechanically, and then brittle fracture of the entire segment can occur even if the tensile stresses are less than 10% of the breaking load of this specific part. Note that this type of corrosion is the most painful, and dangerous sometimes for critical components of an installation in terms of the effects and the results in extremely large and major financial effects of disasters, for little real loss of material from corrosion.

- **Cavitation Corrosion**: This type of corrosion is purely mechanical. Cavitation called the phenomenon in which in one or most points of a surrounding by liquid body, the local static pressure is lower than the saturation pressure corresponding to the temperature of the fluid and thereby vaporizing occurs with the formation of bubbles. These bubbles when transferred to another point with higher pressure, liquefied again at the surface of the solid body. When the bubbles collapse, high pressures are created, which lead to mechanical strain and damage of the solid and indenting, caves, craters are caused by local sublimation of the material. Such conditions occur in pipes and rotating pump vanes, ships and aircraft propellers.

From the above mentioned types of corrosion, the more dangerous ones are considered to be the corrosion with pitting and brittle fracture from corrosion with mechanical stress because a small loss of material can completely destroy the metal surfaces or even whole part of a structure or machine.

The last three types of corrosion, on the contrary to the first type, are characterized as " local or selective corrosion. " The type of corrosion will appear depends on the state of the metal surface, the type, intensity and corrosive environmental conditions.

2.3.3 DISTINCTION ACCORDING TO THE CORROSIVE ENVIRONMENT

As mentioned above, almost every metal or alloy, according to the second thermodynamic law tends to be corroded, whether it is placed in a corrosive environment or not. The corrosive environment plays a role, and ends up in quantitative difference, in terms of corrosion speed, change of corrosion mechanism and corrosion effects.

The following types of corrosive environments can be observed:

- Corrosion in the air (dry or moist, clean or contaminated): Atmospheric air can be categorized based on its composition at industrial, marine and agricultural. Its corrosive action, mainly due to the existence of oxygen and moisture, enhanced by the presence of polluting gases and ammonia (SO_2, NO_x, H_2S, NH_3).

- Corrosion on or in the ground (dry or moist, clean or contaminated): Soil is permeable to water and contains a large number of dissolved bodies. Therefore, the corrosive action of soil is due to moisture, acidity, dissolved salts, micro-organisms, the electrical conductivity and is most pronounced in situations where three surfaces (soil-metal-humid air) are combined.

- Corrosion in fresh water (in, on or around, clean or contaminated): The corrosive action of the water depends mainly on the dissolved oxygen contained in the water, the dissolved salts and gases, the microorganisms, dissolved or simply airborne particles.

- Corrosion in sea water, "water corrosion" (in, on or around, pure or contaminated): The corrosive effects of sea water is due to high salinity, the dissolved oxygen therein and the existence of microorganisms that either produce with their metabolism ions which interrupt the passive action of specific materials, or catalyze electrochemical reactions.

- Corrosion by exhaust gases or hot gases (dry or wet): Most exhaust gases and hot gases are very corrosive and this intensive tendency for corrosion is mainly due to very high temperatures, pressures, flow rates and the ingredients they contain.

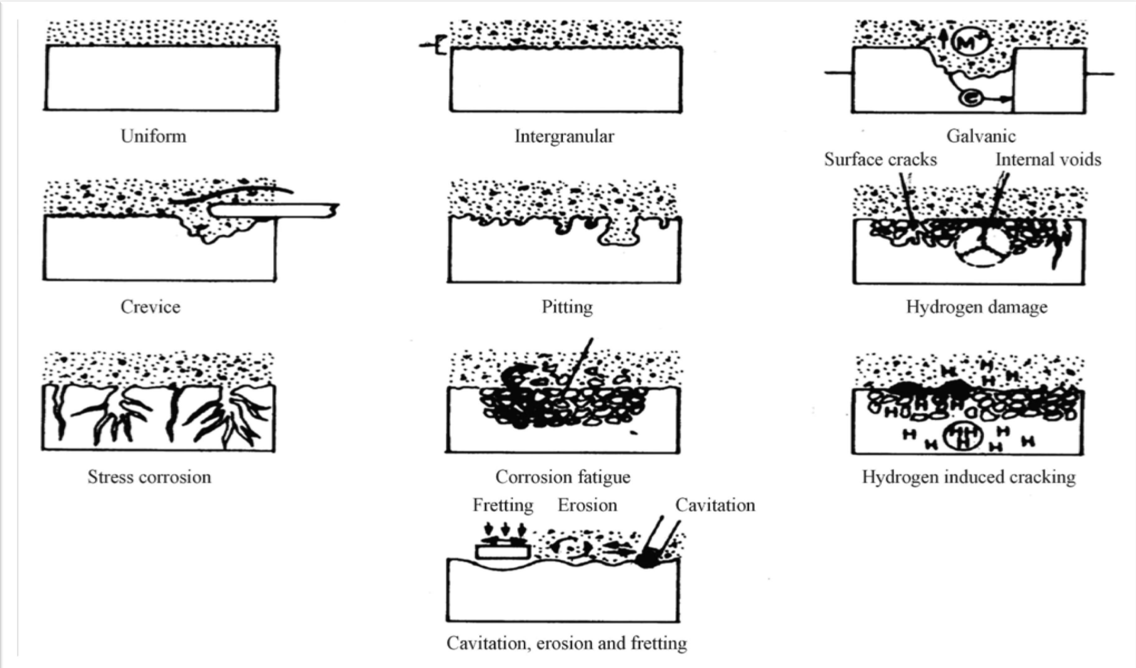
- Chemical corrosion: All chemicals inorganic and organic, are included here, and their strong corrosive effect depends on the chemical affinity of these substances with the metal surfaces they meet, the temperature, the pressure and the flow rate.

- Nuclear Corrosion: The environment in which the usage of radioactive substances is made or nuclear reactions occur is highly corrosive. This is because radiations affect the chemical composition, the structure and electronic properties of the metals (formation of active centers and structure ataxias) and the mechanism of electrochemical reactions (supply of activation energy).

Figure 4: Various types of corrosion

2.4 FACTORS AFFECTING THE PHENOMENON OF CORROSION

In this chapter the macroscopic and microscopic conditions affecting the rate of



corrosion are presented. Corrosion is influenced by environmental conditions (exogenous) and conditions that imposed by the materials themselves (endogenous). The major factors affect the speed of corrosion are the following:

2.4.1 EXOGENOUS FACTORS - ENVIRONMENTAL CONSIDERATIONS

Temperature: The increase of temperature generally increases the rate of corrosion. This effect is due to the general increase of the mobility of the atoms and molecules following the increase of the temperature.

Humidity: Humidity and rainfall accelerate the corrosion rate. It is known that in dry atmosphere corrosion of metals or alloys is presents little progress. Conversely, the presence of moisture speeds up significantly the rate of corrosion.

Presence of oxygen in the water: The dissolved oxygen concentration is a decisive factor in the development of corrosion. Increase of the amount of oxygen contained in a solution generally increases the corrosive action of the solution. Therefore both, fresh and sea water, not degassed, lead to an increased corrosion rate.

Effect of the conductivity of the corrosive environment: As the conductivity of the corrosive environment (e.g. presence of Cl-) is bigger, the corrosion is greater.

Effect of exchange corrosive environment or its properties: For switching the corrosive environment, or its properties (temperature, conductivity, pH, composition) of the environment itself. Such exchange may be the alternating tank filling with different fluids, rotated channeling of different liquids through tubes, alternating use of machinery in different corrosive environments (seabed trenching machines, outboard engines etc.), changing climatic conditions, etc. These changes cause more intense corrosion, than the retention of materials in stable conditions, even in corrosive environments.

Environmental conductivity, pH: Deterioration processes are achieved as the environment becomes more conductive and more acidic. The lower the value of the pH is the greater corrosion is generated. The corrosion rate is affected by the chemical affinity of the metal or alloy and corrosive environment. An increase in the concentration and conductivity leads to increased corrosion rates. Acidic solution intensifies, and alkali reduces steel corrosion (as the generation of Fe3O4 is favoring) and increases the corrosion of Al. So we can say that the pH increases the corrosion rate either because of an increase in conductivity (by increasing of OH^- or $H3O^+$) or due to liquidation of metals, alloys and their oxides in acid or basic environment.

Double or triple surfaces: From visual observations it was concluded that the existence multiple surfaces leads to intense, localized corrosion. This is due to two reasons: firstly, the increase in current density of electrostatic field generated and secondly, because of the creation of a galvanic cell while two different metals contact each other. This is a general phenomenon of corrosion of metals and alloys shown in each case of triple surface, e.g. vessel's load line (steel - salt water - air), the base metal batteries for power transportation (steel - reinforced soil or concrete - air), the free liquid surface contact points – metal containers - air (e.g. canned) etc.

The mechanical stresses: In general, existed mechanical stresses increase the speed of corrosion. Under certain circumstances can cause breakage of the metal element. (Corrosion caused by mechanical stress leading to brittle fracture).

Eluded currents: the electric currents circulating in the ground, walls, construction or water outside the existing circuits because they escape. The itinerary of such currents is determined by the principle that electricity follows the path of least resistance. Particularly strongly corrosive phenomena presented at the points where electrons abandon the metal surfaces (due to anodic dissolution). I should be noted that not only the direct, but also the alternating current may result and accomplish electrochemical actions, when they belong to certain frequencies or when the surface of the metals or alloys is covered by oxides with semiconductor properties, which can act as semi-rectifiers of the AC. Sources of such currents are facilities grounded in more than one location (e.g. electric railways), other conductors or cables using downward protection, telephone installations, or electrical networks, during welding powered cranes on rails, electrolysis installations, etc.

Switch or changing conditions: The corrosion drastically accelerated by the variations in the intensity of the environmental conditions.

2.4.2 ENDOGENOUS FACTORS – MATERIALS

Heterogeneity of surface or mass: It has been found that any heterogeneity of the surface of a metal or alloy exacerbate the corrosion. This is due to creation of local galvanic elements. The disparity may be due to different factors, such as:

- granules (by sandblasting is made for the purification of the surface)
- any other material or impurity
- sea pollution
- unevenness of the composition of the alloy's crystal on the surface
- variations in the chemical composition
- variations in the secondary structure (geometric mischief, mischief structure)
- protruded macroscopic or microscopic geometric abnormalities (geometric active sites) are corroded faster.

Active centers: The active centers, either structurally (crystal mischief by material's nature or processing) or geometric [macroscopically (corners, edges) or microscopically (crystal defects)], make the materials more sensitive and accelerate their deterioration. The active centers of materials generally categorized as ataxias, are of particular importance for corrosion.

Elastic and plastic deformations: Plastic deformation (or additional mischief structure), created by a mechanical or thermal treatment, exacerbate corrosion by leading to local anodized areas of the metal and therefore local galvanic cells. This phenomenon is general and contains all reactions, where a solid body, mostly metal, participates. Elastic deformations intensify corrosion. It is also a general phenomenon for reactions involving a solid body, mostly metal. So, we can generally say that mechanical stresses, internal or external, significantly accelerate the corrosive effects, and which can lead up to brittle metal structures.

Thermal expansion coefficient: Different thermal expansion coefficients, either between the crystals or granules of the same material or between different materials (metal-stone or marble, wood-metal, etc.) lead to accelerated corrosion by mechanical processes.

Contact with other metals: If two different metals or even the same (with different percentage structure ataxias) or alloys (even with the same components, but different composition or structure) are in contact, then one of these corrodes more (the more anodized of them) and the other less, compared to the corrosion that would have undergone if located separately in the same corrosive environment, because of the formation of galvanic cell.

<u>During corrosion are observed:</u>

- Local chemical actions: Two, even extremely adjacent points, which are in microscopically different conditions, present high corrosion difference;
- Swelling metals or alloys: Where the corrosion products can be stay on the surface;
- Diffusion: Of the metal ions and formation of corrosion products on a metallic or non-covering coatings of the metal or alloy which suffers by corrosion, i.e., without direct contact with the corrosive environments.

2.5 PROTECTION AGAINST CORROSION

After what has been mentioned in previous chapters, it is clear that for corrosion protection of installations and constructions one should follow the following procedure:

- Selection of suitable materials;
- Control of material properties with respect to corrosion and corrosive environment;
- Check the type of installation's corrosion;
- Reduction or elimination of the general conditions that accelerate the corrosion.

However it is essential to eliminate the general conditions accelerating the corrosion of metals and alloys.

Regarding the facilities which tend to corrode, the following should be avoided:

- geometric macroscopic and microscopic abnormalities
- structure ataxias
- the contact of two different metals or alloys
- surface unevenness
- triple-surfaces
- the elastic and plastic deformations
- internal mechanical stresses
- ambulatory electric currents
- high temperatures
- take into account the swelling during corrosion.

As for the corrosive environment must be avoided:

- the conductivity and pH (to be around 8.7 where possible)
- the large amount of dissolved oxygen

- the exchange of corrosive environment or the properties.

Usually these operations are sufficient and several application of additional measures and methods of protection which have enough cost, both during installation and at maintenance, are not necessary. But if it is proven, by technical and economic point of view, that will a method of protection should be applied on construction then we should consider what kind of protection should be applied and how.

The basic methods of protection against corrosion applied to all corrosion types are categorized as follows:

Combating corrosion potential:

- Indirect methods
- Nitriding, phosphorylation, carbonation, etc. impregnations
- Plating
- Coverage of steels with Fe_3O_4 and aluminum alloys
- Upward protection
- Direct methods
- Method of sacrificial electrodes or anodes
- Cathodic protection with sacrificial anodes
- Cathodic protection with external voltage
- Cathodic protection by sacrificial mischief
- Cathodic protection pins - channel (using ambient electricity).

Combating corrosion current or increase in electrical resistance with:

- plating with anticorrosion paints containing: substances with bipolar molecules, substances with high resistance, powdered metals or oxides;
- Use retarders or inhibitors;
- Coating with various substances acting as a barrier between the metal and the corrosive environments such as ceramic coatings and enamel.

The methods mentioned above are designed to protect metals and alloys, based on Thermodynamics and Kinetics study of the phenomenon of metal corrosion. This does not mean that some of them cannot be used for other materials (e.g. marble etc.). We can also use more than one for a more effective protection of materials against corrosion. According to above we can say that we have two types of corrosion protection:

- Active protection, prevention of corrosion of the material, acting on the factors that accelerate it and
- Passive protection, by which the contact of the corrosive environment with the material is prevented, by inserting several protection corrosion coatings.

The protection can be temporary (for some time e.g. during transport or storage of materials or devices) or permanent (slowing or/and eliminating the conditions that cause corrosion of materials). Subsequently, the permanent protection methods by corrosion will be developed, which have greater practical value for the protection of materials, particularly metals or alloys.

2.6 MARINE CORROSION

Corrosion of various different floating structures is a constantly evolving process. The aim is to protect the various constructions, so as to ensure safe operation and at the same time saving money.

2.6.1 CORROSION ON SHIPS AND SHIPBUILDING FACILITIES

More specific for ships, the corrosion problem is even more intense since many types of corrosion are faced. Also there are problems with the coastal structures and platforms which are located in severe corrosive environments, often can be compared with conditions created in a cabin sprayed with seawater. The air contains, and thus constantly carries water to the various metal surfaces so the surfaces are continuously wetted, except of course, the cases when there is continuous and direct sunlight. The water carried by air naturally contains salt which is deposited in all surfaces. A more than sufficient amount of oxygen is available and in many areas the average ordinary temperature is high. Concluding, it is obvious that all adverse conditions acting together create a very severe corrosive environment. The marine environment brings together many corrosive elements such as saline, humidity, UV etc. The main cause of corrosion in nature is the presence of oxygen in the air and water. It is proved that the wrecks suffer slow corrosion and this is because in deep waters the amount of oxygen in the water is low.

Figure 5: Ship Corrosion

It is not only the oxygen in the sea water which causes corrosion. It is also done due to the presence of chemicals in contaminated waters, and due to the microorganisms which are creating deposits on different surfaces (ship's bottoms), as seaweed and shells, which is not at all desirable for ships as it is accompanied by an increase in hydrodynamic resistance and thus reduce service speed.

The majorities of large vessels sail on a service speed of 15 to 16 knots and require 80% of the available power. With the current cost of fuel is very important to maintain the minimum roughness in hull. The surface roughness is divided into temporary and permanent. Temporary roughness is due to pollution of the hull during the period between dry-docking. Modern antifouling paints are possible to minimize the temporary roughness. The permanent roughness is due to corrosion and delamination of paint, to blistering (vesicles) and to color coating of pollutant microorganisms.

Fouling of the ship's hull is the whole matter, organic and inorganic, which over time is adhered to the ship's bottom. Organisms that pollute hulls are plant and animal microorganisms, such as barnacles, serpoulides, ascidians, sponges and algae etc., stick to ships when they are stopped in ports, e.g. when not traveling. This adhesion, in addition to growing the corrosion due secretions of these organizations during the exchange of their material and the inhomogeneity they generate, results in the creation of rough surface of the hull, causing deceleration of the ship and therefore should be combated. The increase due to pollution, of propulsion horsepower needed, for attain a certain speed in a year is nearly 24% (which is equivalent to a speed reduction of about 8% for constant horsepower). With a special tool, known as analyst roughness, is estimated the hull pollution, which passes over the surface and records the maximum peaks at 500mm gauge length. Hundreds of measurements taken by a hull to find roughness of the class of 125μm, and an acceptable estimation is, that for every 10mm increase in roughness up to 200mm, 1% increase in power is required in order to maintain the vessel at that speed.

All shipyards have the necessary equipment, for example floating docks, equipped with hydraulic arms and adjustable side backgrounds, dry-dock building slots, ship lifting units, in which ships can be pooled. They also have large along docks / dock, mobile cranes with high lifting capacity, water and air firefighting networks, sheds and warehouse to storage spare parts and materials, and a remarkable electromechanical equipment (cranes, rolling mills, pipework units, electrical repair units, mechanical workshops, carpentries).

One of the major problems in the operation of an integrated and coherent shipbuilding unit is the phenomenon of corrosion. This phenomenon refers to the destruction of the metal parts of the various facilities found in a yard, by the properties of sea water and ambient air.

Many floating structures construct in an area with sea or industrial atmosphere, and thus the corrosion begins from the assembly. In very few structures coating with anticorrosion paint is used, because of great cost. The strong presence of oxygen in certain areas, the flow of the tide, the mud in estuaries and the vibrations of the steel members of the construction quickly alter the oxygen concentration in the cathode areas and this result in an increase of the required power for protection.

The main cause of corrosion in floating tanks is that are placed on an intense aqueous environment. The contact of their metal parts with both water and air causes wear of the surface and overall rusting. The water wave in combination with the fact that it is located in the sea causes their deterioration in short time. The lifetime of the tanks depends on the maintenance done and renewed every time you changed the plates.

In a vessel lifting unit, so the operation of the crane as the stress of the surface where the vessel is deposited degrade the metal surface making them more sensitive to insult from sea water, to the formation of a rust layer and corrosion of stressed surfaces.

Also the cranes and the rails used for lifting metal equipment, corroded because of the fatigue and stress of the surfaces involved in the process leading their surface to be rubbed, to peel off the coating and to permit easy corrosion at that local area. Even the mounting screws used are often of different materials, and it wears out surrounding surfaces.

The problem of corrosion, especially in the marine environment, is hardly solvable if counted, the significantly big size of the surfaces to be protected in an analogous coating cost. There must be a safe choice in proper and reliable protection material.

They need to use different coating depending on the surface that must be covered due to different corrosive environment is each one (hulls, Topsides, decks), with similar results in cost.

The coating process should be carefully studied, so that the coating material chosen to need a relatively short time process of drying, as it is desirable the minimum delay for ship maintaining reasons.

A big part of this problem is solved by sea coatings, which are acting in a protective mean for constructions operating within or on the sea such as ships, floating platforms, buoys, submarines etc.

2.6.1.1 Coatings for marine structures

The marine environment brings many corrosive elements such as brine, humidity, UV radiation etc. Furthermore, the presence of microorganisms creates deposits on surfaces, and the presence of chemicals in polluted waters complicates the problem.

Marine coatings can be defined as protective means for structures that operate in or on the water, such as ships, platforms, buoys etc. Especially for vessels, the coating has to protect from the phenomenon of corrosion, but many times it is required in order to prevent deposits of algae and shells. The area that shows the most intense problems in terms of protection is the hull of the ship, but also other points have particular difficulties in comparison with other cases of coating application. Moreover, the characteristics of the coating that referred to the time for drying is of particular interest since it is always desirable minimum delay for ship maintenance work.

Overall, a marine coating must have the following properties:

- High corrosion resistance
- Fluency in application with brush, roller or spray
- Good resistance to abrasion
- Quick drying process

- Low moisture permeability
- Good affinity with existing coatings
- Low cost
- Applicability to a wide range of temperatures
- Ignition point above 27°C
- Lack of toxicity.

A distinction of the coating is made for a fuller and more meaningful analysis in paints for the hull and coatings for the other parts of the ship.

2.6.1.2 Antifouling paints

Antifouling paints must perform two basic functions. To protect surfaces where applied against corrosion (anticorrosion paints), and the algae and microorganisms deposits (antifouling paints). It is usually not possible to combine the two activities from one type of coating. This is because the antifouling paints containing toxic additives (e.g. Copper compounds) which can accelerate corrosion when in contact with steel. So, first is required the application of anticorrosion paints, which also act as a protective of the surface from the antifouling additives.

2.6.1.3 Anticorrosion antifouling paints

The anticorrosion protection of a steel object which is immersed in seawater can be based on using a coating, forming a film completely impermeable to water, always allow some amount of water to diffuse through the membrane. Thus, organic encapsulants can function as an insulating layer significantly reduces the permeability of water. Certainly more effective method for the protection of the ship's hulls is cathodic protection using voltage or metal electrodes of a more anodized steel element.

Another method of corrosion protection is to use pigments which in certain types of coating inhibit antifouling effect. For these pigments to operate, the polymer connecting them has to be fairly porous and allows the passage of seawater to form suitable ions retarding corrosion. Thus, in selecting a coating two possibilities are shown: the using of an audible sealant or a coating containing anticorrosive pigments.

In conclusion, for inhibiting corrosion on steel surfaces immersed in seawater one or more of the following steps must be followed.

1. Eliminating stress growth points (removal of oxides by abrasive blasting).
2. Use marine coating of high barrier.
3. Use of coatings with anticorrosive pigments.
4. Application of cathodic protection (current or electrodes).

2.6.1.4 Antifouling coatings

The creation of deposits in the vessel should be avoided because their presence affects:

- The fuel consumption due to drag.
- The development speed due to the uneven surface.
- The corrosion resistance since the deposits can damage the anticorrosive coating.

The antifouling can be classified into encapsulants of dissolution and contact encapsulants. The first category is widely used in commercial vessels because of their relatively low cost and act primarily by the slow dissolving of their components from seawater and the local formation of a poisonous environment.

The contact encapsulants are based on the incorporation of high qualities high toxic ingredients. Their life is about three times higher than that of the encapsulants of dissolution and their cost is generally higher, so they are usually used in naval vessels. Finally, it is noted that in certain ship categories the application of antifouling coating is not required. On tankers for example, only corrosion coating is applied since their stay in ports for unloading takes at most forty hours and the deposits do not grow significantly within this short period.

2.6.1.5 Coatings for other parts of the ship

Apart from the hulls, and the remaining parts of a ship show specific requirements that must be considered when selecting corresponding coating. The area above the waterline receives the influence of the water, wind and solar radiation, and intense stress by the friction of the water. So the requirements of a coating should be based on the above elements. For this region it is not required protection with antifouling. Ultimately, the coating for the deck is not subject to such rigorous selection as foregoing. But it needs some attention, so the coating to exhibits high resistance to weather conditions and not forming slippery surface.

Experience has shown that the anti-corrosion paint is a good method of protection particularly to ships and structures place in seawater in combination with antifouling paints. Because of this application, anticorrosive paints have been studied a lot in the past, and now are still investigating and will be fined in the future.

2.6.1.6 Required Properties of coating

Steel is the only conventional material that can be used for most marine structures due to their high strength and the coatings are the most common materials for the protection of structures by corrosion. The use of the coating was started by the time the man created structures near the sea and vary from animal fat coating to high technology one.

The importance of the coating in protecting the surfaces is realized with an understanding of how they work. Via coating the metal surface can be separated from very active chemical chlorides, salts of acids and alkalis. Few mils synthetic material must provide electrical insulation and additionally prevent air, moisture and generally highly corrosive environment to come into contact with the surfaces of the structure. This coating layer should be distinguished by continuity and identical thickness on all surfaces of the structure even in discontinuity of surfaces such as the edges of the various metal structures, various screws and nails used or even in spots where a metal surface encounters and partially overlaps another. If you do not pay attention to these points may be local signs of corrosion to the construction.

Using a coating on a floating structure, something more than a paint is needed, as regards adhesiveness, its chemical and mechanical resistance and durability with regard to weather conditions, moisture and water. A coating is designed for difficult conditions to prevent serious damage even in cases where the same has flaws and is locally detached from the surface. With regard to the salts must prevent the transport of ions through. It also can be spread onto the surface, regardless of their shape, and then to maintain a good maintenance over time. All these functions need to be met for a period adequate to justify its cost.

All these conditions are essential qualities of a coating and yet should have:

- Excellent resistance and low water absorbability
- Resistance to the passage of ions and osmosis
- Permittivity strength
- Weather resistance ability
- Chemical, mechanical strength
- Strong adhesion of the coating to the surface
- Confrontation of the geometric anomalies
- Easy installation and adjustment
- Duration and appearance

2.6.1.7 Modes of coating action

There are different ways of thinking about how coating will protect the surface.

The basic idea of the first way of thinking is substances that cause corrosion, to be forbidden to penetrate the coating. The coating must be sealed not only for air, oxygen, water and dioxide carbon but also for the ions and electrons. Such a coating has to remain idle with chemicals such as acids, alkalis and salts. It should be able to create a thin layer which in turn absorbs minimal moisture, to prevent the movement of water through and firmly adheres to the underlying surface. All this in combination with the fact that there cannot be anodes and cathodes due to the permittivity behavior of the layer, is led to the result of the absence of corrosion.

It is known that water more than any other chemical compound is responsible for the physical fatigue and reduce of the resistance of synthetic coating, after all plastic absorb water and part of it is transferred through. The less impact water has on the coating the greater protection it provides. If the protected area presents some surface irregularities and adhesion of the coating is such as to create between the coating and the surface some gap, then the possibility is given to water, once permeated the coating, to act corrosively over the metal. Conversely, if the surface has been cleaned and has been suitably treated, good adhesion is achieved and then coating also adsorbs water, but now the water remaining in the coating with no effect on surface.

Another idea is to use special pigments either in the primer itself or within a coating. Corrosion is avoided not necessarily because of the nature of the coating but because of the pigments used. When contacted with the humidity is sufficiently ionized so subsequently react with the metal surface and thereby maintain her in a passive or inactive situation. That use of the fact that water penetrates the coating and creates passive ions friendly metal. These materials are poorly soluble in water, but even this small amount dissolved sufficiently to react with the iron and chromate ions and generate an insulating inert, thin layer on the surface.

2.6.1.8 Installation Procedure of ship's coating

Correct surface preparation is the proper basis for effective protection. But, in the end the real protection is provided the entire process of the coating installation. Each coating has its own peculiarities and without careful control of their assignment is not possible to create good protection to the metal surface. Certain areas require particular care and presented several examples below.

The first coating layer is usually placed in "spray" continuously assuring that the coating is wetting the surface properly. Attention also needs the fact that there should be no powder in contact with the surface. If a coating has special characteristics as how to wet the surface then instead of a "spray", manual brushes and rolls are used and because of the force exerted, the coating may sidestep the dust.

In the various corners and edges of marine structures the problem of corrosion is very intense. In these special cases must be given extra attention to the thickness of the coating paved. Coating surface forces tends to detach the edges and therefore need greater amount of coating. This is achieved by spreading an additional coating layer on the edges, before the "spray" or spread in these places two hands of coating. If brushes or rollers are used, the coating should be brushed from webs to the edges and vice versa. In this way, it is achieved higher coating concentration at weak point such as tips and angles. The same treatment is given to bolts and nails, which are always corroded first.

The welding sites are also difficult to protect. The automated welding is relatively easy to protect, as they are smoother and have fewer notches. Instead handmade welds vary from very rough surfaces to relatively smooth. All welds roughness should be smoothed and their residues which located in the slots to be removed because they are sensitive to water, so they tend to create immediate failure of the coating. Welds on or in tanks or high-pressure pipes can be tested for their resistance using air pressure and soap solution. All soap must off site, otherwise you may face coating failure.

Pipes are used in all ships and maritime constructions. The problem in this case is the cylindrical shaped tubes. The coating placed (spray) longitudinally, so on a curve surface the coating is deposited evenly. The area most near to the spray receives more coating, while moving away and following the curvature of the pipe less coating is deposited. This phenomenon can cause quite a discontinuity and premature failure of the coating.

2.6.1.9 Safe use of coatings on vessels.

All encapsulants use volatile solutions. These solutions during the positioning of the coating are evaporated and almost all are flammable. If the vapors of the solution are mixed with the appropriate amount of air then an explosion can be caused. Also dangerous for health is the inhalation of a adequate quantity of coating even for a short time.

It is very important the safe use of the coating in order to prevent such unpleasant impact, and can easily be overcome using certain safety parameters. The key to safety is proper ventilation since the concentration of the vapor of the solution into the air is the critical condition. At low concentrations there is no risk for explosions or health problems. Some general safety rules are:

- Provide extra ventilation from the already proposed site. Proper ventilation is the key to the safe use of the coating in indoors.;
- Usage of mechanical means for removing vapor coating (formation of air current);
- Continue proper ventilation until the coating is completely dry;
- No smoking. All flame sources should be banned in 50ft distance;
- Usage of equipment that does not generate sparks;
- Usage of all the workers who are indoors;
- Appropriate breathing apparatus and protective clothing.
-

2.6.2 PROTECTION METHODS ON SHIPS AND FLOATING STRUCTURES

A description of the various corrosion protection methods applicable to vessels and floating docks is made, referring to the principles and factors for the correct application of protection methods.

2.6.2.1 Cathodic protection for ships

Cathodic protection tends to slow the corrosion, so that recesses and acupuncture on the hull surface do not have enough time to be formed, seals do not wear out and to keep smooth the surface of the reef. Correct implementation of appropriate cathodic protection method performs very well results and significantly reduces the cost of maintenance of the ship from corrosion problem.

Maintaining smooth surface is important because it prevents creating drag forces. As it is known, these forces depend on the length and the speed of the ship and the condition of surface reefs, significantly increasing the ship's resistance and resulting in fuel consumption. Therefore the initial good surface with good quality coating color can be maintained with meticulous application of cathodic protection.

2.6.2.2 Application of anti-corrosion paint on ships

It is known that ships are built separately. Current practice is that they are subjected the plates to abrasive blasting, stained with a special primer, and then to be adhered for the creation of distributors and in end these frames are welded together to create the whole vessel. This primer protects the frames from corrosion and is covered by the final paint system, thus finally protects the whole ship from corrosion. However each area of the ship has different requirements for protection from anticorrosion paints. Listed below are the protection methods with anticorrosive materials for different regions of the vessel.

2.6.2.3 Protection for various areas of the ship

Every different area of the ship, has its own characteristics so the implementation of different methods for protection is required.

2.6.2.3.1 Hulls of the ship

The hulls of the vessel are submerged part of the vessel and is therefore under the direct influence of the marine environment. Therefore coatings should fulfill two purposes, protection against corrosion and good antifouling behavior. Usually these two requirements are not both satisfied by a type of coating. First is required the application of corrosion inhibitor coating and after the antifouling. The corrosion protection is achieved with a combination of cathodic protection and implementing of anticorrosive and antifouling coating. The properties the coating system has to satisfy are the resistance to salt water, smooth surface, good antifouling behavior and compliance with applicable cathodic protection system.

The coating system consists of a number of layers of anticorrosion paint and a pollution antifouling system. The conventional protection systems based on bituminous paints (thickness at least 150μm), tracked two generally coatings from antifouling paints. There are several high-quality systems antifouling paints based on epoxy bitumen (at least 250μm thick), polyurethane tar (≥ 250μm), vinyl tar (≥ 200μm), chlorinated rubber (≥ 200μm) or vinyl copolymers (≥ 200μm), followed by two or more layers of antifouling paint.

Note that in some parts of the ship (or specific ships) where required high abrasion resistance, the hulls can covered with very thick layers. Also, the first layer of antifouling paint is applied a little time before the launching of the ship into the sea, because the usual antifouling paints have little resistance to atmospheric corrosion.

2.6.2.3.2 Waterline Zone

It is a fairly sensitive area, and is under the influence of sea water, air, sunlight, and water waves. Properties that must be met by the coating system is resistance to climatic conditions (wind and solar radiation), smooth surface, resistance in oil and mechanical loads and exhibit compatibility with the applied cathodic protection system.

The coating system consists of a number of layers anti-corrosive paint and one or two layers imparting the desired color at the waterline zone. The colors usually preferred are black, red, dark green or reddish. Conventional coating systems are based on alkyd phenolic resin or asphalt. There are high quality systems based on epoxy resins, polyurethane chlorinated rubber or vinyl copolymers.

It is noted that chlorinated rubber systems have no strength towards oils. Also if light color for the waterline is going to be used, then no anticorrosion coatings should be used with asphalt bases while for better abrasion resistance, the waterline zone area is coated with thick layers containing glass flakes.

2.6.2.3.3 Freeboard and outer parts of the deck

Important properties must be met by the coating system such as corrosion protection, resistance to weathering, abrasion resistance and impact, ease of cleaning and gloss.

Conventional coating systems are based on alkyd resins containing processed oils and are widely used because of its pleasant appearance and the ease with which are applied to the surfaces. They consist of two layers of anti-corrosive primers and two layers topcoat, which gives the desired color on the surface. The total thickness of the system should be at least 140μm. The systems high standards based on epoxy resins, polyurethane resins, chlorinated rubber or vinyl copolymers. The thickness of these systems must be at least 200μm.

Note that, the surface layer of a color system sufficient thickness is not so thick so as to be smooth and decorative. Particularly for deck deckhouses the system must have good color and to be maintained glossy. Finally, all machinery and components that are on the deck should be sufficiently protected.

2.6.2.3.4 Dry cargo holds

Important properties must be met by coating systems of hull dry cargo such as protection from corrosion, impact resistance and scratching, not to peel and to be authorized to carry materials consumption. The coating systems used are based on asphalt or alkyd resin and high demanding systems are based on tar epoxy, polyurethane tar, epoxy resin, resin polyurethane or zinc silicate.

For the transportation of mineral and coal is proposed a system of high requirements. When storage spaces are used for ballast the coating must meet some other requirements. As for the transport of materials consumption (e.g. cereals) the coating system requires formal approval.

2.6.2.3.5 Tanks

Depending on the load for which tanks are destining for, different protection system is required. So the bunkers and lubricants tanks do not need painting, while large parts of crude oil tanks can also be left unpainted.

Tank painting, besides corrosion protection, guarantees ease of cleaning and usability for different loads. Particular attention should be paid to the conditions under which it is painted. In particular, water vapor concentration should be prevented and in coating surfaces, otherwise the coating system will peel off and damage rapidly. The risk is too great when the painting is done while the ship is at sea and in cold water. Therefore the painting is allowed only if the temperature of the cooler portions of the reservoirs is at least 3°C higher than the air dew point inside the tank. Also, the ventilation should be effective and workers' health and lives should not be put at risk.

Requirements that must be met by the coatings systems of the tanks are corrosion protection, non-porous, smooth surface, resistance to the loading cargo, resistance to the substances which are likely to be released from the loading cargo, resistance to cleaning procedures of the tanks and resistance to a large number of different loading cargoes, so that the reservoir can be used for various loads. Finally, the coating system should not produce substances contaminating the loading cargo. For example, the tanks' coating systems for tanks carrying drinking water should not produce toxic substances or substances that alter the color and taste of water.

2.6.2.3.6 Engine room

The coating systems used in the engine room must have specific properties such as corrosion protection, resistance to oils and water, ease of cleaning and to maintain their color, not to turn yellow over time.

The more conventional protection systems are based on alkyd resin paints. Thus, a system may consist of one or two primer layers, an intermediate layer and a top layer of paint which does not yellow with time. For ease of cleaning the last layer is usually glossy. Also high performance systems can be used based on resin polyurethane or resin Coal Tar Epoxy, polyurethane bitumen or epoxy resin. The outer coating should be based on polyurethane or acrylic resins, which are not going to turn yellow after some time. It is also noted that in several countries the paint must contain retardant fire component.

2.6.2.3.7 Areas with high moisture

Coating systems placed in spaces of high moisture levels, should have some specific properties like corrosion protection, water and soaps resistance, ease of cleaning, resistance to scratching and yellowing. Coatings systems based on alkyd resin with thickness at least 120μm usually provide these requirements. There are, however, and high-performance systems based on epoxy resins and polyurethane with thickness greater than 200μm.

2.6.2.3.8 Dry Areas

In these areas are place many different materials and many different methods of protection are required. Some general requirements for all coating systems are ease of coating, good adhesion and good decorative appearance.

The elements made of wood are covered with a special paint layer for wood and then one or two coats of paint, not yellowing (alkyd resin), follows. The hard wood is coated with several layers of varnish. Plywood is treated like wood, and dilute wood coating containing cellulose is used. Particleboard treated like plywood with another coating over the original. The insulating sheets are covered with several layers of chlorinated rubber.

2.7 COMPOSITION OF ANTI-CORROSIVE PAINTS

The anticorrosion paints are mainly consisting of pigments, in a solution of a binding mean (binder). This connecting instrument (Vector) is mostly of organic nature, and it is the most decisive factor for the physical and chemical properties of an antifouling paint which are simply modified according to the nature and the proportion of dispersed solids. Briefly an anticorrosion paint consists of the following:

The vector comprises the following components:

- The liquid portion consisting of the binder, the solvent and diluent

- They coating modulators imparting certain flow characteristics in order to choose the appropriate coating method and
- Additives such as desiccants, antioxidants and additives anti-settling.

The solids pigments which have to act as:

- Coverings for providing an aesthetic appearance (color and transparency or opacity or other special effects), protection (resistance to weather conditions and corrosion), auxiliary properties (strength of the layer hardness, fire resistance, etc.) and anti-corrosion properties;
- Enhancers for cosmetic improvement of coatings (reflectivity, transparency, glow etc.);
- Retardants which are added in combination with the above anticorrosive agents or alone. Thus, using substances like (Pb_3O_4) for ferrous substrates or $ZnCrO_4$ non-ferrous, as well as various phosphates to slow corrosion and
- As pigments to impart color.

2.8 PREPARATION OF THE SURFACE

It is now accepted that the surface preparation is the most important factor in the behavior of a coating. So in order to achieve strong adhesion between the metal surface and the antifouling paint, should be treated suitably, so for this surface both to remove corrosion products and other impurities but also to increase its coarseness.

The corrosion products and impurities are the cause of creation of local galvanic elements with consequent the acceleration of the destruction of anticorrosion paint. As for the increase of roughness, it means an increase of the contact surface and thus a better adhesion.

Preparing a surface to be painted includes the following steps:

2.8.1 Surface cleaning (mechanical or chemical or electrolytic dialysis).

To clean a surface before painting, an important factor is the position in which it is located and its size (e.g. outside of the production factory, maintenance into or nearby marine or industrial atmosphere etc.). It also depends on the surface condition, which is going to be dyed (e.g., the surface is painted or it is rusty, or it comes directly from the factory) and its purity, which influences the choice of the cleaning method.

Thus the cleaning of a surface can be made either by mechanical or chemical methods or a combination of both and/or by electrolysis.

Mechanical clearance is the traditional way of cleaning a surface before painting. This is done to remove any oxides formed on the metal surface or previous paint layers and organizations settled on the hulls of the ships.

On large surfaces sandblasting is used (i.e. particles floated in the air - sand, silicates or metal nuggets - ejected with great speed on the surface so the metal coatings are detached). But there is a risk to create geometric diversity and active centers on the surface or metal nuggets may remain, from where it is possible to start pitting corrosion and actually pretty quickly.

In small surfaces brushes are used (originally wire brushes and cloth brushes with smoothing dusts – e.g. Al_2O_3 etc. - subsequently).

The chemical purification is done in cases that special attention is needed after mechanical clearance or in cases when the clearance cannot be done mechanically. Acids Used contain retardant macromolecular substances, which do not affect the metal itself. Solution of HCl (1-10%), with temperature around 20^oC- 50^oC for 1-5 minutes is mainly used or solution of H_2SO_4, with temperature around 95^oC for 2-10 minutes. The first has the advantage that quickly clears the layers of FeOx (Voustitis) while the second does not. The H_2PO_4 do not thoroughly cleans the rust but affects the iron surface and creates a passive layer. Generally, acid used in the chemical purification, can be recycled (with suitable method) and therefore in long term is a more economical method of clearance.

2.8.2 Degreasing.

Usually degreasing comes before cleaning with acids and t is necessary because the slightest traces of fat or oil on the surface, which is going to be painted, could spoil the paint adhesion to metal and predisposes corrosion with pitting (with the diversity that creates). Organic solvents which used are: acetone, alcohols, benzene, toluene, xylene, carbon tetrachloride and methylene chloride

Also alkaline solutions are used to degrease and clean the metal surface by impurities. These may contain on surface active substances or substances binding of metal ions. Widespread is the use of electrolytic degreasing with alternating poles.

2.8.3 Cleaning control.

Once the cleaning of the surface is over, the surface should be checked whether it is ready for painting or not, ie if the oxides, fats, oils, paint, etc., are completely removed. This could be checked by putting into the bath Cu^{2+} or Fe or liquid crystal.

2.9 FINANCIAL IMPLICATIONS

Nowadays, especially in recent decades, the phenomenon of corrosion is presented extensively. This is because there is a growing use of metals and alloys in all kind of constructions. Also the rapid development of industry and the increasing pollution by air, soil and water of rivers, lakes and seas contribute to accelerate the phenomenon of corrosion.

Corrosion is a natural phenomenon, which tends to bring back the metal or alloys in the original form of natural compounds from which, by many costs and sacrifices, the man has recovered. Therefore man struggling against corrosion. In tthis effort he must not forget that elimination of corrosion is impossible. The goal should be to find ways to slow it down as much as possible.

In particular, the importance of corrosion phenomenon for the economy of a country is understood by the financial implications which entails, but also the intensity of the efforts made internationally to combat it. Thus, developed countries have large amounts of money placed on the research against corrosion and a lot of money spent to protect the installations. It is evident that the greater the industrial developing of a country is, the greater the amounts of money spent are.

Table 1 presents the annual costs for the confrontation of corrosion of the US companies, which are members of N.A.C.E. (National Association of Corrosion Engineers).

Table 1: Annual costs for the treatment of corrosion

Types of protection	Cost in Dollars
Protective coatings	2.907.433 $
Inhibitors (anti-corrosion)	340.834 $
Cathodic protection	447.805 $
Glazing and plastics	453.196 $
Corrosion resistant metal equipment	5.424.198 $
Metal tests and analyzes	99.472 $
Total	**9.672.529 $**

Despite all efforts, the devastation caused by corrosion continues to be very significant. It is reported that 40% of metals and alloys produced worldwide each year are destroyed by corrosion. Approximately 2/3 of the metals destroyed by corrosion, return back in consumption as raw material. Therefore 11% of the total production of metals completely destroyed.

The fact is that our economy will drastically change if there was not corrosion. For example, automobiles, pipes submerged in the soil or household appliances would not need duplication. The stainless steel industry would disappear and copper Cu would be used only in electrical applications. The design of the dimensions of various metal constructions would be different and the thickness of the elements would be smaller. It must be mentioned the problem of reserves of mineral - raw materials for metal production, which requires largest possible deployment.

Because of marine environment around the constructions' hulls and ships, marine organisms are attached which accelerate corrosion and cause a decrease of the original ship cruising speed by 20 to 40% within a year.

Thus, although many researchers around the world and for a long time involved and engaged in the study of the problem of corrosion, however it has not found a unique satisfactory solution. Besides, any method of protection can hardly be effectively applied to another installation operating in another country, either by themselves or any different conditions.

The study and treatment of corrosion phenomenon is of particular importance, for our country too. Thus, apart from the general effect, already mentioned, should be highlighted and the following:

- The marine environment of Greece increases the corrosive properties of the atmosphere.
- Most factories are located near coasts.
- The Greece has increased environmental pollution problems (rational industrial development without appropriate measures to protect environment).

3 PORT STATE CONTROL INSPECTIONS

3.1 INTRODUCTION

Shipping industry is probably the most extensive and internationalized industry, as its nature allows or requires the involvement and participation of a wide range of attitudes, culture and practices. The big advantage over the rest of the transport industry is undoubtedly high capacity per route and hence the low relative cost offered to the charterer. Maritime transport is vital for European Union because of its geography, since more than 90% of the external and 43% of the internal trade, is transported by sea. Also more than one billion tons of freight per year is loaded and unloaded in EU ports. One third of world fleet marine business is under the control of European Union citizens, and about 40% of EU trade is carried by vessels controlled by the interests of EU. This should not be surprising that the international fleet is in a constant rise, with rare downturns since the end of World War. The maritime transport sector – including shipbuilding, ports, fishing and related industries and services - employs approximately 2.5 million people in the European Union.

It is undeniable that the European shipping contributes substantially to the economic development of its member countries, increasing the national product, and strengthening the strategic position of the European Union and its negotiating strength in international organizations. Therefore the safety, competitiveness and ensuring of the maritime transport are some of the immediate priorities for enlarged European Union.

Every ship must be owned by a flag state. This is known as the nationality of the ship or the flag. In particular the vessel is registered in a port of the flag state known as a recording port. According to the international law of each state that allows the registration of ships under the flag has the right to control technical and operational issues. The flag State should take measures for ships flying its flag to ensure safety at sea with regard to the ship's structure and management of, the seaworthiness, the ability of the crew, the working conditions and accident prevention. It is duty of the flag State to take all those necessary measures to ensure that all the ships flying the flag of the state to be harmonized with all international regulations and laws but also the ability to sail in all seas and in all ports. This succeeds with regular inspections made by authorized inspectors to all ships. These inspections are called "Flag Inspections".

The fact that all flag states do not act responsibly, as required by the international regulations - do not control all their ships or make poor controls - forced many states to impose additional inspections on ships entering their ports before allow them to sail. Inspections are called "Port State Control Inspections" and the number of the states applying them is growing. These states, mainly based on their geographical location, form Regional Agreements as the Paris MOU, the Tokyo MOU, the Black Sea MOU etc. which define the controls which will take place during the surveys and give appropriate instructions to their inspectors. They have lists of all possible defects that may be encountered by inspectors on board and the steps to take. Furthermore, they publish the results of inspections in order to know all the ports and the ship-owners, the history of each ship. When necessary proceed with booking ships which do not comply with international regulations and often even go further to banish vessels which repeatedly have been arrested at all ports of the Local Agreement.

3.2 INTERNATIONAL CONVENTIONS AND LEGISLATION

International conventions are unions with many parties, multilateral agreements by which Member States agree to commit themselves to some issues. A convention is an agreement between two or more states to do something, or to refrain from doing something, and are generally not legally enforceable, although this changing. Up to date, the international law of conventions was governed by customary rules of international law. However, many (but not all) of the aspects of the law for the Convention, have been codified in the Vienna Convention regarding to the Law of conventions in 1969, which came into force in 1980. The development of international marine contracts included in the working program of many international organizations such as the IMO, the ILO, the UN. Usually a convention is resulting from a recognized need. Often it is something that arises from a proposal submitted, and a resulting recommendation to a committee or a subcommittee of IMO. As a result of these discussions, the plans of the regulation are prepared and convened a diplomatic conference to review, discuss, amend and finally adopt the resulting treaty.

Member States send recognized representatives to a diplomatic conference to participate on their behalf. If the representative is in agreement with the general principles of the draft contract can be signed on behalf of state, usually "subject to ratification, acceptance or approval." Once the agreement is confirmed by any national authority, it is required that the signature of the representative to be ratified (the state will agree to be bound by the Convention). A treaty or convention usually remains open for signature for a finite period of time, usually for a period of 12 months. States not attended the diplomatic conference can be parties to a convention.

Any State may adopt an IMO convention, even if it is not party to the IMO Convention (which provides membership in IMO). Any State may incorporate the provisions of an international Maritime Convention in national legislation, even if it is not itself part of the IMO.

For the States to implement the international conventions they have ratified, they should incorporate their provisions into national legislation, since the contracts themselves do not contain enforcement provisions. They way to accomplish this depends on the state constitution. In some cases, a contract is part of the national legislation automatically by the instrument of ratification or addition. Often, the state constitution will require that treaties and conventions to which the senior employee wants the state to become a party will require approval by the legislature. This is done in cases where the obligations of the contract will impose sanctions or audits to the public.

The features of the Conventions are written in a "convention language", which provides obligations between states, but not the people in those states who are responsible for state liabilities. The state must often take some active measures to implement practically its international obligations and must "translate" the language of the Convention into national legislation.

In general, contracts are of a more generic point of view. They should be that way in order to cover a wide variety of legal systems in different countries around the world. Member States should translate those general provisions on the details in a way that is in accordance with the traditional legal institutions of the country and be consistent with the administrative system. Generally, international maritime conventions do not include penalties for non-compliance. This is for national legislation to consider, and this is why many conditions must be confirmed by the Legislature before takes effect. Moreover, the application of national obligations would be through national authorities, companies and people. Therefore, the contract must be adapted to suit the local status.

The fact that a country has not signed, not ratified or not accepted a contract means that it has no further interest in that contract. Before the Conventions become legislation at the national legislations, many countries are bound by international law.

When the appropriate conditions are fulfilled, the Convention enters into force for those members which have ratified or accepted it. There is usually a grace period to allow all States to take the necessary measures for its implementation. The recent procurement is open for signature for a period of 12 months. After this period, it is possible for the States, not parties, to accept and implement it. The Conventions are placing an obligation to the States to take the necessary measures.

Often the national legislation should be changed to enforce the provisions of a convention, since the IMO has no power in this regard. The Contracting Governments shall enforce the provisions of IMO treaties in regard to the vessels, with the creation of offenses and the establishment of penalties for infringement. Port authorities have limited powers enforcement in respect of foreign vessels. Some contracts require vessels to carry certain certificates showing that they have been inspected and, that in fact they meet the necessary standards. These certificates are normally accepted as evidence by the port authorities that vessel has met the required standards, although in some cases, further measures may be taken.

3.2.1 REGULATION ON SECURITY

SOLAS 1974, Chapter I, Regulation 19 (a): “Every ship when in a port of another Contracting Government is subject to control by officers duly authorized by such Government in so far as this control is directed towards verifying that the certificates issued under regulation 12 or 13 are valid.” The regulation, according to SOLAS 1974, Chapter I, Regulation 19 (b), underlines that “Such certificates, if valid, shall be accepted unless there are clear grounds for believing that the condition of the ship or of its equipment does not correspond substantially with the particulars of any of the certificates or that the ship and its equipment are not in compliance with the provisions of regulation 11 (a) and (b).” In this case, according to SOLAS 1974, Chapter I, Regulation 19 (c): “In the circumstances given in paragraph (b) or where a certificate has expired or ceased to be valid, the officer carrying out the control shall take steps to ensure that the ship shall not sail until it can proceed to sea or leave the port for the purpose of proceeding to the appropriate repair yard without danger to the ship or persons on board." The surveyor's next action is to inform parties concerned about the delay, according to SOLAS 1974, Chapter I, Regulation 19 (d): "In the event of this control giving rise to an intervention of any kind, the officer carrying out the control shall forthwith inform, in writing, the Consul or, in his absence, the nearest diplomatic representative of the State whose flag the ship is entitled to fly of all the circumstances in which intervention was deemed necessary. In addition, nominated surveyors or recognized organizations responsible for the issue of the certificates shall also be notified. The facts concerning the intervention shall be reported to the Organization."

Ultimately, in case where such measures are received, the flag State and the IMO should be informed. In any case, Port State Control should make every effort possible so any unnecessary delay for the vessel to be avoided.

3.3 PORT STATE CONTROL

"Port State Control (PSC) is the inspection of foreign ships in other national ports by PSC officers (inspectors) for the purpose of verifying that the competency of the master and officers on board, and the condition of the ship and its equipment comply with the requirements of international conventions (e.g. SOLAS, MARPOL, STCW, etc.) and that the vessel is manned and operated in compliance with applicable international law."

3.3.1 HISTORICAL FRAME

As a result of the conference for the Titanic on November 12, 1914, the implementation of international regulations on safety at sea began. Some governments with naval industry in their countries demanded uniform regulations with low «standards» for ship construction. Among these regulations, the basis for common acceptance of security certificates and regulations in sea and control of ships were introduced. Due to the war, these agreements had to be postponed. Already with the approval of the SOLAS '29 (Safety of Life at Sea, 1929) the possibility for implementation of inspections of foreign vessels in ports became a reality. Since then the regulations for the inspection of ships amended and replicated in other international conferences.

In SOLAS 74/78, Chapter I, General Provisions Regulation 19, Port State Control is defined with reference to the IMO Resolution A.787 (19). This regulation determines legal basis for the work of PSCOs (Port State Control Officers). In 1978 the first agreement named 'The Hague Memorandum of Understanding' was prepared by a number of European maritime authorities. In March 1978 the destruction of "Amoco Cadiz" in the British coast caused catastrophic ecological pollution. This fact demanded stronger political activities on safety at sea. Then, in Europe was signed the "Paris

Memorandum of Understanding on Port State Control" by the European governments in order to start the consolidated efforts to monitor the following:

- Standards for improving the safety of life at sea
- Standards for preventing environmental pollution and
- Standards for improving living conditions onboard

The port state control (PSC) is the inspection of foreign vessels in national ports to verify that the safety, construction, management and board equipment complies with the requirements of international seas conventions and that the ship is manned and used in accordance with the applicable national laws.

It comes to the surface when ship-owners, classification societies and flag services fail to comply with the requirements of international maritime contracts. Although it is understood that the ultimate responsibility for contracts left to the flag states, port authorities have the right to inspect the foreign vessels in their ports to ensure that any deficiencies are repaired before being allowed to leave. The port state control is considered to be supplementary to flag state control.

In recent years, the importance of the Port State Control has been recognized widely and has a significant mobilization in different regions towards the establishment of a more harmonized approach to the effective implementation of the control benefits.

3.3.2 INTERNATIONAL FRAME

The United Nations Convention on the Law of the Sea, 1982 (UNCLOS) establishes the general rights and obligations of the flag State. Within the United Nations two specialized agencies consider maritime affairs, the International Maritime Organization (IMO) and the International Labor Organization (ILO), and they are responsible for the development and updating of contracts and directives under which vessels must comply. Generally, topics on safety at sea, prevention of pollution and training seamen considered by the IMO, whereas the ILO examines the issues on work and living conditions on board. While the IMO and ILO are placing the international regulatory framework for the vessels, each member state is responsible for the implementation of international conventions ratified by vessels flying flag.

International conventions developed by IMO form the main context of security, training and pollution prevention regulations, with SOLAS, MARPOL, STCW, Load Line and Tonnage Conditions Cargo to be the other important regulations. They are supported by the rules of the Classification Societies which focus largely on the structure of vessel, including the materials used in the construction, dimensions of the frame and the essential engineering systems such as main engine. The requirements of Classification Societies and international conventions could be correlated.

3.3.3 PORT STATE CONTROL RIGHTS

Coastal states exercise certain specific rights to vessels within the exclusive economic zone of 200 nautical miles from the coast, especially for fishing and the prevention of marine pollution. Within this area, coastal states have dominant rights for the purpose of exploring and exploiting, maintenance and management of living and non-living resources of the sea and the seabed.

When a vessel is in the jurisdiction of another state, flag State jurisdiction is concurrent with that of the coastal or port authorities. Under customary international maritime law, as well as the United Nations Convention on the Law of the Sea, 1982 (UNCLOS), a Government has the right to exercise at some point control on foreign flag ships located within its jurisdiction. However, under UNCLOS, coastal Member only authorized to intervene in the operation of a vessel which has, or is likely to have, effect on the protection and preservation of the marine environment. Any such intervention will be conducted with the due respect to the rights and duties of other states.

In addition to territorial jurisdiction, the International Maritime Organization IMO) and the International Labor Organization conventions (ILO) provide to the states the possibility the PSC to conduct inspections of foreign vessels into their ports. However, the primary responsibility for law and order, on board discipline, proper navigation and seamanship, safety of ships and persons on board and the prevention of marine pollution is up to the flag state where the vessel is registered. The responsibility for a boat that is equipped, operated, maintained and manned in accordance with international maritime contracts also belongs to the flag state.

It is globally recognized that foreign merchant ships are subjected to the jurisdiction of the coastal state when it sails in its internal waters. The countries have used two arguments to justify the exercise of the PSC:

1. The right of self-protection for the public and the environment against the risks related to substandard vessels.
2. International enforcement of contracts considering the safety at sea, by preventing the not-seaworthy boats from sailing out to sea.

Despite this explanation, the UNCLOS has tried to limit the extent of the PSC for the foreign vessels and determine some very accurate procedures. The rights granted to the port authorities under the UNCLOS are limited to the protection of the marine environment and to non-general safety regulations, which are found in IMO and ILO Conventions. Initially, the PSC was limited mainly to ensure compliance with the technical aspects of the IMO Conventions. However, recent changes in SOLAS '74 make it possible for senior PSC staff to master the functional requirements “when there are clear grounds to believe that the captain or crew is not familiar with essential shipboard procedures relating to the safety of the vessel”. Similar changes have been made to MARPOL 73/78 and STCW 1978, as amended in 1995.

The PSC inspections are conducted to ensure that foreign vessels are ships that do not pose a risk of pollution, provide a healthy and safe working environment and comply with the relevant international convention. In most contracts there is a warning that the inspection must not delay unduly the ship. Moreover, the vessels selected for inspection must not be chosen in a discriminatory manner, but the choice must be uniform.

The port authorities apply the conventions which have been entered into force and they have been applied not only to the vessels of their country but also to the vessels flying the flag of states which have not ratified a convention, since from now on there will be no favorable treatment. A member may also adopt domestic laws and impose additional national rules and regulations concerning foreign vessels entering its waters. The United States, for example, have established the law for oil pollution, 1990 (OPA 90).

3.3.4 PORT STATE CONTROL RECEPTION FACILITIES

The coastal States should provide facilities for the boats in order to release their waste (waste oil, chemical residues, sewage, waste) in the ports and not in the sea. All the Participants (in the MARPOL) should ensure sufficient facilities for the reception of oil residues and mixtures in oil loading terminals, in port repairing facilities, etc... However, many oil loading stations are situated in developing countries which often do not have the funds to build such facilities. The instructions of MARPOL do not oblige the governments of these countries to provide these reception facilities, or specify that in case they exist if they must be free or not. It is ironic that many countries which have complained about the marine pollution in their waters are the same countries that have failed to ensure that adequate reception facilities are provided, where necessary, in their ports.

There are various directives on the provision of adequate reception facilities in ports, published by the IMO, that demonstrate how facilities reception for the various substances can be provided at a reasonable cost. Failure to provide such facilities means that vessels should either try to keep the waste produced at sea forever, or derogate in a port where reception facilities are available, adding to operational costs or illegally get rid of them in the middle of the ocean and take the risk of huge penalties.

3.3.5 PORT STATE CONTROL VESSELS

Vessels belonging to the port authority (tugs, pilot boats, storage barges, hydrographic vessels) must comply their operation in port with relevant national legislation and international conventions, such as regulations for preventing collisions at sea. The instructions given by the vessel traffic service, or port authorities, or pilots should be clear, concise and accurate and consideration should be taken to ensure that the orders are fully understood by the receiving vessel.

Under international law, every state has the right to exercise control on vessels of foreign states through their ports. This is not an absolute right. Each state has different rights, responsibilities and obligations. Flag States have full and exclusive responsibility of the vessel on the open sea and it is needed to effectively exercise their jurisdiction and control in administrative, technical and social matters of the vessels flying their flag. This means that flag States should establish a list to be containing the names and details of the vessels flying their flag. The Flag States should also adopt such measures as are necessary to:

a. Construction, equipment and seaworthiness of vessels.
b. The manning of ships, labor conditions and training of crews.
c. The use of signals, the maintenance of communications and conflicts prevention.

3.3.6 PORT STATE CONTROL: REASONS FOR THE NECESSITY OF INSPECTIONS

The maritime world is far from perfect and some flag states are either unable or unwilling to fulfill their international responsibilities. If all flag states performed their duties satisfactorily there would be no need for the PSC. Unfortunately, this is not true, as evidenced by the many maritime accidents worldwide. There are thousands of events including the loss of life, loss of property and damage to the environment that have appeared over the last 40 years, some of which are well known, and others that are largely unnoticed by the press and the public. Some of them are the M/V Exxon Valdez (fig.6), which sunk in 1989 causing a significant oil spill (fig.7), the M/V Prestige (fig.8) which sunk in 2002 and the M/V Sea Diamond (fig.9) which sunk in 2007 leading two people to death.

Figure 6: M/V Exxon Valdez

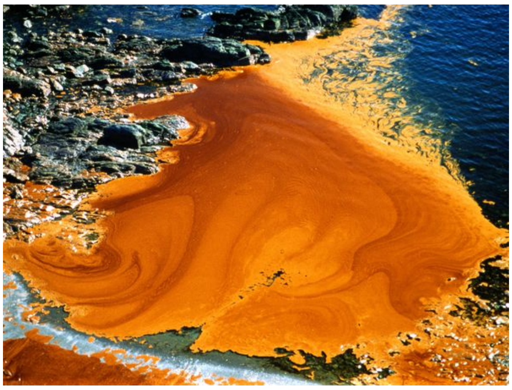


Figure 7: Oil Spill occurred on March 24, 1989 when Exxon Valdez sunk and it is considered to be one of the most devastating human-caused environmental disaster.

Figure 8: M/V Prestige sunk in 2002, polluting thousands of kilometers of coastline and more than one thousand beaches on the Spanish, French and Portuguese coast.

Figure 9: M/V Sea Diamond sunk in 2007, near the island of Santorini, leaving 2 passengers dead

The PSC inspections of foreign flag vessels shall ensure that the flag State maintains the obligations relating to various IMO Conventions and ILO. With the combination of other countries to form regional PSC agreements, the effectiveness of these inspection programs has increased, while the cost to the port authority and the inconvenience to the owner, both have declined.

In real life, many ships do not regularly call the inspectors at ports of the flag state and this may eliminate the ability of the flag state to police effectively and enforce the contract standards on vessels flying heir flag. This encourages some ships to sail in a state below average, thus endangering the safety of other ships, the lives of seafarers and environmental safety.

3.3.7 THE ROLE OF THE FLAG STATE

Evidences proving that the vessel meets the standard of international conventions and rules of the Classification Societies are generally provided by the presence on board of valid certificates. To ensure, each state, that its vessels comply and then maintained up to the standards of international conventions, must have appropriate procedures, which would ensure that vessels are inspected periodically and get new certificates. This liability applies regardless of whether a flag state shall make the investigations using its own inspectors or permits a recognized organization (RO) to carry out investigations and issue international certificates on its behalf. The members of the International Association of Classification Societies (IACS) meet the minimum levels required by an RO. In many cases, therefore, inspectors of Classification Societies undertake all the certification process on a vessel.

3.3.7.1 RESPONSIBILITY OF THE FLAG STATE TOWARDS THE PORT STATE CONTROL

The UNCLOS requires every state to effectively exercise its jurisdiction and control in administrative, technical and social aspects of the vessels flying its flag. This includes construction, equipment and seaworthiness of boats, manning, labor conditions and training of crews, the use of signals, the maintenance of communications and conflicts prevention. Flag States should ensure that vessels flying their flag comply with applicable international rules and standards, as well as the domestic laws and regulations, for prevent, reduce and control pollution of the marine environment from the ships. Flag States have to provide effective enforcement of the rules, irrespective of where a violation occurs.

Maritime law recognizes the concepts of responsibility of the state coastal and port authorities and is based on a form of the principle of territoriality. The first shows the power of the state to territorial waters and exclusive economic zone, while the latter shows the state responsibility beyond the vessels in its ports, usually, but not always, in the internal waters.

With regard to pollution from ships, the UNCLOS imposes obligations to the flag states and to the coastal states. Coastal States may, in the exercise of their dominant rights within their territorial waters, to issue the laws and regulations to prevent, reduce and control marine pollution from foreign vessels. The states that are parties to an agreement accept certain obligations, but also acquire certain rights and privileges over other states which are also parties. The flag State agrees to take certain measures against vessels registered in its jurisdiction, but also accepts that coastal and port authorities may take certain measures against the flag state vessels when they are simultaneously under their jurisdiction. However, both parties accept that the measures that can be taken are limited to those contained in the convention.

Some flag states have worse safety measures for vessels entering their list. This is a result of various factors, including an insufficient number of qualified inspectors, small marine management, and a lack of political will to improved security and legislative measures, proper administration and enforcement. While the "black list" of high risk flag states varies from year to year, some flag states succeed to be included in this infamous list for many years. These states activate "open registries" leaving the management of their fleets to individuals trying to act without the minimum number of staff or inspectors, without the necessary ability, experience, knowledge or insufficient motivation.

3.3.8 INTERNATIONAL CONVENTIONS

The MARPOL convention covers all aspects of pollution from ships, including the prevention of pollution from oil, from the harmful fluids, from harmful substances packaged, from contamination of sewage waste, and more recently, from greenhouse gas emissions from the machinery on deck. It applies to vessels of all types except warships and government vessels in non-commercial service, and allows the parties to check that a vessel in a port or an offshore terminal has been supplied with valid certificates. Inspections may also be carried out to check if a boat has release any harmful substances into the sea. So while the prototypes applied are those usually included in international agreements providing PSC, there is a need for consistency at the application.

There are several international maritime agreements with the PSC benefits. The right to inspect vessels is defined in the following conventions:

- SOLAS Convention 74/78
- MARPOL Convention 73/78
- Load line Convention 1966
- STCW Convention 1995
- Collision Prevention Regulations 1972, (COLREG 72)
- International Convention on Tonnage Measurement of Ships 1969 (TONNAGE 1969)
- Merchant Shipping (Minimum Standards) Convention, 1976 (ILO Convention)

In addition, there are over 200 resolutions that examine technical specifications, providing more detailed recommendations based on prototypes, codes and guidelines. There are also some resolutions adopted by the Maritime Safety Committee. An activity which is also included in some regional PSC agreements is the control of merchant shipping convention, ILO (minimum standards), 1976.

Flag States are obliged to establish and maintain effective control of vessels flying their flag. This requirement is determined in Article 94, UNCLOS and specifically included in the conventions listed above. The flag state inspectors must have excellent education, as well as appropriate qualifications and experience. However, it is recognized that some countries may not have the satisfactory numbers of capable people. In these cases, the states may authorize and transfer their responsibilities to some "recognized organizations acting on behalf of the administration". The IMO has published "instructions allow organizations to act on behalf of an administration" in Resolution A.739 (18). Most of these organizations are authorized Classification societies.

There are some states that have additional legal provisions as far as vessels entering their waters, such as USA as well as other current members of the International Association of Classification Societies (IACS) that compete with each other for economic benefits. Under the domination of IMO there is a significant degree of harmonization of the rules and the regulations of each country with those of the IMO. Thus, most issues related to the safe operation of vessels are covered by contracts supported by the IMO, and most nations have adopted these provisions in national legislation with few, if any, modifications or amendments. However, there are some discrepancies when interpreting, and IMO has published several resolutions and circulars on procedures for the PSC.

3.3.9 THE INTERNATIONAL SAFETY MANAGEMENT CODE (ISM CODE)

Investigations regarding accidents occurred have revealed that deficiencies in management of shipping companies concerning the operation of their vessels are a contributing factor in many maritime accidents. Accordingly, specific measures taken to encode certain administrative procedures and to ensure that safety management standards are established and maintained should be checked later by the functional audits.

The ISM Code applies to all vessels since July 2002. It is considered that this code will have a profound effect to the on board safety of the vessels and to the protection of the marine environment, as it requires shipping companies to make specific changes in their structure, to implement the safety administrative procedures and maintain appropriate files. The ISM should be implemented by ship-owners and controlled by flag States, but it is also subjected to inspection by the port authorities. Vessels that do not bring the necessary certification can be prevented from entering foreign ports.

3.3.10 REGIONAL AGREEMENTS

An uncoordinated effort for inspections by the PSC within a region can result in a recurrence of the phenomenon to sail in the seas ships which don't comply with the minimum standards. If the PSC inspectors have no prior knowledge of previous inspections, they cannot follow the deficiencies mentioned and check if they have been fixed. Also ships not meeting the minimum requirements will visit ports where the inspections of PSC are looser. This can hamper the economic state of the ports carrying out appropriate inspections. To avoid the above unpleasant situation several regional agreements are assigned.

The most important functions within these regional agreements is the formation of a secretariat and the establishment of central databases so that national PSC control functions can expose information and all its members can access the database and examine the story of a PSC on a vessel. This allows members to exchange the information on vessels, their records and inspection results made. This information is important since allow the next ports of call to target only those vessels not recently inspected. In general, vessels inspected within previous six months are not inspected again unless there are clear reasons. Another reason is to ensure that the identified substandard vessels are effectively controlled, especially those who have been allowed to sail with some minor blemishes provided that these will be restored at the next port.

In November 1995, the IMO adopted the resolution A.787 (19) – procedures for the port state control - which was amended in 1999 by the resolution A.882 (21) and will undoubtedly further modified in the future. These procedures intend to provide basic guidance on how the Port State Control inspections should be managed and how to identify deficiencies in a vessel, its equipment, or its crew, to ensure that contracts benefits are consistently applied all over the world from port to port.

The procedures are not mandatory and they only offer guidance at port authorities, although these procedures have been developed and agreed internationally. While the port authorities of local contracts to use these procedures when exercising state control ports, in practice there are many variations in the way interpreted. For example if the control procedures are strictly interpreted, an overhaul or a routine inspection would be limited to the control of the vessel certificates, except in some cases where the condition of the vessel was judged doubtful. Often, however, is argued that only the presence of the certificates may not be proof that the vessel is in good condition and for this reason, some senior port state control officers (PSCO) proceeding to more stringent inspections.

Three regimes of Port State Control (PSC) provide to the Equasis, data on inspections and reservations. The agreement protocol Paris (for Europe and North Atlantic), the Coast Guard of US and the Tokyo MOU (for the region of Asia Pacific). The frequency of updates of the data from PSC reports received from different areas varies and therefore the accuracy of the information presented varies accordingly. The information received by the Paris MOU on inspections, detentions and possible corrections to earlier reports, updated weekly. The Information received from the USCG updated monthly. The Updates from the Tokyo MOU received from Equasis are received in bigger and irregular time intervals.

3.4 CONSISTENCY OF THE PSC

While the most important benefit of regional cooperation is the uniformity of PSC inspections between countries and between regions, this time the standards and inspection procedures vary greatly throughout the world and among members of regional MOU. Uniformity can be achieved by standard procedures and inspection manuals, the training and exchange of inspectors in other countries, and the use of seminars between members of regional agreements in order to harmonize the procedures.

However, the ultimate goal will be the integration of all regional MOU. To do this, there should be uniformity in the systems information, databases and other technical issues. Although data storage and exchange systems have evolved broadly in each region, the long term benefits of a standardized coding system have now been recognized. Most database systems are developed using the complex coding sets of the computer protocol of the Paris Convention. Furthermore, changes are required in attitude of the owners and marine governors, who in the past have tended to be secretive. This system will provide opportunities for charterers to choose the appropriate vessels preserved well and are thoroughly regulated by quality operators.

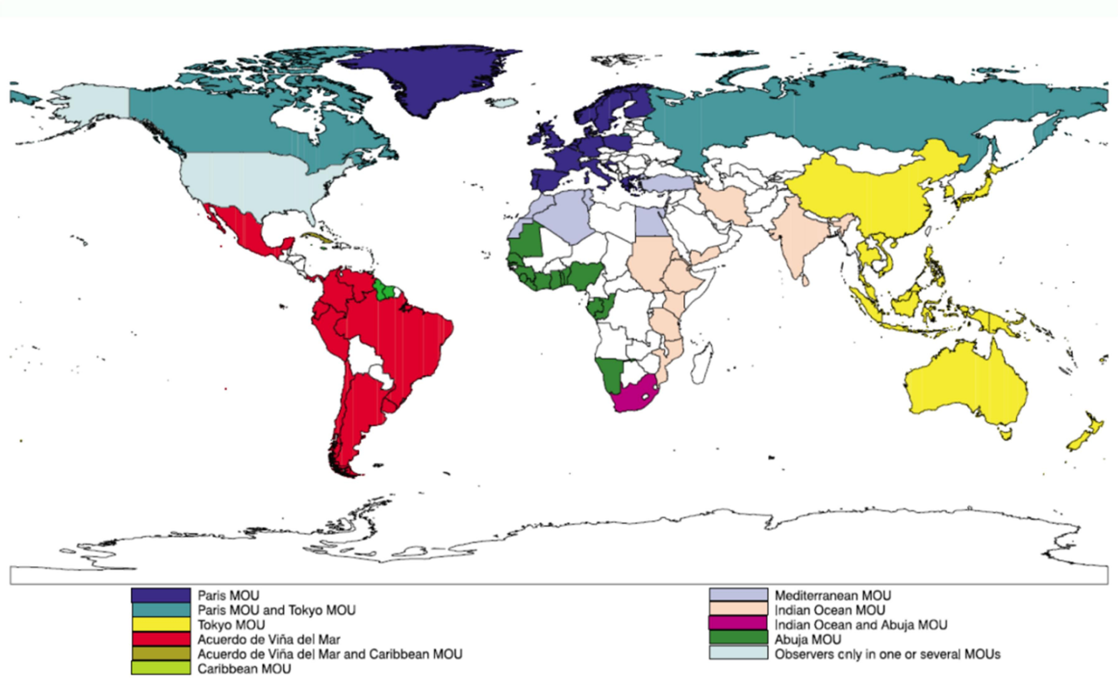


Figure 10: PSC Regional Agreements Worldwide

3.4.1 REGIONAL PORT STATE CONTROL AGREEMENTS WORLDWIDE

In 1978, the Hague Memorandum (Hague-Memorandum) between different maritime authorities in Western Europe was developed. It dealt mainly with the enforcement of shipboard living and working conditions, as required by the Convention No. 147 of the ILO. However, when the memorandum was ready to be put into practice, in March 1978, a massive oil spill occurred near the coast of Brittany (France), as a result of the grounding of the supertanker 'Amoco Cadiz'. This fact caused a strong political and public outcry in Europe for much more strict regulations in maritime safety. Then, a new and more effective instrument known as Paris Memorandum of Agreement (PARIS MOU) on port State control adopted in January 1982 and initially signed by fourteen European countries. It entered into practice on 1 July 1982. From that date, the Paris Memorandum has been amended several times to adapt to new security and maritime environmental requirements from the international maritime organization (IMO) as well as other important developments such as the various EU directives considering maritime safety. Since then, the Paris Memorandum has been extended and now enumerates 27 members.

- Paris Memorandum of Understanding on Port State Control (Paris MOU) adopted in Paris (France) on 1 July 1982

Member countries are: 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, United Kingdom

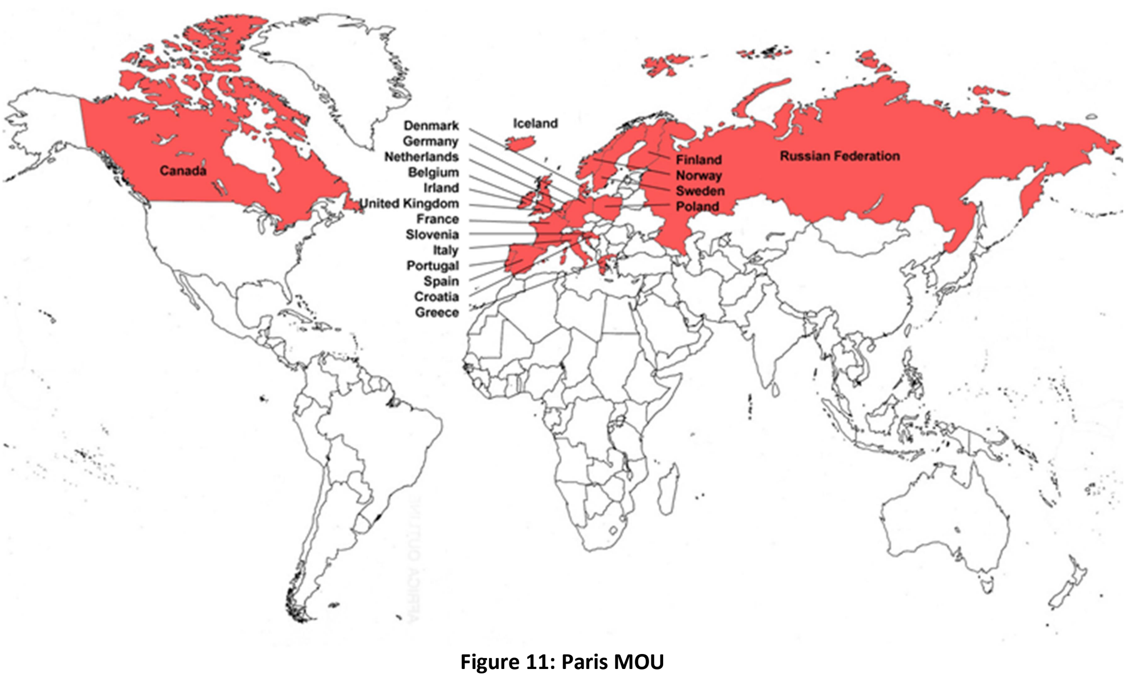


Figure 11: Paris MOU

In the early 90s, about ten years after the Paris MOU was formed, in the Far East another large regional grouping of states known as the Pacific-Asian MoU contract or Tokyo MOU established. Its members almost all Asian countries bordering with the Pacific Ocean, Australia, New Zealand as well as Canada and the Russian Federation.

- Memorandum of Understanding on Port State Control in the Asia-Pacific Region (Tokyo MOU), signed in Tokyo (Japan) on 2 December 1993

Member countries are: Australia, Canada, Chile, China, Fiji, Indonesia, Japan, Republic of Korea, Malaysia, Marshall Islands, New Zealand, Papua New Guinea, Peru, Philippines, Russian Federation, Singapore, Thailand, Vanuatu, Viet Nam, Hong Kong (China).
On October 5, 2015 the Republic of Panama was accepted as a Cooperating Member of the Memorandum of Understanding (Tokyo MOU)

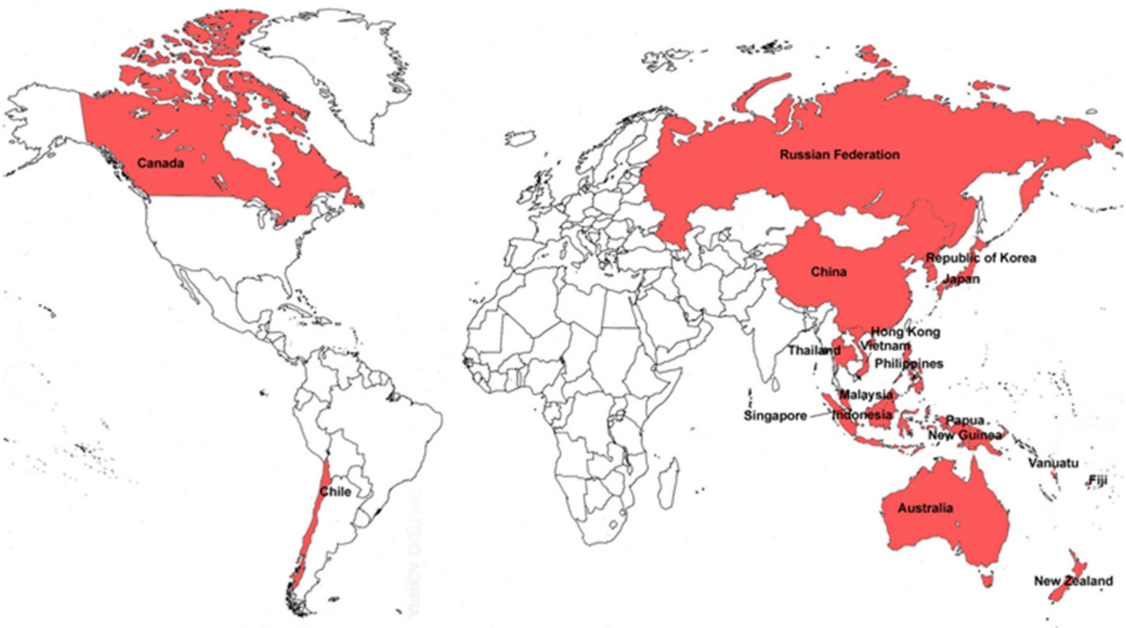


Figure 12: Tokyo MOU

At the same time South American States, along with Mexico and Cuba, formed the Viva Del Mar Agreement (Latin American Agreement).

- Acuerdo de Viña del Mar (Viña del Mar or Latin-America Agreement), signed in Viña del Mar (Chile) on 5 November 1992

Member countries are: Argentina, Bolivia, Brazil, Chile, Columbia, Cuba, Ecuador, Mexico, Panama, Peru, Uruguay, Venezuela, Honduras.

Figure 13: Vina del Mar or Latin America Agreement

The agreement memorandum Indian Ocean (Indian Ocean MOU) followed, which is a regional grouping of countries stretching west from India to South Africa, including Australia.

- Indian Ocean Memorandum of Understanding on Port State Control (Indian Ocean MOU), signed in Pretoria (South Africa) on 05 June 1998

Member countries are: Australia, Bangladesh, Djibouti, Eritrea, Ethiopia, India, Iran, Kenya, Maldives, Mauritius, Mozambique, Myanmar, Oman, Seychelles, South Africa, Sri Lanka, Sudan, Tanzania, Yemen.

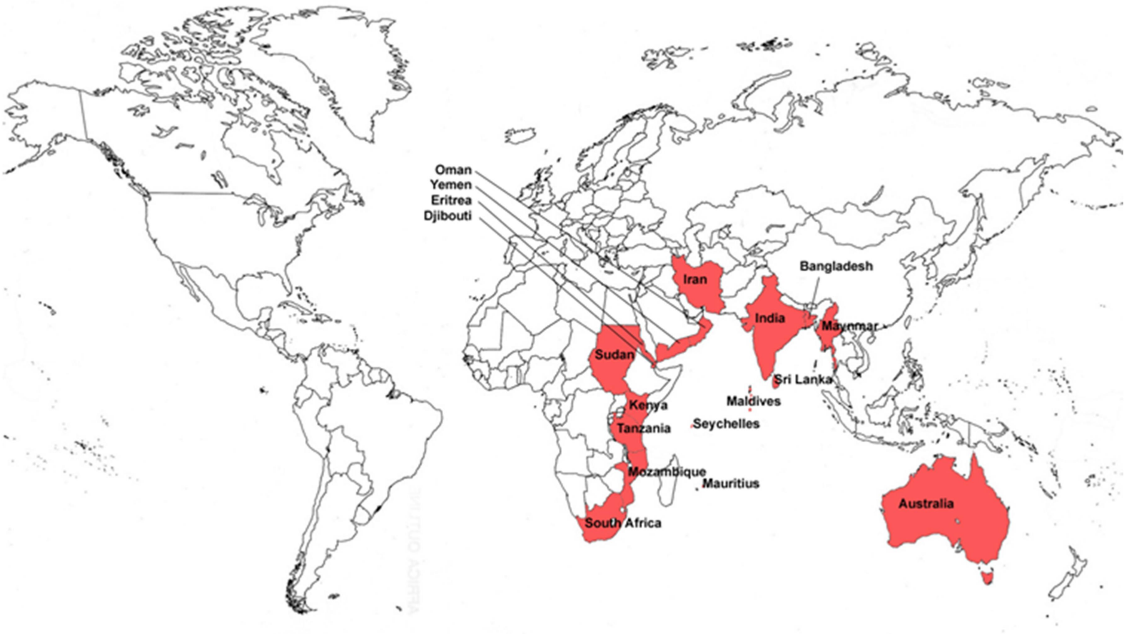


Figure 14: Indian Ocean MOU

In recent years created the Mediterranean Memorandum Convention (Mediterranean MOU) by the States bordering the Southern Mediterranean and Cyprus.

- Memorandum of Understanding on Port State Control in the Mediterranean Region (Mediterranean MOU), signed in Valetta (Malta) on 11 July 1997

Member countries are: Algeria, Cyprus, Egypt, Israel, Jordan, Malta, Lebanon, Morocco , Tunisia, Turkey and the Palestinian Authority.

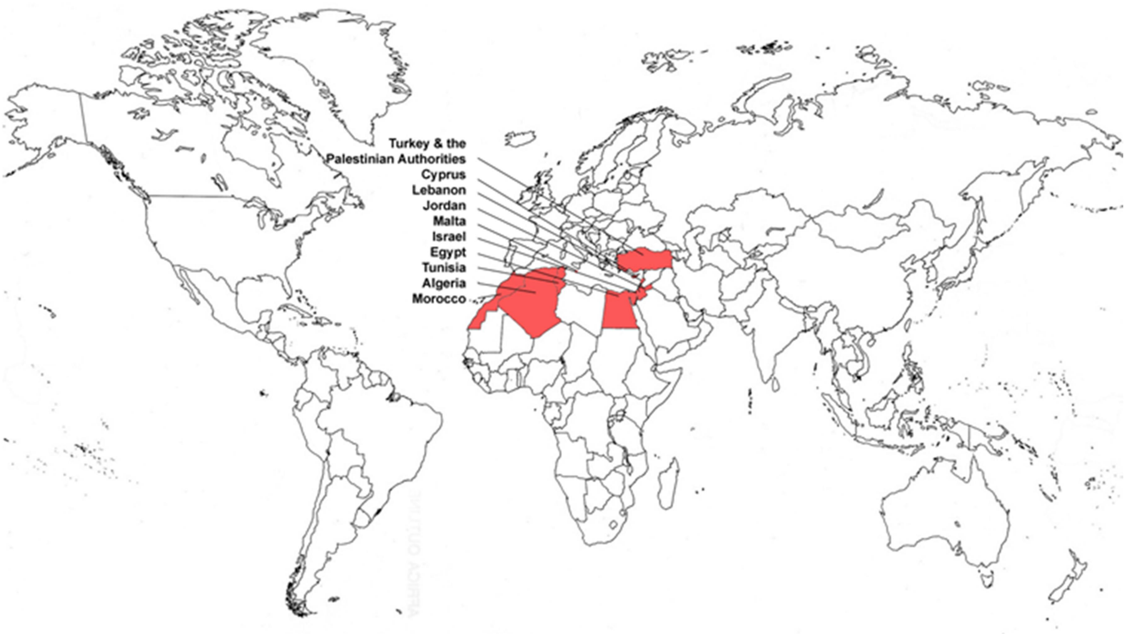


Figure 15: Mediterranean MOU

The West and Central African Memorandum of Understanding (Abuja MOU) that has been recently established in Nigeria and the Memorandum of Understanding between the countries of the Black Sea (Black sea MOU) which is going to establish in Istanbul Turkey, are two new contracts whose Member States remain to be finalized. A further protocol is planned to cover the Arab region of the Persian Gulf.

- Memorandum of Understanding on Port State Control for the West and Central African Region (Abuja MOU), signed in Abuja (Nigeria) on 22 October 1999.

Member countries are: Benin, Cape Verde, Congo, Côte d.Ivoire, Gabon, Gambia, Ghana, Guinea, Liberia,Mauritania, Namibia, Nigeria, Senegal, Sierra Leone, South Africa, Togo.

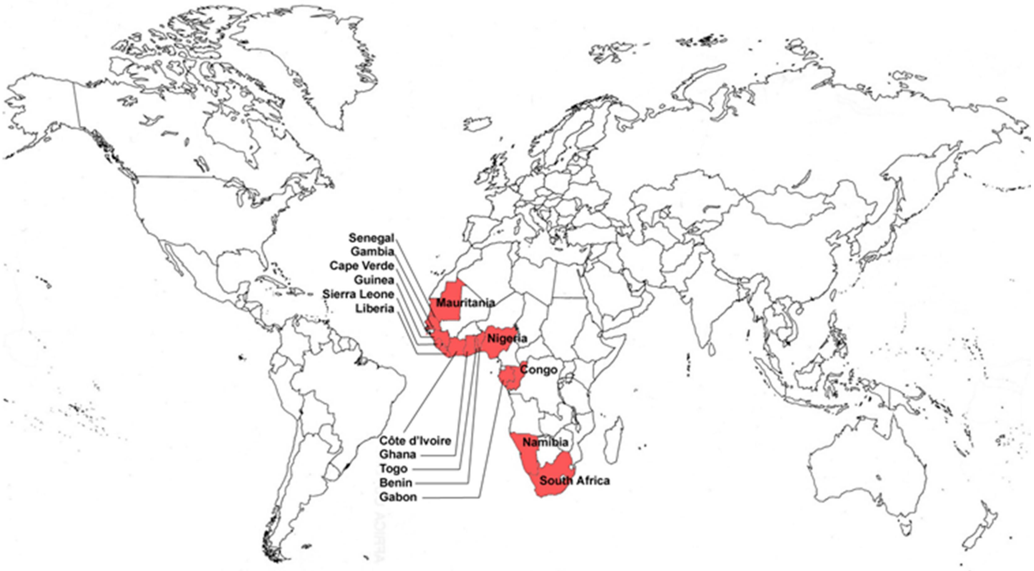


Figure 16: Abuja MOU

- Memorandum of Understanding on Port State Control in the Black Sea Region (Black Sea MOU), in 2000

Member countries are: Bulgaria, Georgia, Romania, Russian Federation, Turkey, Ukraine

Figure 17: Black Sea MOU

Another Memorandum of Understanding was signed in Christ Church, Barbados on February 9, 1996 between the countries around the Caribbean Sea.

- Memorandum of Understanding on Port State Control in the Caribbean Region (Caribbean MOU), signed in Barbados on 9 February 1996

Member countries are: Anguilla, Antigua & Barbuda, Aruba, Bahamas, Barbados, Bermuda, British Virgin Islds, Cayman Islds, Cuba, Dominica, Dominican Republic, Grenada, Guyana Haiti, Jamaica, Montserrat, Netherlands Antilles, Saint Kitts & Nevis, Saint Lucia, Saint Vincent & the Grenadines, Suriname, Trinidad & Tobago, Turks and Caicos Islds.

Figure 18: Caribbean MOU

The United States of America have chosen to remain outside of any local MOU under the government control program of the US ports taking measures on a unilateral basis.

- United States Coast Guard, created by Congress on 4 August 1790 at the request of Alexander Hamilton as the "Revenue Marine", it is the oldest continuous seagoing service of the United States.

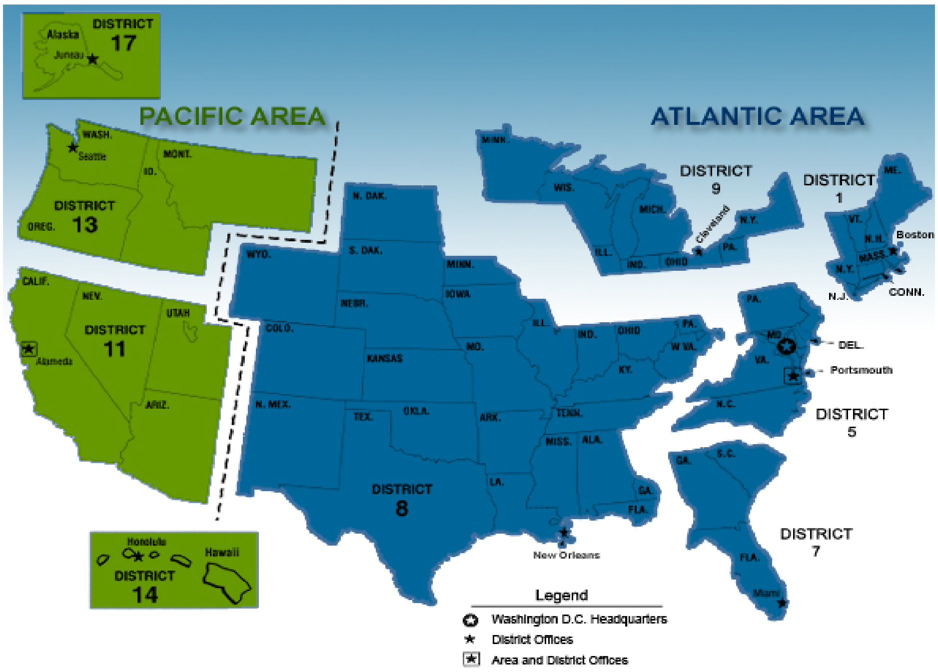


Figure 19: United States Coast Guard (USCG)

Table 2: Summarizing table on the operation of PSC worldwide

MOU	ADOPTED	OPERATION	MEMBERS
PARIS MOU	January 1982	1982	27
TOKYO MOU	December 1993	1994	21
VINA DEL MAR	November 1992	1992	13
INDIAN MOU	June 1998	1999	19
MEDITERRANEAN MOU	July 1997	1997	11
ABUJA MOU	October 1999	1999	16
BLACK SEA MOU	2000	December 2002	6
CARIBBEAN MOU	February 1996	1996	23
USCG		1970	USA

Some of the above mentioned PSC organizations publish information about their work, objectives and campaigns as well as the lists containing detained vessels and other statistics on the Internet.

3.5 GENERAL ELEMENTS FOR INSPECTIONS

All Port State Control visits on a vessel start with the Port State Control Officer (PSCO) conducting an initial inspection, unless there are serious indications which will force him to immediately proceed to a more detailed inspection. If during the initial inspection the PSCO finds elements indicating important deficiencies / remarks to the vessel, its crew or to its operation, then he will have clear reasons to conduct a more detailed inspection to the vessel to ascertain the actual situation.

The existence of a concentrated inspection campaign or an extended inspection program will certainly cause the PSCO inspector to conduct a more thorough investigation than that required in an initial inspection. The shortcomings can be identified at any stage of the process of inspection, and depending on how serious they will be, the detention of the vessel may follow or not.

If a vessel is inspected by the port authorities and the inspection hasn't reported any significant deficiencies, then the ship should not expect a new inspection within the next six months. It should be exempted from further inspections apart from the cases when there are special reasons to justify them. In fact, data show that vessels often are re-inspected, for no particular reason, in intervals of less than six months, especially when moving between areas of port authorities. Therefore both owners and captains should not complacent in the coming months after an inspection as they do not know when the next inspection is going to take place.

The PSCO originally announced his visit at the captain. During his passage towards the bridge, he takes an initial overall impression about the state of the ship. It controls the ship certificates and forms an opinion regarding the conditions above the ship. It is based on his judgment how he will get this impression: by looking on the deck, in the engine room, on the navigation deck etc.

There are four types of inspections based on the inspection's purpose of consolidation:

- General Inspection
- More detailed Inspection
- ISM Inspection
- ISPS Inspection

3.5.1 GENERAL INSPECTION

The PSCO is boarding on the vessel without notice. During his passage, in his way to the Captain gets a first impression about the condition of the ship. He presents himself to the Captain and in any case checks the certificates and do a tour around the ship to get an impression of the vessel's maintenance.

3.5.2 MORE DETAILED INSPECTION

If the PSCO suspects through his research that the ship is not essentially subject to the international rules he has to decide whether or not to make a more detailed inspection of the ship. Some PSC authorities have issued checklists for PSCO according to the purpose of the inspection. A more detailed inspection, however, is not required by any international agreement.

The scope of a more detailed inspection will include a complete tour around the vessel, a detailed inspection of equipment and security settings as well as the arrangements for environmental protection, housing crews and operational knowledge of the crew.

The decision for a more detailed inspection is up to the professional judgment of the PSCO and will generally be obtained if

- Deficiencies are observed in the certification (invalid or missing certificates);
- The overall impression of the vessel's condition could lead to the assumption that the international regulations are obeyed;
- The reports about the shortcomings from third parties are known, and such inspection is required.

Agreements contain exactly the clear reasons, with examples, for a more detailed inspection. A detailed specification regarding the parts of the vessel that should be inspected does not exist. A more detailed inspection does not claim to be complete. The PSCO decides which areas of the ship is going to inspect based on his discretion.

3.5.3 ISM INSPECTION

According to the IMO RES. A.882 (21) the PSC inspectors can check the ISM system on board. Since there is generally any controller, they may just check the documentation and submit questions to find out if the ISM operates. The presence of several technical deficiencies will give step to the assumption that the ISM does not work satisfactorily. The PSC inspectors can list a lack stating that SMS works poorly and that owners should consider checking the safety system in order to find possible non-compliances.

3.5.4 ISPS INSPECTION

The PSCO is entitled to check the compliance with the ISPS Code on board. The IMO RES. MSC.159 (78) gives instructions on how a senior official properly authorized should check the controls of the security system. The United States Coast Guard has decided to make a complete control, while other countries have decided that the PSC inspections are limited to a general inspection and the verification of the certificates. The PSCO has no right to review the safety manual. If he finds clear reasons why the security system is not kept on board in accordance with the regulations he will call port security.

If the ship does not substantially conform to the regulations, the port authority (PSC) can detain or expel the vessel from the port, if considered existing threat to the security of the country.

According to the agreements of the MOU some types of ships are inspected once a year with "expanded inspection". These ship types are:

- Cruise vessels
- Bulk carriers over 12 years
- Oil Tanker over 20000GT, Oil Product Carriers over 30000GT and 20 years,
- Gas- and Chemical tankers over 10 years.

3.5.5 PORT STATE CONTROL OFFICER

The PSCO has an identity as evidence of the right to carry out inspections. All PSCO must also bear a copy of general procedural instructions for PSCO [IMO Resolution A.787 (19)] for reference in case of an emergency when they are making inspections.

The PSCO should be able to communicate with the captain and key members of the crew in English. He does not need to have experience as captain or chief engineer or have any experience on board. He should have no commercial interest for the port, the vessel or be used by or on behalf of any classification society. If he lacks the experience in a field of inspections then an expert could accompany him. It is considered that the PSCO is qualified and well trained and familiar with the vessels.

3.5.6 CHOOSING VESSELS TO BE INSPECTED

Port authorities recognize that the inspection of every foreign vessel enter their ports would be uneconomical and unnecessary since not all vessels are in condition below average. The general approach adopted by local port authorities is generally to put inspection rates to ensure that a minimum number of vessels are inspected, and use an evaluation system to inspect vessels likely below average. In addition, vessels of a certain age and a type specifically selected for the purpose of conducting extensive inspections and special inspection campaigns focused on the control of special subjects and areas of the vessels. Generally each vessel is inspected once every six months.

The rate of the vessels inspected is not the same for all local agreements and is designed to ensure that a fair amount of different foreign vessels will be inspected every year. Due to the fact that some ports or states have more PSCO than others, the inspection rate often vary from one port to another, even within the same MOU. However an annual inspection rate is set for the entire region. The agreement protocol Paris MOU, for example, has an annual inspection rate of 25%.

3.6 DATA BASES

For the port authorities to be able to determine the appropriate vessels for inspection, they cooperate and use databases such as SIRENAC and APCIS, managed by the Paris MOU and Tokyo MOU respectively. They provide them with information such as lists of arrival in ports, shipping programs, vessel position reports, and previous inspection reports. There are also international databases that provide information not only to inspections carried out in a particular region but worldwide. The European Commission and various other marine services (France, Japan, Singapore, Spain, England and the USA) established in 2000 EQUASIS.

The choice of vessels that will be inspected is based purely on numbers You cannot physically separate the vessels in good and in bad ones. Port authorities have started seriously considering creating a grading scale of vessels according to their history of the inspections they have passed. Thus vessels with high scores would have more likely to be inspected than those with low scores. The Inspection agreed rate for each region will be achieved more easily and inspections will be more effective.

The most common databases used by the PSC worldwide are:

3.6.1 SIRENAC

It is a database maintained by the PARIS MOU. According to this some selection criteria such as the flag of the vessel, the age and type of the vessel are considered to directly affect the condition that the ship will be found during the inspection. Allocating points for each criterion will create a score and each vessel will have its grade. Vessels with rate-target of more than 50 must be inspected. The rate-target of 50 or greater is considered as high risk.

3.6.2 APCIS

The Asia Pacific Computerized Information System (APCIS) is established because of the execution of the decision of the Tokyo MOU. The information system of the Tokyo Convention Protocol fulfills functions such as gathering and keeping information on vessels and inspections, taking the full story board, preparing reports, statistics and more.

3.6.3 EQUASIS

While much information is collected and available, they are scattered and often difficult to access. One of the main conclusions of the conference in Lisbon in June 1998, was the unanimous demand of the countries participating from all sectors of maritime industry such as ship-owners, cargo owners, insurers, brokers, classification societies, agents, ports and terminals, to make this information more accessible since one of the greatest obstacles to a genuine quality culture in shipping is the lack of transparency of information on the quality of vessels and their operator. In response to this requirement, the European Commission and the French government decided to cooperate in developing an informational system. This system should collate the existing information regarding the safety of vessels from public and private sources and making them available online.

The EQUASIS database aims to collect and disseminate quality and relevant to the safety information for the global merchant ships provided by the holders of such information. The EQUASIS is not meant to be a profitable business. For this reason it is funded with public money and will continue to be supported by the public authorities in the future. France and the European Commission shared the cost of the EQUASIS database until December 31, 2001 when maritime authorities of United Kingdom, Spain, Singapore and Japan also agreed to support the EQUASIS database finances.

3.7 REMARKS-DEFICIENCIES

The number and nature of the comments from the PSCO determine the corrective measures to be taken on board and whether the vessel will be detained or not.

It is important the Captain to fully understand what the comments are and what are the remedies that must be taken. This is particularly important when the observations are sufficient to lead to an order for detention of the vessel. He also needs to know when he has the right to appeal against this order. Any misunderstanding could delay the boat in harbor unduly. The captain has to check if the details of the observations entered correctly in the reservation's supporting documents and ask clarification from the PSCO, where necessary. When comments concerning a point of law, the captain should call an inspector of Classification society authorized to examine such information on behalf of flag.

The senior Port State Control officers should enumerate the comments he finds, along with the details of the corresponding certificate in each case, including the name of the issuer and date of the last survey. These lists must include:

- All observation regarding hardware systems and management recorded in the inspection report of the port authorities, including code number or reservation, for each failure;
- Details of the actions taken;
- Details of significant observations. A date should be put, so every observation to be checked on this date.

The following codes, presented in Table 3, are used to determine the severity of observations by inspectors PSC (action codes)

Table 3: Action codes used by PSC inspectors

00	No action taken
10	Deficiency rectified
12	All deficiencies rectified
15	Rectify deficiency at next port
16	Rectify deficiency within 14 days
17	Master instructed to rectify deficiency before departure
18	Rectify non-conformity within 3 months
19	Rectify major non-conformity before departure
20	Ship delayed for rectification of deficiencies
25	Ship allowed to sail after delay
26	Competent Security Authority (CSA) informed
30	Ship Detained
35	Detention Raised
36	Ship allowed to sail after follow-up detention
40	Next port of call informed
47	Agreed Class condition
50	Flag State/ Consul informed
55	Flag State Consul informed
60	Region State informed
65	Prohibition to continue an operation
70	Classification Society informed
80	Temporary substitution of equipment
81	Temporary repair effected - permanent repair to do
82	Alternative equipment or method used
85	Investigation of contravention of discharge provision (MARPOL)
90	Letter of warning issued
95	Re-inspection connection with Code 90
96	Letter of warning withdrawn
99	Other (specify)

Not all codes are found in the reports. The majority of them are mainly used to introduce the information in the PSC computer database. Some regions use different codes of action, however, the main codes are used worldwide.

3.7.1 BLACK LIST

In an effort to assist the PSC in selecting ships for inspection, the MOU evaluating the results of inspections in recent years, publish annually the "Black, Grey, White Lists", which show information about the performance of each flag State with regard to the reservations imposed on their vessels by foreign PSC.

The lists show the full range between quality flags and flags with poor performance considered high or very high risk. These lists are taken into consideration whether a ship is considered a candidate for inspection. It is obvious that if a ship flies a flag which is in black list, is supposed to be inspected more times and consequently delays more than some others. So the countries that are in the white list are more attractive in regard of delays of their vessels.

4 COATING LIFETIME AND CORROSION MODEL

4.1 DATA

For both the coating lifetime and corrosion some data are required as inputs for the model. Some further data are arising from the database available from HIS Maritime & Trade.

The following tables are presenting the input data required as well as the data arising from them.

Table 4: Input data required for the model

YEAR today
IMO
No of owner changes
Time at sea (in days)
Time at port (in hours)
Cargo Corrosivity
Cargo Abrasivity
Cargo Temperature
Operating in tropics /subtropics
Time with ballast (Ballast ratio)
Building Class
Abrasive cargo handling
Cargo Frequency
Detentions
Deficiencies
Time to next docking survey
Year Build
Ship age (years)
Ship size (tons)
Ship Type
Flag
country of yard
Class

4.2 COATING LIFETIME MODEL

4.2.1 GRAPHICAL REPRESENTATION

A graphical representation of the coating lifetime model is presenting below.

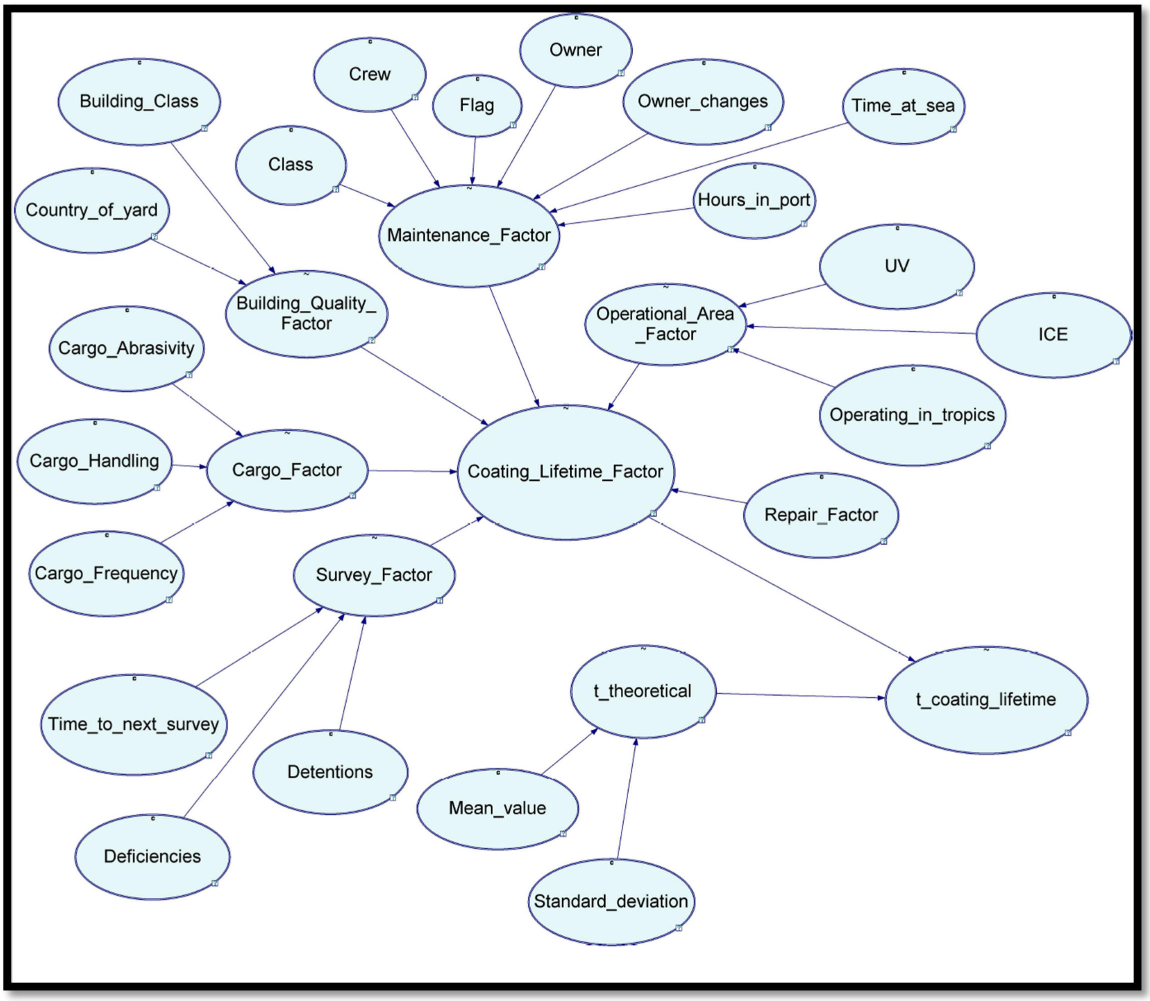


Figure 20: Graphical representation of coating lifetime model

4.2.2 THE COUNTRY OF YARD

The country where the ship is built plays an important role in the coating lifetime as the workmanship and the quality of materials varies between different countries and different continents. So, by evaluating the data the following table indicates how the country of the yard is affecting the coating lifetime.

Table 5: Country of the yard as a factor affecting coating lifetime

Country of Yard	
Country Name	Factor
China	0.67
Europe	1.06
Japan	1.17
S.Korea	1.11
other	0.67
unknown	0.67

4.2.3 THE BUILDING CLASS

The classification society where the ship belonged to during the period it was under construction, may give enough information about the building quality of the ship.

Table 6: The building class society as a factor affecting coating lifetime

Classification Society	
Class	Factor
IACS	1.1
non-IACS	0.9
unknown	0.9

The above mentioned factors, the country of yard and the building class, are affecting the total factor for building quality.

4.2.4 THE FLAG

Based on the data, collected by the database of PARIS MOU and the PSC reports regarding corrosion deficiencies found per inspection, an attempt to categorize the flags has been made. Then, and in order to normalize the list, for each flag separately, the number of deficiencies per inspection was divided with the average number of deficiencies per inspection for all flags in general. Ultimately, the flag vessels are carrying are categorized in three categories, BLACK, GREY and WHITE. Each of the above mention categories affects the coating lifetime of a vessel with a factor, F_{flag}.

Table 7: Flag categorized based on deficiencies found during inspections

FLAG			
Name	**corr.def/ins**	**factor for coating**	
Bulgaria	0.179	5.424	BLACK
Comoros	0.152	4.606	BLACK
Tanzania	0.147	4.455	BLACK
Cambodia	0.142	4.303	BLACK
Ukraine	0.138	4.182	BLACK
Sierra Leone	0.136	4.121	BLACK
Lebanon	0.119	3.606	BLACK
Dominica	0.098	2.970	BLACK
Algeria	0.097	2.939	BLACK
Moldovia	0.096	2.909	BLACK
Albania	0.092	2.788	BLACK
Togo	0.079	2.394	BLACK
Tuvalu	0.069	2.091	BLACK
Belize	0.064	1.939	GREY
Thailand	0.053	1.606	GREY
Morocco	0.053	1.606	GREY
Cook Islands	0.051	1.545	GREY
Iran	0.048	1.455	GREY
Russian Fed	0.047	1.424	GREY
St. Vincent/Grena	0.045	1.364	GREY
Belgium	0.042	1.273	GREY
St.Kittis/ Nevis	0.041	1.242	GREY
Switzerland	0.034	1.030	GREY
Korea, Rep of	0.031	0.939	WHITE
Turkey	0.029	0.879	WHITE
Vanuatu	0.028	0.848	WHITE
Barbados	0.023	0.697	WHITE
Panama	0.02	0.606	WHITE
Lithuania	0.02	0.606	WHITE
Egypt	0.02	0.606	WHITE
China	0.019	0.576	WHITE
USA	0.018	0.545	WHITE
India	0.014	0.424	WHITE
Philippines	0.014	0.424	WHITE
Liberia	0.014	0.424	WHITE
Malta	0.013	0.394	WHITE
Marshall Islands	0.012	0.364	WHITE
Italy	0.011	0.333	WHITE
Portugal	0.011	0.333	WHITE
Cyprus	0.01	0.303	WHITE

Bermuda	0.009	0.273	WHITE
Antigua Barbuda	0.009	0.273	WHITE
Croatia	0.008	0.242	WHITE
France	0.008	0.242	WHITE
Germany	0.008	0.242	WHITE
Bahamas	0.007	0.212	WHITE
Singapore	0.007	0.212	WHITE
Curacao	0.006	0.182	WHITE
UK	0.005	0.152	WHITE
Spain	0.005	0.152	WHITE
Gibraltar	0.005	0.152	WHITE
Norway	0.005	0.152	WHITE
Finland	0.005	0.152	WHITE
Greece	0.002	0.061	WHITE
Isle of Man	0.001	0.030	WHITE
Hongkong	0.001	0.030	WHITE
Netherlands	0.001	0.030	WHITE
Denmark	0.001	0.030	WHITE
Malaysia	0	0.000	WHITE
Poland	0	0.000	WHITE
Libya	0	0.000	WHITE
Tunisia	0	0.000	WHITE
Sweden	0	0.000	WHITE
Cayman Islands	0	0.000	WHITE
Faroe Islands	0	0.000	WHITE
Saudi Arabia	0	0.000	WHITE
Kazakhstan	0	0.000	WHITE
Estonia	0	0.000	WHITE
Japan	0	0.000	WHITE
Latvia	0	0.000	WHITE
Ireland	0	0.000	WHITE
Luxemburg		0.000	WHITE

Table 8: Flag as a factor for coating lifetime

FLAG	FACTOR FOR CL
WHITE	1.1
GREY	1
BLACK	0.9

4.2.5 THE CLASS

The classification society where the ship belongs to, may give enough information about the maintenance of the ship. Therefore classification societies which are part of IACS tend to extend the duration of life, a fact that is not noted otherwise. The following table indicates how the class society of the ship is affecting the coating lifetime.

Table 9: Class society as a factor affecting coating lifetime

Classification Society	
Class	Factor
IACS	1.1
non-IACS	0.9
unknown	0.9

4.2.6 OWNER/MANAGER

Due to the large number of owners and/or managers holding vessels worldwide, it is not possible to evaluate the data and create a list for owner/managers with white-grey-black zones. So, for the time being, the factor is set to 1.

4.2.7 NUMBER OF CREW

Every flag state requires different number of crew onboard, depending on the ship type, the ship size, the operating area etc. For every ship the owner/manager submit the crew list to the flag state in order to get approval and the minimum safe manning certificate.

As there are no official data for the number of crew needed for every different vessel the factor is set to 1.

4.2.8 OWNER CHANGES

A vessel may change many owners during its life cycle. However, the more owners a ship change the worse its maintenance tends to be. So, another factor affecting the lifespan of the coating is presenting in the following table and it is mainly influenced by the number of owner changes.

Table 10: Number of owner changes as a factor affecting coating lifetime

No of Owner Changes	Factor
0	1.2
1 or 2	1
over 3	0.9
unknown	0.9

4.2.9 TIME AT SEA

The hours a vessel is sailing at sea is another factor affecting the coating lifetime. The more hours a vessel is sailing the more hours are available for maintaining the vessel. The following table indicates how the time a ship is sailing at sea is affecting the coating lifetime.

Table 11: Time at sea as a factor affecting coating lifetime

Time at sea	Average sailing time between two ports	Factor for CL
unknown	unknown	1
Short	<3	1
Long	>=3	1.2

4.2.10 HOURS IN PORT

Another factor, additional to the time spend at sea, is the hours the ship is in port. The following table indicates how the hour a ship is in port is affecting the coating lifetime.

Table 12: Hours in port as a factor affecting coating lifetime

Hours at port	Average time in ports	Factor for CL
unknown	unknown	1
Short	<24	1
Short	>=24	1

The above mentioned factors, the flag, the class, the owner/manager, the number of crew, the number of owner changes, the time spend at sea and in port, are affecting the total factor for maintenance.

4.2.11 CARGO ABRASIVITY

The abrasivity of the cargo is another important factor affecting the coating lifetime of the vessel's hull. The following table indicates how the corrosivity of the cargo is affecting the coating lifetime.

Table 13: Abrasivity of the cargo as a factor for coating lifetime

Abrasivity of the Cargo	
	Factor for CL
Never	1
occasionally	0.95
regularly	0.95
unknown	0.95

4.2.12 CARGO HANDLING

The cargo handling method mainly depends on the type of cargo carried. The following table indicates how the handling method of the cargo is affecting the coating lifetime.

Table 14: Handling of the cargo as a factor for coating lifetime

Cargo Handling	
Abrasive cargo handling	Factor for CL
Never	1
Occasionally	0.95
Regularly	0.9
unknown	0.9

4.2.13 CARGO FREQUENCY

The cargo change frequency is also affecting the coating lifetime. The following table indicates how the frequency of cargo changes is affecting the coating lifetime.

Table 15: Frequency of the cargo as a factor for coating lifetime

Cargo Frequency	
Cargo Changes	Factor for CL
Often (more than once per week)	0.9

Medium (at least once per 14 days)	0.95
Rarely (less than once per 14 days)	1
unknown	0.9

The above mentioned factors, the cargo abrasivity, the cargo handling and the cargo frequency, are affecting the total factor for cargo.

4.2.14 UV RADIATION

The environmental condition are mainly affecting by the operational area of the vessel. It is obvious, that the impact of the UV Radiation is higher on the outer parts of a ship. So for the ballast tanks and/or cargo holds the factor is set to 1.

4.2.15 ICE

Ice is also an environmental factor, so similarly to the UV Radiation is affecting more the outer parts of the ship. The factor for ice is also set to 1 for the ballast tanks and/or the cargo holds.

4.2.16 OPERATING IN TROPICS/SUBTROPICS

The areas a ship is traveling, especially the characteristics of the sea in various places worldwide also affect the coating lifetime of a vessel. So the frequency a ship is sailing in tropic and/or sub-tropic water may influence the coating lifetime. The following table indicates how the operation of a ship in tropics and/or sub-tropics is affecting the coating lifetime.

Table 16: Operation in tropics and/or sub-tropics as a factor for coating lifetime

Operating in tropics /subtropics	
	Factor for CL
Mostly (>75%)	0.9
Occasionally (25%-75%)	0.95
Seldom (<25%)	1
Unknown	0.9

The above mentioned factors, the UV radiation, the ice and the operation in tropics/subtropics, are affecting the total factor for operating area.

4.2.17 REPAIRS

As there are no efficient data, for the time being the factor for repairs is set to 1.

4.2.18 NUMBER OF DEFICIENCIES

The number of deficiencies represents the actual situation of the vessel. The bigger the number of deficiencies is, the worse the situation of the vessel. The following table indicates how the number of deficiencies is affecting the coating lifetime.

Table 17: Number of Deficiencies as a factor for coating lifetime

No of DEFICIENCIES in last 36 months	
	Factor for CL
Many (5+)	0.9
Some (<5)	0.95
None	1
unknown	0.9

4.2.19 NUMBER OF DETENTIONS

The number of detentions also represents the actual situation of the vessel. The following table indicates how the number of detentions is affecting the coating lifetime.

Table 18: Number of Detentions as a factor for coating lifetime

No of DETENTIONS in last 36 months	
	Factor for CL
Many (>2)	0.9
Some (1 or 2)	0.95
None	1
unknown	0.9

4.2.20 TIME TO NEXT DOCKING SURVEY

The time to next docking survey indicates how long ago the ship was maintained. The following table indicates how the number of detentions is affecting the coating lifetime.

Table 19: Time to next docking survey as a factor for coating lifetime

Time to next docking survey	
	Factor for CL
< 1 year	0.9
1-3 years	0.95
> 3 years	1
unknown	0.9
overdue	0.9

The above mentioned factors, the number of deficiencies and detentions and the time to next docking survey, are affecting the total factor for surveys.

All the above mentioned factors are affecting a total factor for coating lifetime, F_{CL}. This factor, F_{CL}, is multiplied with the theoretical lifetime of the coating in order to lead to a more realistic value for the coating lifetime in years.

The $t_{theoretical}$, is a value best described by normal distribution and it varies between different section of a vessel. In the following table are shown the mean value and the standard deviation for various ship sections.

Table 20: Mean value and standard deviation parameters for various ship sections

Locations	Coating Life (years)	
	Mean	Stdv.
Living Space	10	2
Exterior Deck	9	2.7
Interior Deck	10	2
Bottom	10	3
Dry Cargo Space		
Interior Deck	10	3
Bulkhead	7	2.8
Inner Bottom	3	0.9
Floor	10	3
Side Shell	7	2.8
Ballast Tank	*5*	*1.5*
Interior Deck (if present)	8	3.2
Bulkhead	8	3.2

Floor (if present)	10	3
Inner Bottom	6	2.4
Side Shell	8	3.2
Liquid Cargo Space (= Fuel oil tanks)	*7*	*2.1*
Deck (inner)	9	2.7
Bulkhead	9	2.7
Inner Bottom	7	2.1
Floor	8	2.4
Side Shell	9	2.7

These values are based on information collected by experts' judgments.

4.3 CORROSION MODEL

4.3.1 GRAPHICAL REPRESENTATION

A graphical representation of the corrosion model is presenting below.

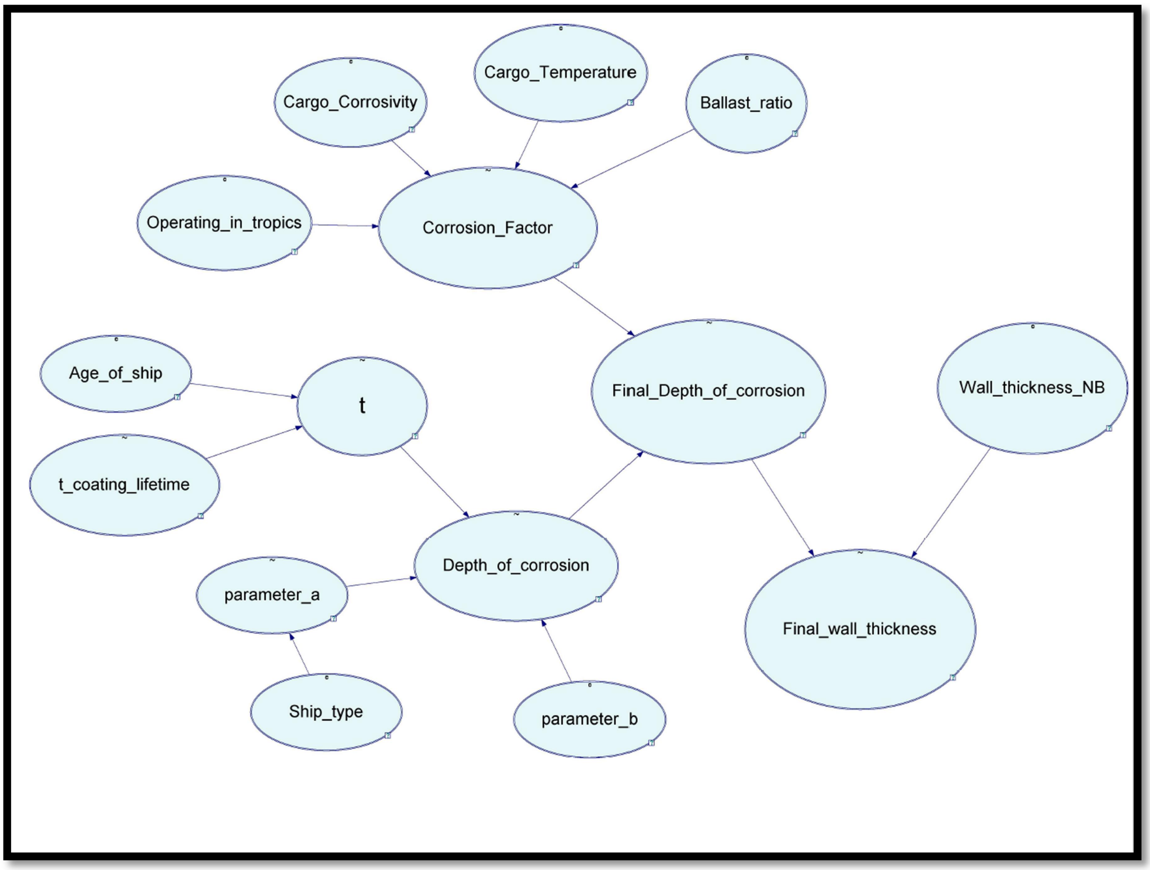


Figure 21: Graphical representation of corrosion model in GeNie

4.3.2 BALLAST RATIO

The ballast ratio can be defined as:

$$Balla \quad Ratio = \frac{time\ with\ ballast}{age\ of\ ship}$$

Even though the age of the ship is an accurate number, the same does not apply for the time with ballast for a vessel as it is based on reports from the vessel's crew members and the human mistake and/or irregularity is always a possibility.

A factor based on the ballast ratio is affecting the corrosion process and in the following table indicates how the ballast ratio is affecting it.

Table 21: Ballast ratio as a factor for corrosion process

Ballast Ratio		
		Factor for corrosion
High	>50%	1.1
Medium	10..50%	1.05
Low	<10%	1
Unknown	unknown	1.1

4.3.3 OPERATING IN TROPICS/SUBTROPICS

The areas a ship is traveling, especially the characteristics of the sea in various places worldwide also affect the corrosion process for a vessel's hull. So the frequency a ship is sailing in tropic and/or sub-tropic water may influence the corrosion rate of the vessel's hull. The following table indicates how the operation of a ship in tropics and/or sub-tropics is affecting the corrosion process.

Table 22: Operation in tropics and/or sub-tropics as a factor for corrosion process

Operating in tropics /subtropics	
	Factor for corrosion
Mostly (>75%)	1.11
Occasionally (25%-75%)	1.05
Seldom (<25%)	1
Unknown	1.11

4.3.4 CARGO CORROSIVITY

The corrosivity of the cargo is another important factor affecting the corrosion rate of the vessel's hull. The following table indicates how the corrosivity of the cargo is affecting the corrosion process.

Table 23: Corrosivity of the cargo as a factor for corrosion rate

Corrosivity of the Cargo	
	Factor for corrosion
Never	1
occasionally	1.2
regularly	1.5
unknown	1.5

4.3.5 CARGO TEMPERATURE

Besides corrosivity of the cargo, cargo temperature also influences the corrosion rate of the vessel's hull. The following table indicates how the temperature of the cargo the ship is carrying is affecting the corrosion process.

Table 24: Temperature of the cargo as a factor for corrosion rate

Cargo temperature	
	Factor for corrosion
High (>45°C)	1.5
Medium (25..45°C)	1.2
Low (<25°C)	1
unknown	1.5

The above mentioned factors, the ballast ratio, the operation in tropics/subtropics, the cargo corrosivity and the cargo temperature, are affecting the total factor for corrosion.

All the above mentioned factors are affecting a total factor, $F_{corrosion}$. This factor, $F_{corrosion}$, is multiplied with the theoretical depth of corrosion in order to lead to a more practical value for the corrosion rate.

There are various models estimating the corrosion rate.

- Yamamoto (1997): two parameter power approximation.

$$z(\tau) = a_{corr} \cdot \tau^{b_{corr}}$$

where z the wear in terms of mm of plate thickness, a_{Corr} as a constant govern characteristic of corrosion growth, b_{Corr} characterising the shape/slope of the function z and time τ, i.e. age of the vessel minus life of coating.

- Southwell et al. (1979) based on their observations proposed linear and bilinear models

$$z(\tau) = 0.076 + 0.038 \cdot \tau$$

$$z(\tau) = \begin{cases} 0.090 \cdot \tau & 0.0 \leq \tau < 1.46 \\ 0.076 + 0.038 \cdot \tau & 1.46 \leq \tau < 16 \end{cases}$$

- Melchers & Ahammed (1998) suggested a model distinguishing initial corrosion, oxygen diffusion control stage and anaerobic stage, and proposed different sets of parameter values (Melchers, 2001):

$$z(\tau) = \begin{cases} 0.170 \cdot \tau & 0 \le \tau < 1 \\ 0.152 + 1.0186 \cdot \tau & 1 \le \tau < 8 \\ -0.364 + 0.083 \cdot \tau & 8 \le \tau < 16 \end{cases}$$

- Soares & Garbatov (1999) proposed an exponential model:

$$z(\tau) = \begin{cases} d_\infty \left(1 - e^{-\frac{(t-\tau_c)}{\tau_t}}\right) & t > \tau_c \\ 0 & t \le \tau_c \end{cases}$$

With τ_c coating life, τ_t transition time and d_∞ as maximum corrosion wastage. Soares & Garbatov suggested using d_∞ equal to maximum corrosion allowance.

The depth of corrosion, for the present model is based on the Yamamoto (1997) model and results from the equation:

$$D(t) = a \cdot t^b$$

where, a = is given in the table 26, and it varies between different structural points of the vessel and different ship types.

b = 2/3

Table 25: Parameter a for various ship types and different structural points

Locations	Corrosion Model parameter a				
	BC	Tanker	GCS	Container	Pax
Living Space	0.61	0.61	0.61	0.61	0.61
Exterior Deck	0.61	0.61	0.61	0.61	0.61
Interior Deck	0.21	0.21	0.21	0.21	0.21
Bottom	0.2	0.2	0.2	0.2	0.2
Dry Cargo Space					
Interior Deck	0.21	x	0.21	0.21	x
Bulkhead	0.58	x	0.58	0.28	x
Inner Bottom	0.28	x	0.28	0.28	x
Floor	0.57	x	0.57	0.28	x
Side Shell	0.31	x	0.31	0.31	x

Ballast Tank					
Interior Deck					
Bulkhead	0.52	0.52	0.52	0.52	0.52
Floor (if present)					
Inner Bottom	0.38	0.38	0.38	0.38	0.38
Side Shell					
Liquid Cargo Space (= Fuel oil tanks)					
Deck (inner)	x	0.3	x	x	x
Bulkhead	x	0.4	x	x	x
Inner Bottom	x	0.3	x	x	x
Floor	x	0.31	x	x	x
Side Shell	x	0.35	x	x	x

The final model is graphically presented in fig. 22.

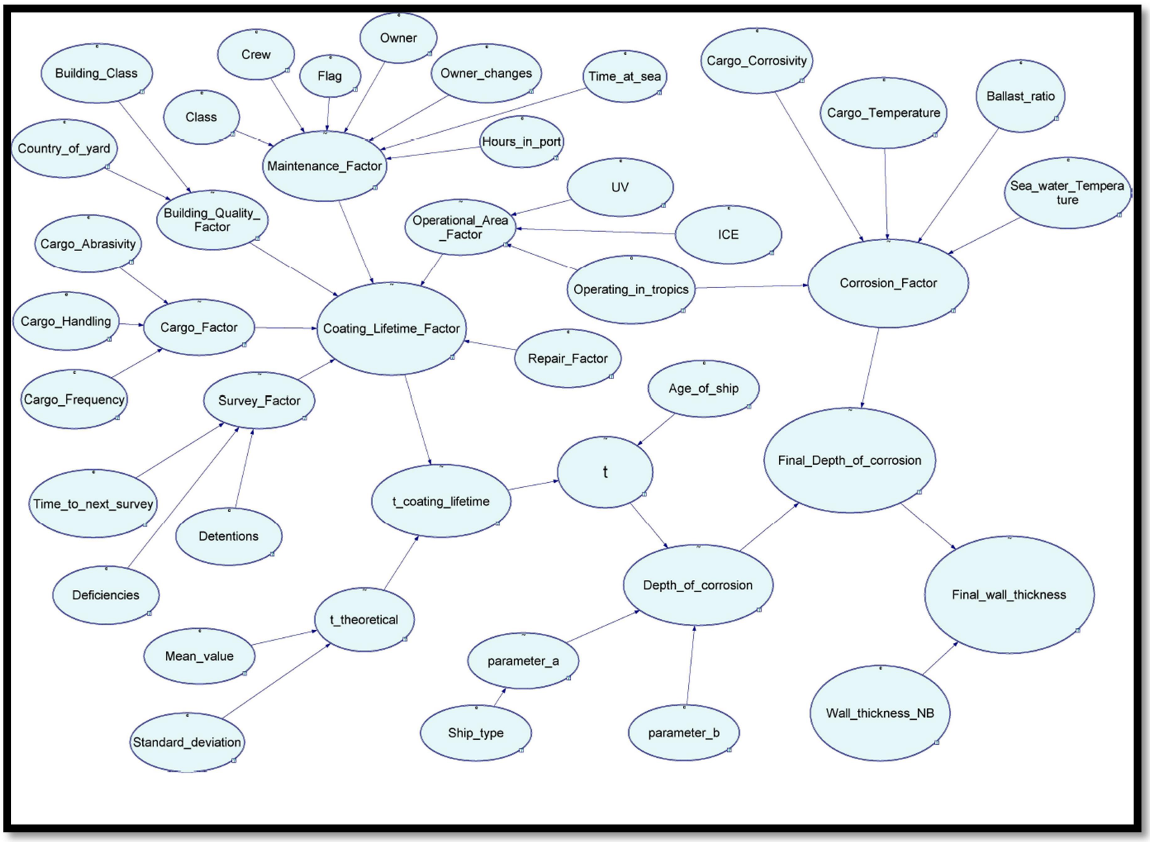


Figure 22: Final model graphical representation

The data are from the IHS MARINE & TRADE database, from AIS marine traffic and form PSC Inspection search (https://www.parismou.org/inspection-search/inspectionsearch, period 30.05.2013 – 30.05.2016). The values for the parameters used are based on experts' judgement (inspectors from classification societies)

5 MODEL RESULTS

5.1 INTRODUCTION

After the completion of the model, three ship types were selected in order to check the model and get some results. The three ship types are tanker, bulk carrier and general cargo ship. For every ship type, the areas under examination are the cargo holds and the ballast tanks. The vessels described in the table 27, are the vessels based on which the model was tested.

Table 26: Vessels used in the coating lifetime and corrosion model

IMO	9289518	9437098	9312729
Name	Ajax	Constantinos	Ventura
ship type	Tanker	BC	GCS
ship size (DWT)	53095	87447	5780
No of TEU	0	0	240
Year Built	2005	2011	2006
flag	Bahamas	Marshall Islands	Antigua Barbuda
country of Yard	S.Korea	China	Europe
Class	IACS	IACS	IACS
No of owner changes	1	0	1
Time at sea (in days)	Long (>=3)	unknown	Long (>=3)
Time at port (in hours)	Long (>=1)	unknown	Long (>=1)
Cargo Corrosivity	unknown	unknown	unknown
Cargo Abrasivity	Never	unknown	unknown
Cargo Temperature	unknown	unknown	unknown
Operating in tropics /subtropics	occasionally (25%-75%)	unknown	occasionally (25%-75%)
Time with ballast (Ballast ratio)	High	unknown	Medium
Building Class	unknown	unknown	unknown
Abrasive cargo handling	Never	unknown	unknown
Cargo Frequency	unknown	unknown	Often (more than once per week)
Detentions	None	None	None
Deficiencies	None	None	Many (5+)
Time to next docking survey	overdue	overdue	unknown

After, the selection of the areas to be examined, the structural points to be explored should also be defined. The structural points for the cargo holds are the interior deck, the side shell, the bulkhead, the inner bottom and the floor. As for the ballast tanks, the structural points are the bulkhead and the inner bottom.

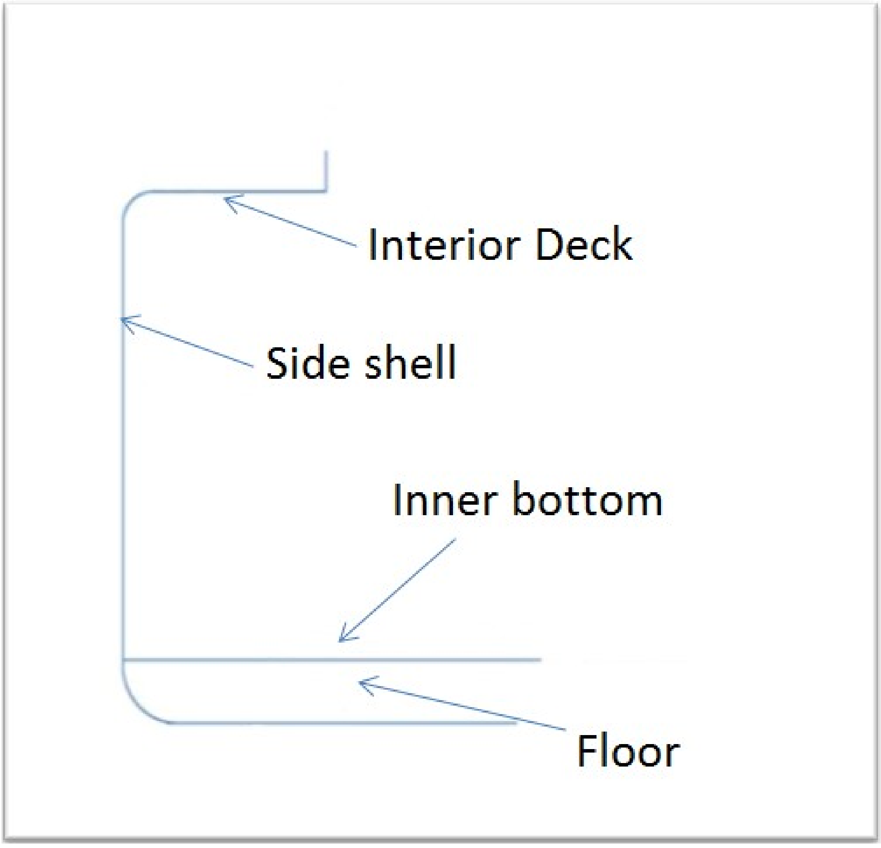


Figure 23: Structural points in cargo spaces

Theoretical coating life is approximately around 15 years. In the model, the $t_{coating\ lifetime}$ is calculated, based on the coating lifetime $t_{theoretical}$ and the coating lifetime factor. The first five years after the construction or the maintenance work the phenomenon of corrosion only affects vessel's coating. After the first five years, the phenomenon of corrosion affects both the coating of the vessel and the vessel's plates. The corrosion rate increases rapidly from the moment when the coating has been ruined and cannot protect the metal anymore. In this case, there are two options: the vessels should go for repairs and the coating should be placed again or the depth of corrosion will increase as the time passes and at some point the plate will be replaced. The permissible limit for the corrosion depth is approximately 20% of the new building metal thickness. The time for corrosion onset is different for every ship type and it is the age of the vessel (in years).

5.2 TANKER

The structural areas under examination are the ballast tanks and the cargo holds of the vessel.

For the cargo holds, the structural points are:

- Deck
- Bulkhead
- Side shell
- Inner bottom
- Floor

For the ballast tanks, the structural points are:

- Bulkhead
- Inner bottom

5.2.1 Ballast Tank

For the ballast tanks, the structural areas are the bulkhead and the inner bottom.

5.2.1.1 Bulkhead

In 99% of the cases, the depth of corrosion varies between 0.12mm and 7.29mm. The higher value for the depth of corrosion is 2.65mm with a frequency of 5.01% (Fig.24). The distribution, which best fits with the data is a Beta General distribution described in Fig.25 and in table 28.

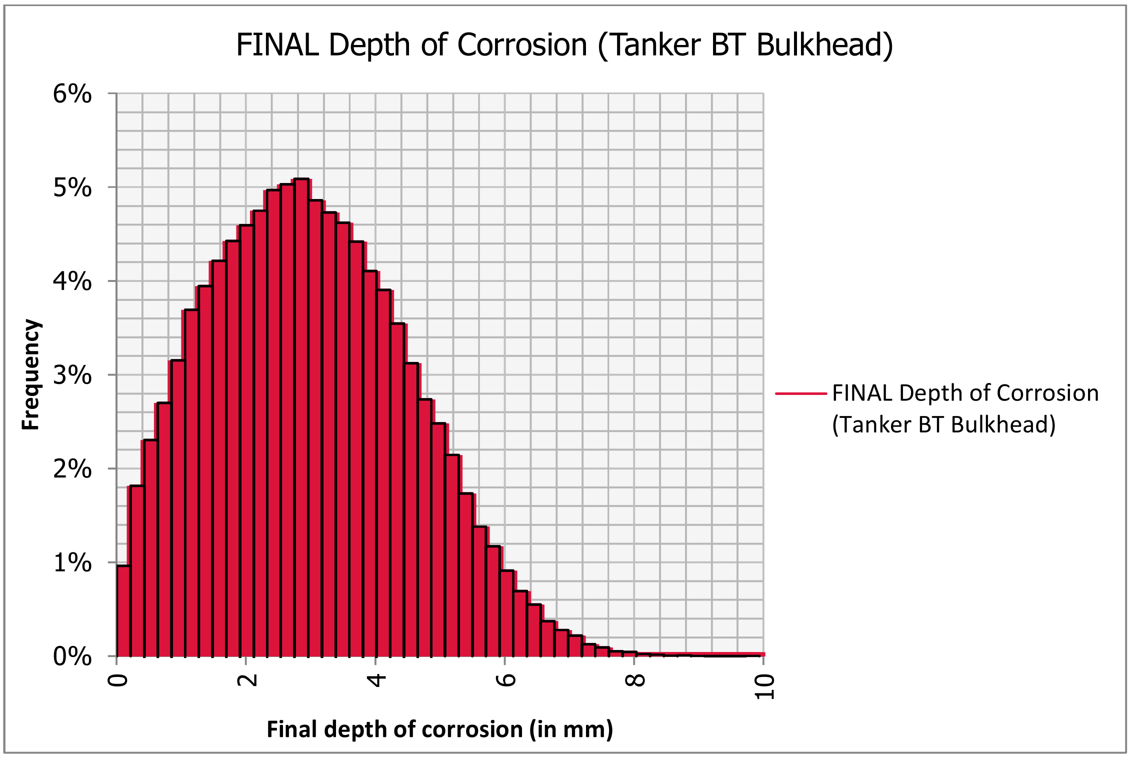


Figure 24: Calculated final depth of corrosion [in mm] for bulkhead in ballast tank, in tanker.

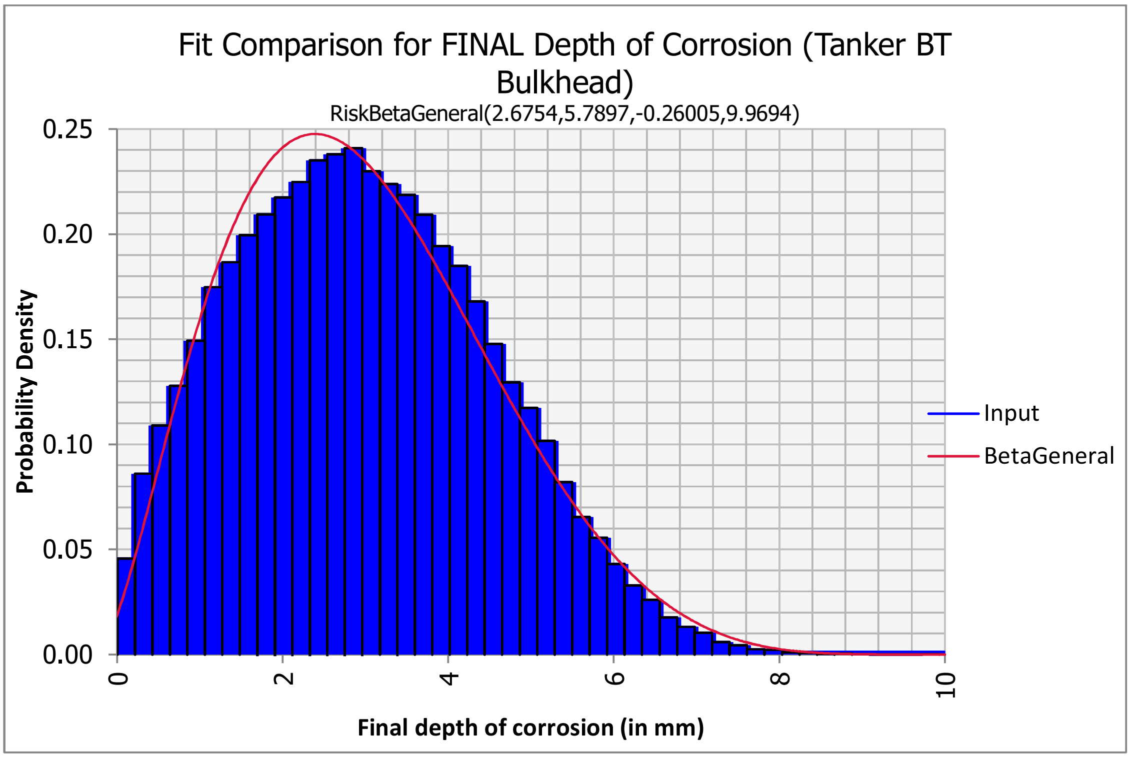


Figure 25: Fit distribution for Tanker Ballast tank, bulkhead

Table 27: Calculated corrosion depth [in mm] for bulkhead in ballast tank, in tanker.

	Beta General
a	2.6754
b	5.7897
Minimum	-0.26
Maximum	9.969

Corrosion is a natural phenomenon, and therefore the values received are only positive. The negative value, of -0.26 is only presented for the distribution to be defined. The same applies for the following distributions, where the minimum point gets negative value.

5.2.1.2 Inner Bottom

With confidence level 99%, the range of corrosion depth is between 0.09mm and 5.087mm. The higher value for the depth of corrosion is 2.66mm with a frequency of 4.83% (Fig.26). A Weibul distribution described in Fig. 27 and in table 29 fits best with the data.

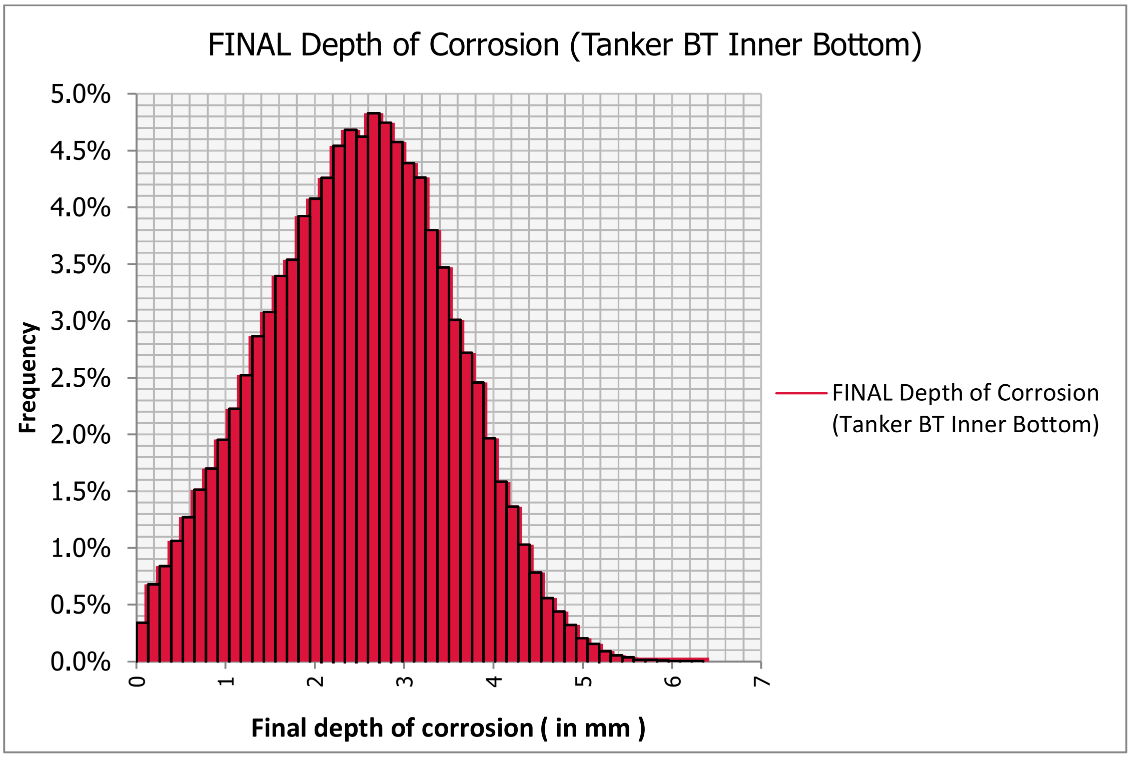


Figure 26: Calculated final depth of corrosion [in mm] for inner bottom in ballast tank, in tanker.

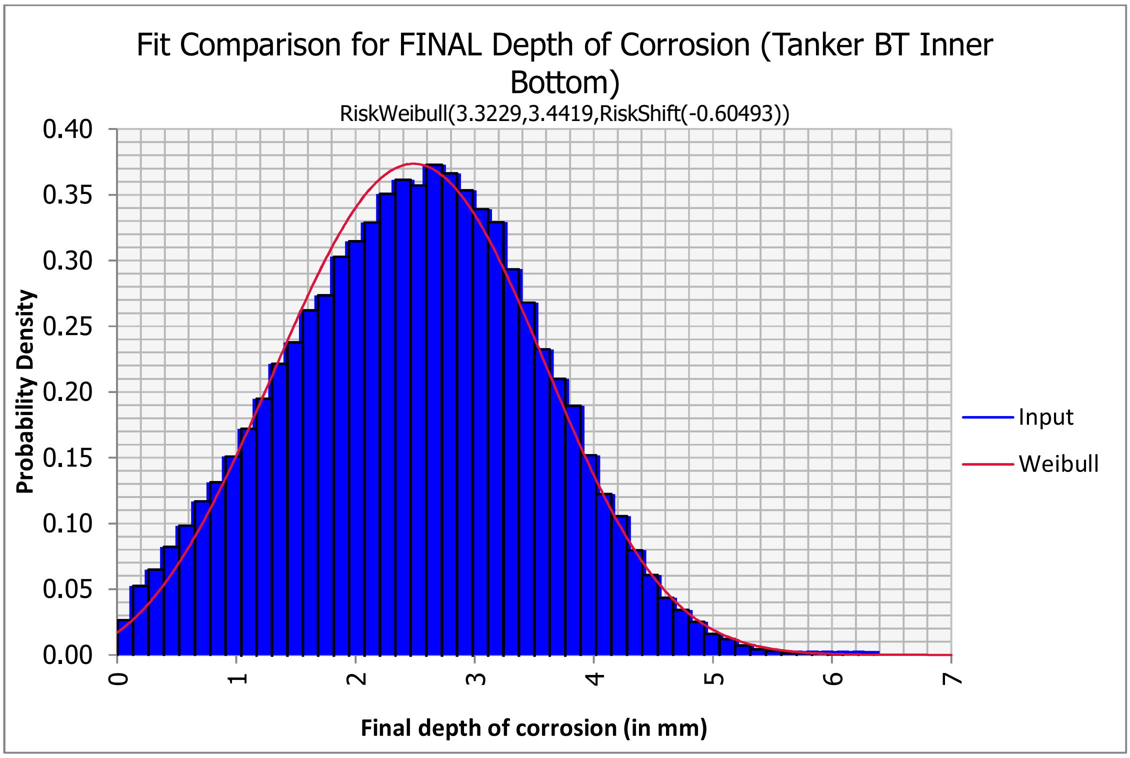


Figure 27: Fit distribution for Tanker Ballast tank, inner bottom

Table 28: Calculated corrosion depth [in mm] for inner bottom in ballast tank, in tanker.

	Weibul
a	3.3229
b	3.4419

5.2.2 Cargo Hold

For the cargo holds, the structural areas are the deck, the bulkhead, the side shell, the inner bottom and the floor.

5.2.2.1 Deck

In 99% of the cases, the depth of corrosion varies between 0.064mm and 3.475mm. The higher value for the depth of corrosion is 1.2mm with a frequency of 4.72% (Fig.28). A Beta General distribution described in Fig. 29 and in table 30 fits best with the data.

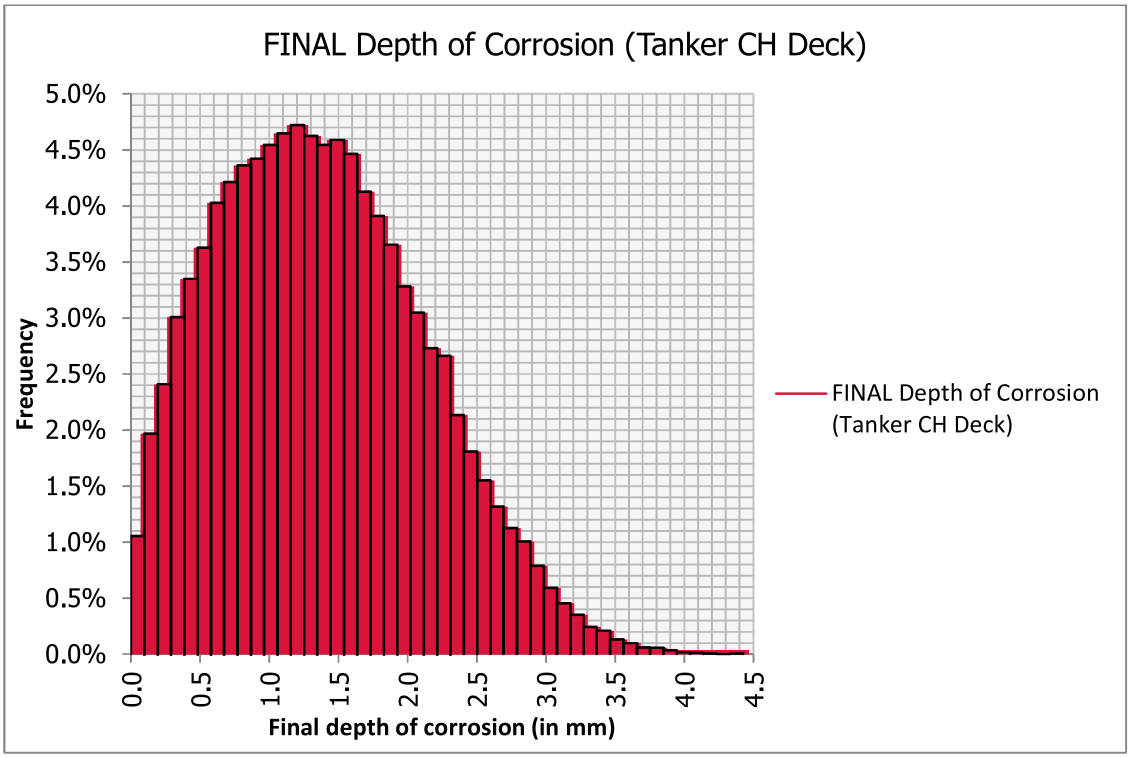


Figure 28: Calculated final depth of corrosion [in mm] for deck in cargo space, in tanker.

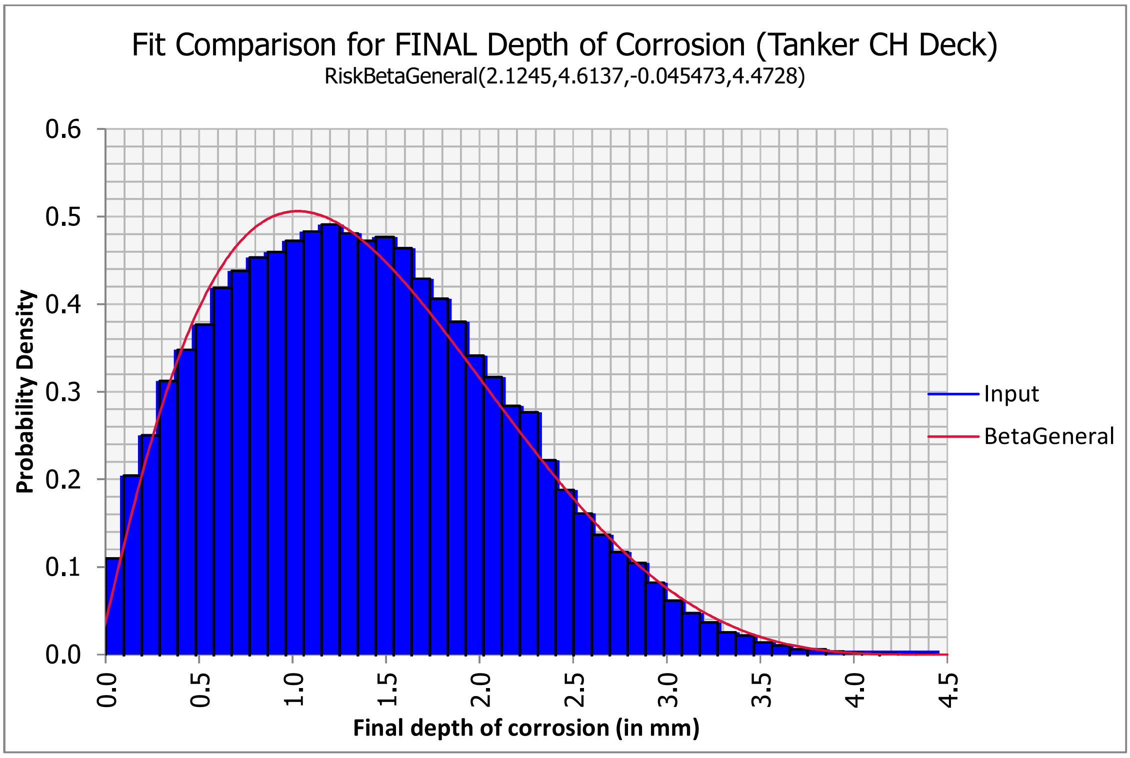


Figure 29: Fit distribution for Tanker cargo space, deck

Table 29: Calculated corrosion depth [in mm] for deck in cargo space, in tanker.

	Beta General
a	2.1245
b	4.6137
Minimum	-0.0455
Maximum	4.4728

5.2.2.2 Bulkhead

The breadth of the corrosion depth gets values between 0.08mm and 4.69 mm, in 99% of cases. The higher value for the depth of corrosion is 1.63mm with a frequency of 4.95% (Fig.30). The distribution, which best fits with the data is a Beta General distribution described in Fig. 31 and in table 31.

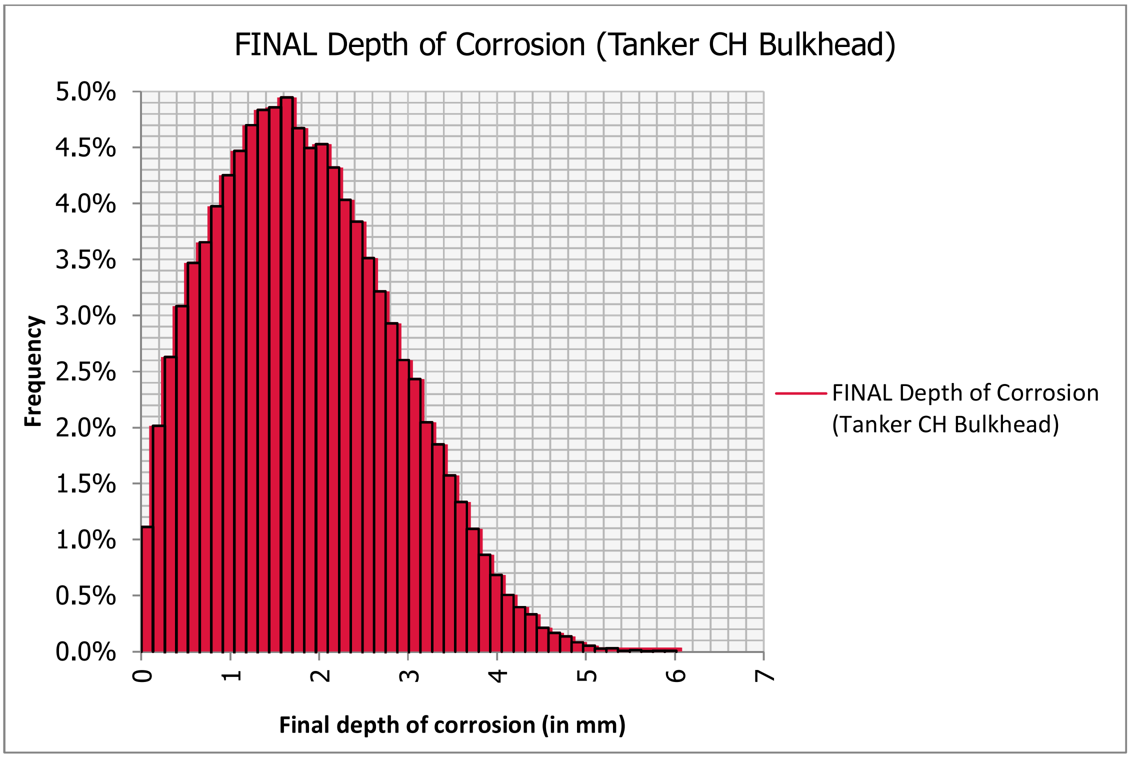


Figure 30: Calculated final depth of corrosion [in mm] for bulkhead in cargo space, in tanker.

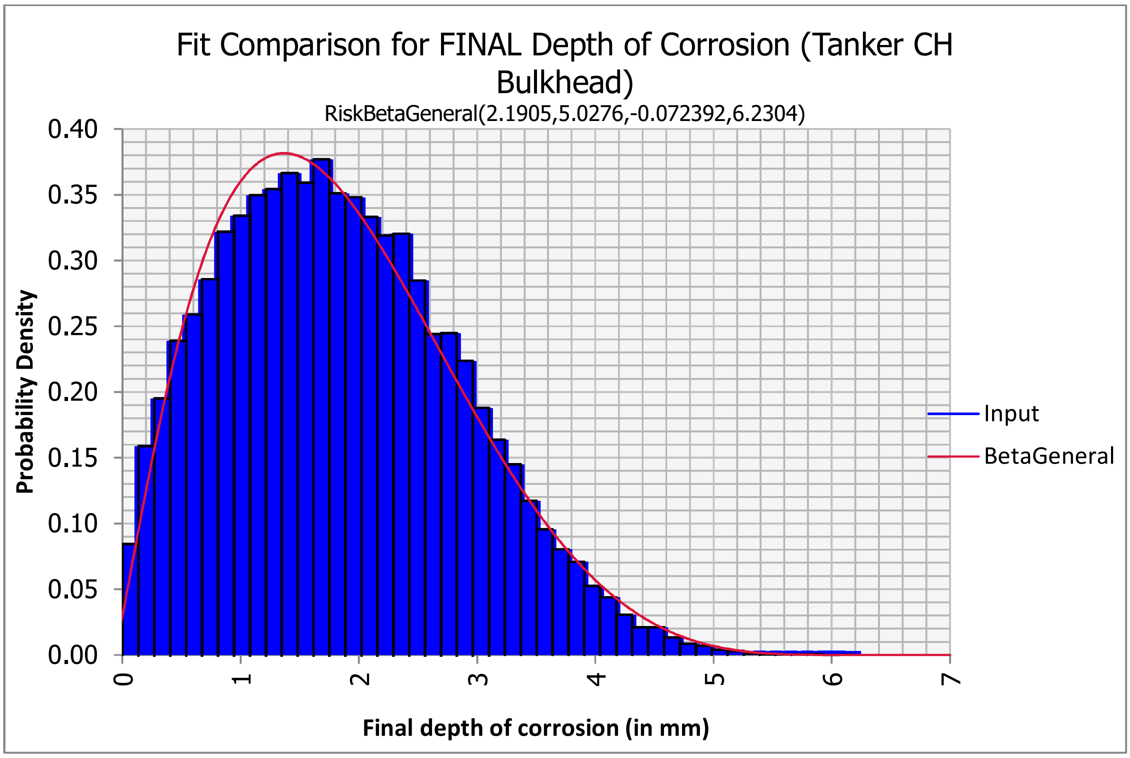


Figure 31: Fit distribution for Tanker cargo space, bulkhead

Table 30: Calculated corrosion depth [in mm] for bulkhead in cargo space, in tanker.

	Beta General
a	2.1905
b	5.0276
Minimum	-0.0724
Maximum	6.2304

5.2.2.3 Side Shell

With a confidence level 99%, the range of corrosion depth is between 0.07mm and 4.09mm. The higher value for the depth of corrosion is 1.23mm with a frequency of 5.03% (Fig.32). A Beta General distribution described in Fig. 33 and in table 32 fits best with the data.

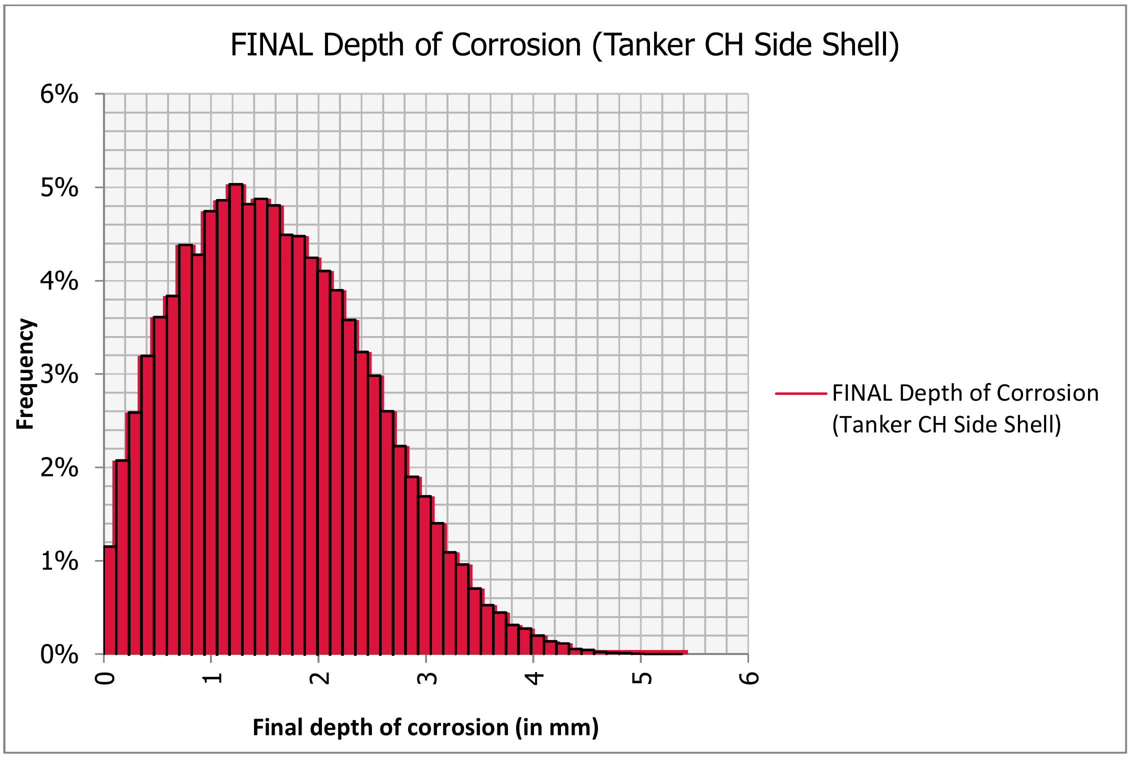


Figure 32: Calculated final depth of corrosion [in mm] for side shell in cargo space, in tanker.

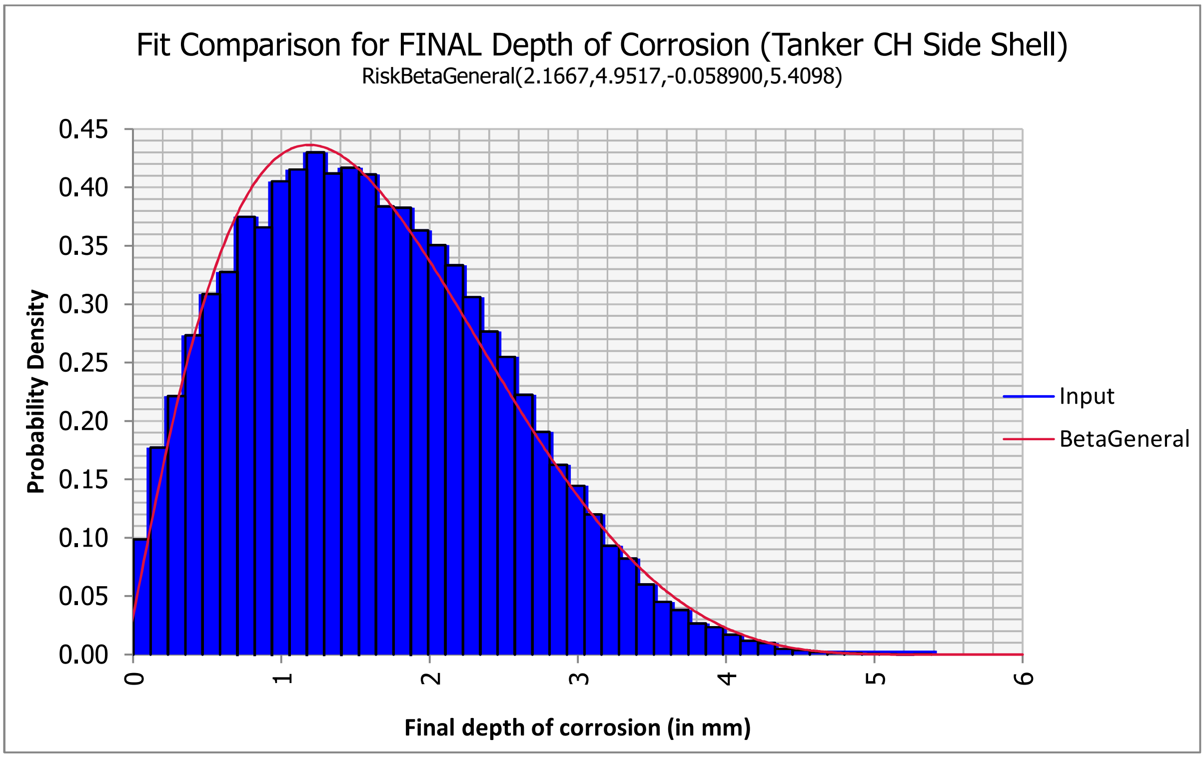


Figure 33: Fit distribution for Tanker cargo space, side shell

Table 31: Calculated corrosion depth [in mm] for side shell in cargo space, in tanker.

	Beta General
a	2.1667
b	4.9517
Minimum	-0.0589
Maximum	5.4098

5.2.2.4 Inner Bottom

In 99% of the cases, the depth of corrosion varies between 0.059mm and 3.473m. The higher value for the depth of corrosion is 1.67mm with a frequency of 4.68% (Fig.34).The distribution, which best fits with the data is a Beta General distribution described in Fig. 35 and in table 33.

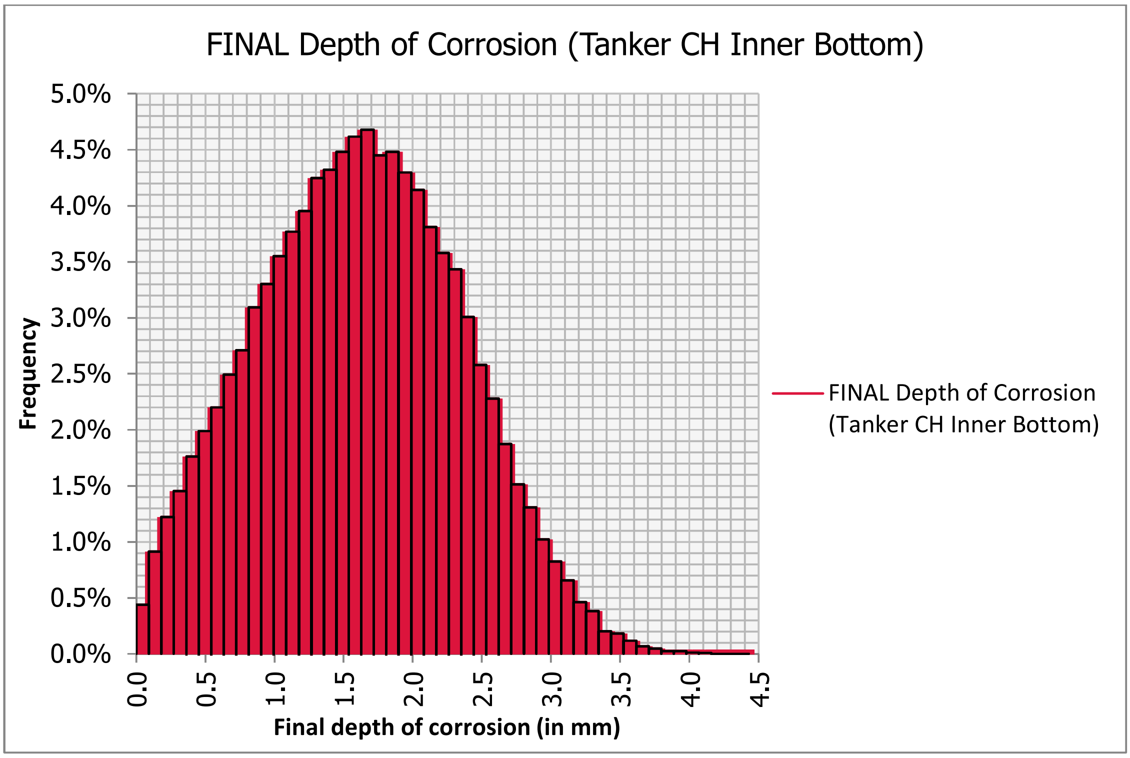


Figure 34: Calculated final depth of corrosion [in mm] for inner bottom in cargo space, in tanker.

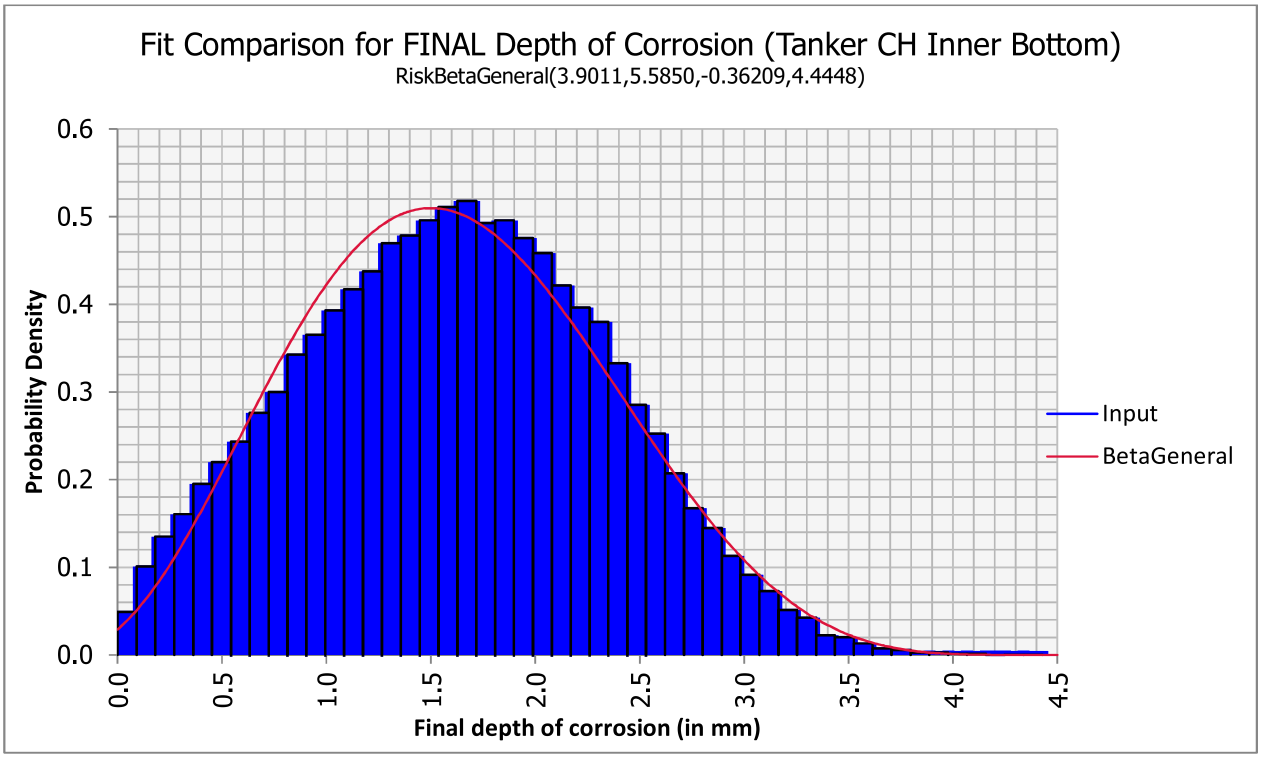


Figure 35: Fit distribution for Tanker cargo space, inner bottom

Table 32: Calculated corrosion depth [in mm] for inner bottom in cargo space, in tanker.

	Beta General
a	3.9011
b	5.585
Minimum	-0.3621
Maximum	4.4448

5.2.2.5 Floor

The breadth of the corrosion depth gets values between 0.06mm and 3.607mm. The higher value for the depth of corrosion is 1.44mm with a frequency of 4.80% (Fig.36). A Beta General distribution described in Fig. 37 and in table 34 fits best with the data.

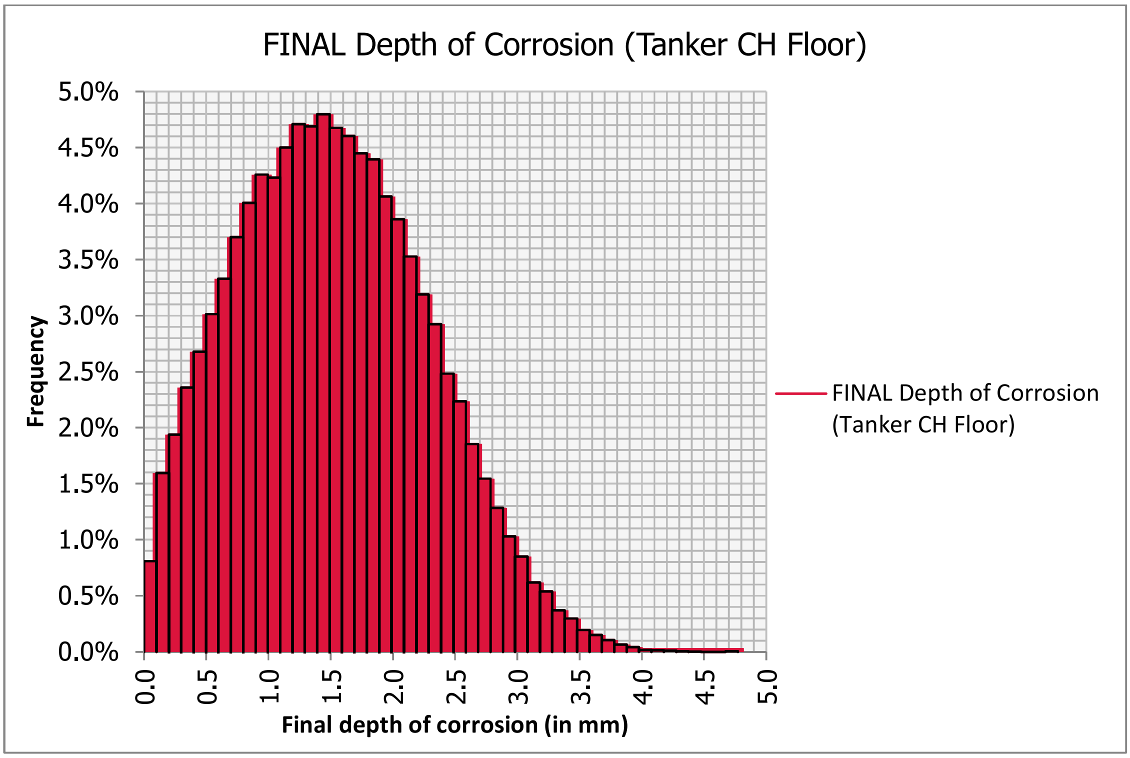


Figure 36: Calculated final depth of corrosion [in mm] for floor in cargo space, in tanker.

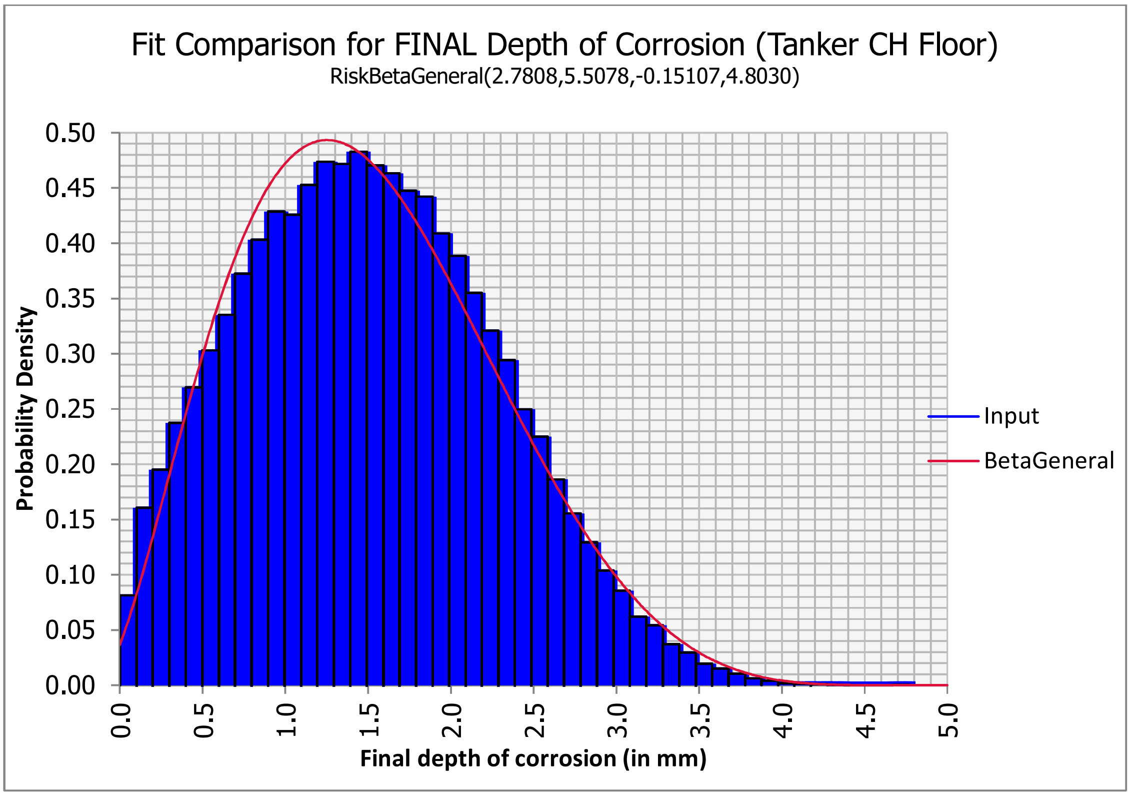


Figure 37: Fit distribution for Tanker cargo space, floor

Table 33: Calculated corrosion depth [in mm] for floor in cargo space, in tanker.

	Beta General
a	2.7808
b	5.5078
Minimum	-0.1511
Maximum	4.803

5.3 BULK CARRIER

The structural areas which are explored are the ballast tanks and the cargo holds of the vessel.

For the cargo holds, the structural points are:

- Deck
- Bulkhead
- Side shell
- Inner bottom
- Floor

For the ballast tanks, the structural points are:

- Bulkhead
- Inner bottom

5.3.1 Ballast Tank

For the ballast tanks, the structural areas are the bulkhead and the inner bottom.

5.3.1.1 Bulkhead

With a confidence level 99%, the range of corrosion depth is between 0.08mm and 4.46mm. The higher value for the depth of corrosion is 1.94mm with a frequency of 4.52% (Fig.38). The distribution, which best fits with the data is a Beta General distribution described in Fig. 39 and in table 35.

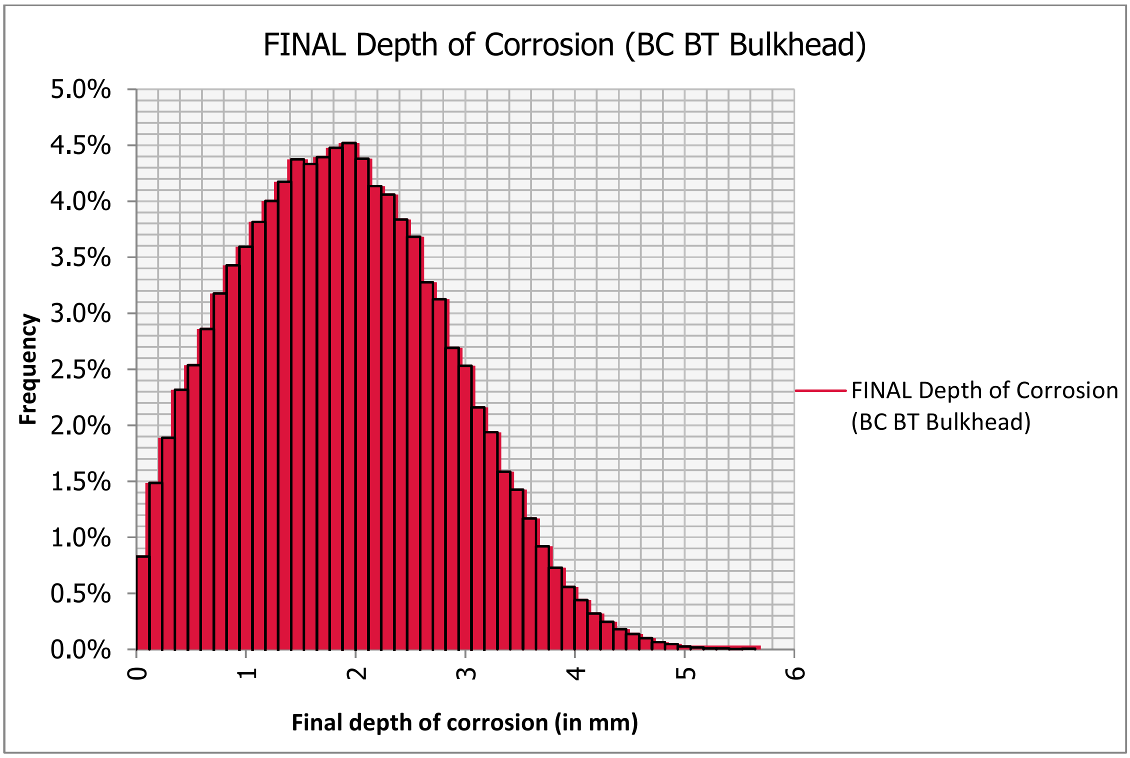


Figure 38: Calculated final depth of corrosion [in mm] for bulkhead in ballast tank, in Bulk carrier.

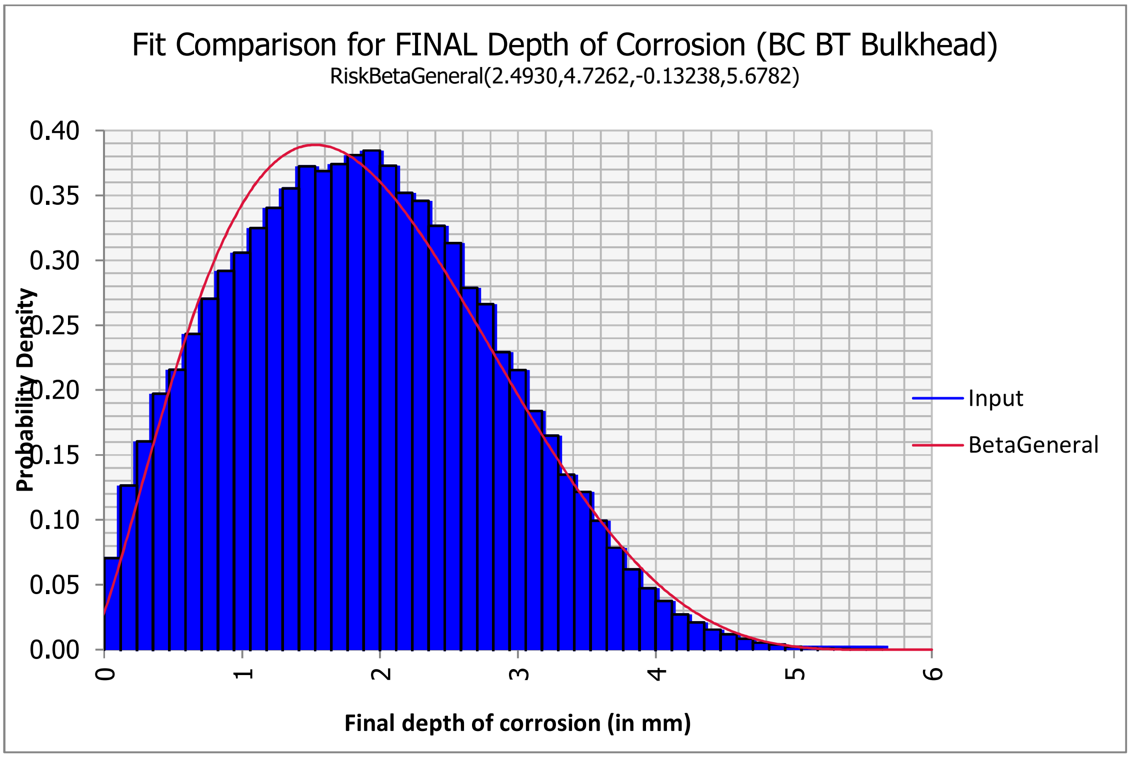


Figure 39: Fit distribution for Bulk carrier ballast tank, bulkhead

Table 34: Calculated corrosion depth [in mm] for bulkhead in ballast tank, in Bulk carrier.

	Beta General
a	2.493
b	4.7262
Minimum	-0.1324
Maximum	5.6782

5.3.1.2 Inner Bottom

The breadth of the corrosion depth gets values between 0.068mm and 3.163mm. The higher value for the depth of corrosion is 1.67mm with a frequency of 4.86% (Fig.40). A Weibul distribution described in Fig. 41 and in table 36 fits best with the data.

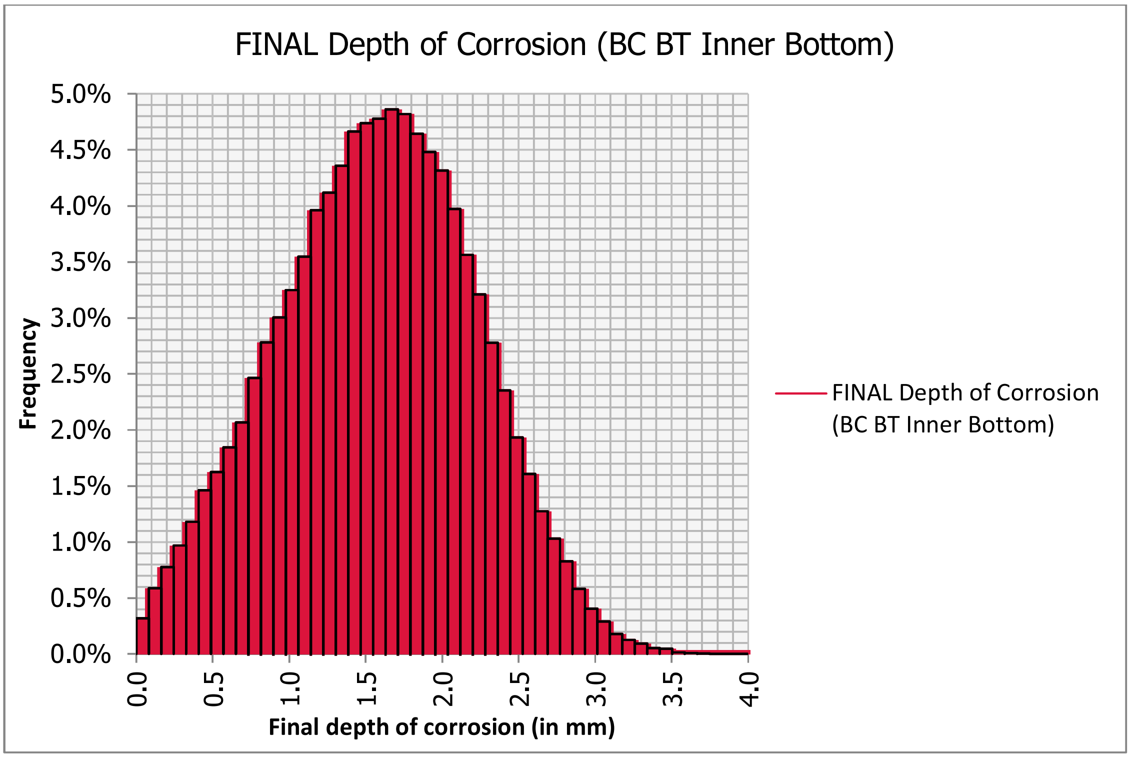


Figure 40: Calculated final depth of corrosion [in mm] for inner bottom in ballast tank, in Bulk carrier.

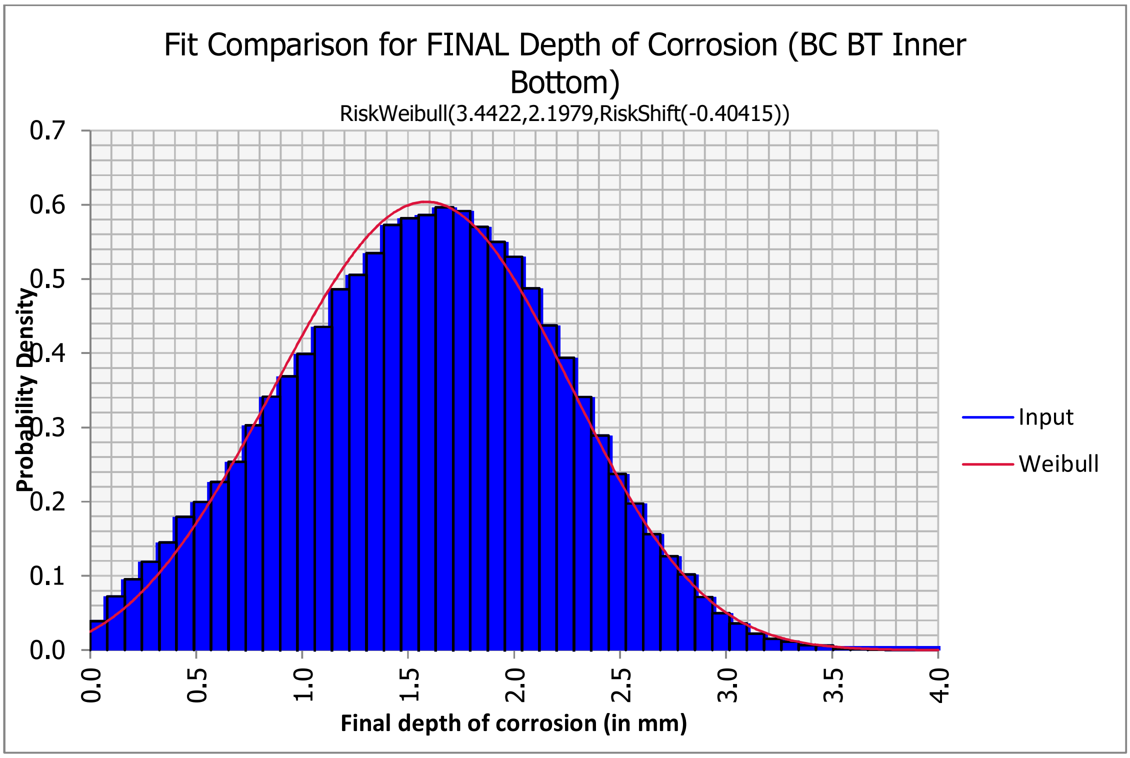


Figure 41: Fit distribution for Bulk carrier ballast tank, inner bottom

Table 35: Calculated corrosion depth [in mm] for inner bottom in ballast tank, in Bulk carrier.

	Weibul
a	3.4422
b	2.1979

5.3.2 Cargo Hold

For the cargo holds, the structural areas are the deck, the bulkhead, the side shell, the inner bottom and the floor.

5.3.2.1 Deck

In 99% of the cases, the depth of corrosion varies between 0.027mm and 1.540m. The higher value for the depth of corrosion is 0.52mm with a frequency of 5.20% (Fig.42). The distribution, which best fits with the data is a Beta General distribution described in Fig. 43 and in table 37.

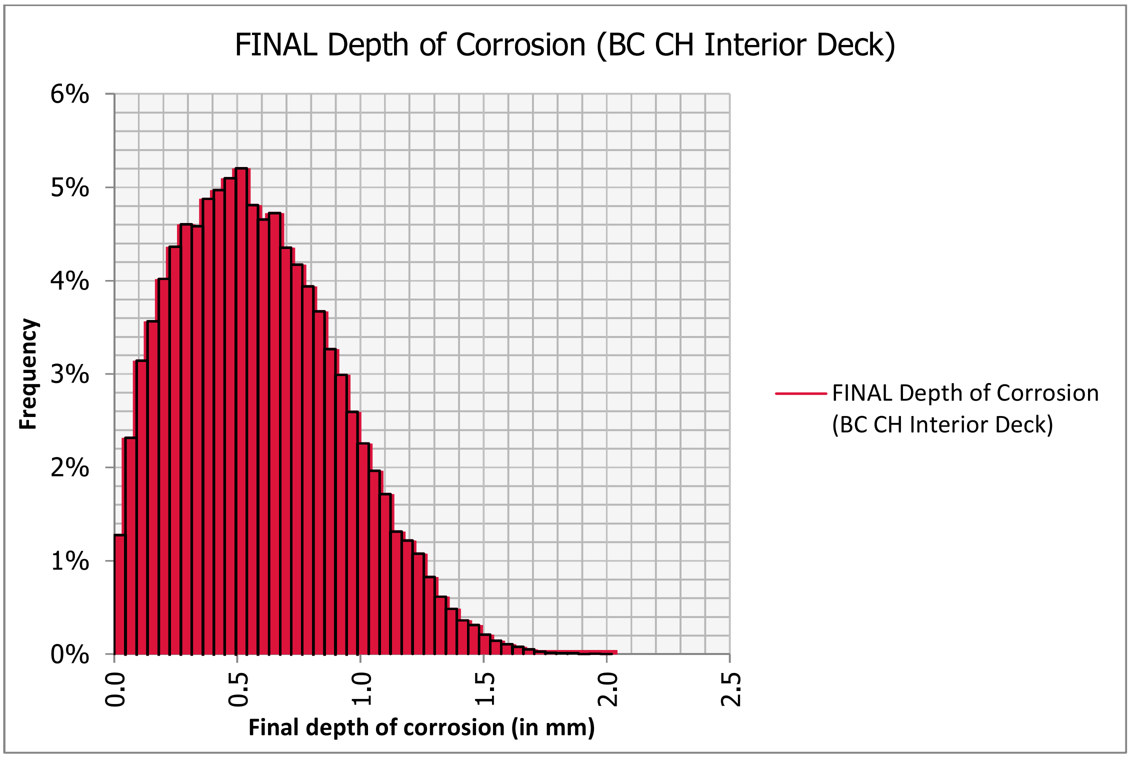


Figure 42: Calculated final depth of corrosion [in mm] for deck in cargo space, in Bulk carrier.

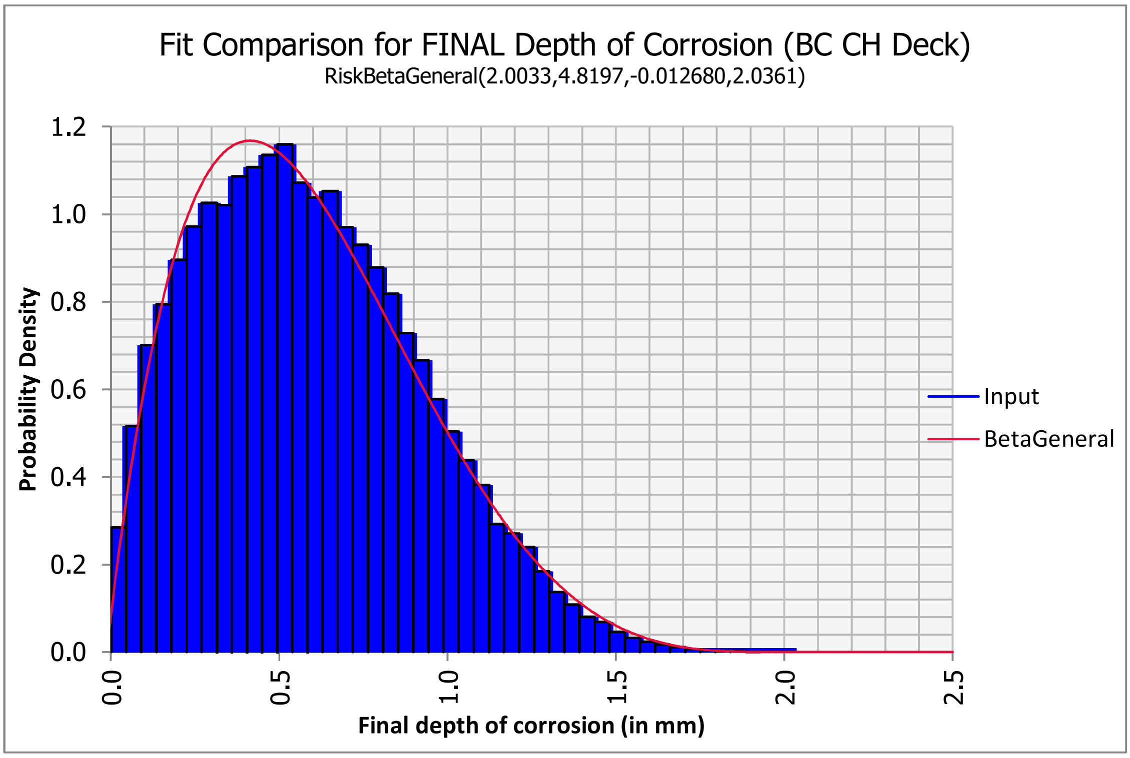


Figure 43: Fit distribution for Bulk carrier cargo space, deck

Table 36: Calculated corrosion depth [in mm] for deck in cargo space, in Bulk carrier.

	Beta General
a	2.0033
b	4.8197
Minimum	-0.0127
Maximum	2.0361

5.3.2.2 Bulkhead

The breadth of the corrosion depth gets values between 0.07mm and 4.89mm. The higher value for the depth of corrosion is 2.43mm with a frequency of 4.73% (Fig.44). A Beta General distribution described in Fig. 45 and in table 38 fits best with the data.

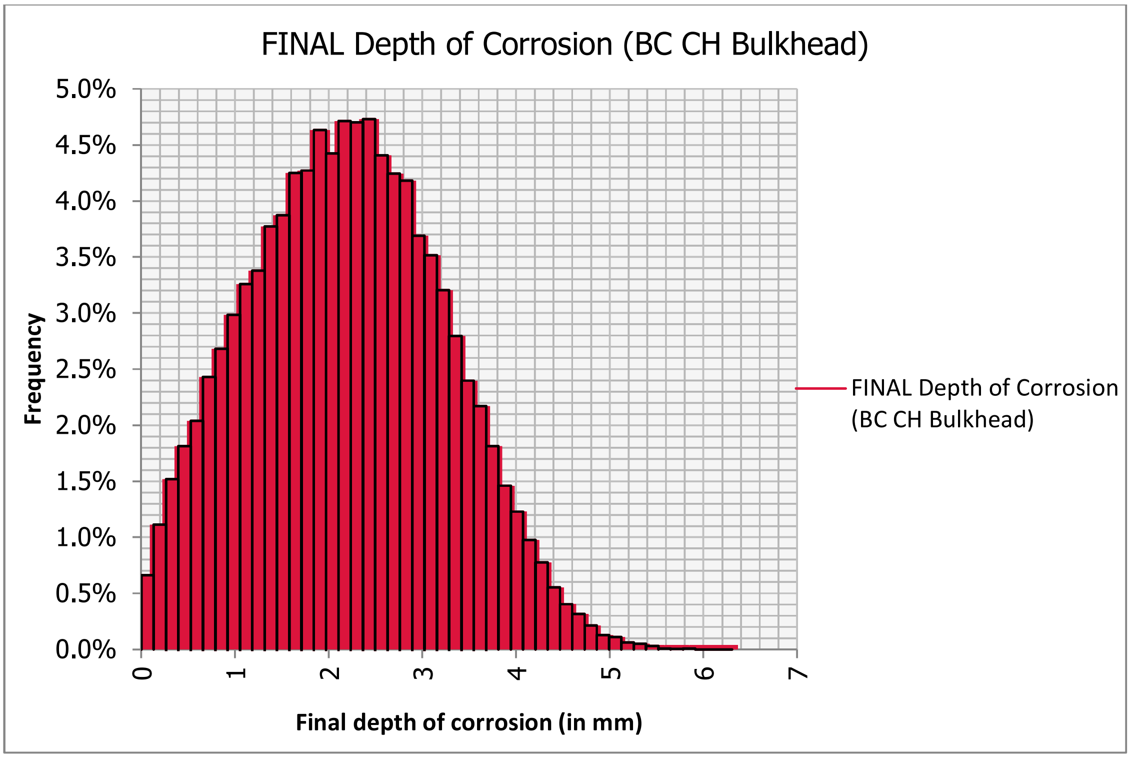


Figure 44: Calculated final depth of corrosion [in mm] for bulkhead in cargo space, in Bulk carrier.

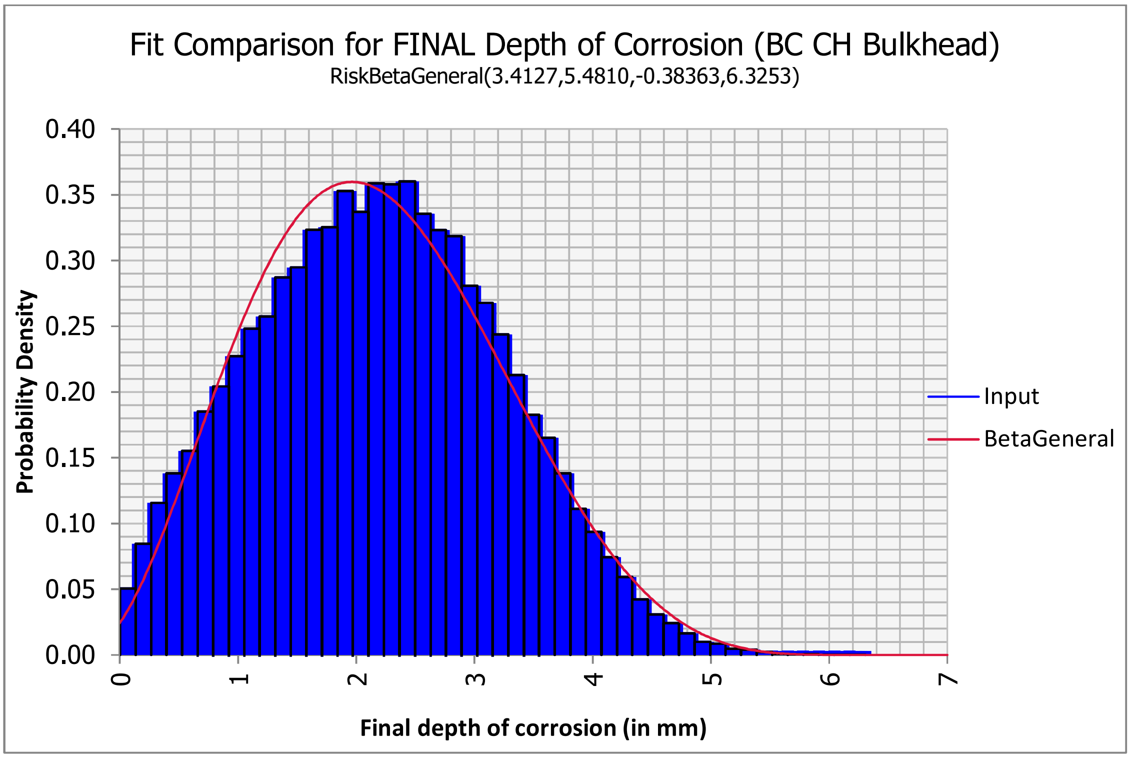


Figure 45: Fit distribution for Bulk carrier cargo space, bulkhead

Table 37: Calculated corrosion depth [in mm] for bulkhead in cargo space, in Bulk carrier.

	Beta General
a	3.4127
b	5.481
Minimum	-0.3836
Maximum	6.3253

5.3.2.3 Side Shell

With a confidence level 99%, the range of corrosion depth is between 0.040mm and 2.612mm. The higher value for the depth of corrosion is 1.23mm with a frequency of 4.72% (Fig.46). The distribution, which best fits with the data is a Beta General distribution described in Fig. 47 and in table 39.

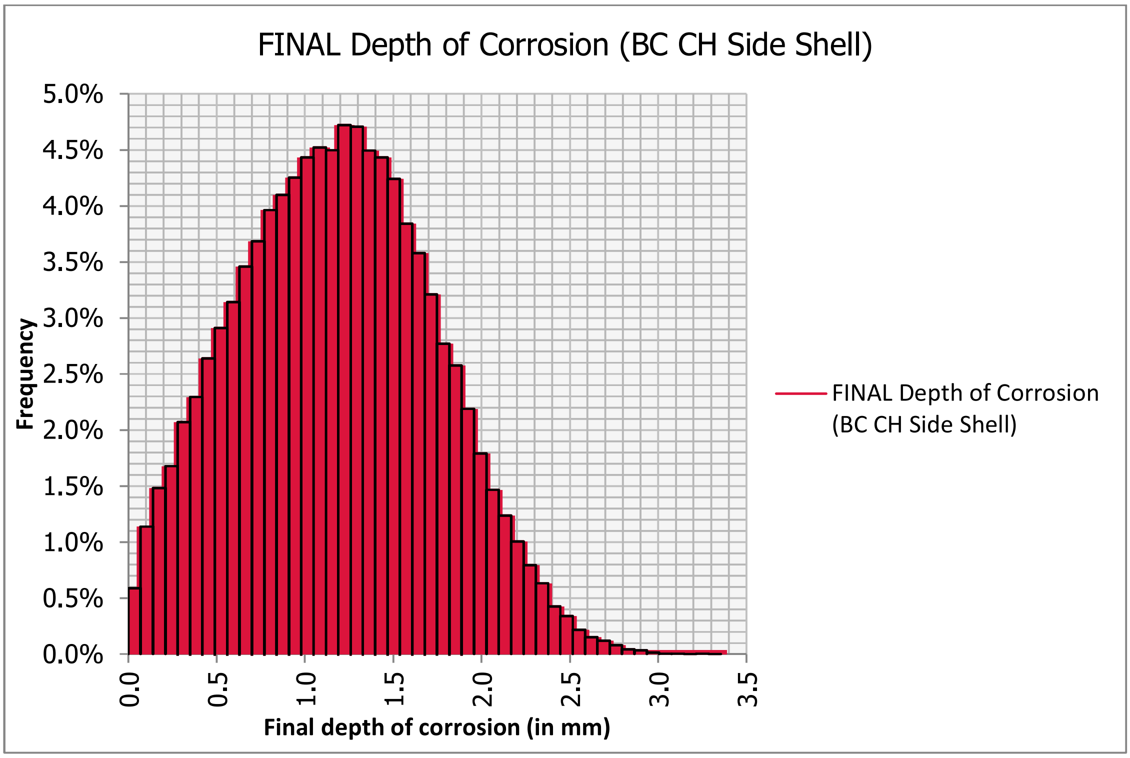


Figure 46: Calculated final depth of corrosion [in mm] for side shell in cargo space, in Bulk carrier.

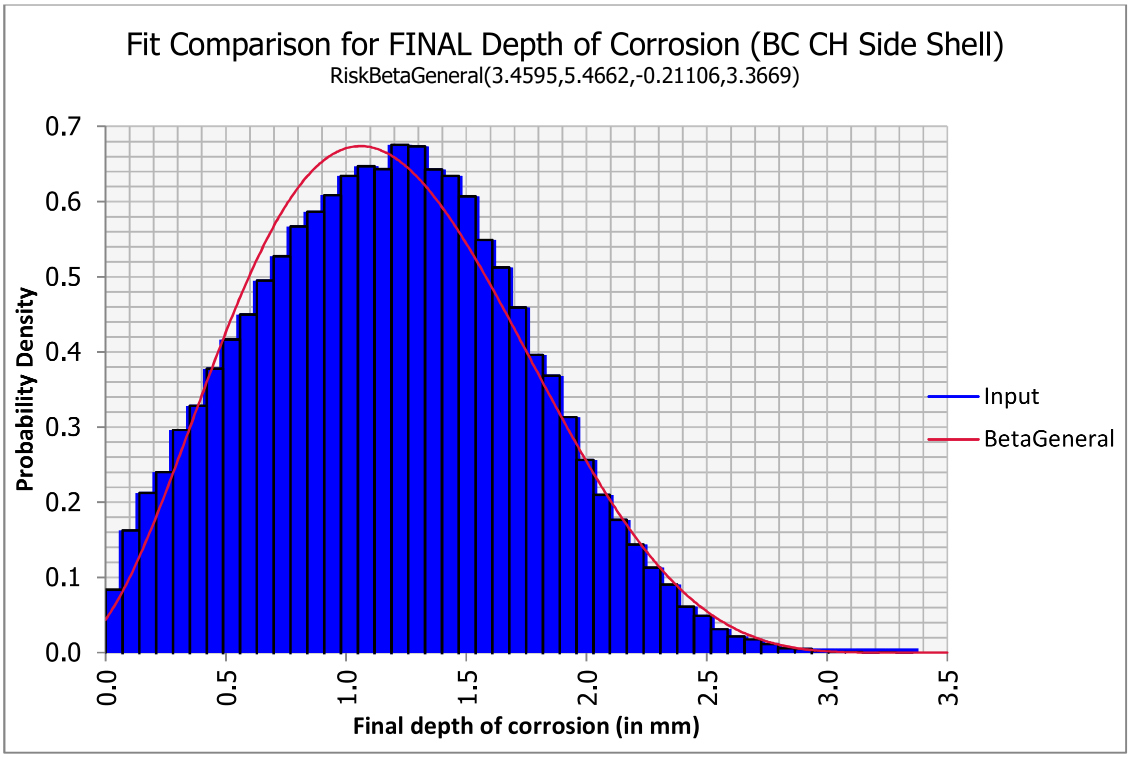


Figure 47: Fit distribution for Bulk carrier cargo space, side shell

Table 38: Calculated corrosion depth [in mm] for side shell in cargo space, in Bulk carrier.

	Beta General
a	3.4595
b	5.4662
Minimum	-0.2111
Maximum	3.3669

5.3.2.4 Inner Bottom

The breadth of the corrosion depth gets values between 1.285mm and 2.159mm. The higher value for the depth of corrosion is 1.73mm with a frequency of 7.22% (Fig.48). The distribution, which best fits with the data is a Normal distribution described in Fig. 49 and in table 40.

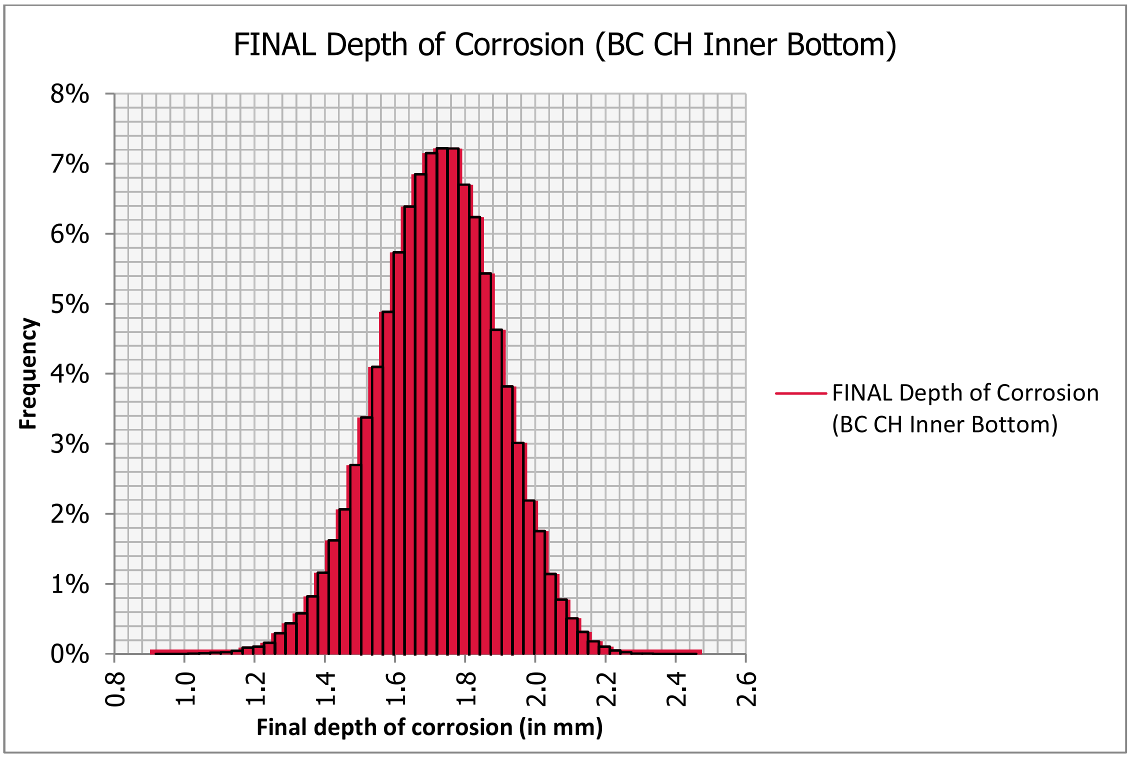


Figure 48: Calculated final depth of corrosion [in mm] for inner bottom in cargo space, in Bulk carrier.

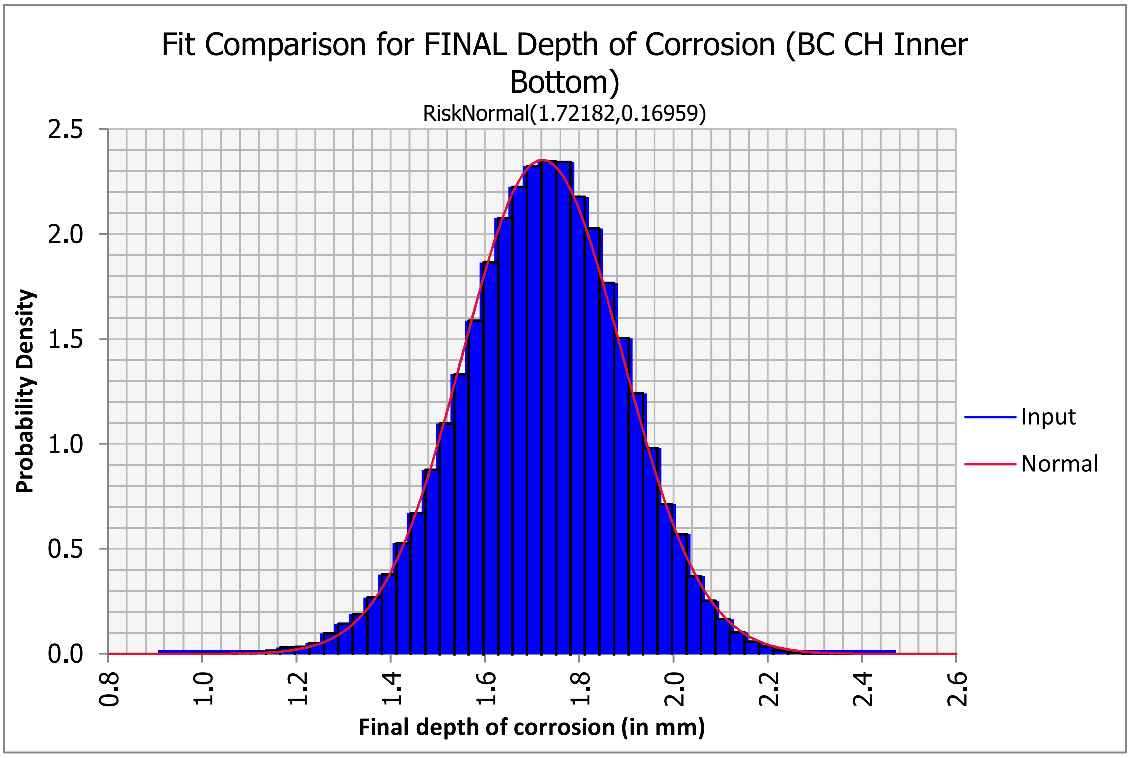


Figure 49: Fit distribution for Bulk carrier cargo space, inner bottom

Table 39: Calculated corrosion depth [in mm] for inner bottom in cargo space, in Bulk carrier.

	Normal
Mean	1.72182
Standard Deviation	0.16959

5.3.2.5 Floor

In 99% of the cases, the depth of corrosion varies between 0.07mm and 4.26m. The higher value for the depth of corrosion is 1.4mm with a frequency of 5.65% (Fig.50). A Beta General distribution described in Fig. 51 and in table 41 fits best with the data.

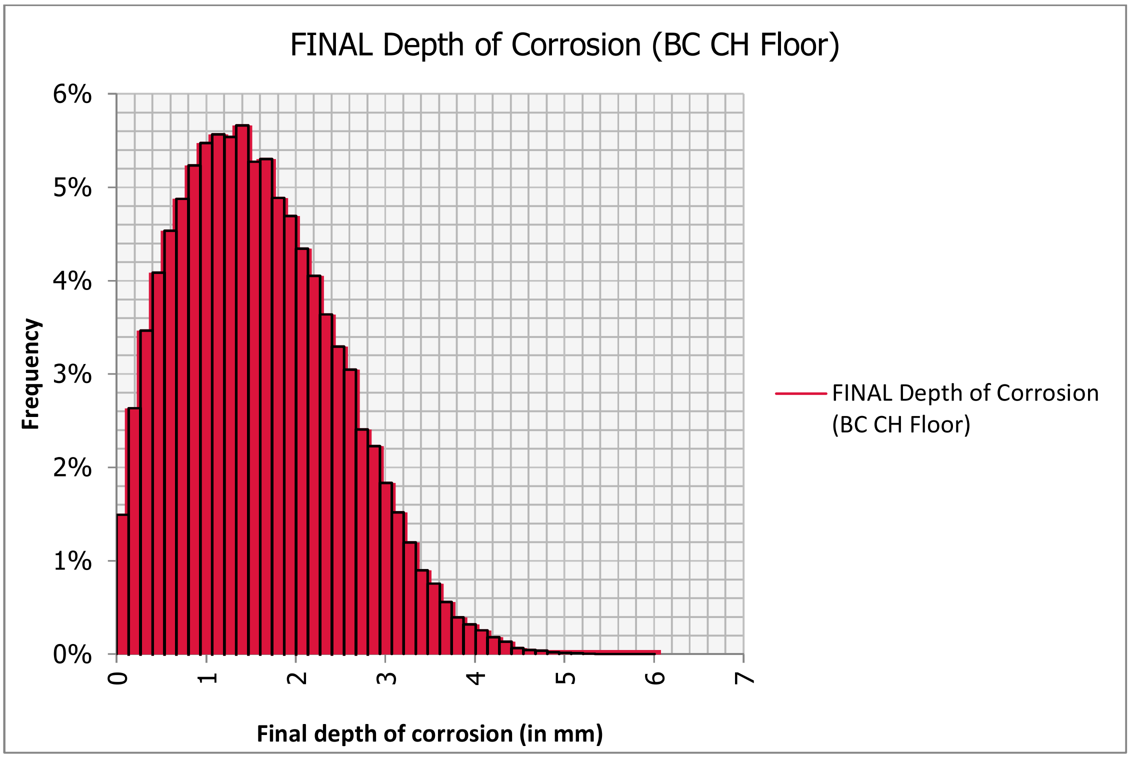


Figure 50: Calculated final depth of corrosion [in mm] for floor in cargo space, in Bulk carrier.

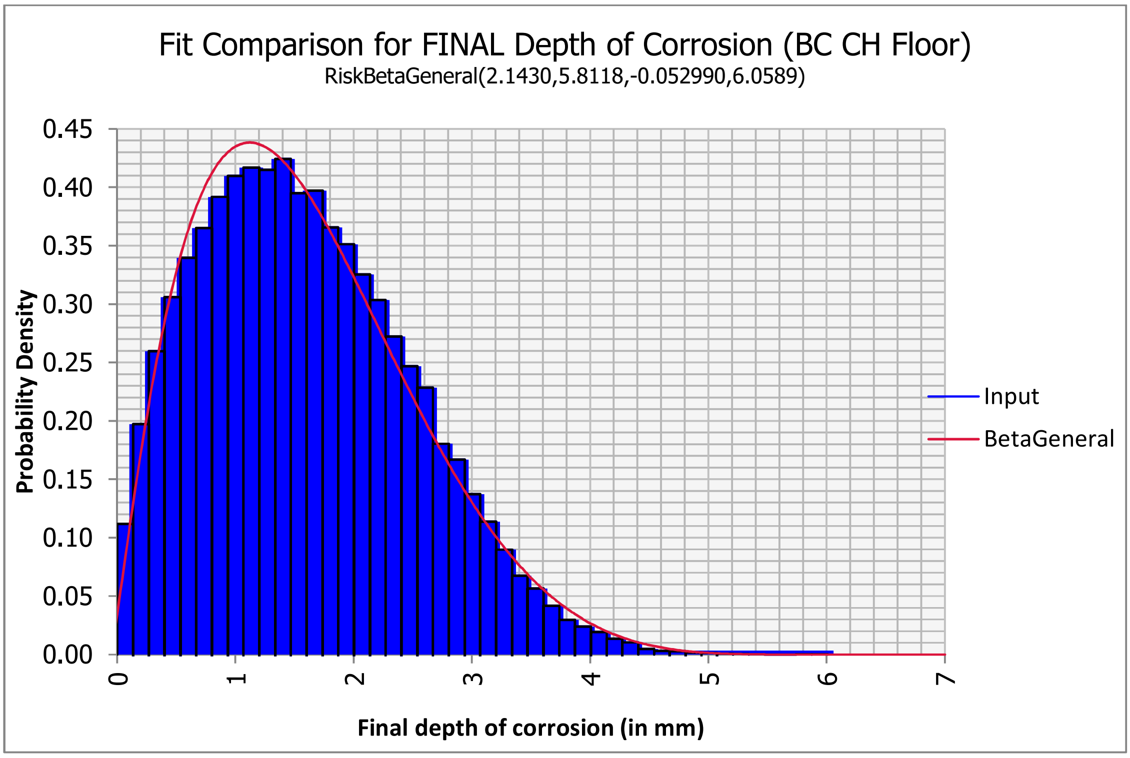


Figure 51: Fit distribution for Bulk carrier cargo space, floor

Table 40: Calculated corrosion depth [in mm] for floor in cargo space, in Bulk carrier.

	Beta General
a	2.143
b	5.8118
Minimum	-0.053
Maximum	6.0589

5.4 GENERAL CARGO

The structural areas under consideration are the ballast tanks and the cargo holds of the vessel.

For the cargo holds, the structural points are:

- Deck
- Bulkhead
- Side shell
- Inner bottom
- Floor

For the ballast tanks, the structural points are:

- Bulkhead
- Inner bottom

5.4.1 Ballast Tank

For the ballast tanks, the structural areas are the bulkhead and the inner bottom.

5.4.1.1 Bulkhead

With a confidence level 99%, the range of corrosion depth is between 0.08mm and 6.32mm. The higher value for the depth of corrosion is 2.88mm with a frequency of 4.71% (Fig.52). The distribution, which best fits with the data is a Weibul distribution described in Fig. 53 and in table 42.

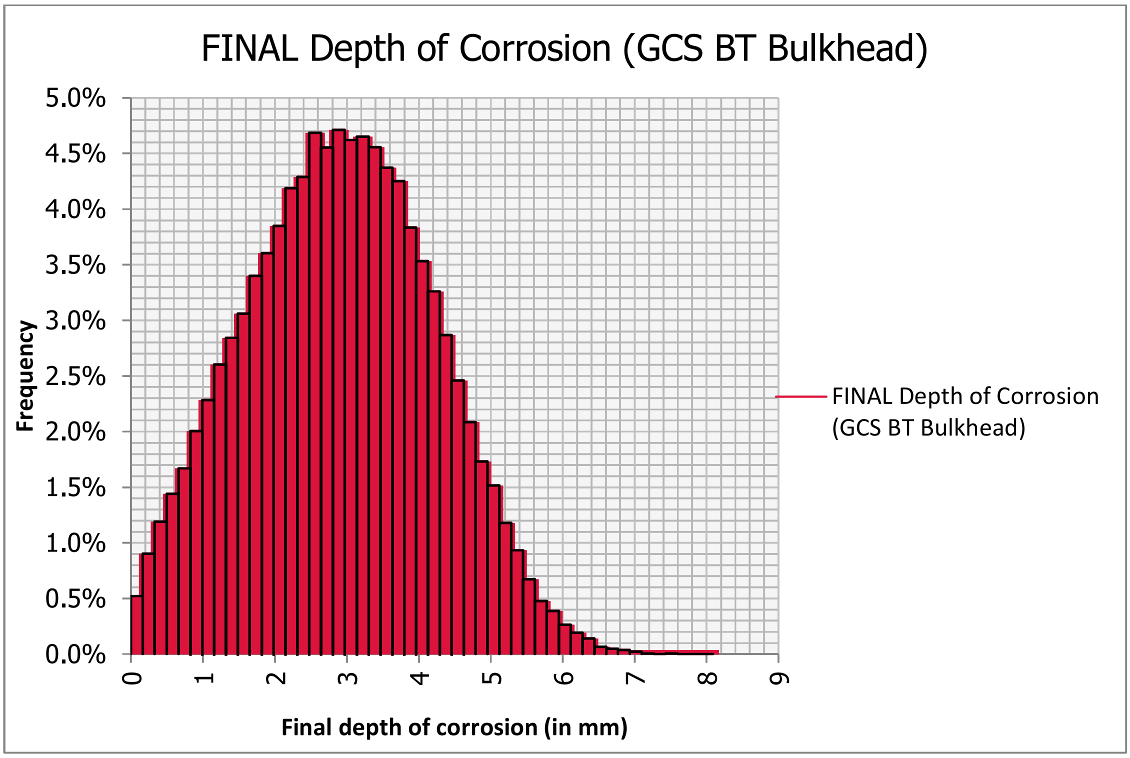


Figure 52: Calculated final depth of corrosion [in mm] for bulkhead in ballast tank, in General Cargo Ship.

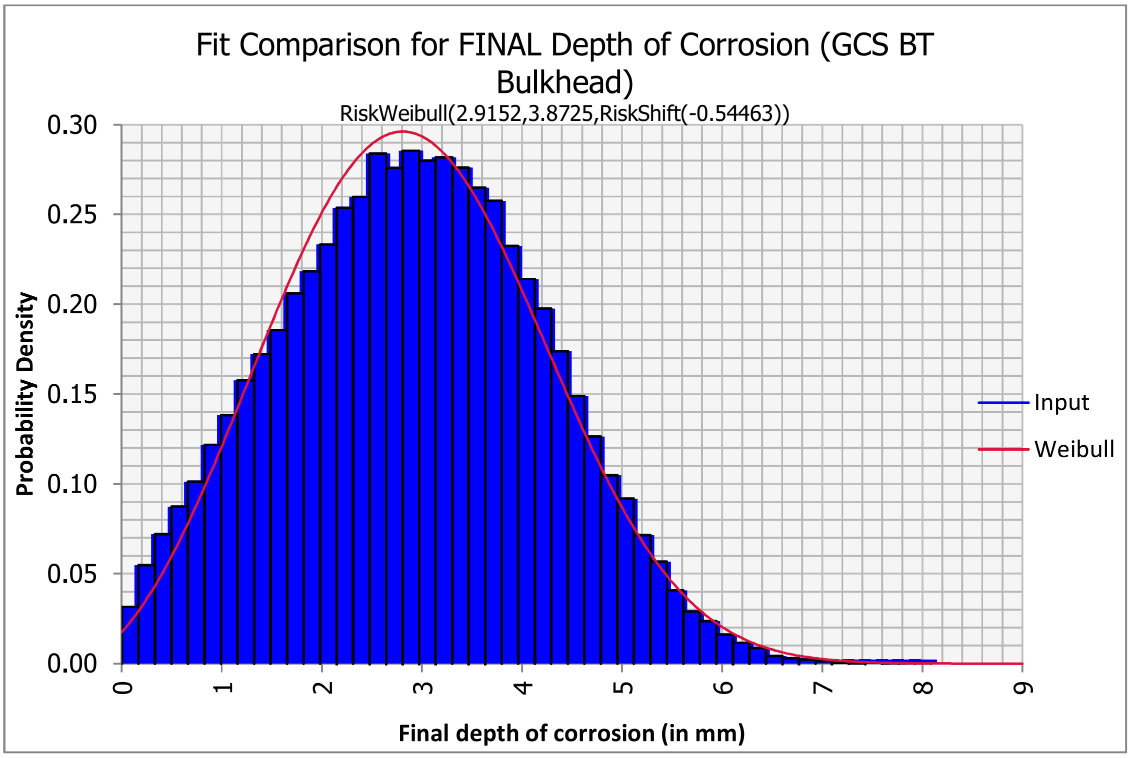


Figure 53: Fit distribution for General cargo ship ballast tank, bulkhead

Table 41: Calculated corrosion depth [in mm] for bulkhead in ballast tank, in General Cargo Ship.

	Weibul
a	2.9152
b	3.8725

5.4.1.2 Inner Bottom

In 99% of the cases, the depth of corrosion varies between 0.37mm and 4.42m. The higher value for the depth of corrosion is 2.83mm with a frequency of 5.57% (Fig.54). A Weibul distribution described in Fig. 55 and in table 43 fits best with the data.

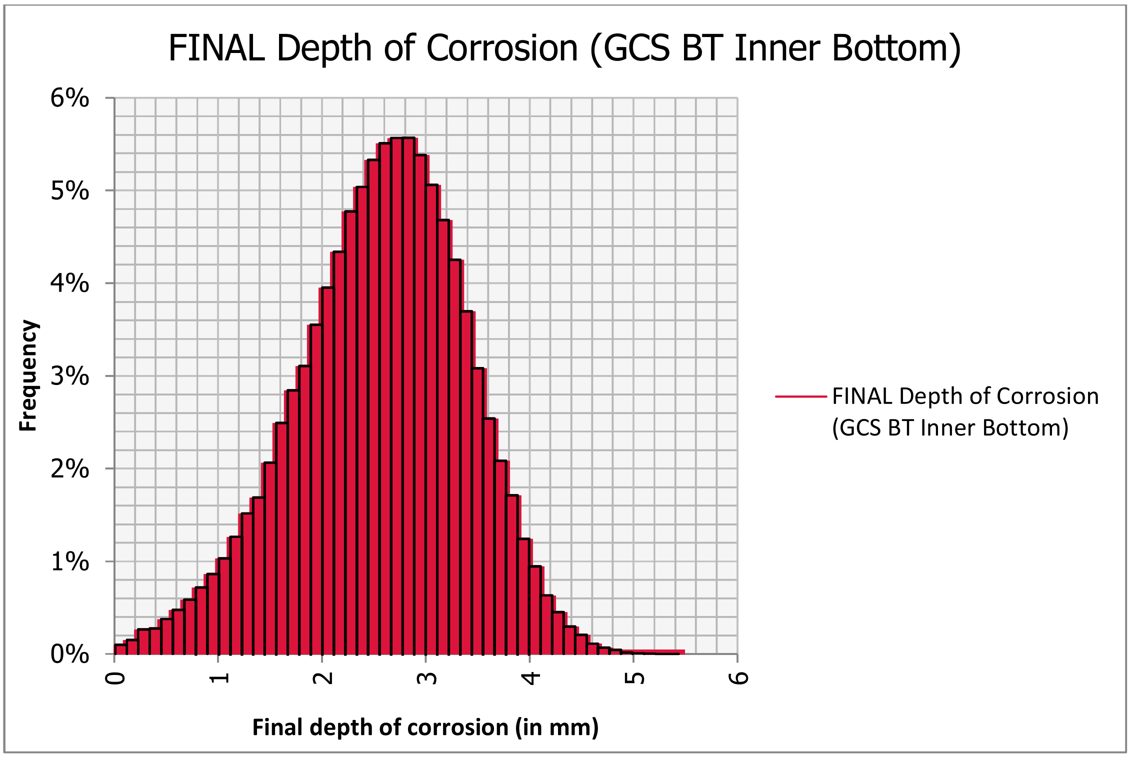


Figure 54: Calculated final depth of corrosion [in mm] for inner bottom in ballast tank, in General Cargo Ship.

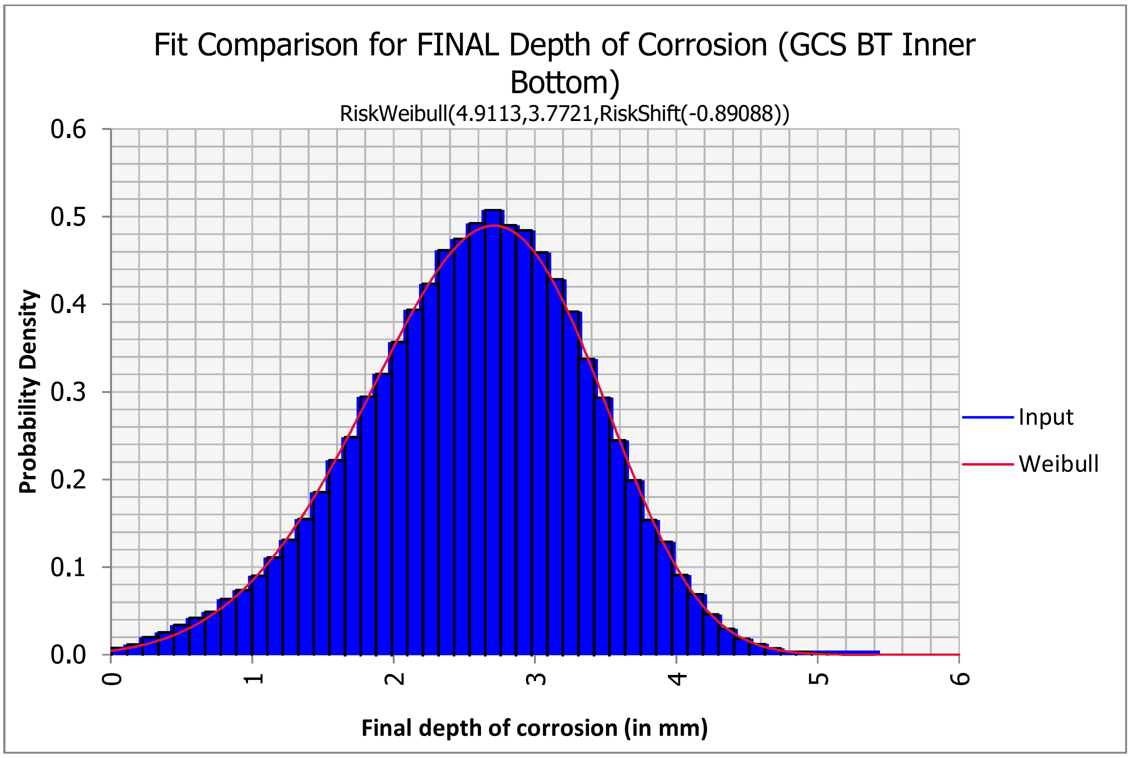


Figure 55: Fit distribution for General cargo ship ballast tank, inner bottom

Table 42: Calculated corrosion depth [in mm] for inner bottom in ballast tank, in General Cargo Ship.

	Weibul
a	4.9113
b	3.7721

5.4.2 Cargo Hold

For the cargo holds, the structural areas are the deck, the bulkhead, the side shell, the inner bottom and the floor.

5.4.2.1 Deck

The breadth of the corrosion depth gets values between 0.025mm and 2. 921mm. The higher value for the depth of corrosion is 0.89mm with a frequency of 4.66% (Fig.56). The distribution, which best fits with the data is a Beta General distribution described in Fig.57 and in table 44.

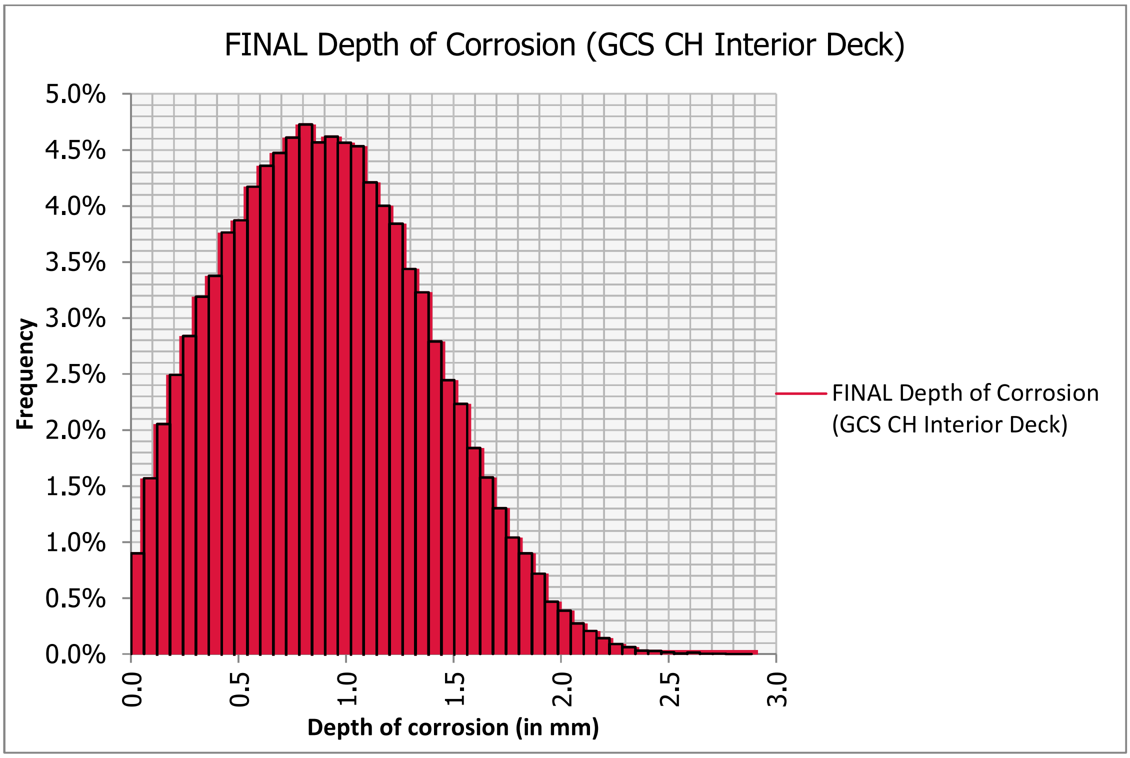


Figure 56: Calculated final depth of corrosion [in mm] for deck in cargo space, in General Cargo Ship.

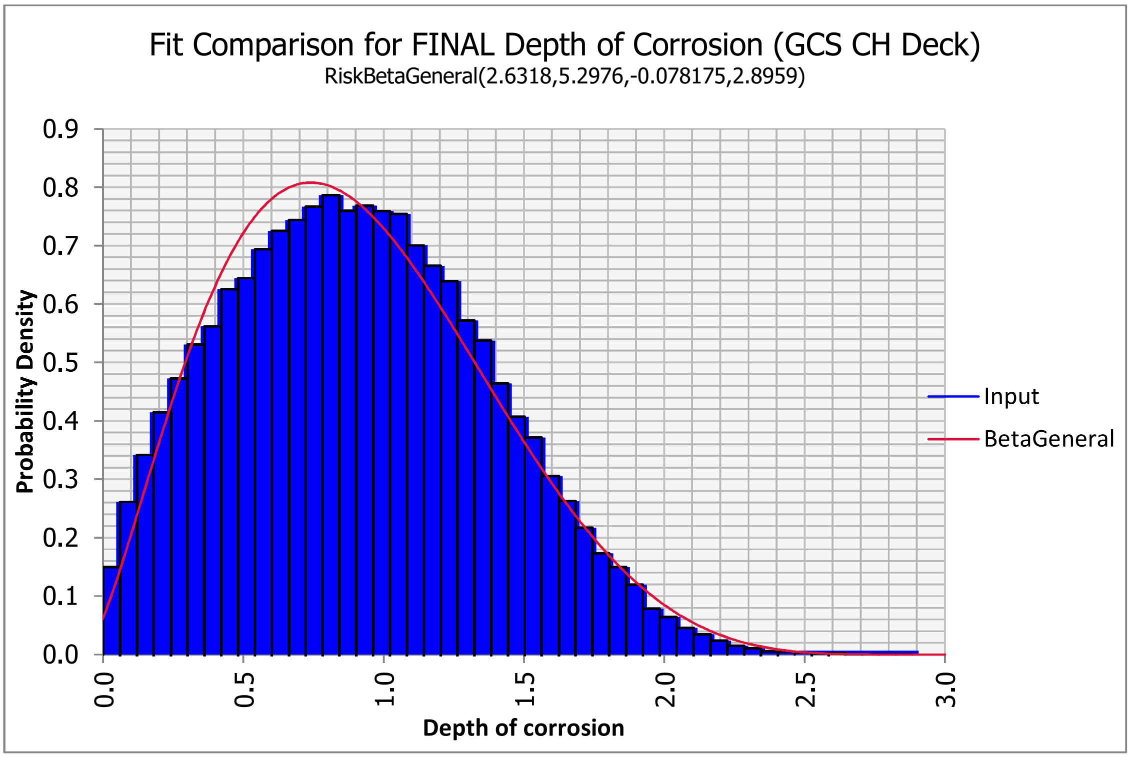


Figure 57: Fit distribution for General cargo ship cargo space, deck

Table 43: Calculated corrosion depth [in mm] for deck in cargo space, in General Cargo Ship.

	Beta General
a	2.6318
b	5.2976
Minimum	-0.0782
Maximum	2.8959

5.4.2.2 Bulkhead

In 99% of the cases, the depth of corrosion varies between 0.084mm and 3.320m. The higher value for the depth of corrosion is 1.78mm with a frequency of 4.86% (Fig.58). The distribution, which best fits with the data is a Weibul distribution described in Fig.59 and in table 45.

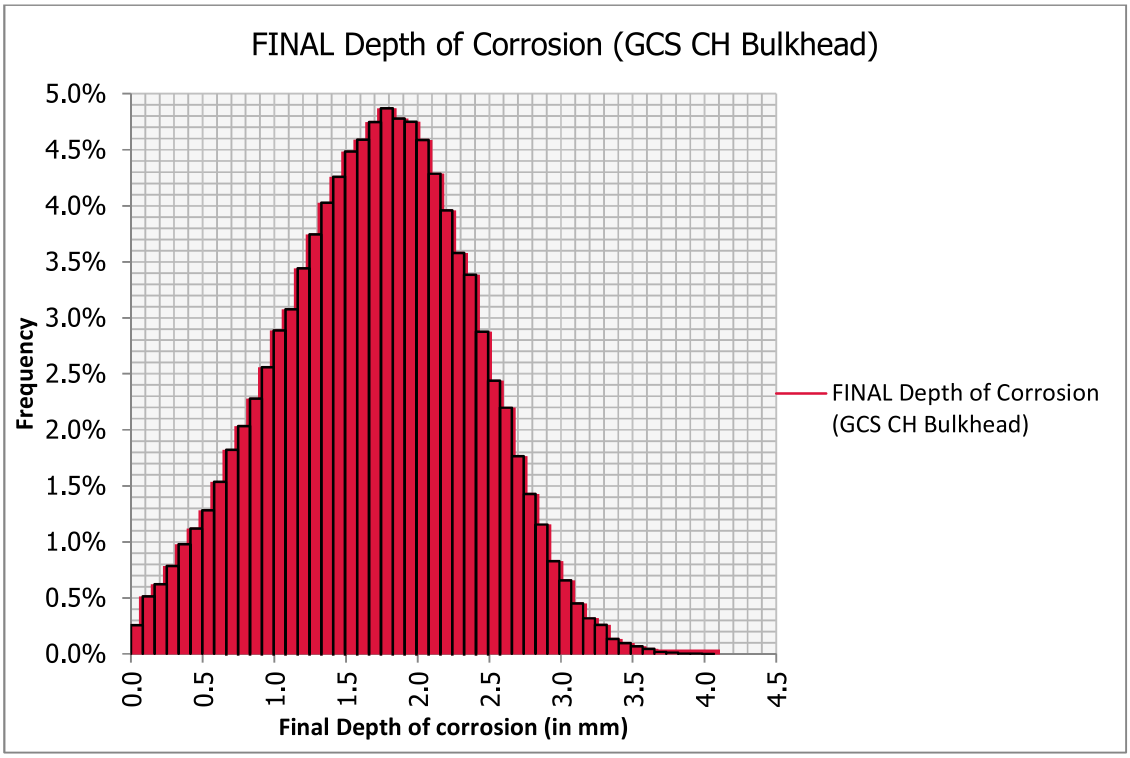


Figure 58: Calculated final depth of corrosion [in mm] for bulkhead in cargo space, in General Cargo Ship.

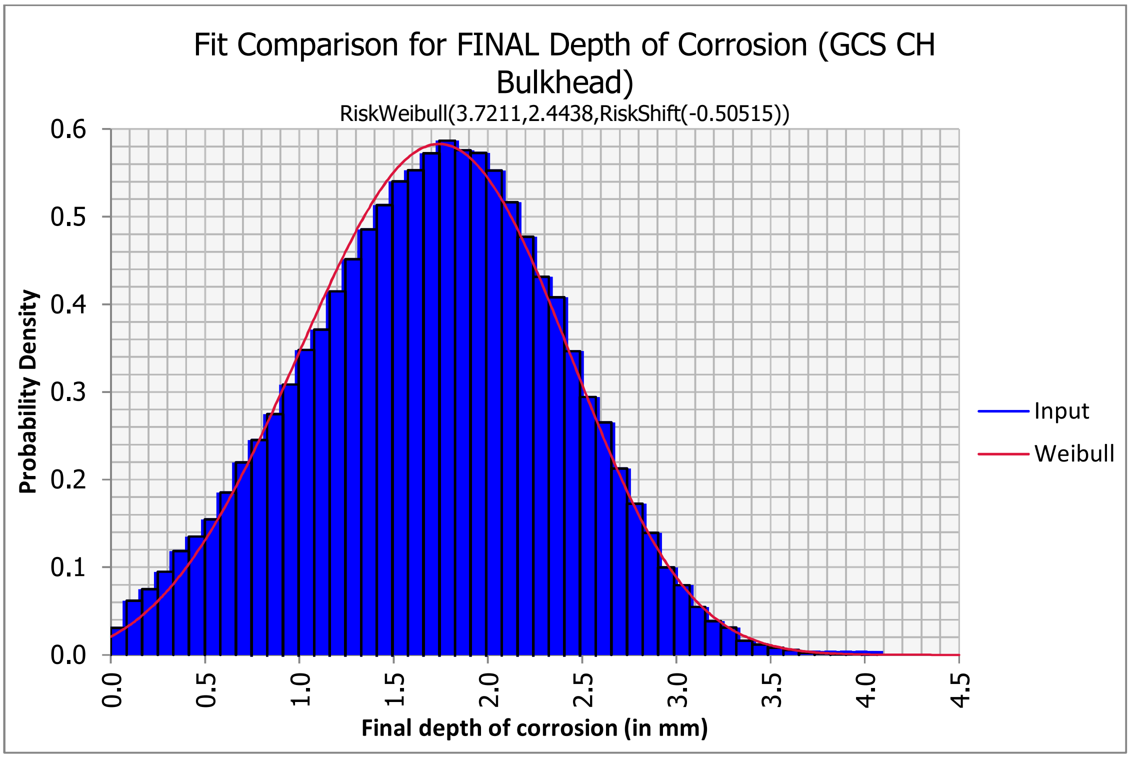


Figure 59: Fit distribution for General cargo ship cargo space, bulkhead

Table 44: Calculated corrosion depth [in mm] for bulkhead in cargo space, in General Cargo Ship.

	Weibull
a	3.7211
b	2.4438

5.4.2.3 Side Shell

With a confidence level 99%, the range of corrosion depth is between 0.097mm and 3.679mm. The higher value for the depth of corrosion is 2mm with a frequency of 4.93% (Fig.60). A Weibul distribution described in Fig.61 and in table 46 fits best with the data.

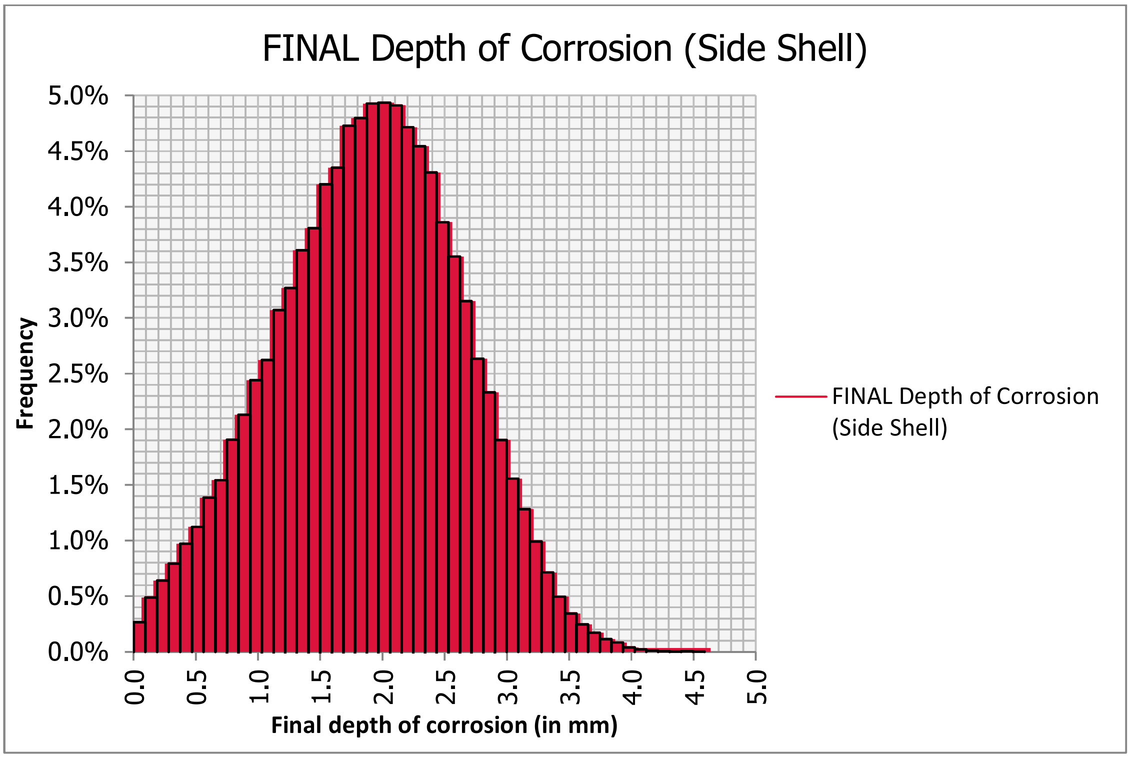


Figure 60: Calculated final depth of corrosion [in mm] for side shell in cargo space, in General Cargo Ship.

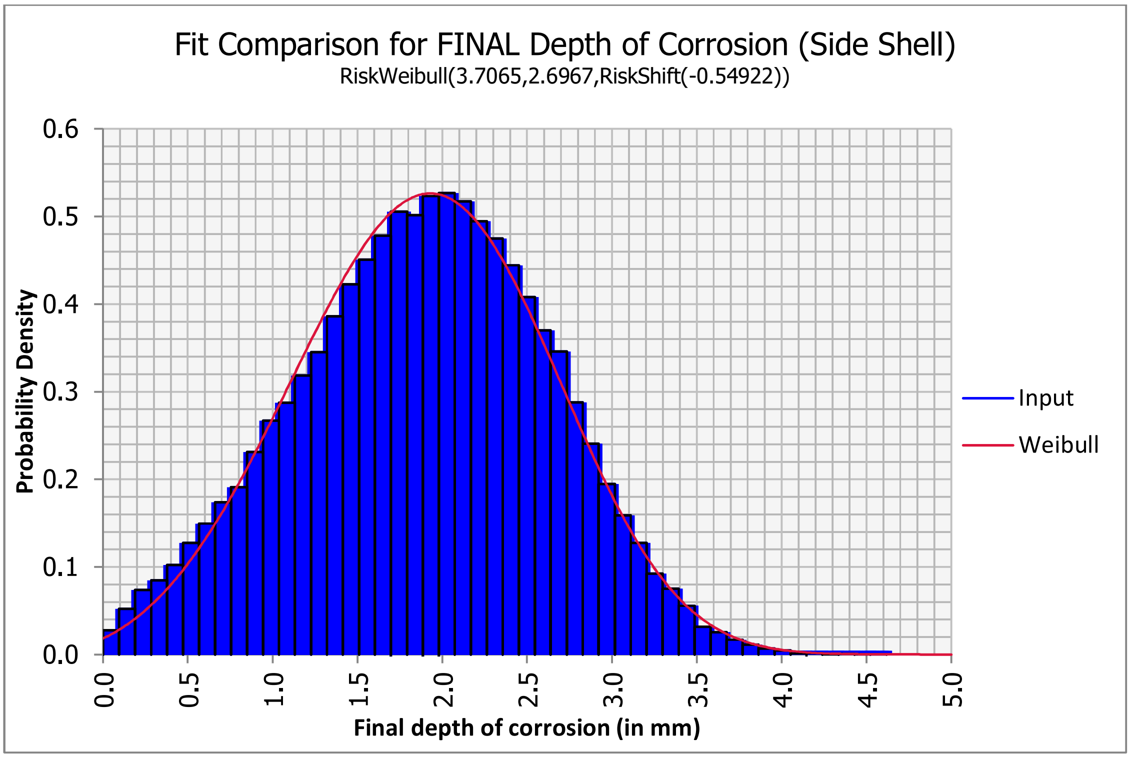


Figure 61: Fit distribution for General cargo ship cargo space, side shell

Table 45: Calculated corrosion depth [in mm] for side shell in cargo space, in General Cargo Ship.

	Weibul
a	3.7065
b	2.6967

5.4.2.4 Inner Bottom

The breadth of the corrosion depth gets values between 2.107mm and 3.109mm. The higher value for the depth of corrosion is 2.6mm with a frequency of 7.20% (Fig.62). A Normal distribution described in Fig.63 and in table 47 fits best with the data.

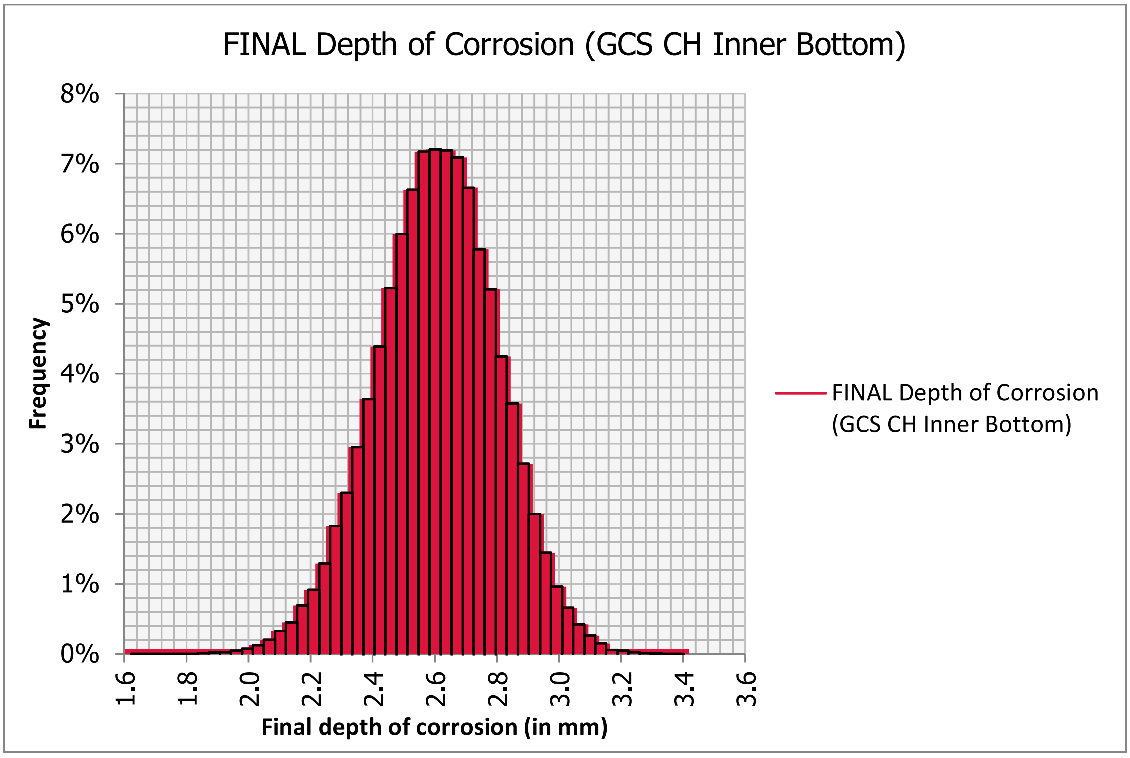


Figure 62: Calculated final depth of corrosion [in mm] for inner bottom in cargo space, in General Cargo Ship.

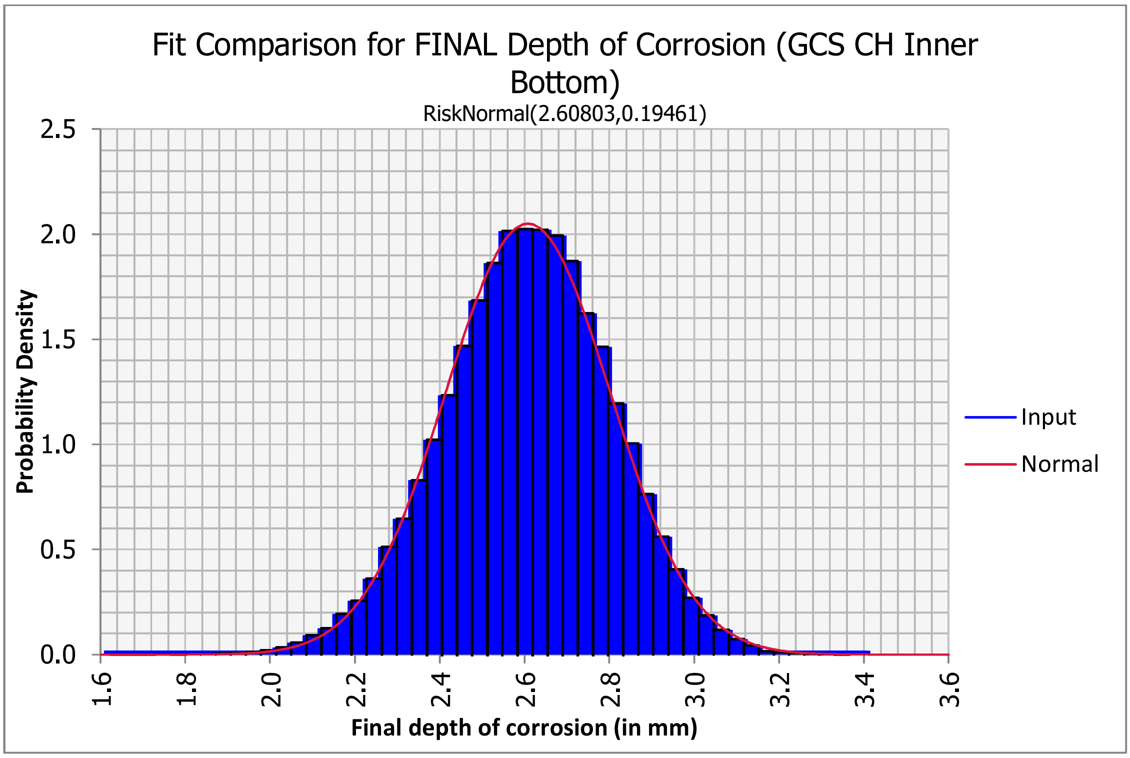


Figure 63: Fit distribution for General cargo ship cargo space, inner bottom

Table 46: Calculated corrosion depth [in mm] for inner bottom in cargo space, in General Cargo Ship.

	Normal
Mean	2.60803
Std Dev	0.19461

5.4.2.5 Floor

With a confidence level 99%, the range of corrosion depth is between 0.10mm and 5.96mm. The higher value for the depth of corrosion is 2.23mm with a frequency of 4.77% (Fig.64). The distribution, which best fits with the data is a Beta General distribution described in Fig.65 and in table 48.

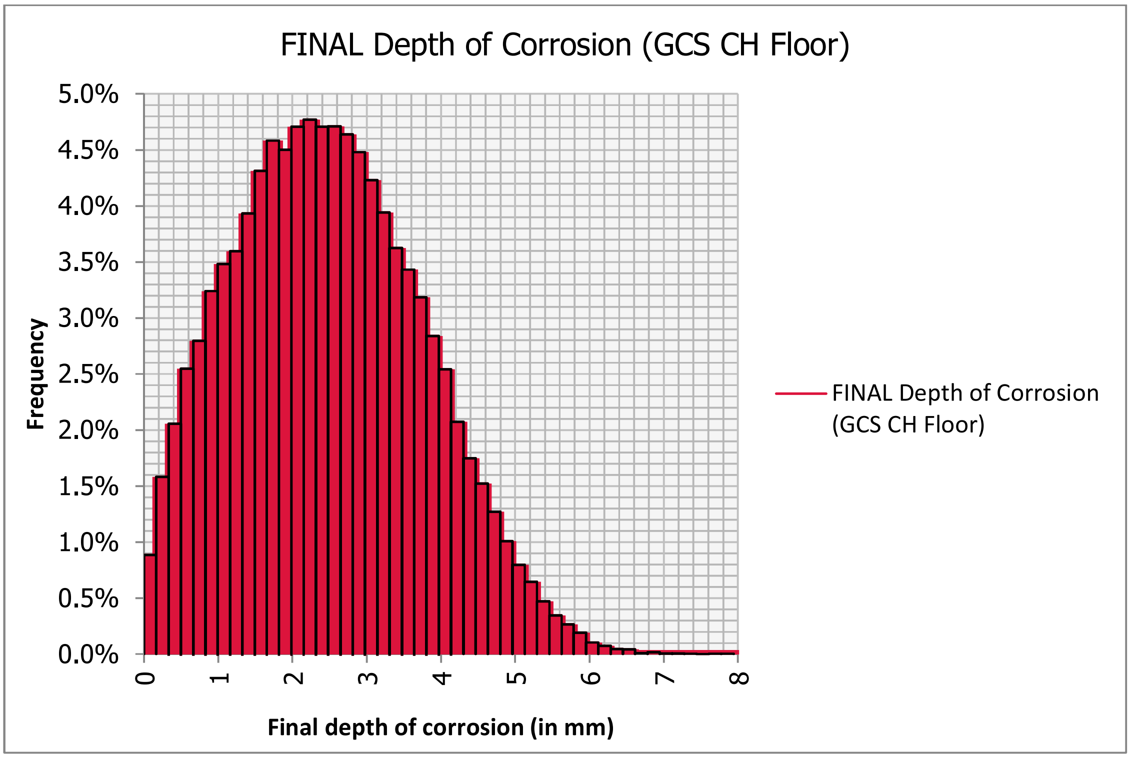


Figure 64: Calculated final depth of corrosion [in mm] for floor in cargo space, in General Cargo Ship.

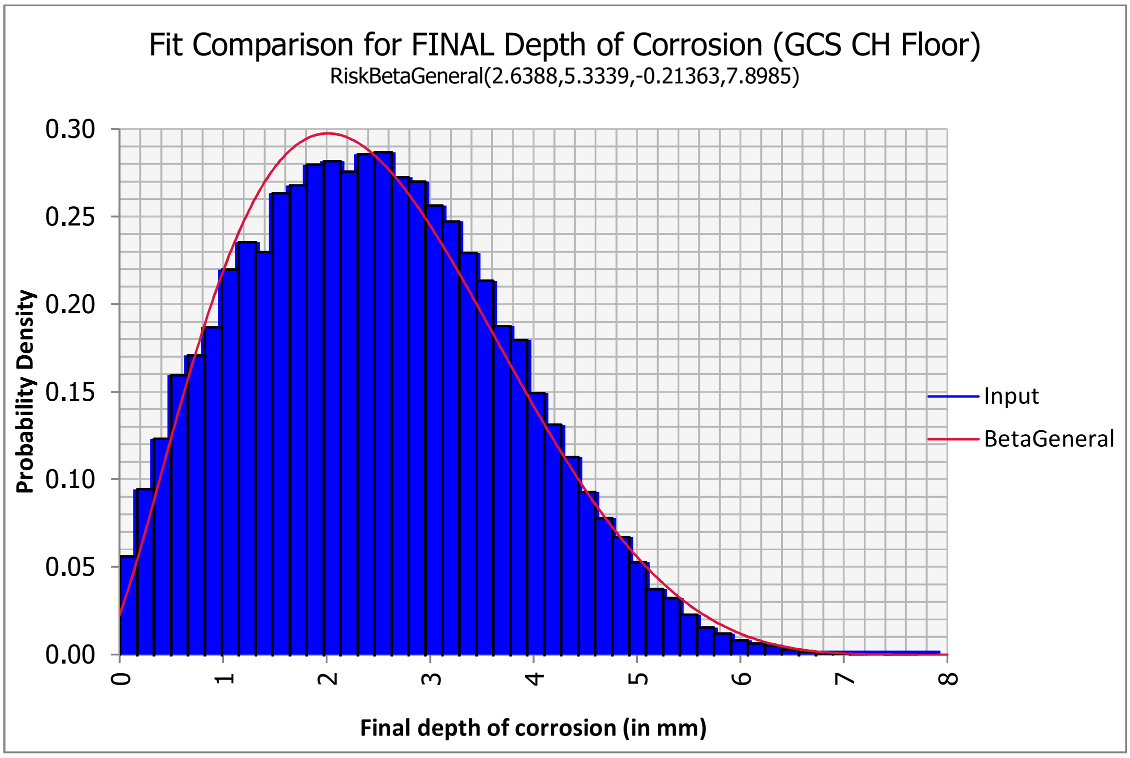


Figure 65: Fit distribution for General cargo ship cargo space, floor

Table 47: Calculated corrosion depth [in mm] for floor in cargo space, in General Cargo Ship.

	Beta General
a	2.6388
b	5.3339
Minimum	-0.2136
Maximum	7.8985

5.5 COMPARISON BETWEEN DIFFERENT SHIP TYPES

The three vessels under examination are a General cargo ship, a Tanker and a Bulk carrier. The Tanker and the General cargo ship are of similar ages, tanker was built in 2005 and GCS in 2006. The BC is the younger one built in 2011. All the examined vessels belong to classification societies which are all part of IACS and their flag states belong to the White Flag category. The areas under examination are the cargo holds and the ballast tanks and are common among the three different ship types.

5.5.1 Cargo Hold

For the cargo holds, the structural areas are the deck, the bulkhead, the side shell, the inner bottom and the floor.

5.5.1.1 Deck

A comparison between the depths of corrosion between the three different ship types for the deck in the cargo space is presented in Fig. 66. The depth of corrosion takes higher values for the Tanker, with max value for corrosion depth around 1.27mm with frequency 5,37%. The bulk carrier presents the smallest max value for the depth of corrosion, 0.74mm with frequency 12.62%, as shown in table 48.

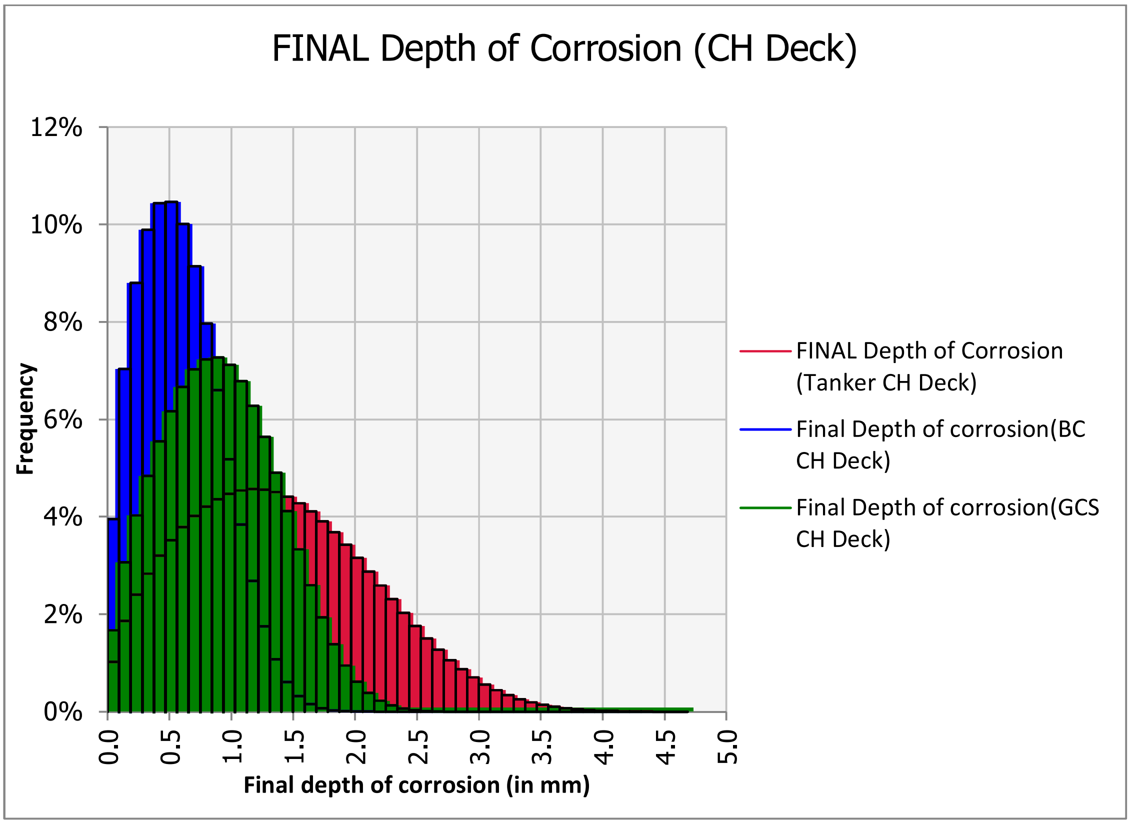


Figure 66: Calculated final depth of corrosion [in mm] for deck in cargo space, in three different types of ships.

Table 48: Max value and frequency for depth of corrosion in the comparative diagram for cargo hold, deck

	tanker	BC	GCS
Max value	1.2	0.52	0.88
frequency	4.72%	10.40%	7.25%

5.5.1.2 Bulkhead

The depths of corrosion between the three different ship types for the bulkhead in the cargo space are compared and presented in Fig. 67. The depth of corrosion takes higher values for the BC, where the max value for corrosion depth is 2.05mm. As for the tanker, the maximum value for the depth of corrosion is 1.7mm which is the smallest among the ship types (table 49).

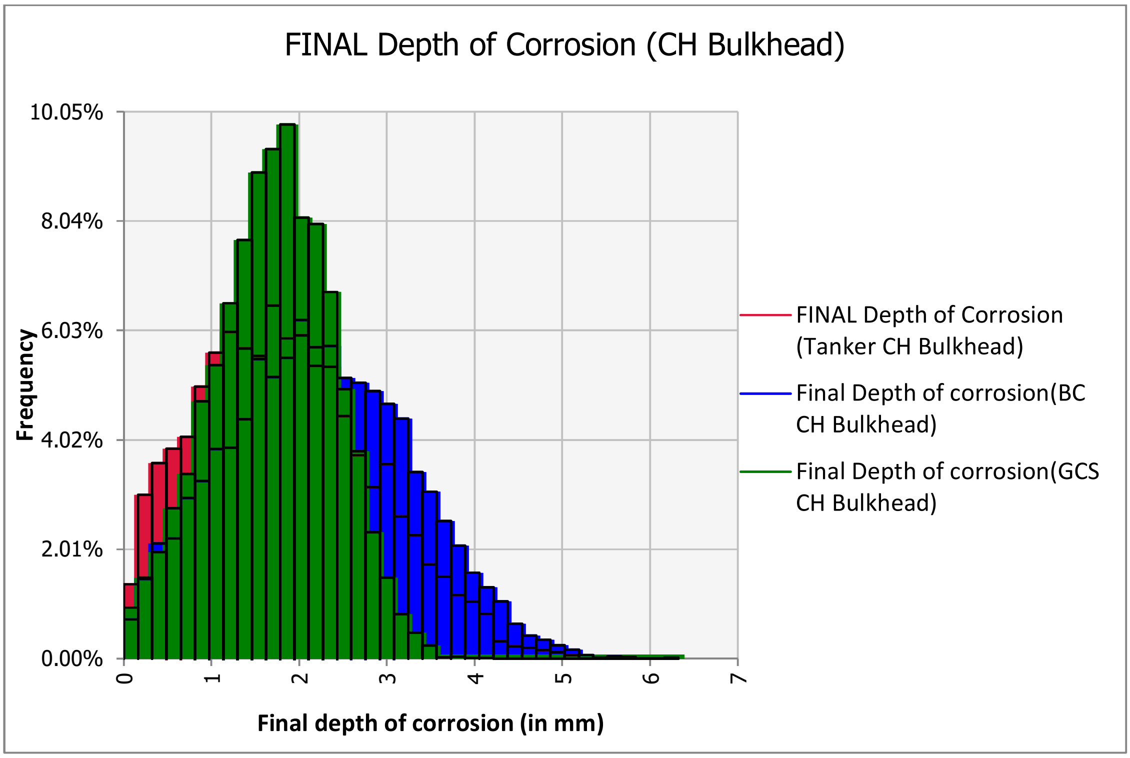


Figure 67: Calculated final depth of corrosion [in mm] for bulkhead in cargo space, in three different types of ships.

Table 49: Max value and frequency for depth of corrosion in the comparative diagram for cargo hold, bulkhead

	tanker	BC	GCS
Max value	1.7	2.05	1.88
Frequency	6.48%	6.21%	9.82%

5.5.1.3 Side Shell

A comparison between the depths of corrosion between the three different ship types for the side shell in the cargo space is presented in Fig. 68. The depth of corrosion takes higher values for the General cargo ship, with depth of corrosion equals to 2.12mm. The bulk carrier presents the lower max value for corrosion depth, 1.22 mm (table 50).

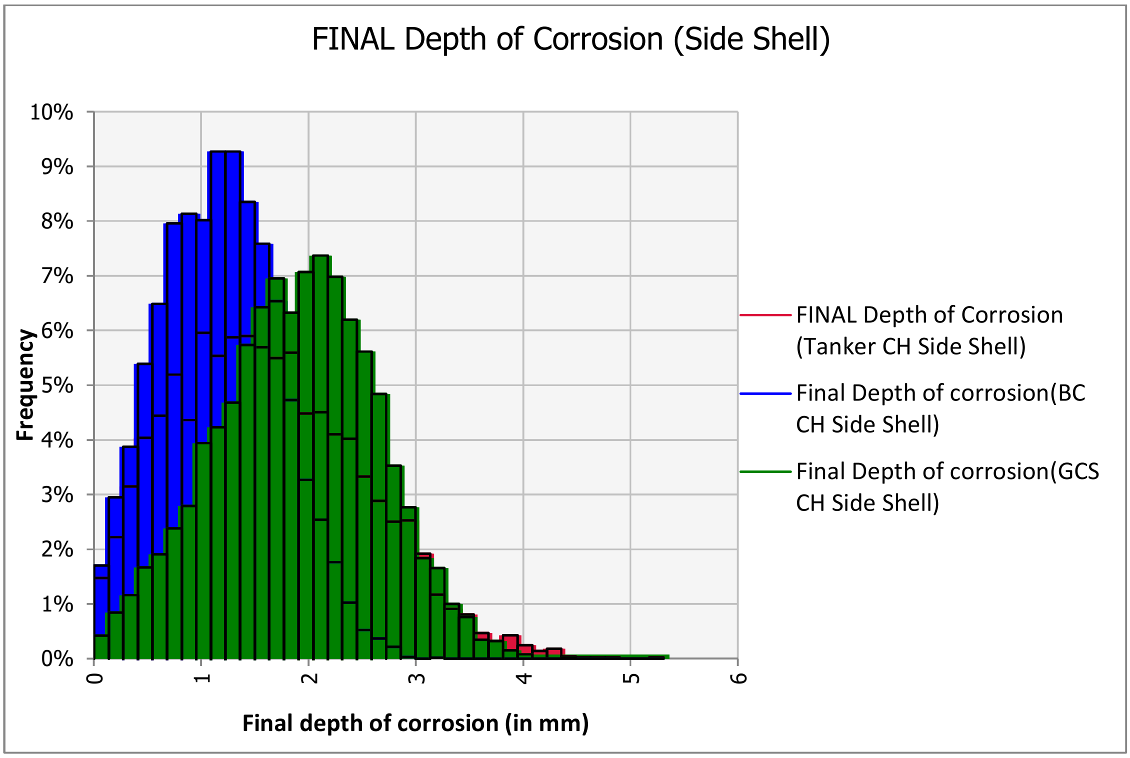


Figure 68: Calculated final depth of corrosion [in mm] for side shell in cargo space, in three different types of ships.

Table 50: Max value and frequency for depth of corrosion in the comparative diagram for cargo hold, side shell

	tanker	BC	GCS
Max value	1.44	1.22	2.12
frequency	5.74%	9.27%	7.39%

5.5.1.4 Inner Bottom

The depths of corrosion between the three different ship types for the inner bottom in the cargo space are compared and presented in Fig. 69. The depth of corrosion takes higher values at the general cargo ship, around 2.64mm. For the bulk carrier the depth of corrosion is around 1.7mm (table 51). The sharp difference between the distributions of the tanker and the other two, is due to significant difference in the distribution of the $t_{theoretical}$ of the coating lifetime for this specific structural area. The distributions for the $t_{theoretical}$ of the coating lifetime for the tanker, is a normal distribution with mean value 7 and standard deviation 2.1, while for the other two ship types the distribution for the $t_{theoretical}$ of the coating lifetime is a normal distribution with mean value 3 and standard deviation 0.9.

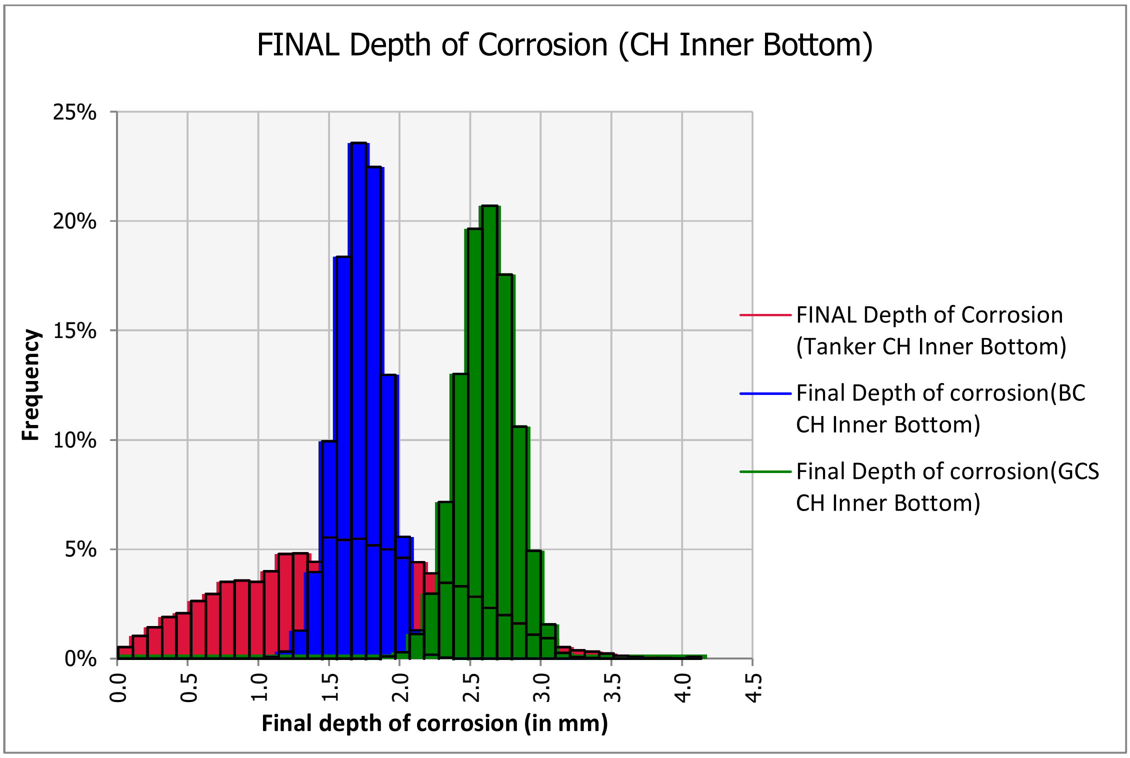


Figure 69: Calculated final depth of corrosion [in mm] for inner bottom in cargo space, in three different types of ships.

Table 51: Max value and frequency for depth of corrosion in the comparative diagram for cargo hold, Inner bottom

	tanker	BC	GCS
Max value	1.5	1.7	2.64
frequency	5.53%	23.55%	20.68

5.5.1.5 Floor

A comparison between the depths of corrosion between the three different ship types for the floor in the cargo space is presented in Fig. 70. The depth of corrosion has similar values for the Tanker and the BC, with values for corrosion depth 1.64mm and 1.25 respectively. For the General cargo ship, the maximum value for the depth of corrosion much higher than the maximum value for depth of corrosion for the other two ship types and its value is 2.41% (table 52).

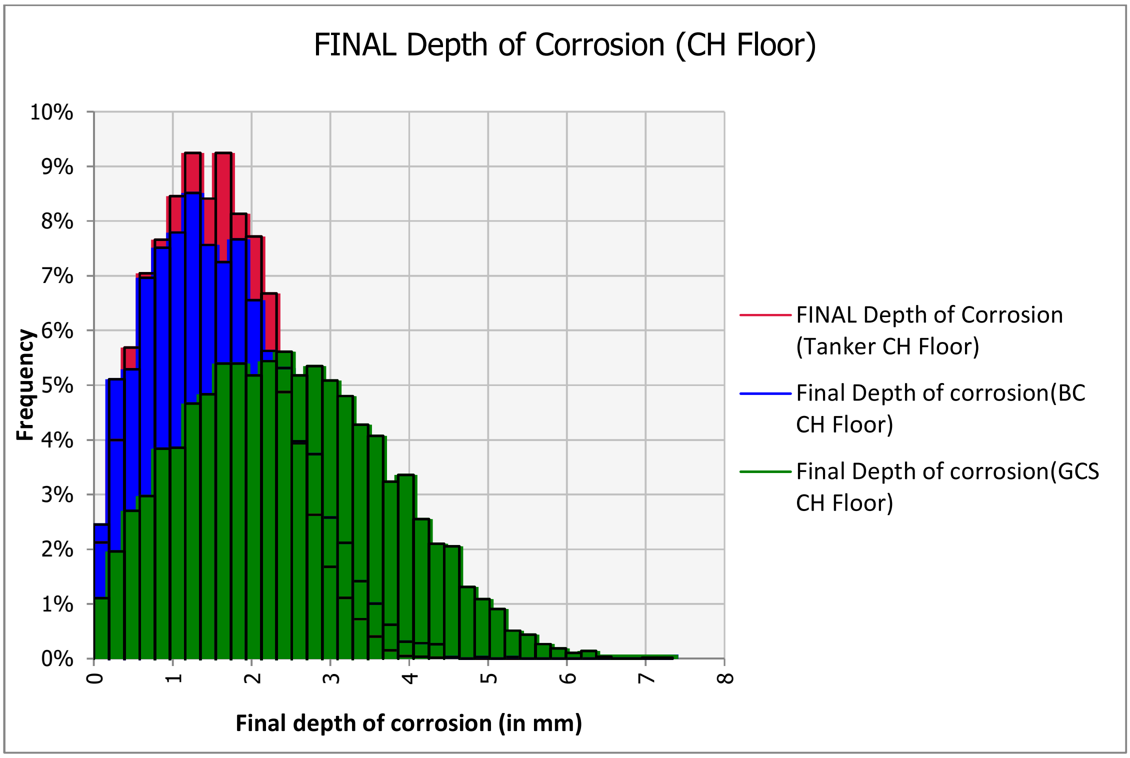


Figure 70: Calculated final depth of corrosion [in mm] for floor in cargo space, in three different types of ships.

Table 52: Max value and frequency for depth of corrosion in the comparative diagram for cargo hold, floor

	tanker	BC	GCS
Max value	1.64	1.25	2.41
frequency	9.24%	8.51%	5.60%

5.5.2 Ballast Tank

For the ballast tank, the structural areas are the bulkhead and the inner bottom.

5.5.2.1 Bulkhead

The depths of corrosion between the three different ship types for the bulkhead in the ballast tank are compared and presented in Fig. 71. The depth of corrosion takes higher values for the Tanker and the General cargo ship, as the max values for corrosion depth are 2.88mm and 2.77mmrespectively. The Bulk carrier presents higher frequency of corrosion while at the same time the values for the depth of corrosion is lower, 1.84mm, than the other two ship types (table 53).

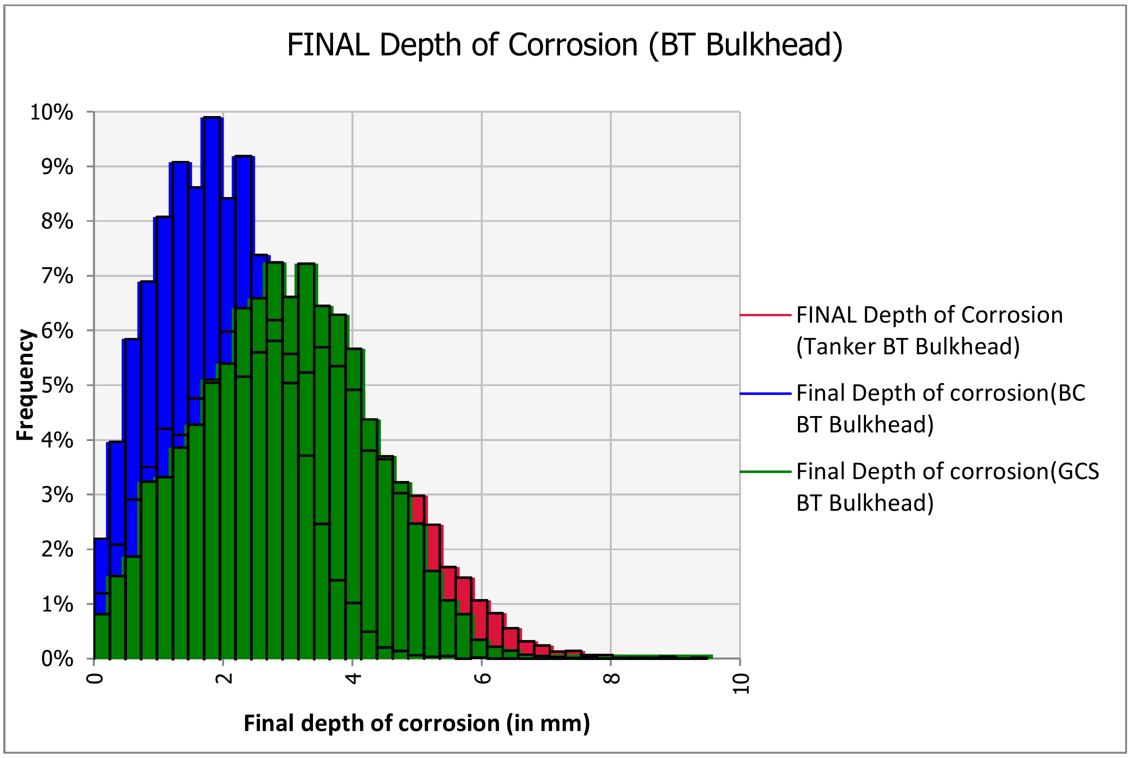


Figure 71: Calculated final depth of corrosion [in mm] for bulkhead in ballast tank, in three different types of ships.

Table 53: Max value and frequency for depth of corrosion in the comparative diagram for ballast tank, bulkhead

	Tanker	BC	GCS
Max value	2.88	1.84	2.77
frequency	5.20%	9.89%	7.24%

5.5.2.2 Inner Bottom

A comparison between the depths of corrosion between the three different ship types for the inner bottom in the ballast tank is presented in Fig. 72. The frequency of corrosion is higher for the bulk carrier while the max value for the depth of corrosion is 1.63mm. The depth of corrosion takes higher values for the tanker and the general cargo ship with values for corrosion depth 2.6mm and 2.78mm respectively.

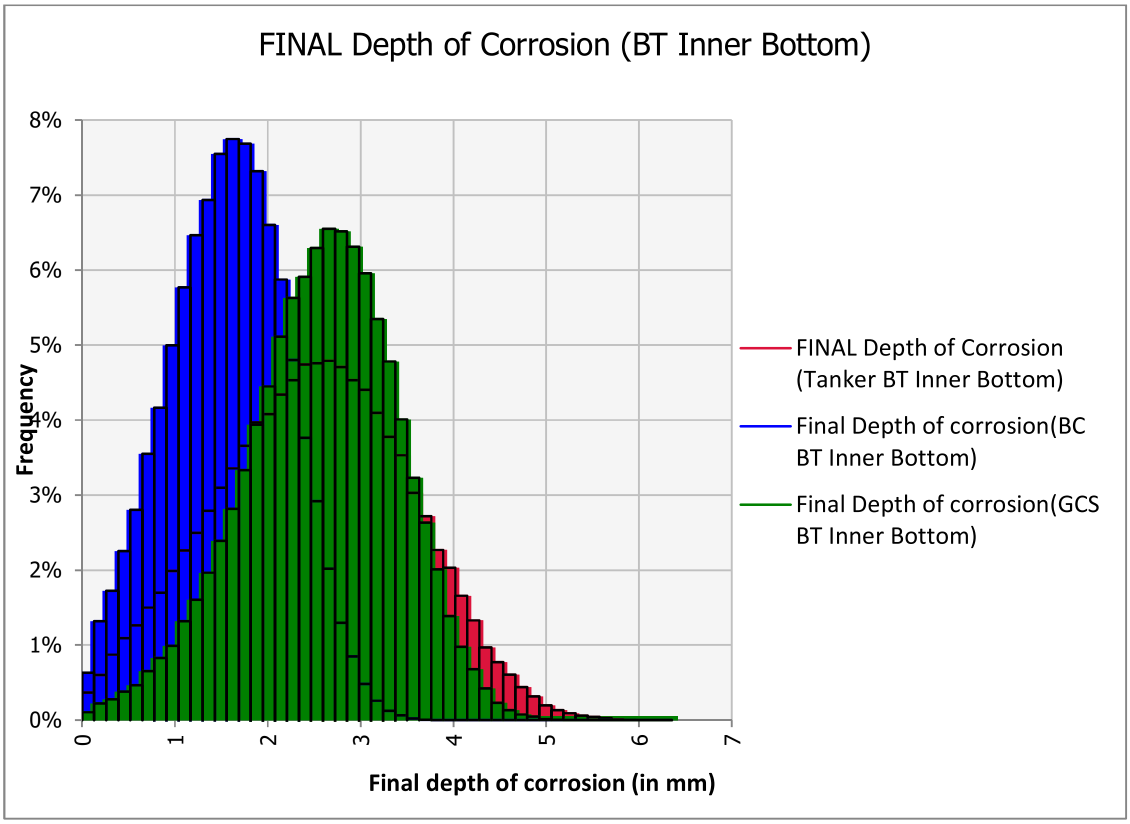


Figure 72: Calculated final depth of corrosion [in mm] for inner bottom in ballast tan, in three different types of ships.

Table 54: Max value and frequency for depth of corrosion in the comparative diagram for ballast tank, Inner bottom

	Tanker	BC	GCS
Max value	2.6	1.63	2.78
frequency	4.83%	7.72%	6.52%

6 SENSITIVITY ANALYSIS

6.1 What is sensitivity analysis

Sensitivity analysis is the study of how the uncertainty in a result of a model or system can by distributed proportionally to various sources of uncertainty in the data, used as inputs by the model. As the model proposed is based on many different input variables, the process of sensitivity analysis is necessary in order to assure the quality of the results taken.

6.2 Data statistical analysis

A list of tankers with status: in service or in commission or in repairs exported from www.ihs.com/index.html, was studied. Based on this list, the tankers divided into various age groups and in categories depending on their flag, the classification society they belong and the country where they were built. The total number of tanker vessels included in the list were 16419.

6.2.1 Ships by Age

The tankers were categorized into some age groups and their distribution is shown in Fig. 73. In table 55, is presented the number of tankers in each age category, as well as the relevant percentage.

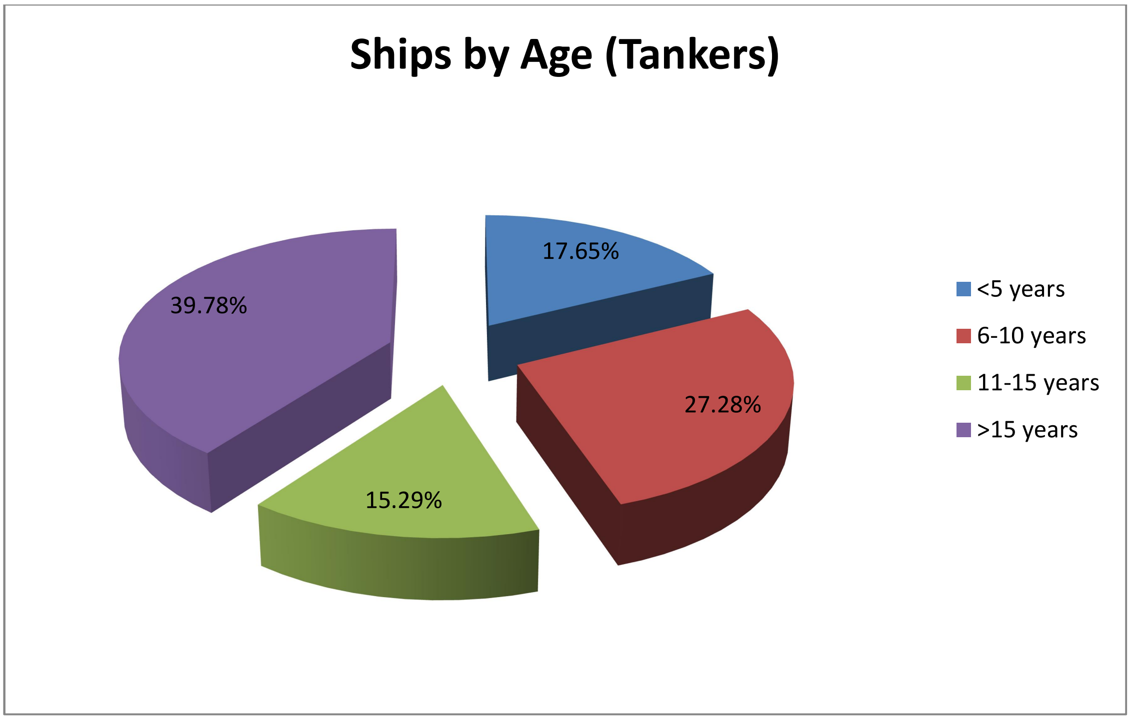


Figure 73: Percentage of tankers belonging to each age group

Table 55: Number of tankers in each group age and relevant percentage

Ships by age (Tankers)		
	no. of ships	percentage
<5 years	2580	17.65%
6-10 years	3988	27.28%
11-15 years	2235	15.29%
>15 years	5816	39.78%

6.2.2 Ships by country of build.

In Fig. 74 is shown the distribution of tankers based on the country where they were built. In table 56, is presented the number of tankers build in each country/continent, as well as the relevant percentage.

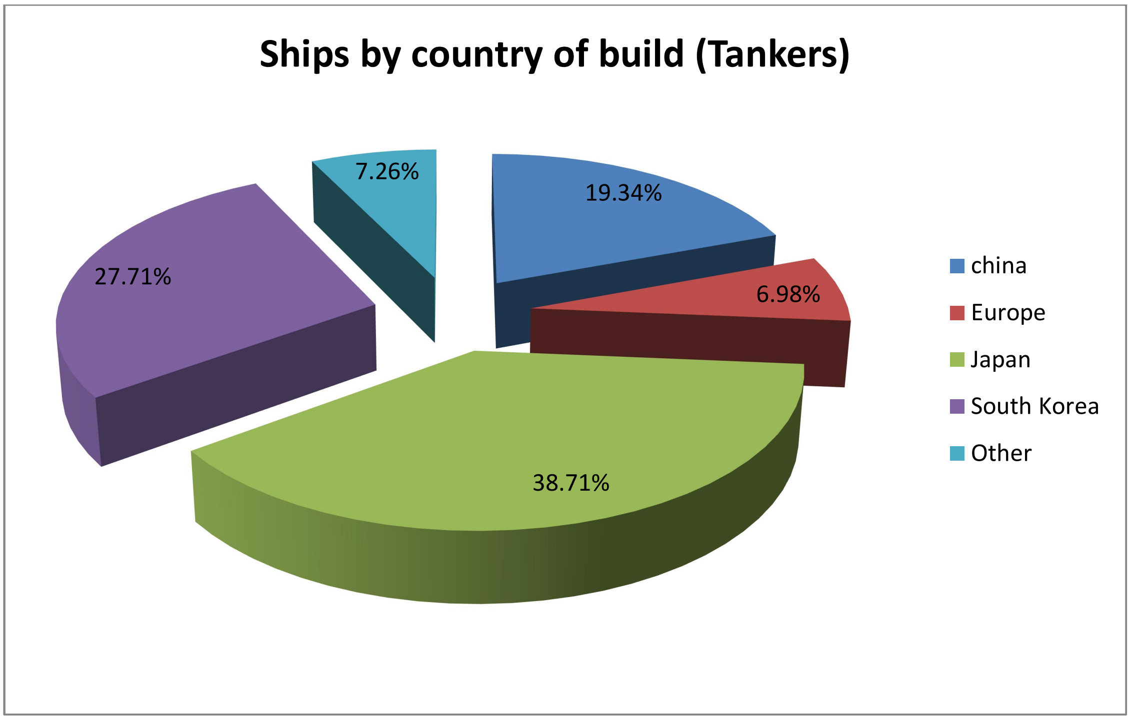


Figure 74: Percentage of tankers built in each country/continent

Table 56: Number of tankers build in each country./continent and relevant percentage

Distribution based on country of construction		
	Number of ships	percentage
china	2827	19.34%

Europe	1021	6.98%
Japan	5659	38.71%
South Korea	4052	27.71%
Other	1062	7.26%

6.2.3 Ships by flag

Each vessel is under a flag state. A possible classification for the flag states, as already mentioned is their categorization in white, grey, black and other flag categories. Fig. 75 is shown the percentage of tankers belonging to each flag category and in table 57 is presented both the number of tankers and their percentage for every flag category.

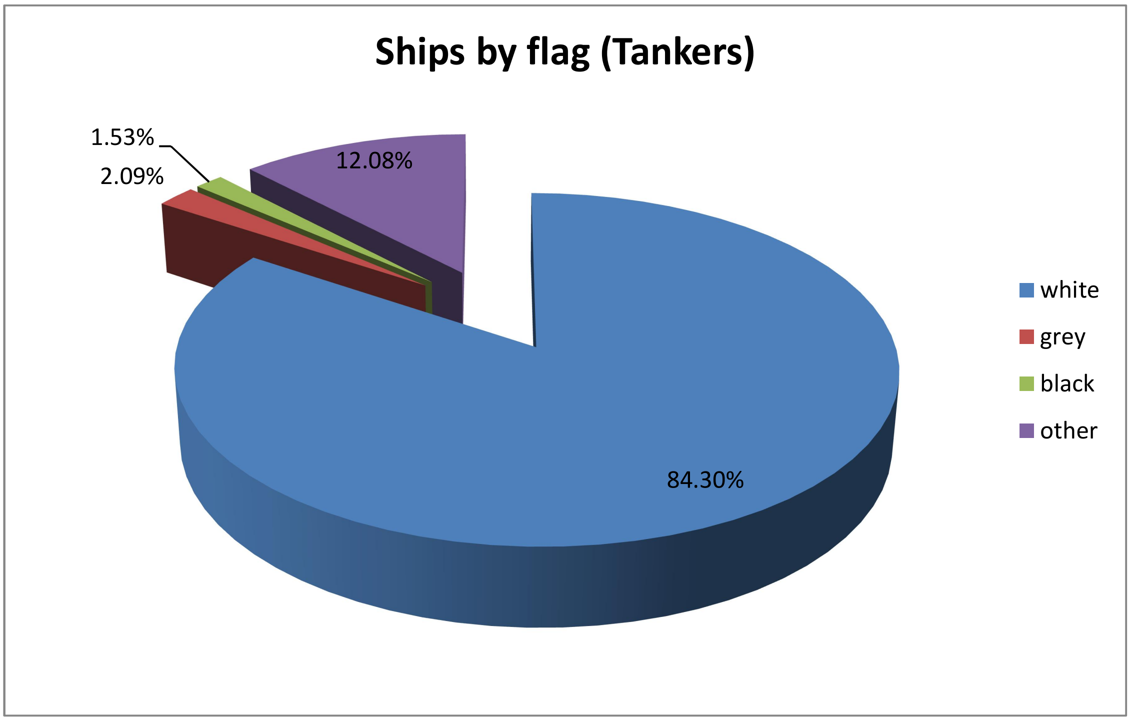


Figure 75: Percentage of tankers belonging to each of the flag category

Table 57: Number of tankers and relevant percentage in each flag category

Distribution based on flag state		
	Number of ships	percentage
white	12324	84.30%
grey	305	2.09%
black	224	1.53%
other	1766	12.08%

6.2.4 Ships by class

Each vessel is also part of a classification society. A possible clustering for the classification societies is their categorization as member of IACS or not a member of IACS. In Fig. 76 is shown the percentage of tankers whose classification societies is a member of IACS (or not) and in table 58 is presented both the number of tankers and their percentage for each of these categories.

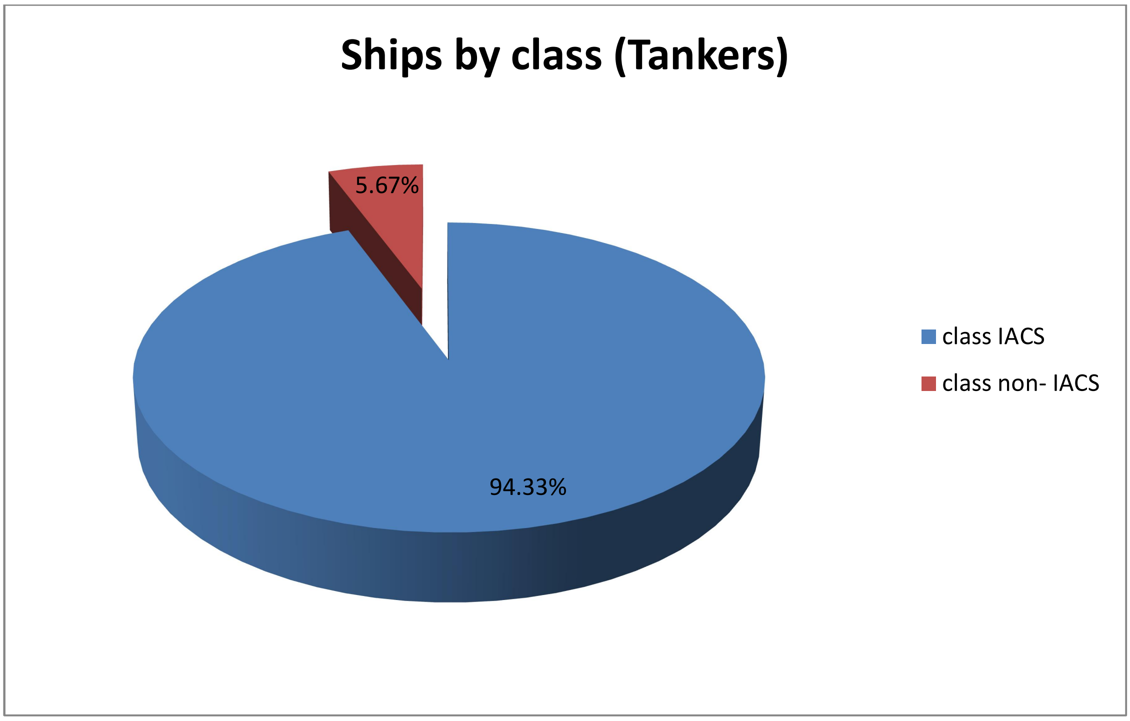


Figure 76: Percentage of tankers whose classification societies is member of IACS (or not)

Table 58: Number of tankers and relevant percentage whose classification societies is member of IACS (or not)

Distribution based on classification society		
	Number of ships	percentage
class IACS	13790	94.33%
class non- IACS	829	5.67%

6.3 Coating Lifetime Factor

The coating lifetime factor is mostly influenced by the building quality, the maintenance and the cargo. Each of these categories is influenced by some other subcategories as presented below.

6.3.1 Building Quality

The building quality is influenced by the country of the yard where the tanker was built and the classification society in charge at that time, as shown in Fig. 77. The country of yard, influences the total factor of building quality by 42,78% while the building class only by 10% (table 59).

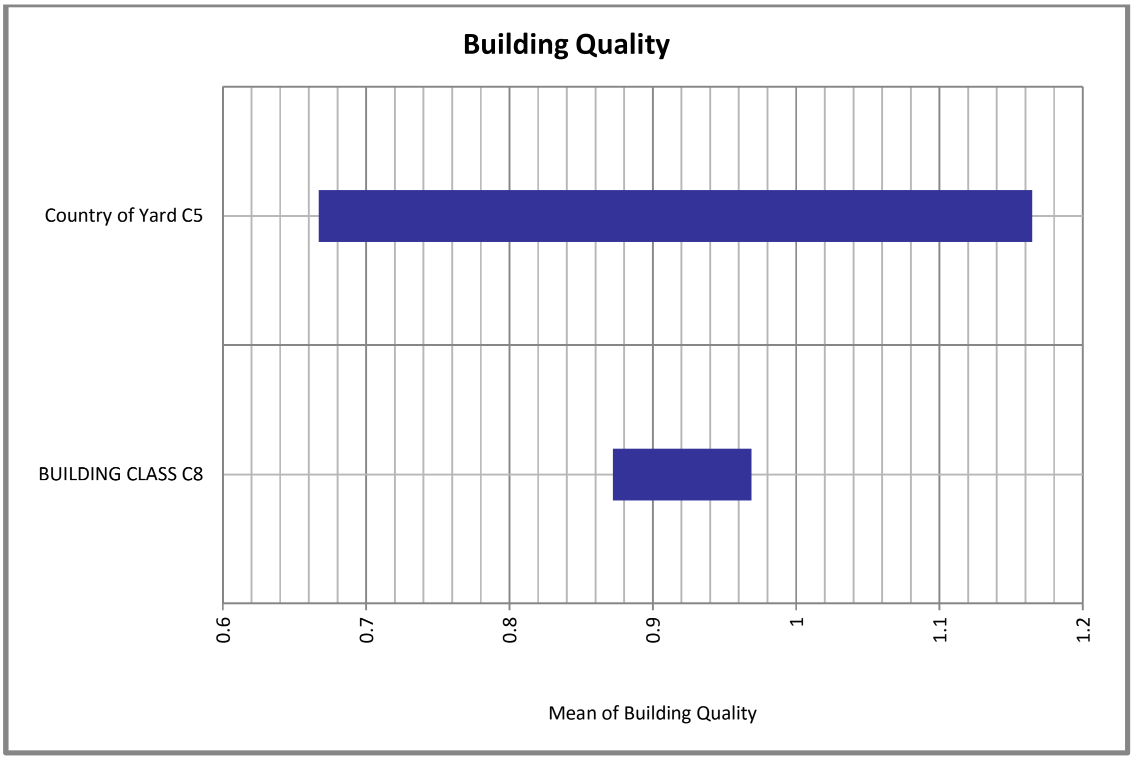


Figure 77: Factors affecting Building quality

Table 59: Influence percentage of factors influencing building quality.

Country of yard	42.78%
Building class	10.01%

6.3.2 Maintenance

Maintenance is influenced by the number of owner changes, the flag, the class, the time spend at sea and the time spend in port, as shown in Fig. 78. The number of owner changes plays the most important role as it affects the total factor of maintenance by a quarter. The flag and the classification societies influence the total factor of maintenance approximately 18% while the time spend at sea and in port, 16.71% and 9.11% respectively (table 60).

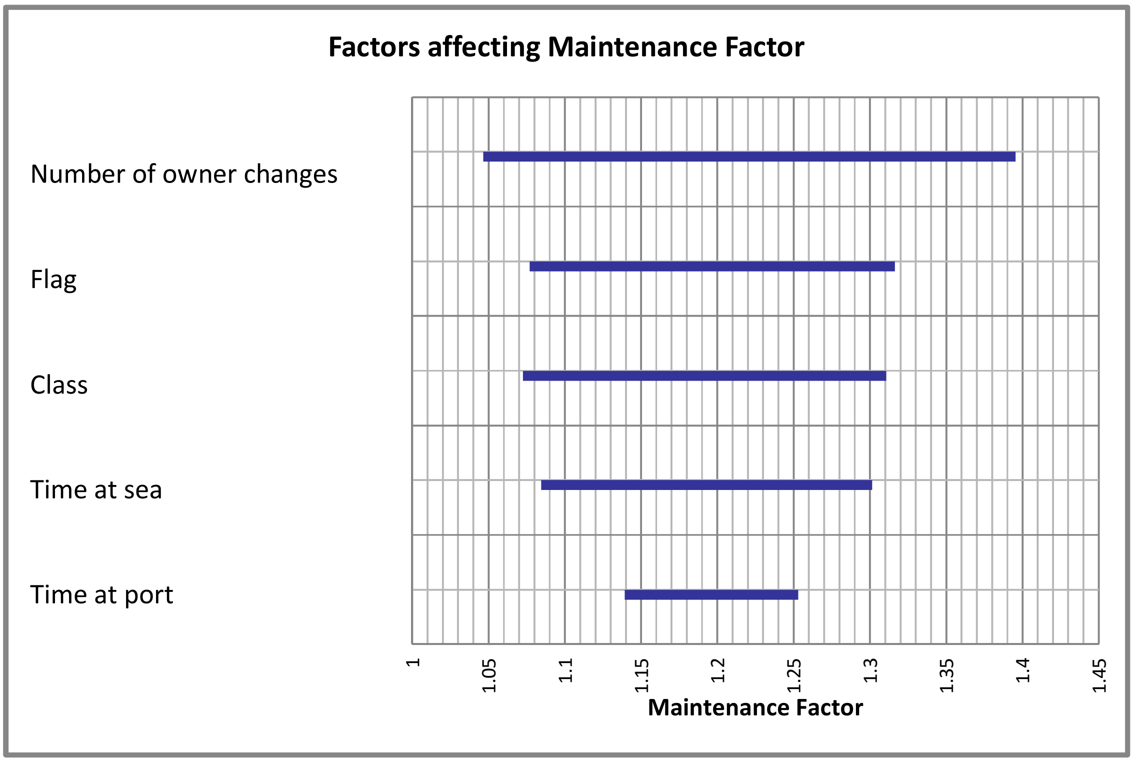


Figure 78: Factors affecting maintenance

Table 60: Influence percentage of factors influencing maintenance

Owner changes	25.02%
Flag	18.21%
Class	18.12%
Time at sea	16.71%
Time at port	9.11%

6.3.3 Coating Lifetime Factor

The coating lifetime factor is influenced by all the above mentioned subcategories, as shown in Fig. 80. In table 61, the percentage with which each of these subcategories is influencing the total coating lifetime factor is presented. The two factors playing the most important role are the country where the ship was built (42,78%) and how many owners the vessel has change (25,05%). Furthermore, the classification society, the flag and the time a vessel spends at sea are affecting the final result with lower rates, 18,23%, 18,19% and 16.67% respectively. The remaining factors influence the coating lifetime factor with a percentage around 10%.

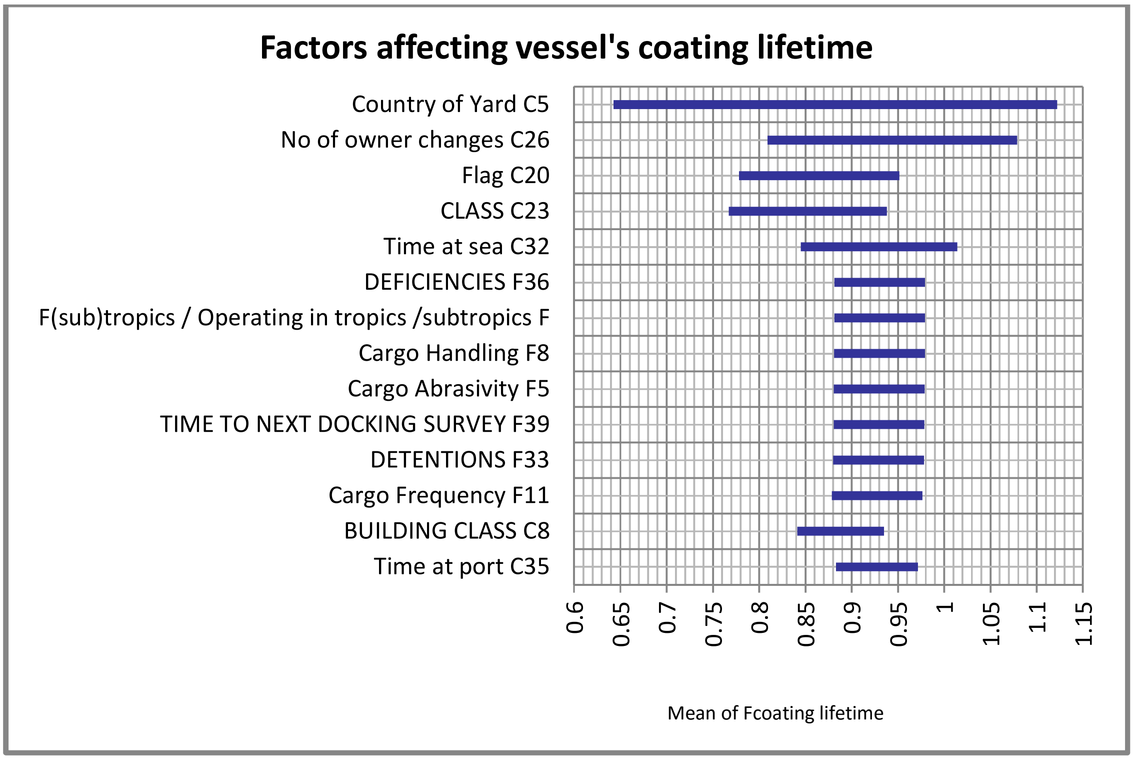


Figure 79: Factors influencing coating lifetime

Table 61: Influence percentage of factors affecting coating lifetime

Country of yard	42.78%
No of owner changes	25.05%
Flag	18.19%
Class	18.23%
Time at sea	16.67%
Deficiencies	10.01%
Operating in (sub)tropics	9.91%
Cargo handling	10.01%

Cargo abrasivity	10.11%
Time to next docking survey	10.02%
Detentions	10.02%
Cargo frequency	10.04%
Building class	10.05%
Time at port	9.06%

6.4 Corrosion Factor

Corrosion factor is influenced by cargo temperature, cargo corrosivity, ballast ratio and whether the ship is operating in tropics/subtropics areas, as shown in Fig. 81. The cargo temperature and corrosivity influence the total corrosion factor approximately 33% while the operation in tropics/subtropics areas and the ballast ratio with a percentage around 9% (table 62).

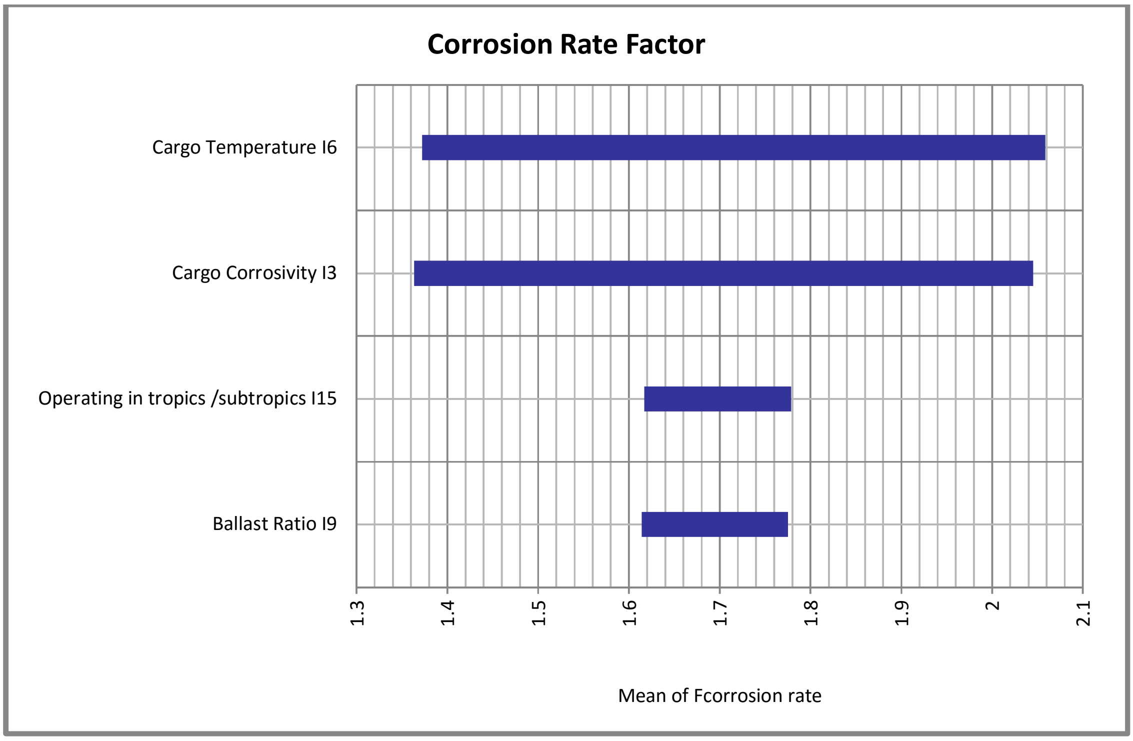


Figure 80: Factors influencing corrosion

Table 62: Influence percentage of factors affecting corrosion

Cargo Temperature	33.35%
Cargo Corrosivity	33.33%
Operating in (sub)tropics	9.07%
Ballast ratio	9.11%

6.5 Cargo Hold

For the cargo holds, the structural areas are the deck, the bulkhead, the side shell, the inner bottom and the floor.

6.5.1 Deck

The final depth of corrosion at the deck of the cargo space deck is influenced by the age of the ship, the corrosion rate factor, the coating lifetime factor and the theoretical lifetime of the coating for the deck of the cargo space (Fig. 82). With a percentage around 90% the age and the corrosion factor are influencing the depth of corrosion at the deck of the cargo space is presented in table 63. The influence of the other two is significantly lower, 29.67% for the coating lifetime factor and 17,27% for the $t_{theoretical}$ of the coating lifetime for the deck of the cargo space.

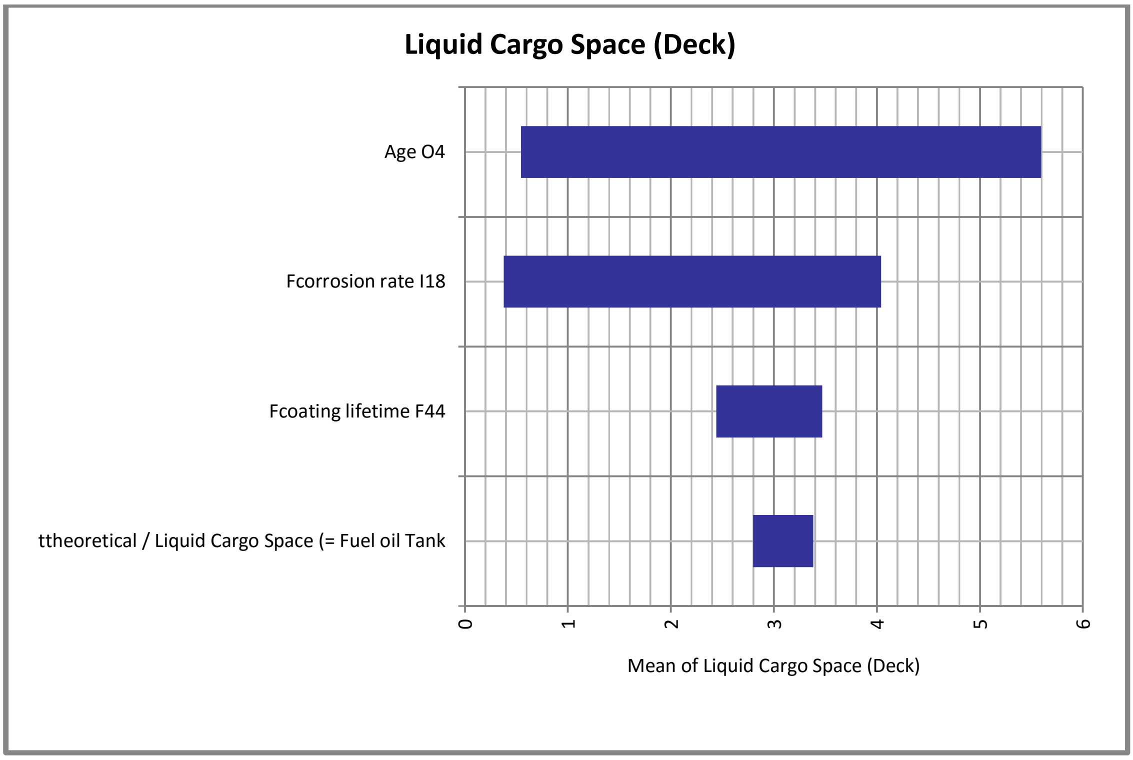


Figure 81: Factors influencing the deck in the cargo space

Table 63: Influence percentage of factors affecting the deck in the cargo space

Age	90.25%
Corrosion factor	90.65%
Coating lifetime factor	29.67%
CL $t_{theoritical}$ (deck CH)	17.27%

6.5.2 Bulkhead

The corrosion rate of the bulkhead in the cargo space is influenced by the age of the ship, the corrosion rate factor, the coating lifetime factor and the theoretical lifetime of the coating for the bulkhead of the cargo space (Fig. 83). The influence of the Coating lifetime factor and the $t_{theoretical}$ of the coating lifetime is relatively low, 32.72% for the coating lifetime factor and 20,26% for the $t_{theoretical}$ of the coating lifetime for the deck of the cargo space. The influence of the other two is much higher, with a percentage around 90% as presented in table 64.

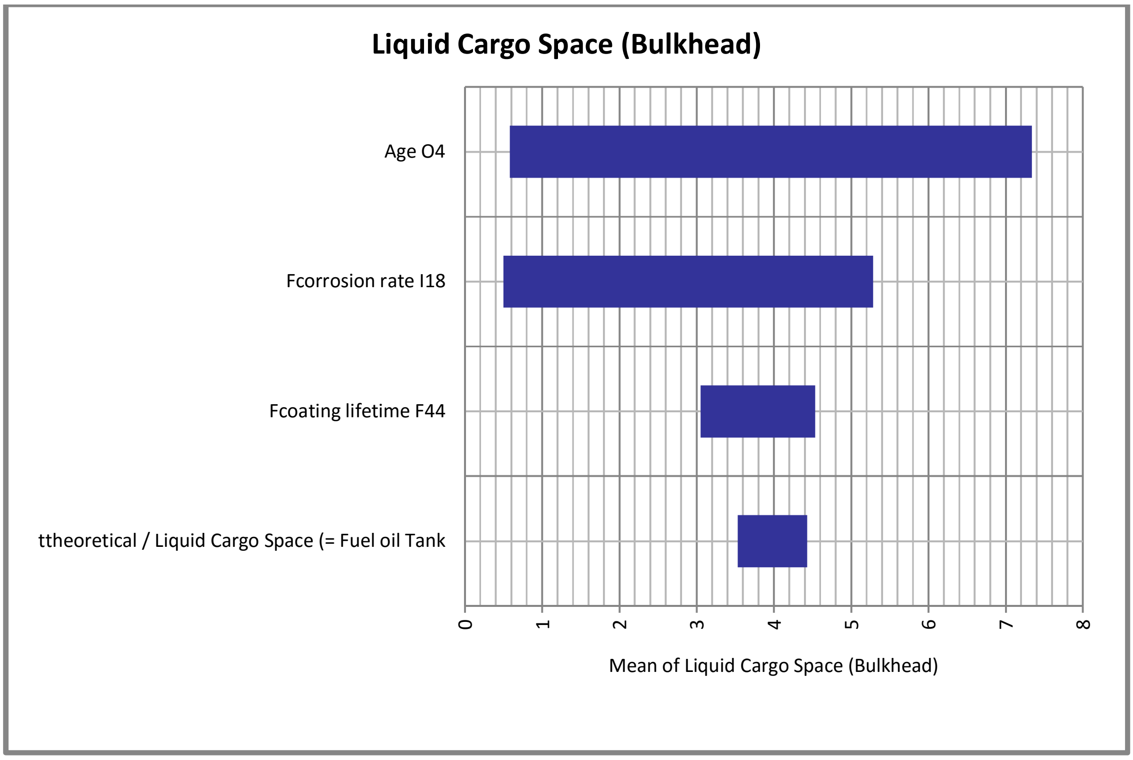


Figure 82: Factors influencing the bulkhead in the cargo space

Table 64: Influence percentage of factors affecting the bulkhead in the cargo space

Age	92.07%
Corrosion factor	90.63%
Coating lifetime factor	32.72%
CL $t_{theoritical}$ (bulkhead CH)	20.26%

6.5.3 Inner Bottom

The final depth of corrosion at the inner bottom of the cargo space deck is influenced by the age of the ship, the corrosion rate factor, the coating lifetime factor and the theoretical lifetime of the coating for the deck of the cargo space (Fig. 84). With a percentage around 90-92% the age and the corrosion factor are influencing the depth of corrosion at the deck of the cargo space is presented in table 65. The influence of the other two is significantly lower, 26.09% for the coating lifetime factor and 16,87% for the $t_{theoretical}$ of the coating lifetime for the deck of the cargo space.

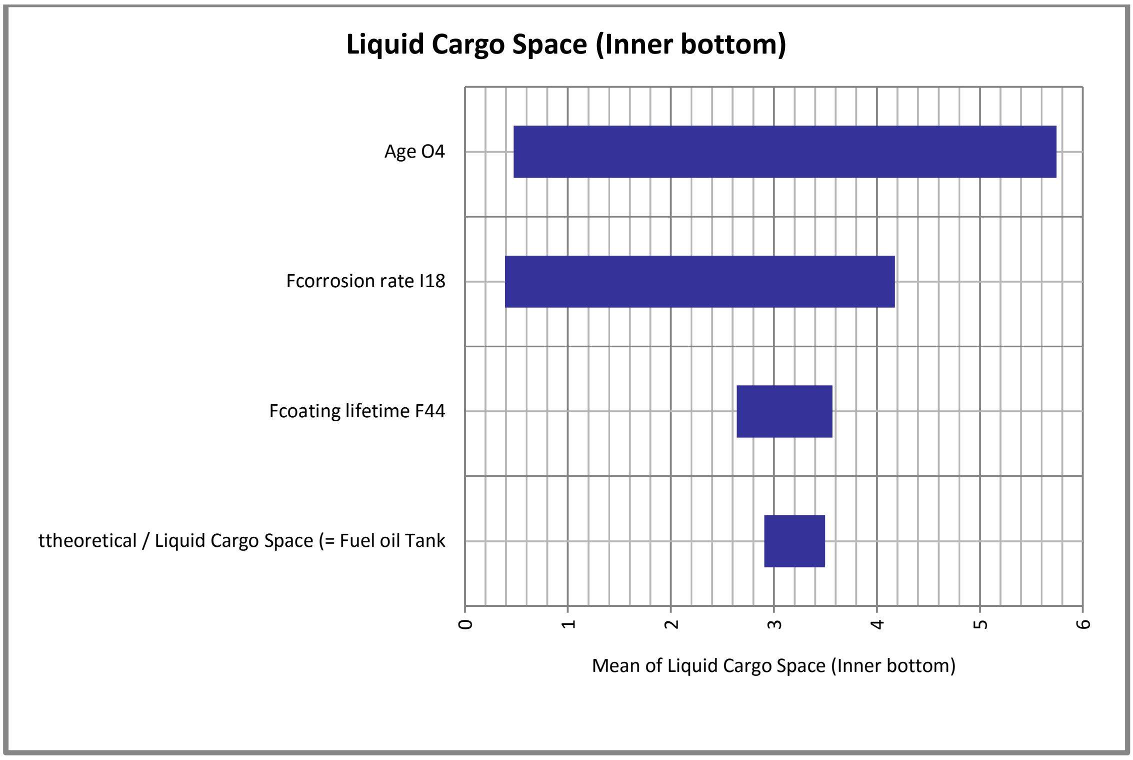


Figure 83: Factors influencing the inner bottom in the cargo space

Table 65: Influence percentage of factors affecting the inner bottom in the cargo space

Age	91.77%
Corrosion factor	90.63%
Coating lifetime factor	26.09%
CL $t_{theoritical}$ (inner bottom CH)	16.87%

6.5.4 Floor

The corrosion rate of the floor in the cargo space is influenced by the age of the ship, the corrosion rate factor, the coating lifetime factor and the theoretical lifetime of the coating for the bulkhead of the cargo space (Fig. 85). The influence of the Coating lifetime factor and the $t_{theoretical}$ of the coating lifetime is relatively low, 31.10% for the coating lifetime factor and 16,97% for the $t_{theoretical}$ of the coating lifetime for the deck of the cargo space. The influence of the other two is much higher, with a percentage of 90.63% and 92.43% for the corrosion factor and the age respectively, as shown in table 66.

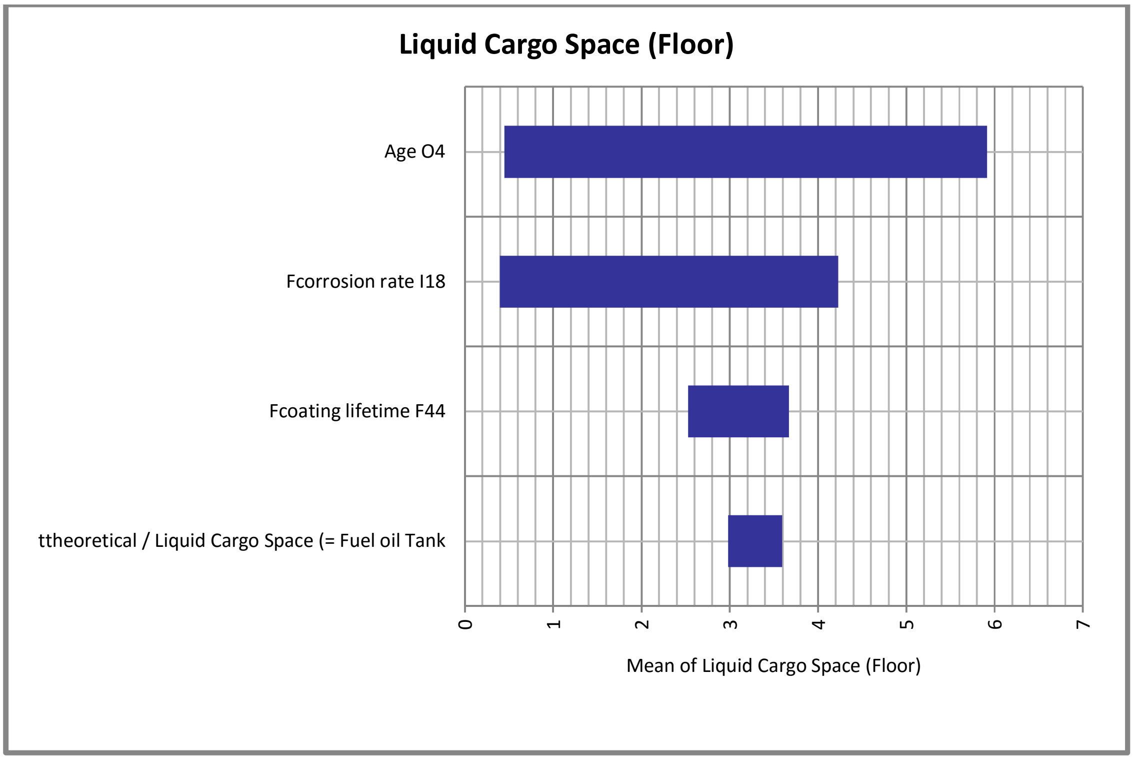


Figure 84: Factors influencing the floor in the cargo space

Table 66: Influence percentage of factors affecting the floor in the cargo space

Age	92.43%
Corrosion factor	90.63%
Coating lifetime factor	31.10%
CL $t_{theoritical}$ (floor CH)	16.97%

6.5.5 Side Shell

The final depth of corrosion at the side shell of the cargo space deck is influenced by the age of the ship, the corrosion rate factor, the coating lifetime factor and the theoretical lifetime of the coating for the side shell of the cargo space (Fig. 86). With a percentage around 90% the age and the corrosion factor are influencing the depth of corrosion at the deck of the cargo space is presented in table 67. The influence of the other two is significantly lower, 30.94% for the coating lifetime factor and 16,52% for the $t_{theoretical}$ of the coating lifetime for the deck of the cargo space.

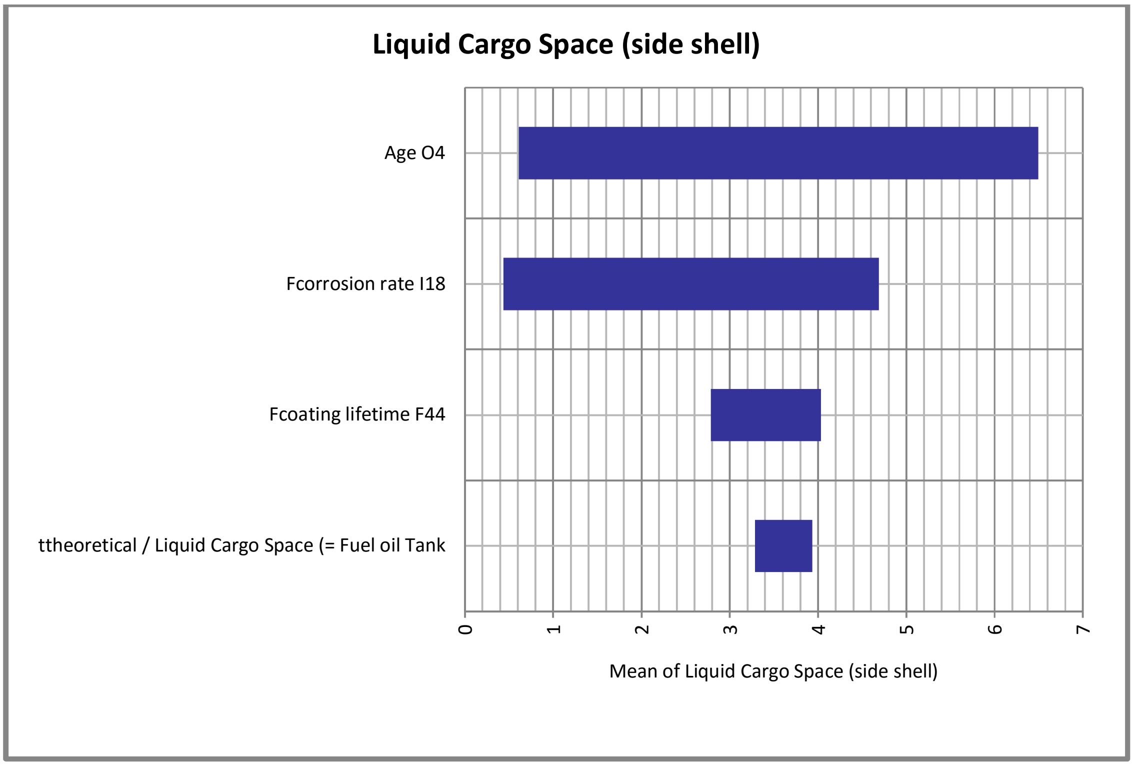


Figure 85: Factors influencing the side shell in the cargo space

Table 67: Influence percentage of factors affecting the side shell in the cargo space

Age	90.61%
Corrosion factor	90.64%
Coating lifetime factor	30.94%
CL $t_{theoritical}$ (side shell CH)	16.52%

6.6 Ballast Tank

For the ballast tanks, the structural areas are the bulkhead and the inner bottom.

6.6.1 Bulkhead

The corrosion rate of the bulkhead in the ballast tank is influenced by the age of the ship, the corrosion rate factor, the coating lifetime factor and the theoretical lifetime of the coating for the bulkhead of the cargo space (Fig. 87). The influence of the Coating lifetime factor and the $t_{theoretical}$ of the coating lifetime is relatively low, 35.81% for the coating lifetime factor and 24,50% for the $t_{theoretical}$ of the coating lifetime for the deck of the cargo space. The influence of the other two is much higher, with a percentage around 90% as presented in table 68.

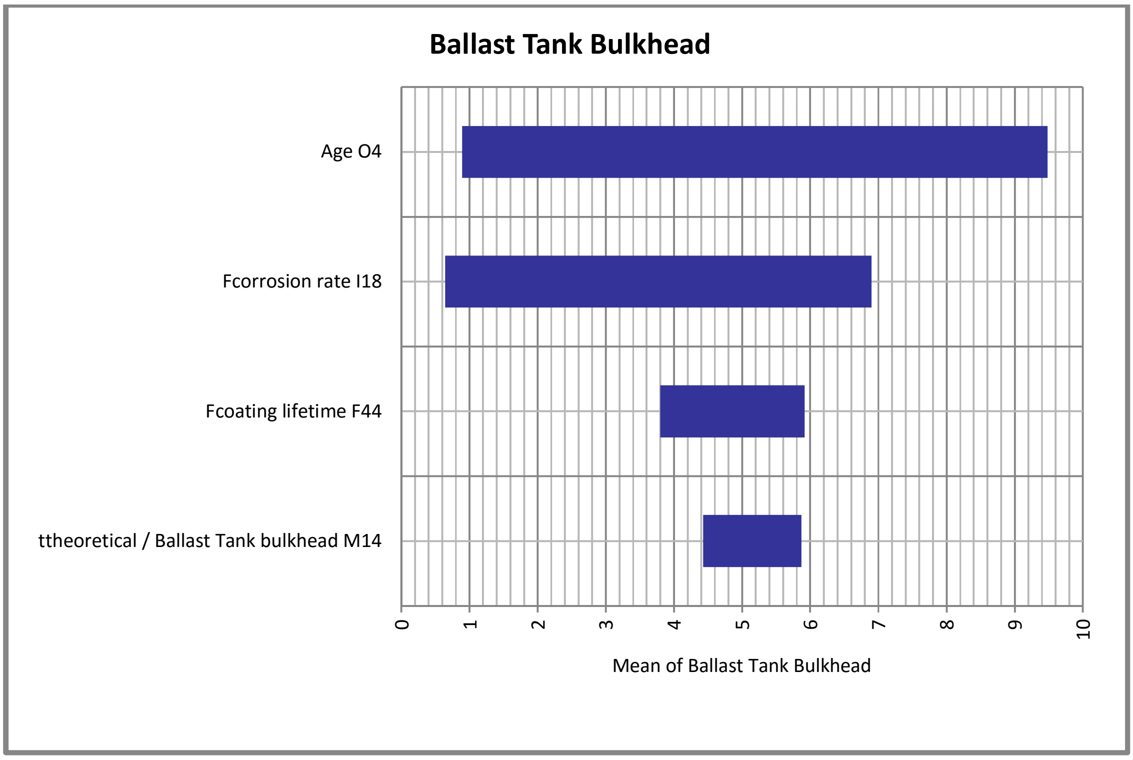


Figure 86: Factors influencing the bulkhead in the ballast tank

Table 68: Influence percentage of factors affecting the bulkhead in the ballast tank

Age	90.57%
Corrosion factor	90.63%
Coating lifetime factor	35.81%
CL $t_{theoritical}$ (bulkhead BT)	24.50%

6.6.2 Inner Bottom

The final depth of corrosion at the inner bottom of the ballast tank deck is influenced by the age of the ship, the corrosion rate factor, the coating lifetime factor and the theoretical lifetime of the coating for the deck of the cargo space (Fig. 88). With a percentage around 90-92% the age and the corrosion factor are influencing the depth of corrosion at the deck of the cargo space is presented in table 63. The influence of the other two is significantly lower, 35.24% for the coating lifetime factor and 24,12% for the $t_{theoretical}$ of the coating lifetime for the deck of the cargo space.

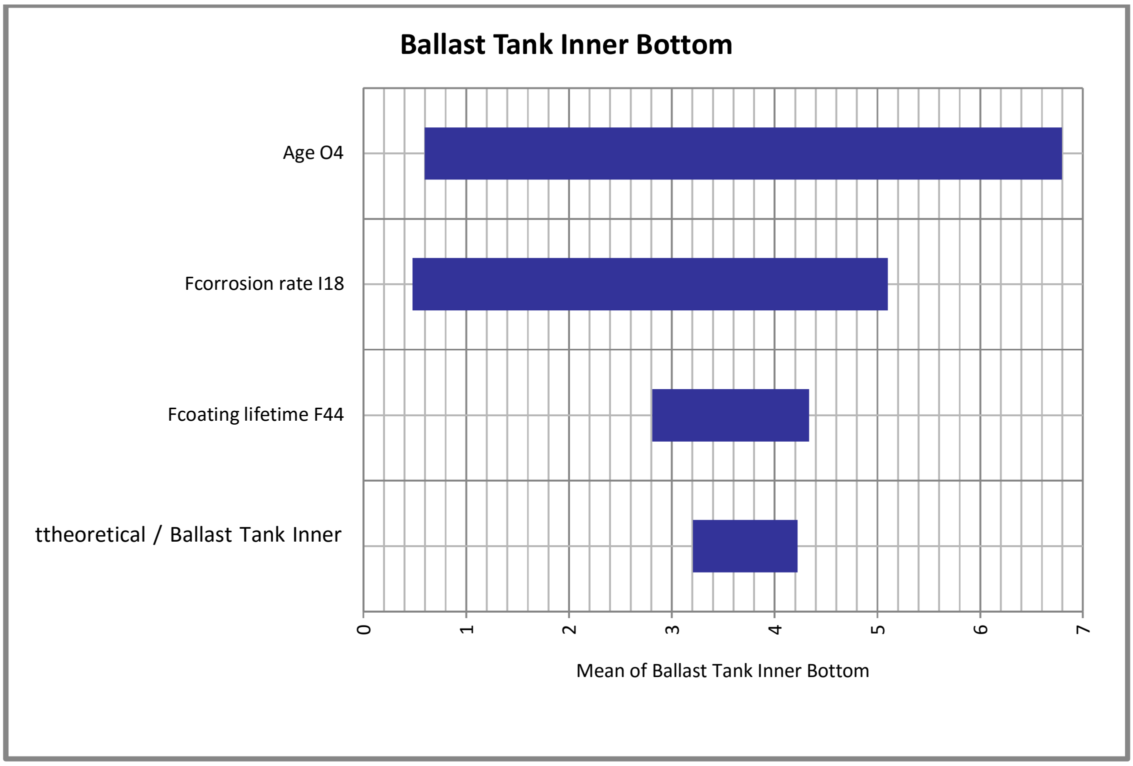


Figure 87: Factors influencing the inner bottom in the ballast tank

Table 69: Influence percentage of factors affecting the inner bottom in the ballast tank

Age	91.24%
Corrosion factor	90.63%
Coating lifetime factor	35.24%
CL $t_{theoritical}$ (inner bottom BT)	24.12%

6.7 Comparative table and aggregated charts

Based on all the above data arises the comparative table 64.In this table, there are four factors: age of the vessel, corrosion factor, coating lifetime factor and $t_{theoretical}$ of coating lifetime, which are affecting the final depth of corrosion. Moreover, the percentage with which each of these factors is affecting the corrosion depth for every structural point of the examined areas is also presented in table 64.

Table 70: Comparative table, percentages per factor and per structural area

	Cargo Hold					Ballast Tank	
	Inner bottom	Floor	Deck	Bulkhead	Side shell	Bulkhead	Floor
Age	91.77%	92.43%	90.25%	92.07%	90.61%	90.57%	91.24%
Corrosion factor	90.63%	90.63%	90.65%	90.63%	90.64%	90.63%	90.63%
Coating lifetime factor	26.09%	31.10%	29.67%	32.72%	30.94%	35.81%	35.24%
$t_{theoritical}$ of coating lifetime	16.87%	16.97%	17.27%	20.26%	16.52%	24.50%	24.12%

In Fig. 89, it is obvious that the age of the ship is a very important factor, as it influences all the structural areas with high percentages. For all the areas, the percentage of the age factor is above 90%

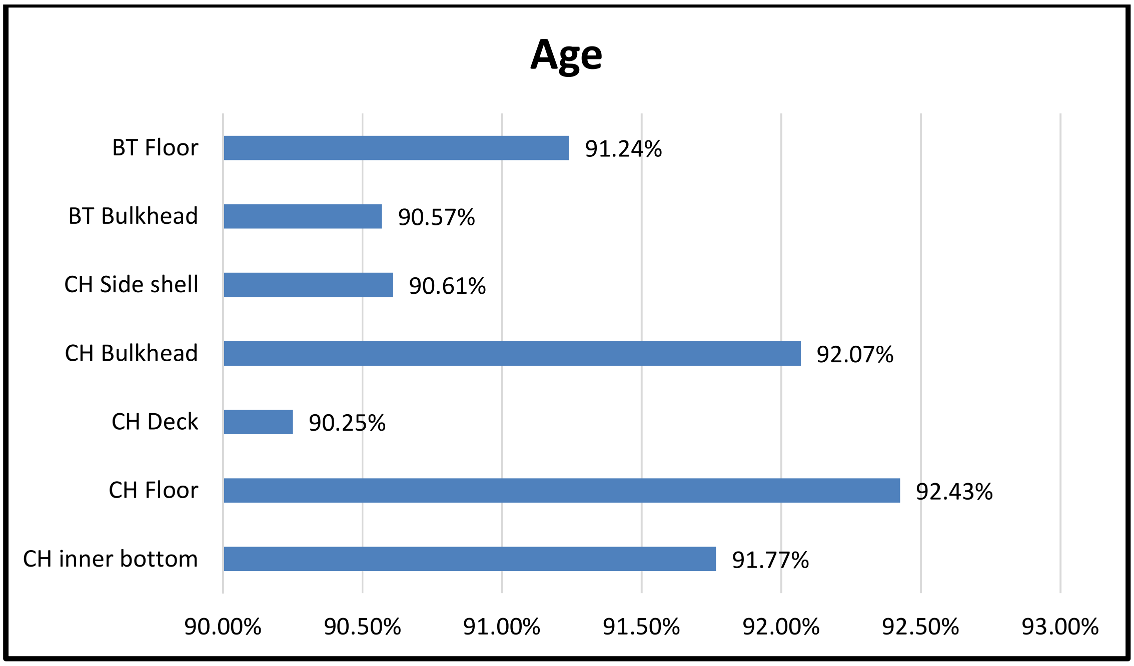


Figure 88: Age weighting per structural area

Corrosion factor is another very important factor for all the structural areas. However, as observed in Fig. 90, it remains stable for all the different areas under examination, with a rate around 90%.

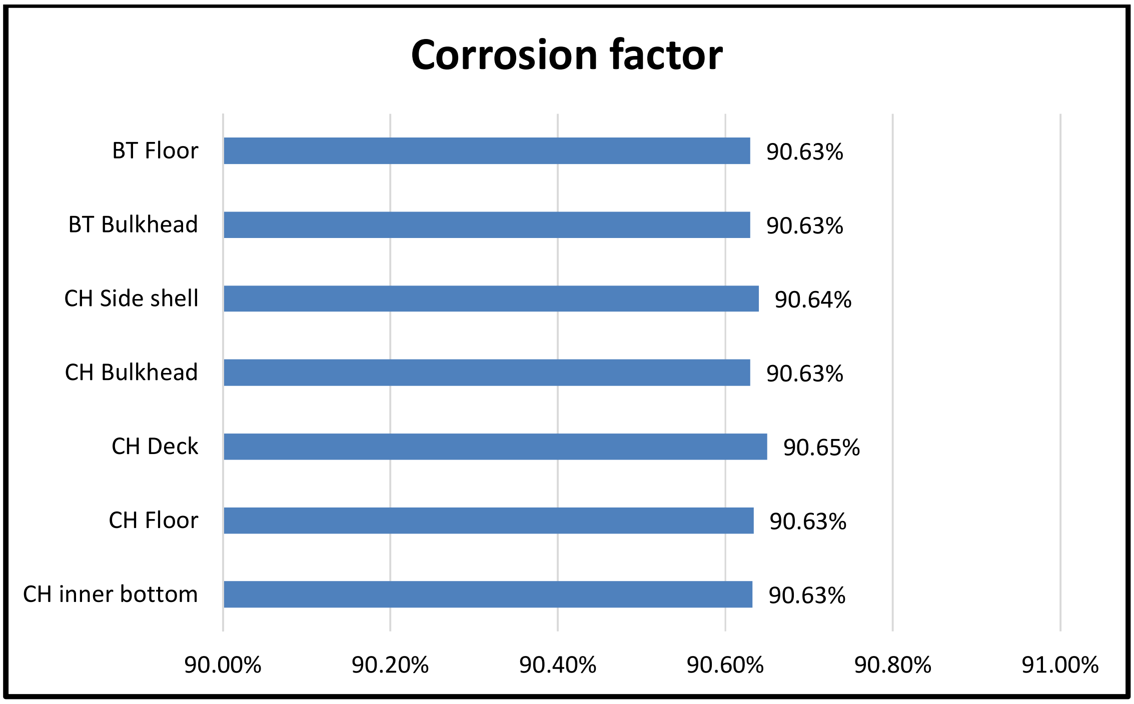


Figure 89: Corrosion factor weighting per structural area

Coating lifetime factor influences the depth of corrosion in every structural area explored, with smaller percentage. The breadth of the influence percentage is between 26% and nearly 36%.

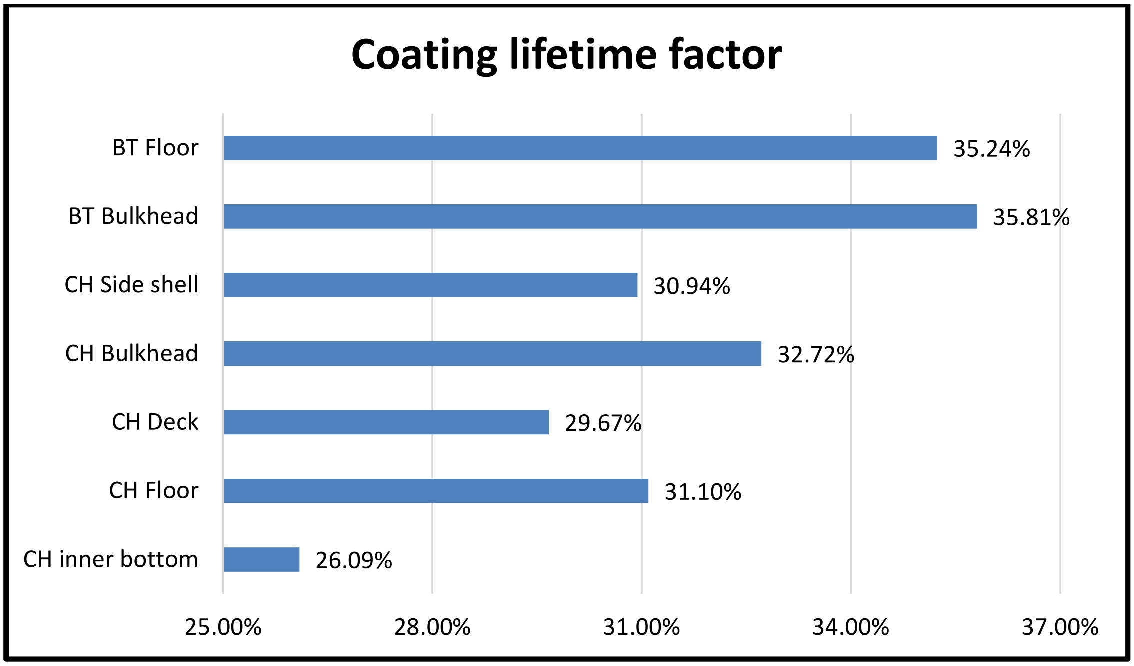


Figure 90: Coating lifetime factor weighting per structural area

The least important factor, which influences the depth of corrosion between various areas of the ship, is the theoretical lifetime of the coating (Fig. 92) However, this percentage is not negligible, as in the ballast tank is around 25%. For the cargo hold areas, the percentage for the bulkhead is nearly 20% and for the remaining areas is approximately 17%.

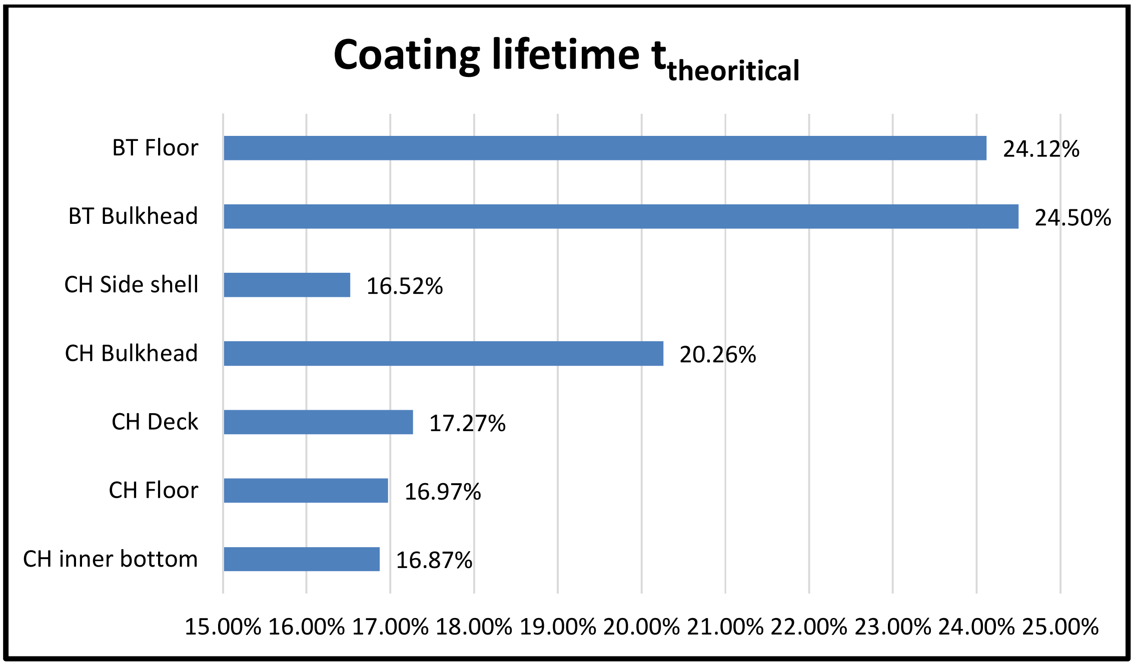


Figure 91: $t_{theoretical}$ weighting per structural area

The final figure below shows the percentage of influence of each of the four factors, age of the ship, coating lifetime factor, corrosion factor and $t_{theoretical}$ of coating lifetime, in the final depth of corrosion for each structural area under examination. The above mention factors influence these areas with different percentages. It is obvious that the age and the corrosion factor is really important for the final results of corrosion depth.

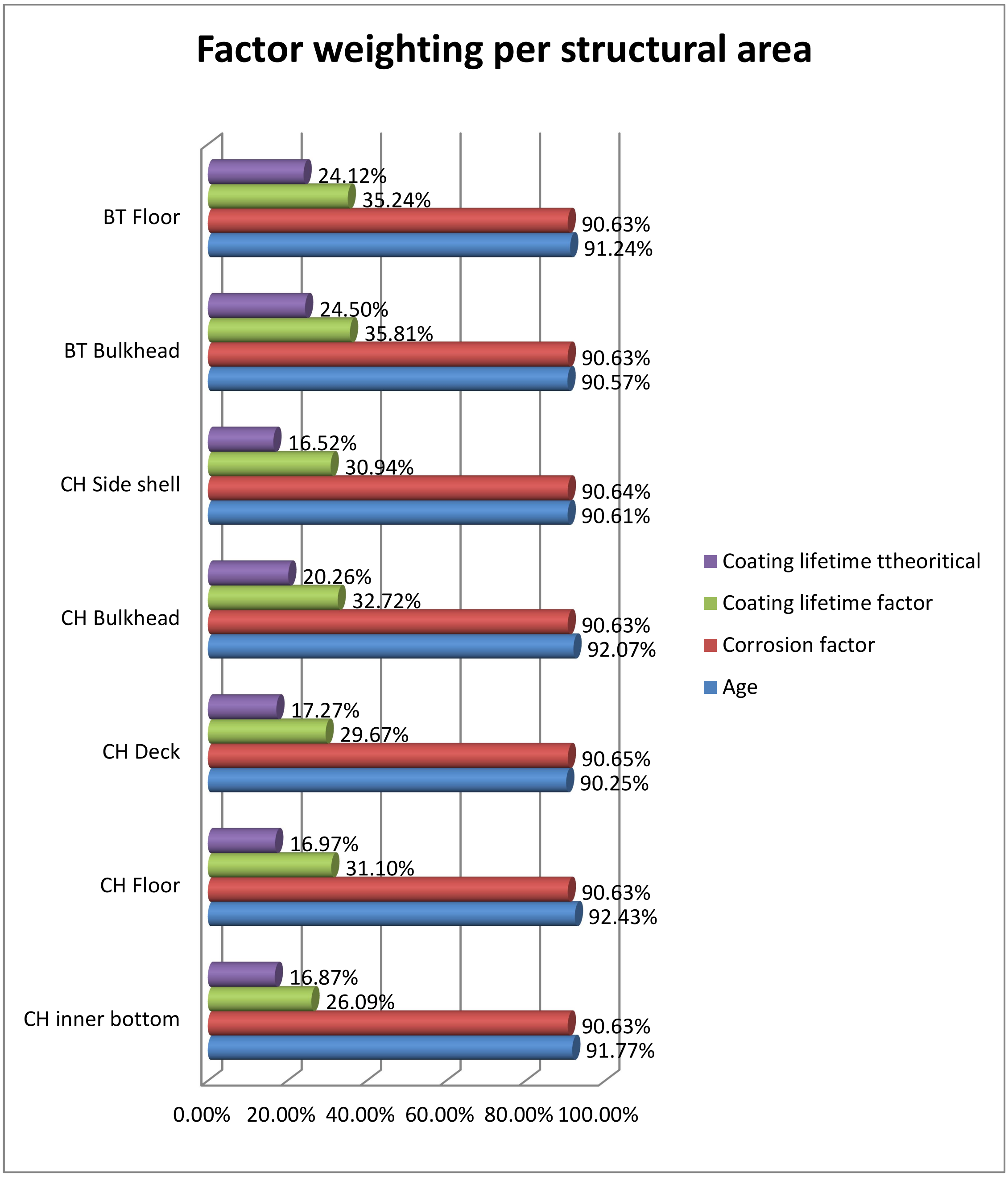


Figure 92: Factor weighting per structural area

7 CONCLUSIONS

7.1 Conclusions and proposals for further studies

It is obvious that at the structural points of the bulk carrier the values for the final depth of corrosion is a lot lower than the other two, the tanker and the general cargo ship. These results were expecting considering the age of the vessel. So, the age of the vessel is the most important factor for the determination of the final corrosion depth. The corrosion factor plays the second most important role in order to determine the final depth of corrosion. Furthermore, based on the results presented the ballast tanks are more likely to appear greater values for the corrosion depth.

The use of a risk based inspection model, could lead to an allocation of the available resources aiming to an optimization of the inspection process. This is possible, as the risk based inspection model could calculate the likelihood of failure for a specific structural area, so the inspector could pay more attention to more susceptible areas.

As for further future studies, the model could examine more factors affecting both the coating lifetime and the corrosion factors, which are already defined qualitatively but due to lack of information could not be accessed quantitative with numerical values in order to be used by the model, for the time being.

Ultimately, the model could be applied to other ship types, such as container ships, passenger ships etc. In addition, it could also be applied to other areas within the vessels, for example in the lubricant oil tanks, in the engine room or the exterior deck of the vessel, which is one of the most exposed area to environmental factors.

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