Naval Architecture and Marine Engineering

A Joint Department of the Universities of Glasgow and Strathclyde

Operational Risk Management of Bulk Carriers

by

George Ad. Psarros

A thesis presented and submitted in
fulfilment of the requirements for
the degree of

Doctor of Philosophy

November 2008

"The copyright of this thesis belongs to the author under the terms of the United Kingdom Copyright Acts as qualified by University of Strathclyde Regulation 3.51. Due acknowledgement must always be made of the use of any material contained in, or derived from, this thesis"

© George Ad Psarros, All rights reserved

Αφιερώνεται στους γονείς μου

~

Dedicated to my parents

Table of Contents

Appendices

This page is intentionally left blank

Preface

"Studium Ad Prosperandum – The Will to Succeed"

Anonymous, quoted in Deal and Kennedy (2000)

This research proved to be a three-year suffering process "dancing" with loneliness, reading and cooking. Yet, it can be compared to a ship (knowledge) voyaging under the command of the author (skipper) with the assistance of the available bibliography, software and hardware (crew) so that the destination (degree) is reached on time, although the seas that had been encountered were not always calm. The outcome can be characterized similar to Jacques-Yves Cousteau's experience *"ever since that magical moment when my eyes opened under the sea I have been unable to see, think or live as I had done before. My body floated weightlessly through space, the water took possession of my skin, the clear outlines of marine creatures had something almost provocative, and economy of movement acquired moral significance".*

Above all, the reader is invited to join the author and enjoy that voyage!

George Ad. Psarros

Glasgow, April 2008

This page is intentionally left blank

Acknowledgements

The author would like to express his gratitude to the European Funded Research Project SAFEDOR (IP 516278, 6th FP of the EC) for funding the current research.

The author is grateful to his supervisor Prof. Dracos Vassalos for supporting, providing him the freedom to implement his idea and the constructive feedback during the reviewing process.

The author is pleased to acknowledge everyone who assisted him in the current research by providing the requested information, more specifically:
The United States National Transportation Safety Board (US NTSB).
Mr Ian Dundas, The House of Representatives Standing Committee on Transport and Regional Services, Parliament of the Commonwealth of Australia.
Capt. Nicolaos Economides, Marine Casualty Investigation Division, Department of Merchant Shipping, Ministry of Communications and Works, Cyprus.
Ms Adamantia Traiforou, National Hellenic Statistical Service.
Ms Mette Nore, Det Norske Veritas (DNV) Library.
Mr Kostas Markou, Nippon Kaiji Kyokai (Class NK), Piraeus Office.
Mr Rob Lomas, the International Association of Dry Cargo Shipowners, (Intercargo).
Mr Panos Zachariadis, Atlantic Bulk Carriers Management Ltd.
Mr Athanasios Crassaris, Sprinfield Shipping Co.
Ms Maria Lemos, Alcyon Shipbroking and Trading Ltd.
Mr Stefanos Tsonakis, Eastern Mediterranean Maritime Ltd.
Mr Eleftherios Belessis, Carras Hellas S.A.
Mr Savvas Papadatos, Tsakos Shipping & Trading S.A.
Mr Christos Papadimitriou, Time & Tide Shipping Ltd.

Mr George Halaris, Fafalios Shipping S.A.
Mr Jakob Steffensen, Lauritzen Bulkers A/S.
Mr M Paspalas, Chartworld Shipping Corp.
Mr Ronald De Pauw, Bocimar International NV.
Mr Nicolas Hornos, Marmaras Navigation Ltd.
Mr Ioannis Petikas, Good Faith Shipping Co. S.A.
Mr Dieter Rohdenburg, Intership Navigation Co. Ltd.
Mr Dimitris Monioudis, Rethymnis & Kulukundis Ltd.
Dr Luis Guarin, Safety At Sea Ltd.

The persons who replied to the author's e-mails for being unable to assist him.

Dr Dimitris Konovessis, The Ship Stability Research Centre, Department of Naval Architecture and Marine Engineering, Universities of Glasgow & Strathclyde, for the initial guidance and providing the requested documents.

Sincere thanks should be expressed to Dr Fuat Kara, Cranfield University, for the useful advice and the unforgettable "spicy" discussions, a necessary break during working hours.

This study could not be completed successfully without the support and encouragement of the author's parents and brother. A simple acknowledgement is not enough.

Declarations

The beliefs expressed in this thesis are those of the author and should not be interpreted that reflect the views of the funding source, the individuals and their institutions /enterprises or any governmental organization and of course the author is responsible for the content of them.

Parts of this dissertation are going to be published/presented at:

a) Psarros, G., A., Vassalos, D., 200X, "Risk Assessment of Bulk Carriers", submitted to Reliability Engineering & System Safety.

b) Psarros, G., A., Vassalos, D., 200X, "Risk Analysis of Bulk Carriers", submitted to Ships and Offshore Structures.

c) Psarros, G., A., Vassalos, D., 200X, "Effectiveness of corrosion measures to bulk carriers with Life Cycle Cost Analysis", submitted to International Shipbuilding Progress.

d) Psarros, G., A., Vassalos, D., 200X, "Operational Risk Management Methodology with a case study applied to dry bulk shipping", SNAME Transactions, (prepared for submission)

e) Psarros, G., A., Vassalos, D., 2009, "Trends in bulk carrier foundering accidents and their historical risk profile", paper presented at the *RINA International Conference Design and Operation of Bulk Carriers*, 26-27 October, Athens.

This thesis has been distributed also, upon availability, to:

Dr Rolf Skjong, Det Norske Veritas AS
Mr Jorge Ballesio, American Bureau of Shipping
Prof. Harilaos Psaraftis, National Technical University of Athens

Prof. Kostas Spyrou, National Technical University of Athens
Prof. Manolis Samuelides, National Technical University of Athens
Dr Jean Otto De Kat, A.P. Moller – Maersk AS
Dr B S Lee, Universities of Glasgow & Strathclyde
Dr Osman Turan, Universities of Glasgow & Strathclyde

A summary has been sent to:

Mr Fujio Kaneko, National Maritime Research Institute
Mr George Gratsos, Hellenic Chamber of Shipping
The shipping companies who have provided data

Abstract

The proposed study had been performed behind the premise of proposing a methodology for estimating the current operational risk of bulk carriers. Hence, a high level risk assessment has been conducted for evaluating the safety performance of dry bulk cargo transportation. This included the preparatory step for setting the problem's boundary limits, hazard identification for the prioritization of causes and effects, risk analysis for the quantification of risks and risk evaluation for assessing the significance and the acceptability of the estimated risk. The relevant aspects that are taken into account consist of the vessel's function (carriage of payload), operational phase (ocean transit), external (weather conditions, routeing) and internal (cargoes) influences, accident category (foundering) and the risk associated with crew (fatalities) and property (loss of vessel and cargo). Apparently, many factors were competing for attracting attention, and therefore, the Pareto principle was applied for narrowing the analysis where corrosion was identified as a main situation of causing harm. The attached uncertainty in the aforementioned operational domain is dealt with the Bayesian Networks technology and concurrently the construed prioritization to corrosion is verified by the developed risk model. The estimated risk was found As Low As Reasonably Practicable and the potential of improvement is considered by addressing preventive (design) and mitigating (operational) measures. Furthermore, their effectiveness as action implementing risk management decision is illustrated by employing Life Cycle Cost Analysis, a decision making technique for exploiting different investment opportunities.

This page is intentionally left blank

Glossary

- ***Accident:*** a sudden unintended departure from normal operating conditions in which some degree of harm is caused (HSE 2002a).
- ***Consequence (Index):*** the probability of expected effects (i.e. number of deaths) of an event occurring (HSE 2002a).
- ***Cost – benefit assessment:*** a technique for comparing the costs and benefits of a measure, usually in financial terms (HSE 2002a).
- ***Cost effectiveness analysis:*** the approach for justifying that the determined amount of risk reduction can be in the acceptable region (IMO 2002b, 2007b).
- ***Event:*** a non – specific term used to describe any incident, accident, failure case or outcome as appropriate and thus an occurrence of a particular set of circumstances (HSE 2002a, Aven 2003).
- ***Failure:*** a condition when a system fails to perform its intended function (HSE 2002a).
- ***Failure case:*** representation in a risk assessment of the range of possible accidents which might occur in reality (HSE 2002a).
- ***Frequency:*** the number of occurrences of an event per unit time usually expressed as No/year (HSE 2002a).
- ***Harm:*** the adverse impact of accidents, such as sickness, injuries, deaths, damage to property, degradation of the environment, or interruption of business (HSE 2002a).
- ***Hazard:*** a situation with a potential for causing harm (HSE 2002a).
- ***Hazardous activity:*** an industrial process, such as dry bulk cargo transportation, with inherent hazards (HSE 2002a).
- ***Incident:*** a relatively minor accident, i.e. unintended departures from normal operating conditions in which little or no harm was caused (HSE 2002a).
- ***Likelihood (Index):*** the probability of an event occurring (HSE 2002a).
- ***Observable quantity:*** quantity expressing a state of the "world", i.e. a quantity of the physical reality or nature, that is unknown at the time of the analysis but will, if the

system being analysed is actually implemented, take some value in the future, and possibly become known (Aven 2003).

- ***Probability:*** the chance (uncertainty measure) of an event occurring in specific circumstances and is a (dimensionless) number between 0 and 1 (HSE 2002a, Aven 2003)[1].
- ***Quality:*** the freedom from deficiencies and thus "fitness to use" i.e., the users of a product or service should be able to count on it for what they needed or wanted to do with it (Juran 2000a).
- ***Risk (Index):*** the potential for realization of unwanted, negative outcomes of an event and thus uncertainty of the performance of a system (the "world"), quantified by probabilities of observable quantities (Rowe 1988, Aven 2003). *Mathematically* can be expressed as the combination[2] of likelihood and consequence of hazards being realised, i.e. the chance of a specific event occurring within a specific period (HSE 2002a).
- ***Risk analysis:*** the quantification of risks without making judgements about their significance and thus is a systematic use of information to identify sources and assign risk values. This involves identifying hazards and estimating their frequencies and consequences, so that the results can be presented as risks (HSE 2002a, Aven 2003).
- ***Risk assessment:*** a means of making a systematic evaluation of the risk from hazardous activities (qualitative or quantitative) and making a rational evaluation of their significance in order to provide input to a decision making process. Thus, the overall process of risk analysis and risk evaluation (HSE 2002a, Aven 2003).
- ***Risk control:*** the actions implementing risk management decisions (Aven 2003).
- ***Risk control measure:*** a means of controlling a single element of risk and thus providing risk reduction (IMO 2002b, 2007b, Aven 2003).
- ***Risk control option:*** a combination of risk control measures and therefore action implementing risk management decisions (IMO 2002b, 2007b, Aven 2003).
- ***Risk (acceptance) criteria:*** standards to help evaluate the significance of risk results. They relate quantitative risk estimates to qualitative value judgements about the significance of the risks (HSE 2002a).

---

[1] The most widely accepted definition of probability had been formalized by Kolmogorov's classic ***Foundations of the Theory of Probability (1933)*** where it is stated that probability is a positive normalized measure over a field of "possible worlds" or "possible states of nature" (Bedford and Cooke 2004).

[2] Risk = Likelihood × Consequence

- ***Risk evaluation:*** assessing the significance (and sometimes the acceptability) of the estimated risks and thus is a process of comparing risk against given risk criteria to determine the significance of the risk. It may use also cost – benefit assessment of possible risk reduction measures to show whether the risks are as low as reasonably practicable (HSE 2002a, Aven 2003).
- ***Risk management:*** the making of decisions concerning the risk, the subsequent implementation of the decisions in the safety management system and thus coordinated activities to direct and control an organization with regard to risk (HSE 2002a, Aven 2003).
- ***Risk model:*** a model of uncertainties related to the prediction of performance (usually negative outcome) of an operating system (Nilsen and Aven 2003).
- ***Risk reduction:*** actions taken to reduce risk (Aven 2003).
- ***Safety (Index):*** the quality of a system that allows the system to function under predetermined conditions with an acceptable minimum of accidental loss (Roland and Moriarty 1990). *Mathematically* (in terms of probability) can be expressed as the complement/absence of risk (HSE 2002a).
- ***Safety management:*** a systematic control of worker performance, machine performance and physical environment and hence both prevention and correction of unsafe conditions and circumstances (Heinrich et al. 1980).
- ***Safety management system:*** the set of arrangements in place to manage the safety of a hazardous activity (HSE 2002a).
- ***Source:*** thing or activity with a potential for consequence (Aven 2003). In the current study concept is hazard or hazardous activity.
- ***System:*** a composite of people, procedures and equipment that are integrated to perform a specific operational task or function within a specific environment (Roland and Moriarty 1990).
- ***Uncertainty:*** lack of knowledge about the performance of a system (the "world") and observable quantities (Aven 2003).

This page is intentionally left blank

Nomenclature

ABS	:	American Bureau of Shipping
ALARP	:	As Low As Reasonably Practicable
ASM	:	American Society of Metals
ASTM	:	American Society of Testing Materials
ATSB	:	Australian Transport Safety Bureau
BC(s)	:	Bulk Carrier(s)
BEAmer	:	Bureau d'enquêtes sur les événements de mer
BIMCO	:	The Baltic and International Maritime Council
Black Sea MOU	:	Black Sea Memorandum of Understanding on PSC
BLU Code	:	Code of Practice for the Safe Loading and Unloading of BCs
BMT	:	British Maritime Technology
BN(s)	:	Bayesian Network(s)
BSI	:	British Standards Institution
BTCE	:	Bureau of Transport and Communication Economics
CAF	:	Cost of Averting a Fatality
CBA	:	Cost – Benefit Assessment

CCD	:	Central Composite Design
CCPS	:	Center for Chemical Process Safety
CEA	:	Cost Effectiveness Analysis
Clarksons	:	Clarkson Research Services Limited
Class NK	:	Nippon Kaiji Kyokai
COV	:	Coefficient of Variation
CPT(s)	:	Conditional Probability Table(s)
DAG	:	Directed Acyclic Graph
DBN(s)	:	Dynamic BN(s)
DFT	:	The UK Department for Transport
DNV	:	Det Norske Veritas
DOOBN(s)	:	Dynamic Object – Oriented BN(s)
Drewry	:	Drewry Shipping Consultants Ltd.
DWT	:	Deadweight Tonnage
EMSA	:	European Maritime Safety Agency
ESP	:	Enhanced Programme of inspections during Surveys
ETA	:	Event Tree Analysis
FMEA	:	Failure Modes Effect Analysis
FMECA	:	Failure Modes, Effect and Criticality Analysis
FSA	:	Formal Safety Assessment

FTA	:	Fault Tree Analysis
GL	:	Germanischer Lloyd AG
HAZID	:	Hazard Identification
HAZOP	:	Hazard and Operability Analysis
HMSO	:	Her Majesty's Stationary Office
HORSCTCI	:	The House of Representatives Standing Committee on Transport, Communications and Infrastructure
HSE	:	Health and Safety Executive
IACS	:	The International Association of Classification Societies
ID(s)	:	Influence Diagram(s)
IMO	:	International Maritime Organization
Indian Ocean MOU	:	Indian Ocean Memorandum of Understanding on PSC
Intercargo	:	The International Association of Dry Cargo Shipowners
ISM Code	:	The International Safety Management Code
ISO	:	International Organization for Standardization
ISSC	:	International Ship and Offshore Structures Congress
LCCA	:	Life Cycle Cost Analysis
LMIS	:	Lloyd's Maritime Information Services
LMIU	:	Lloyd's Marine Intelligence Unit
LR	:	Lloyd's Register

MAIIF : Marine Accident Investigators' International Forum

MARS : Marine Accident Reporting Scheme

MSC : Maritime Safety Committee

(N)PV : (Net) Present Value

NTSB : National Transportation Safety Board

NTUA : National Technical University of Athens

OECD : Organisation for Economic Co-operation and Development

OOBN(s) : Object – Oriented BN(s)

ORM : Operational Risk Management

Paris MOU : The Paris Memorandum of Understanding on PSC

PDF(s) : Probability Density Function(s)

PLL : Potential Loss of Life

PRS : Polski Rejestr Statków

PSC : Port State Control

QRA : Quantitative Risk Assessment

RAE : The Royal Academy of Engineering

RCM(s) : Risk Control Measure(s)

RCO(s) : Risk Control Option(s)

RINA : The Royal Institution of Naval Architects

RSM : Response Surface Methodology

SMS	:	Safety Management System
SNAME	:	The Society of Naval Architects and Marine Engineers
SOLAS	:	The International Convention for the Safety of Life at Sea, 1974, and the 1988 Protocol
Standard-Club	:	The Standard Steamship Owners' Protection & Indemnity Association (Bermuda) Limited
Tokyo MOU	:	Memorandum of Understanding on PSC in the Asia – Pacific Region
TSB	:	The Transportation Safety Board of Canada
UK	:	United Kingdom
UK P&I	:	The UK Protection & Indemnity Club
UKHO	:	The UK Hydrographic Office
UN	:	United Nations
UNCTAD	:	UN Conference on Trade and Development
UR	:	Unified Requirements
USA	:	United States of America
USCG	:	United States Coast Guard
USD	:	United States Dollar
Viña del Mar	:	Latin American Agreement on PSC
West P&I	:	The West of England Ship Owners Mutual Insurance Association

This page is intentionally left blank

List of Tables

List of Figures

This page is intentionally left blank

1 Introduction

"How safe is safe enough?"

Anonymous

BCs are cargo ships designed primarily for the transportation of solid bulk cargoes, i.e. cargoes generally uniform in composition which are loaded directly into the cargo space without any intermediate form of containment. The advantage of carrying such cargoes in bulk is that packaging costs can be greatly reduced and loading and unloading operations can be speeded up. These vessels can be characterized as the "workhorses" of maritime commerce since commodities such as ores, coal, minerals, grains – usually located on different continents; are transported effectively by sea. As demand increased and shipbuilding technology advanced, BCs tended to become bigger in size and carrying capacity, for the reason that such trades require a sufficient volume of cargo suitable for bulk handling and hence justify a shipping operation tailored to the producer's and consumer's needs. Yet for their importance to the modern industrial society, are among the most anonymous of ships and when they sink; which they did during the early 1980s and 1990s, they do so unnoticed by the world at large due to little unsightly pollution.

However, this outlook seemed to be challenged since the elevated casualty records accompanied with the loss of human life, which typically affected the entire crew when BCs suddenly disappeared without trace (i.e. M/V Derbyshire), has been witnessed with dismay. The resulting development was so dramatic and unexpected that BCs have gained notoriety in merchant shipping, whereas in the event of an accident, with very few exceptions, everybody stands to lose. Although seafarers are often the chief victims of maritime accidents, a broader range is covered i.e. shipowner, cargo owner, charterer, classification societies, country of registration, international regulatory bodies, shipyards and repair facilities, insurance companies, port authorities, coastguards, among others. Thus, as a matter of priority, after care for human safety, is of doing anything that can be achieved to avoid BC wrecks occurring and keep fleets shipshape.

Because shipping is such a global industry, it is generally accepted that safety and other issues (pollution from vessels, security) have to be dealt with at an international level. The organization chiefly responsible for maritime safety has been IMO and different treaties have been developed concerning the safety of life at sea, the prevention of collisions, the improvement of radio communications at sea, load lines and tonnage matters, prevention of pollution, water ballast management, the training and certification of seafarers, the creation of an international system for search and rescue and other matters. The most important of all the adopted Conventions is SOLAS, where the referred regulations are based on the premise that all possible technical, organizational, operational and human aspects should be considered. With regard to BCs, attention is concentrated on construction (SOLAS Chapter II), life – saving appliances (SOLAS Chapter III), navigational aids (SOLAS Chapters IV and V), carriage of cargoes (SOLAS Chapter VI), management issues (SOLAS Chapter IX), enhancing their inspection and survey regimes (SOLAS Chapter XI-1) and additional measures covering survivability and structural requirements (SOLAS Chapter XII). The great deal of SOLAS' existing text is that its provisions are backed by a number of Codes (i.e. BC Code, BLU Code, ISM Code, ISPS Code, among others) which can be amended much more easily than the Convention itself.

The actions taken by IMO undoubtedly helped to solve many of the problems associated with BC safety (cargo shift, loss of stability, structural degradation) and their impact was (and still is) beneficial since today the majority of BCs has been trading on worldwide safely with the number of sunk bulk carriers being reduced dramatically. It is recognized that many of the adopted measures have been formulated in the wake of serious accidents, whilst truth being universal, under political expediency and pressure from environmental groups and particularly from the media to act decisively with the advocated tendency of reverting to the previous condition. From one point of view it is legitimate, but on the other hand, instead of solely responding to disasters (or waiting to occur) it would be more logical to try to *prevent* them from happening in the first place. Therefore, planned action in anticipation of potential events or circumstances that could have negative effects on operational safety, which may eventually lead to accidents, is considered necessary. To this end, the causal factors influencing BC safe operations need to be identified at an *early stage* for establishing the areas of concern and contributing to the eradication of failure implications. The latter is of paramount importance, since the benefit of investing in safety improvements would be realised and any new measures are ensured to be kept updated in a rational manner.

Notwithstanding the above, with technology advancements and customer expectations for better service, proof quality, increased competitiveness moving faster than knowledge can be assimilated and experience gained, there might be a widely held concern that BC operational performance does not reflect practice evolution and remains hindered to tradition. Due to the significant economic issues involved, the perception of close monitoring and implementation – especially for the ageing fleet – without adhering prescription to anyone should be reinforced. Hence, the task that needs to be faced is determining the linkage between measures and performance. Of course, this can be achieved by deciding upon a target level where performance can be measured with the utilization of appropriate tools and processes and be compared to acceptable criteria if the target is reached or exceeded. Broadly speaking, the observation of performance appears to be attractive in decision – making, simple because it can be supported and sometimes be explained by science. Thus, the success of regulatory art is facilitated by careful analysis and interpretation of performance observations with the input being organized around of what needs to be done.

Traditionally, the decision – making process has been governed by the habit to uncover the causes of failures or accidents and concurrently to adopt measures that will either reduce the occurrence or mitigate the outcome of such circumstances in the future. Having in mind the difficulty of identifying root causes of accidents, it is with no surprise conceivable that the causes might never be ascertained precisely due to the weakness of treating a collection of individual and unconnected sources. Instead, it is suggested to recognise all the relevant sources by observing the operation of BCs and afterwards consider the possible failure cases that could occur. In this respect, input and output of the whole procedure can be addressed uniformly, avoiding any criticism from the various parties involved in shipping. Though, the key aspect that needs to be stressed is the interface of qualitative and quantitative assessment, with the first aiming at drawing a draft picture of the encountered situation and the second one at verifying where action should be taken, assisted by the construction of suitable models. The extracted information from past records is vital ingredient for quantifying current or future trends and determining causal chains of events. However, a better understanding of this approach is provided through the subsequent chapters, as the introductory pages intended on fostering some thoughts with regard to the decision – making process.

2 Specification of the thesis

"Things don't just happen, you have to make them happen"

Procter & Gamble

2.1 Preamble

In this chapter the basic incentives are unfolded of conducting the current research and also a picture is drawn of the thesis' structure.

2.2 Aim and Objectives

In connection with what was pointed out in the previous chapter, BC operational safety needs to be maintained and enhanced at a measurable level by adopting an integrated and holistic approach in which risk assessment and decision – making are linked, so that safety is treated as an objective rather than a constraint and optimum solutions can be attained. *It is the purpose of this research to advance a methodological understanding of that approach and to verify its potential and practicality by applying it to the dry bulk cargo transport.* In this context, the objectives of the proposed research could be underlied as follows:

- ☑ Develop a systematic and documented framework for ORM.
- ☑ Provide a rational decision support tool where the factors influencing the safe operation of a BC can be identified at an *early stage.*
- ☑ Establish and prioritize the areas of concern to *prevent* undesirable events.

- ☑ Construct suitable risk models for assessing the performance of dry bulk cargo transportation.
- ☑ Propose a methodology for estimating/predicting the operational safety of BCs.
- ☑ Implement the complete risk assessment process.
- ☑ Comment upon the gained knowledge through the entailed discussion.
- ☑ Recommend possible improvements in the decision – making process.

2.3. Thesis' structure

The conducted research can be separated in five stages as illustrated at **Figure 2.1**, starting with ***Chapters 3*** and ***4*** aimed at providing firstly the state – of the – art review in the current ORM of BCs, a documented procedure to arrive at decisions that provide desirable and achievable controls to manage their (operational) safety and secondly a selective literature review in the area of risk assessment which can be briefly described as a process for evaluating the safety of a system. The associated terminology is addressed, whilst the available tools for performing a risk assessment are outlined. Additionally, the utilization of the BNs technology in the graphical representation of the whole process is discussed. Furthermore, the elaboration of RSM for approximating risk and LCCA in the CBA are outlined. The purpose of ***Chapter 5*** is to set up the informed basis (problem definition) upon which that approach will be formulated and be addressed in measuring the operational safety of BCs.

The aim of ***Chapter 6*** is to address the hazards associated with the dry bulk cargo transportation in relation to the problem under consideration and information retrieved from existing HAZID studies. The safety performance of BCs is influenced by hazardous substances onboard such as corrosive cargoes while weather conditions, routeing and the company's management with regard to the commercial pressure represent external hazards. It is generally accepted that safe BC operational practices can be affected by the management infrastructure and decision – making onboard and ashore.

In ***Chapter 7***, a probabilistic model is developed for estimating the operational risk of dry bulk transport. The DOOBN technology is used to model the uncertainties of the aforementioned operational domain. A methodology is proposed for estimating the current risk level of dry bulk cargo transportation and concurrently measuring its safety. It is asserted that HAZID (qualitative assessment) and risk analysis (quantitative assessment) are viewed as a means of making a systematic evaluation of the risk from hazardous activities, i.e. the ocean transportation of dry bulk cargoes, and making a rational evaluation of their significance (prioritization).

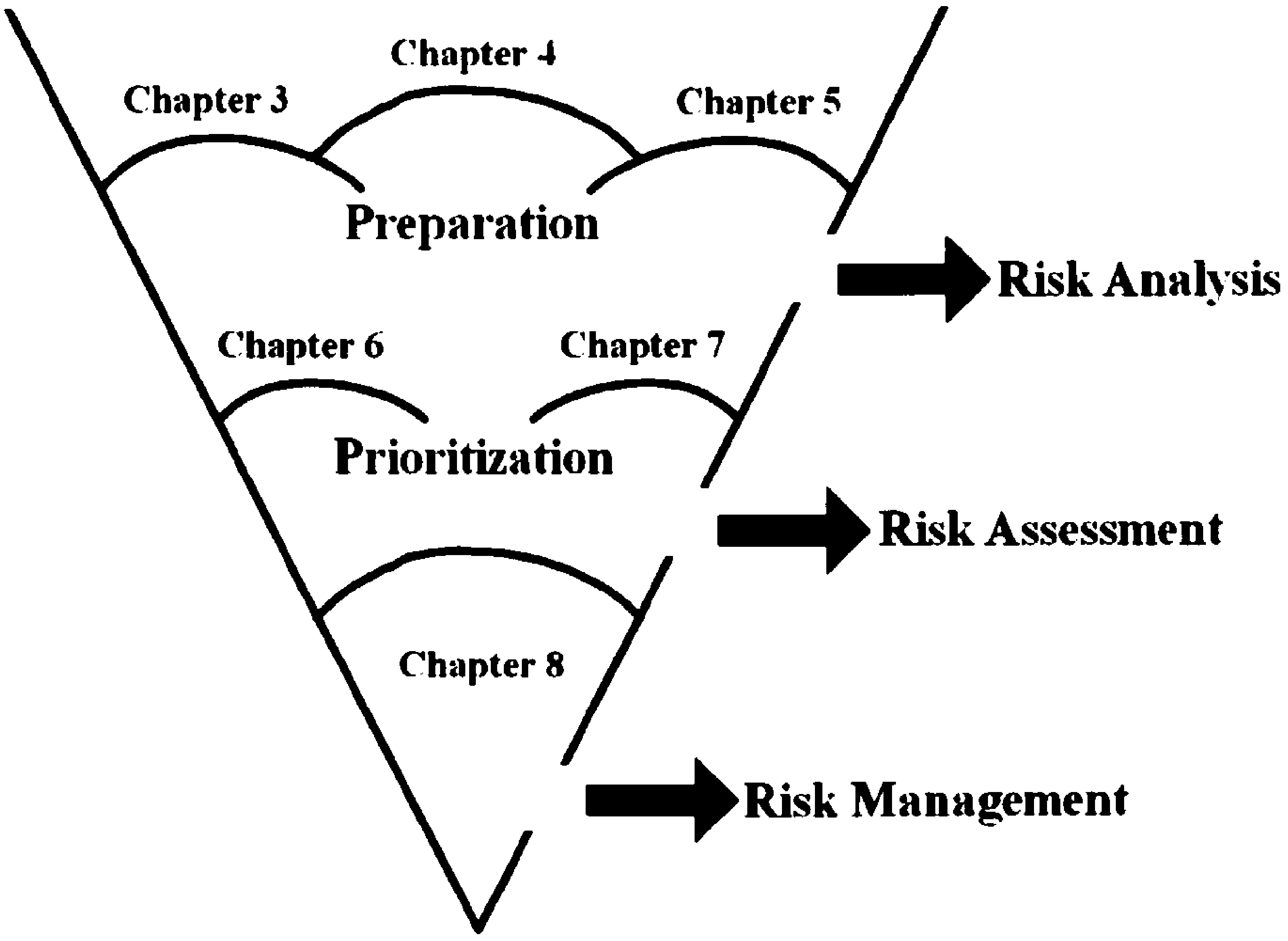


Figure 2.1. *Stages of the conducted research*

Finally, in ***Chapter 8***, the BN developed as a high level risk model is extended to an ID where different design (passive) and operational (active) measures addressing corrosion are evaluated as an action implementing risk management decision. Additionally, their effectiveness as an option for accident prevention **and** mitigation is demonstrated by employing LCCA in the whole process. The "kernel" of this thesis is ***Chapter 9***, targeted at presenting and providing a framework for ORM in a sense that is explained how the different steps fit together and is generic enough to constitute an ORM tool for consideration by other vessel types. ***Chapter 10*** is offered for leaving aside any arisen doubts, whilst the findings of the conducted research are presented in ***Chapter 11***. All the details of the performed calculations and reviews are included in the ***Appendices***.

This page is intentionally left blank

3 Critical Review

"The uncertainty of the consequences, which is controlling for behaviour, is understood to be that existing in the mind of the chooser. Of course, such subjective uncertainty or risk may very well stem from observations on the external world"

Kenneth J. Arrow

3.1 Preamble

This chapter aims at providing the state – of the – art review in the current ORM of BCs. The purpose behind the conduct of risk management is to arrive at decisions that provide desirable and achievable controls to manage the (operational) safety of dry bulk sea transport. Additionally, the utilization of the BNs technology in the graphical representation of the whole process is discussed, whilst the concept of RSM in risk analysis is introduced for quantifying the operational risk. Finally, the adoption of a probabilistic approach for CBA of proposed options is discussed.

3.2 Introduction

The role of risk management has been extended to many business areas of the modern industrial community including health, safety, environment, finance, marketing, politics, engineering and although their apparent differences, the applied philosophy is essentially the same. Generally, it is used as a powerful tool which encompasses the implementation of cost – effective controls or contingency plans embedded in the ongoing operations of an organization with the intent of minimising its costs, timescales and liabilities (RAE 2003).

3.3 ORM of BCs

Broadly speaking, risk management within the dry cargo industry is traditionally associated with the prospect of helping to avoid or control the economic disbenefits that result from shortages in the flow of goods and services. In this sense, shipowners are considered as asset holders who want to maximise return and minimise loss from their operations (transport chain/customer, management choices, insurance issues), subject to unforeseen changes emanating from fluctuations in freight rates, bunker prices, the price of the vessels or even the level of interest and exchange rates (Aury 2007, Kavussanos 2002, Nomikos and Alizadeh 2002, Attikouris 2003). Bearing in mind that the ORM in the current study is viewed from an engineering perspective, it can be described as the making of decisions concerning the systematic control of worker/employee and machine/ equipment performance, physical environment and the implementation of the decisions in the set of arrangements in place to manage the safety of a hazardous activity, i.e. dry cargo sea transport. Thus, it includes the coordinated activities to direct and control (both prevention and correction) an organization with regard to unsafe conditions and circumstances (HSE 2002a, Heinrich et al. 1980, Aven 2003).

Obviously, the task that needs to be faced is the minimisation of decisions that could have negative effects on operational safety, which may eventually lead to accidents and the assurance that every action affecting safety is based on a rational understanding of its consequences. This is expected to be reflected through the ISM Code which was developed by IMO to provide the maritime community with an internationally recognized standard for the safe management and operation of ships and for pollution prevention and was incorporated into SOLAS Ch. IX (IMO 2002a, 2004a). It is stated that a proper SMS should be adopted – although not described in detail how this can be accomplished – with clearly defined roles, responsibilities and practical operational procedures in order to (IMO 2002a):

- Provide safe practices in operating ships and a safe working environment,
- Establish safeguards against all identified risks,

- Improve the safety management skills of the personnel aboard and ashore continuously, including preparation for emergencies related both to safety and environmental protection.

In fact, the development and implementation of a documented SMS is a trial in risk management where attention is drawn to the need for changed attitudes towards safety management, i.e. learning from past mistakes and understanding how the external world responses to make past mistakes less likely to occur in future. It is pointed out that the drafting or amendment of written procedures involves looking at the organization's activities and operations, identifying what could go wrong and deciding what should be done to try to prevent it (before the problem appears). These documented procedures are the means by which the controls are applied, provide evidence of the decision – making process and have to be reviewed regularly in light of experience (audits, routine reporting). Thus, the aim is to move towards a culture of *self – regulation* where the targets for safety performance are set by those who are directly affected by the implications of failure (IACS 2004a, Kristiansen 2005).

These issues have been discussed in Parker (1999), Tallack (1999) and Bailey (1999) but lack of a formal justification which was dismissed due to their many years of sea service and it was so obvious for them. **No analytical work has been carried out yet in the literature for the dry bulk sector**, but one would expect similarity with the offshore industry (**Figure 3.1**).

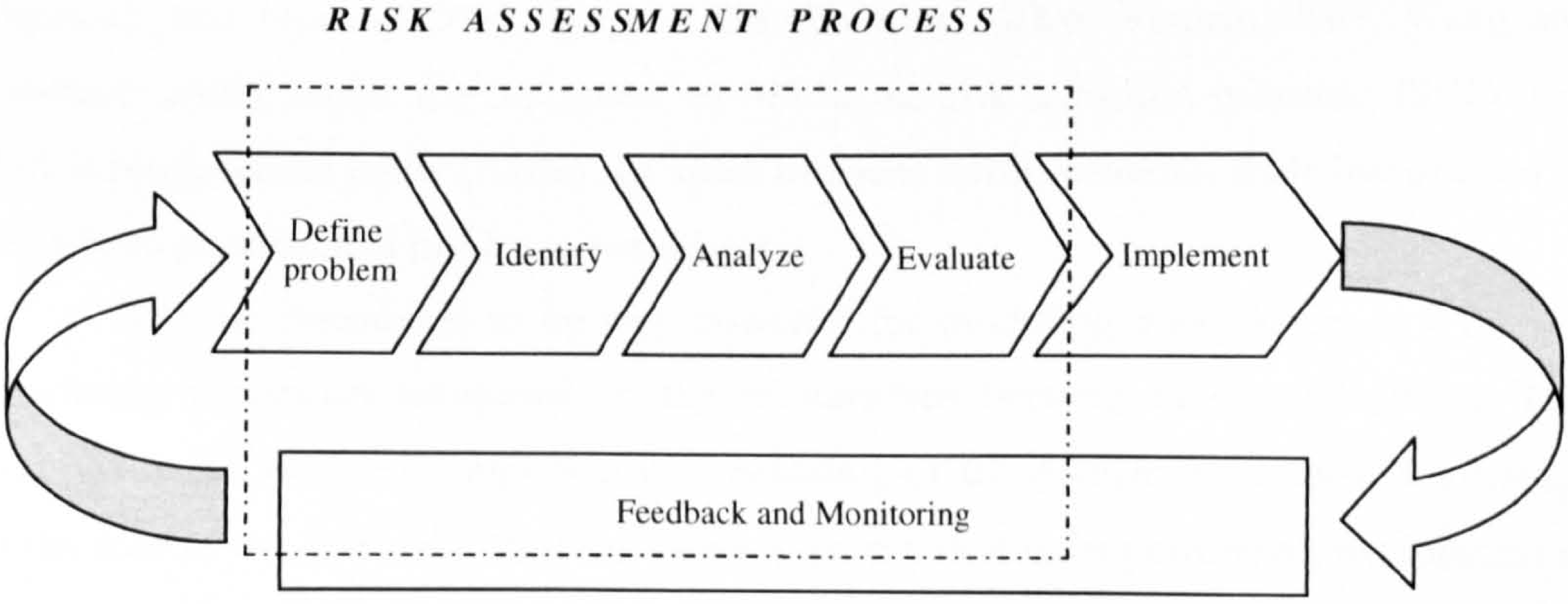


Figure 3.1. *The cycle of ORM*

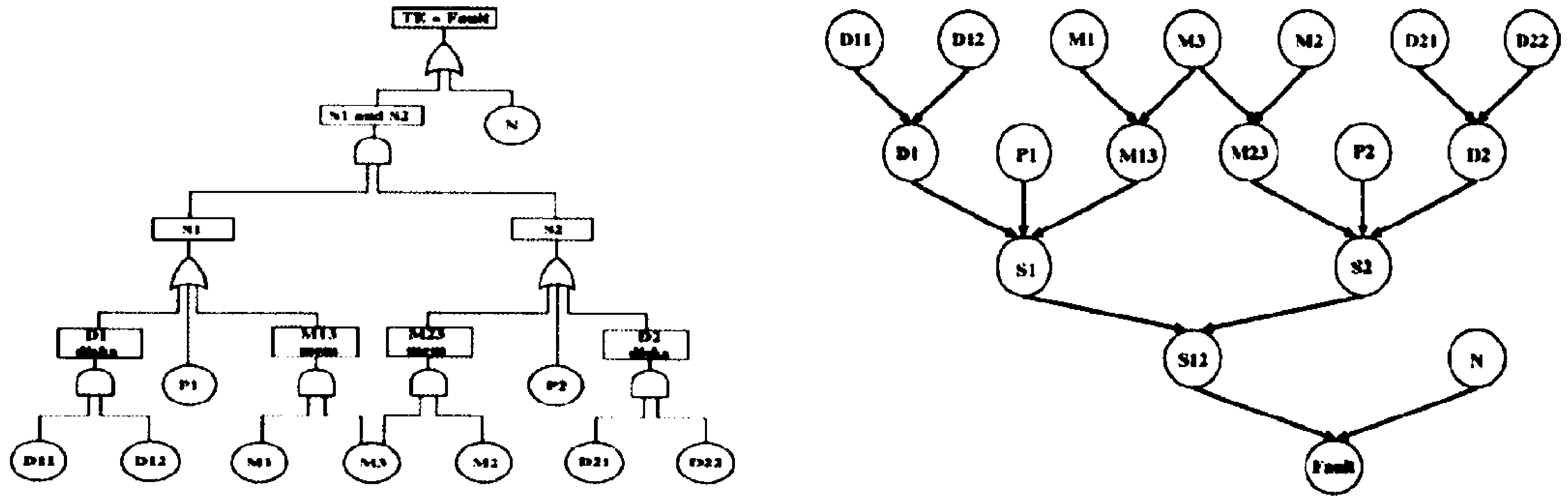
Source: Reproduced and edited from Aven and Vinnem (2007)

As shown, ORM is an iterative task consisting of sequential steps with integral and core part the risk assessment process which is covered in the subsequent chapter.

3.4 Risk Analysis

Although fault trees and event trees are considered standard risk analysis techniques which are engaged for constructing and quantifying a risk model due to their logical representation either of the many initiating events that lead to the single top event (FTA) or only one initiating event that leads to many possible outcomes (ETA), when are applied to a complex system, their clarity and efficiency are lost as all events are assumed to be independent and fall into simple failure or working states (i.e. human error, adverse weather) (HSE 2002a). In this sense, BNs can be used at any stage of risk analysis and both fault and event trees may be readily substituted by a BN in a logical tree analysis (**Figures 3.2.b**, **3.3.b**) since their formulation is more generic and their basic inference techniques may be used for representing the states of a system, its elements and the environment being analysed (Faber 2006, Bobbio et al. 2001, Bedford and Cooke 2004, Bearfield and Marsh 2005). By way of reference, BNs were developed during the last two decades as a decision support tool originally targeted for purposes of artificial intelligence engineering (Jensen 1996, 2001, Pearl 1988), but only in recent years their usage has been expanded to marine safety applications (Friis – Hansen 2000, Norway 2005, Guarin and Drennan 2005, Denmark and Norway 2006, Eleye – Datubo et al. 2006, Vinnem 2007, Wang and Trbojevic 2007), whilst the utilization of BN in the risk reduction measures (RCO's) of FSA is proposed by Japan (2006a). **In spite of these achievements, their integration in the whole process has not been tested yet.**

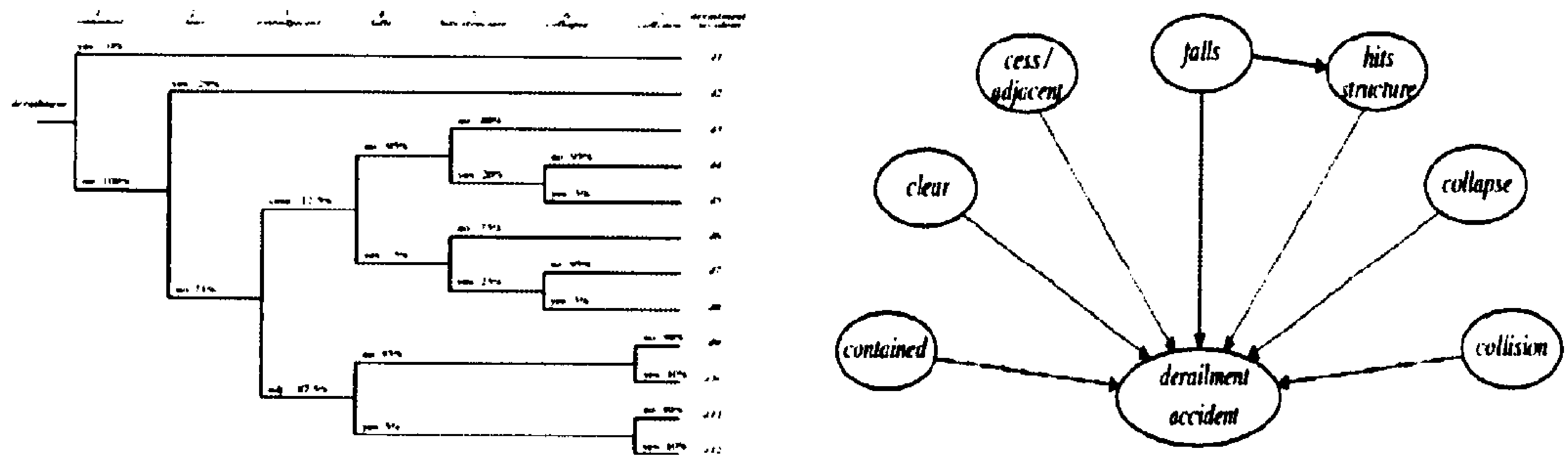
BNs are considered to be very powerful for modelling dependences in a domain containing uncertainty integrated on the relationships between causes and effects. This uncertainty can be due to imperfect understanding of the domain, incomplete knowledge of the state of the domain at the time where a given task is to be performed, randomness in the mechanisms governing the behaviour of the domain, or a combination of these. The model's performance in diagnostics can be increased as BNs are prepared to perform new calculations (learning) when particular information (evidence) is achieved and consequently the diagnosis can be checked in how sensitive might be to minor changes (sensitivity analysis). Since systems are often composed of collections of identical or almost identical components, repetitive patterns are frequently contained (i.e. commonly occurring solutions or problem types) which in BNs are network fragments (objects) and with this notion multiple identical instances are constructed easily (Jensen 1996, Koller and Pfeffer 1997, Neapolitan 2004).



a. *Fault tree* **b.** *Bayesian network*

Figure 3.2. *Transforming a fault tree into BN*

Source: Bobbio et al. (2001)



a. *Event tree* **b.** *Bayesian network*

Figure 3.3. *Transforming an event tree into BN*

Source: Bearfield and Marsh (2005)

Also, a simple or static BN can be extended to a dynamic BN by including multiple instances (time slices) of the static one, hence not only the current situation is formalised but temporal sequences are modelled, i.e. the past is concerned and the future is predicted (Neapolitan 2004, Sanghai et al. 2005). Additionally, bearing in mind the difficulties involved in making decisions between different alternatives, this problem is overcome by

IDs which are BNs augmented with utilities and decisions (Jensen 2001, Neapolitan 2004), thus the whole risk management process might be represented in a graph! In Gómez et al. (2004) the widespread use of IDs is mentioned. **It needs to be stressed that despite IDs are mentioned in HSE (2002a) and IMO (2002b, 2007b) as modelling techniques for HAZID, are not commonly preferred in risk assessment.**

Notwithstanding the above, through the causal graph modelling (BN), a framework is provided for accomplishing the most important goals of risk analysis without changing the model. These include (Cox 2002):

- *Representing and consolidating causal knowledge* about how changes in some variables are hypothesized to propagate along possible paths and change the probability distribution of outcomes.
- *Testing and refining* whether the causal hypotheses and models are consistent with available data.
- *Learning possible causal patterns from data* where the statistical associations are identified.
- *Inferring* probable true exposure – effect relation from observations with errors and missing data.
- *Estimating* effects of unobserved variables.
- *Predicting* probable consequences of decisions and *optimizing* decisions with the usage of *influence diagrams.*
- *Attributing* risks/allocating blames for undesired outcomes (or exposures) to their possible contributing causes.

Based on the developed model from risk analysis, it would be appropriate to establish a general function Y so that for some observable quantities $X_1, X_2, X_3, \dots, X_n$ can be written $Y = f(X_1, X_2, X_3, \dots, X_n)$, as an approximation to risk. One approach of approximating this function is the application of RSM where an experimental design process is performed to select sets of input parameters for use in the quantification of risk (Modarres 2006). RSM comprises a group of statistical techniques for empirical model building and model exploitation. A response variable Y is related to the levels of a number of input variables by careful design and analysis of experiments by quantifying the risk model for the selected observable quantities. A variety of possible designs exists i.e. blocked, factorial, nested or response surface, but the latter one is preferred with the objective to provide empirical maps (contour diagrams) illustrative of how factors under the experimenter's control influence the response (Hunter et al. 2000). The RSM CCD:

$$\hat{Y} = \beta_0 + \sum_{j=1}^{k} \beta_j X_j + \sum_{i<j}\sum \beta_{i,j} X_i X_j + \sum_{j=1}^{k} \beta_{j,j} X_j^2 + \varepsilon \tag{3.1}$$

was chosen for its reasonable robustness against missing values, ability to estimate second order effects and thus contribute to the approximation of the current risk level whilst a reasonable distribution of data points is required through the region of interest. Of course a competitor of CCD is the three level factorial design for any estimation that curvature in the response function is concerned. However, it needs to be emphasized that the latter design is not the most efficient way to model a quadratic relationship since with the CCD the size and complexity of the model is kept low. Furthermore, the CCD consists of a two level factorial design augmented with centre points (an excellent way to obtain indication of curvature) and axial runs for the quadratic interactions (Box and Draper 1987, Myers and Montgomery 1995, Montgomery 2005).

3.5 CBA of proposed solutions

The flexibility of each solution (option) concerning its alternatives also at the CBA, can be evaluated by performing LCCA where the decision maker is allowed to select the optimum solution. The basic theory behind using an economic evaluation technique such as LCCA is that all the impacts of the proposed option(s) can be accounted for and converted to their monetary value so that any comparison between them or their alternatives can be made directly. The negative impacts are considered costs and the positive impacts are considered benefits, which might be calculated as the reduction of negative impacts:

$$NPV = PV_{Benefits} - PV_{Costs} = \text{Initial impact} + \sum_{t=0}^{T_0} \left(\frac{\sum_{i=1}^{M} impact_i}{(1+r)^t} \right) \tag{3.2}$$

The LCCA can be defined as the total cost associated to one activity performed over one fixed horizon T_0. Its calculation can be executed concerning projects, investments and whatever activity needs to be analyzed over one defined time horizon to assess its effectiveness. LCCA is typically referred to machineries and equipments taking into account their cost of acquisition, operation, maintenance, conversion, and/or decommission aiming at their lifecycle economic evaluation. It can be either a mere assessment of lifecycle performances or a decision – making instrument, and, depending on the field of application, the emphasis in a LCCA calculation process can be put on different aspects of the investment. The principle of LCCA calculation is the same as the NPV calculation, which consists in discounting cash flows with rate r over the time horizon of one investment. While NPV is typically used as a decision – making tool for strategic decisions and business planning, LCCA techniques normally aim at taking a wide range of technical data into account with big emphasis, in particular, on operation and maintenance. What is more, the LCCA calculation takes only cost figures into account so that the least negative or maximum positive NPV is the decision criteria when comparing alternative production solutions (Fabrycky and Blanchard 1991, Boussabaine and Kirkham 2004).

Most of the LCCA input parameters are inherently uncertain, such as the discount rate r that should be employed to convert costs occurring at different points in time to a common time frame, the analysis period T_0 over which the options are to be evaluated, the timing of future rehabilitation (maintenance) activities that will take place in each of the life cycle options. Therefore, it is generally recommended that the probabilistic approach should be adopted. The deterministic approach uses point estimates for all input variables for the model, whereas the probabilistic approach uses probability distributions for all unsure variables and therefore treats the inherent uncertainty in the model (Boussabaine and Kirkham 2004, Osman 2005, Ozbay et al. 2003). In this sense, Monte Carlo simulation is applied, where values for each parameter in the model are randomly selected, based on the probability of that value occurring for the specific parameter. Then, the system's or model's response is obtained and its value is recorded. The sequence is performed many times. Each repetition will result in a value for the system response, and these responses will be used to construct the probability distribution of the final outcome. The number of iterations in Monte Carlo simulation depends on the required level of accuracy and the available computing power. The larger the number of iterations, the better the result, until the simulation starts to converge and any additional iteration does not affect the final distribution (Modarres 2006). **It should be pointed out that in the conducted CBA** (UK 2002a, Japan 2002d, Norway 2005, Denmark and Norway 2006)**, the deterministic approach has been used and therefore the parameter uncertainty was excluded.**

3.6 Conclusions

The role of risk management in shipping operations has become increasingly important in recent years since it is related to the continuous improvement of safety. It is also regarded as a systematic and documented task where the implementation of cost – effective controls is justified through the risk assessment process. Moreover, through the graphical representation of the whole process with the BNs technique will be attempted to consider uncertainty into the model development in a consistent fashion. In addition, a close approximation to the operational risk will achieved through the RSM whereas the probabilistic approach for CBA will be employed for dealing with the parameters' uncertainties.

This page is intentionally left blank

4 Risk Assessment: Approaches and elements

"The sciences do not try to explain, they hardly even try to interpret, they mainly make models. By a model is meant a mathematical construct, which, with the addition of certain verbal interpretations, describes observed phenomena. The justification of such a mathematical construct is solely and precisely that it is expected to work"

John Von Neumann

4.1 Preamble

The purpose of this chapter is to provide a selective literature review in the area of risk assessment which can be briefly described as a process for evaluating the safety of a system. The associated terminology is addressed, whilst the available tools for conducting a risk assessment are outlined.

4.2 Introduction

The notion of ***risk*** is frequently referred in a variety of ways in everyday speech since is generally felt to be understood and applied to different professional disciplines i.e. insurance, engineering, finance, science, medicine, politics, yet it can be admitted that its nature is multidimensional, has many **subjective** interpretations (Waring and Glendon

1998) and lacks from a formal definition. However, for the current study the definition given by Rowe (1988) in conjunction with that stated by Aven (2003) is preferred, hence: *"the potential for realization of unwanted, negative outcomes of an event and thus uncertainty (lack of knowledge) in the performance of a system, quantified by probabilities"*. In this respect, mathematically can be expressed as the product of the probabilities of an occurring event and expected effects being realised by *hazards* – conditions or activities that can cause injury or death, damage or deterioration to or loss of equipment or property, or environmental impact (Roland and Moriarty 1990, Bahr 1997, HSE 2002a). By way of reference, the term *"system"* is used to represent a *"composite of people, procedures and equipment that are integrated to perform a specific operational task or function within a specific environment"* (Roland and Moriarty 1990).

4.3 The risk assessment process

It has been accepted that the purpose behind almost any risk assessment is to support some form of decision – making on safety matters. Decisions may be needed on issues such as: whether or not an activity should be permitted; whether measures are necessary to reduce its risks; which of various options should be selected and in final concept how much should be invested in enhancing the safety of an installation (HSE 2002a). The term ***safety*** is used to determine *"the quality of a system that allows the system to function under predetermined conditions with an acceptable minimum of accidental loss"* (Roland and Moriarty 1990), whilst a formal definition of ***quality*** is given by Juran (2000a), the freedom from deficiencies and thus *"fitness to use"* i.e., the users of a product or service should be able to count on it for what they needed or wanted to do with it. To this end, mathematically – in terms of probability, ***safety*** can be expressed as the complement/absence of ***risk*** (HSE 2002a).

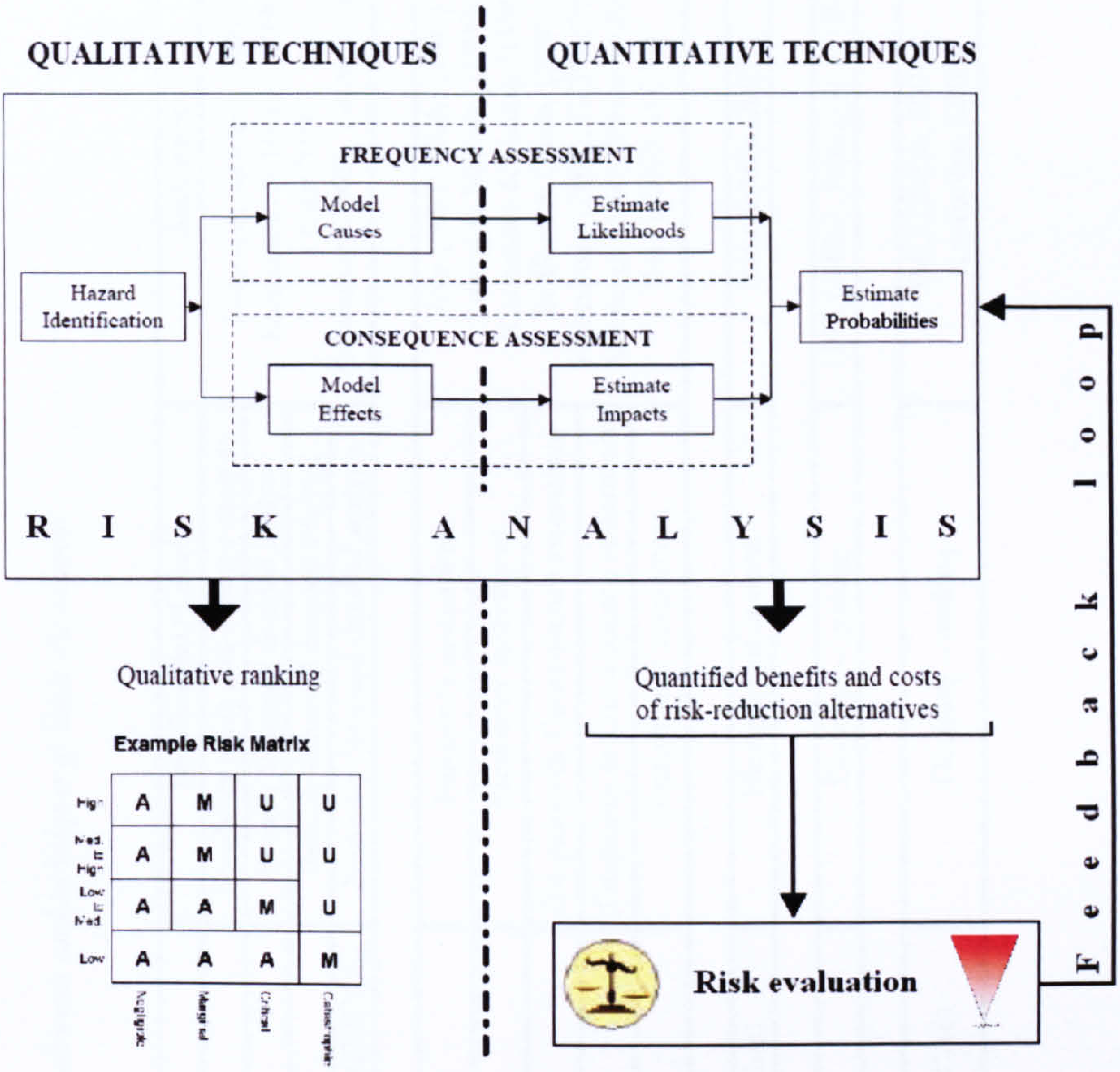
The risk assessment process is applied in order to make a systematic evaluation of the risk level from any industrial process, for instance the dry bulk cargo sea transport (qualitative/quantitative) and the trial of various risk reduction measures. Given the complexity of real world applications, it is not possible to create a simple flowchart with branches defining a suitable approach for risk assessment whilst a generalised format has been attempted through **Figure 4.1**. In fact, an excellent review for offshore applications which can be extended to the marine industry is provided from ABS (2000) and HSE (2002a) and can be summarized as follows including other necessary sources:

- **Preparatory step (problem definition)** where the goals for conducting the study are addressed including type of activity/system and targeted event loss, boundaries and limitations are established, the required knowledge and availability of resources, which approach will be selected (*qualitative:* risk matrix ranking method for the assignment of frequency and consequence indices – *quantitative:* model development or *both*), the different stakeholders being involved and the risk acceptance criteria.
- **Hazard identification (HAZID)** and associated scenarios are prioritized by risk level specific to the problem under review. The appropriate technique is chosen depending on the available resources and scope, i.e. *Hazard Review* if the widespread experience and understanding exists, *FMECA/FMEA* for identifying the failure modes of a mechanical or electrical system (narrowly focussed detailed analysis), *What If Analysis* if the assessment is performed on a proposed activity (less detailed analysis) or *HAZOP* for installation under operation. It should be noted that the first two can be performed by a single analyst, while for the latter a brainstorming session is needed. Furthermore, a HAZID is usually a qualitative exercise based on expert judgement involving a group of specialists (professionals with knowledge and experience), since few individuals have knowledge on all hazards and more can be stimulated through group interactions. The results are coded in the format of a *Hazard Register*, a table where all the hazards that have been identified together with representative causes, effects, safeguards and numerical (usually) frequency and consequence indices for each are recorded.
- **Risk analysis** is considered to be a tool for the quantification of risks without making judgements about their significance and thus a systematic use of information to identify sources and assign risk values. The estimation of frequencies and consequences (probability values) can be achieved by developing a model of uncertainties (lack of knowledge) related to the prediction of performance (usually negative outcome) of an operating system (Aven 2003, Nilsen and Aven 2003). *FTA* (logical representation of the many events and component failures that may *combine to* cause one critical event using Boolean symbols – **Figure 3.2.a**) and *ETA* (logical representation usually in paired branches of the various events that may *follow from* an initiating event using

decision trees – **Figure 3.3.a**) are included as standard modelling techniques for frequency and consequence assessment.

- **Risk evaluation** is used for assessing the significance (and sometimes the acceptability) of the estimated risks by comparing them against given risk criteria to determine their significance. The risk acceptance criteria related to loss of life are divided into *(i) single statistics representing risk:* Individual risk – the risk experienced by crew members onboard the vessel or Activity specific period mortality rate (Societal Risk: PLL) – the risk experienced by the whole crew exposed to the targeted event loss and *(ii) frequency vs. consequence lines* (Societal Risk) – F-N diagram, which is a continuous graph representing the cumulative distribution of multiple fatality events in a logarithmic scale (Bedford and Cooke 2004). Depending on the outcome, a range of risk reduction measures (RCOs) focusing on potential risk areas (prioritization) is applied by reviewing **risk analysis** in order to show whether the risks are ALARP (ALARP Principle). CBA may be adapted for comparing the costs and benefits of a measure, usually in financial terms.

As stated by ISSC (2000, 2003), the awareness of risk assessment applied in the decision – making process has increased rapidly over the recent years and since a large number of well established techniques exist; for more information on applying a particular method or tool or their combination, the cited references should be consulted (**Table 4.I**). If a *risk assessment* is conducted in the context of developing or evaluating rules and regulations within the marine industry, the process is addressed as *FSA* (IMO 2002b, 2007b); whereas if it is applied for showing the compliance of individual offshore installations, is denoted as *QRA* (Vinnem 2007). Of course, as a golden rule for any successful risk assessment is envisaged to perform the minimum level of analysis necessary to provide information that is just adequate for decision – making, i.e. begin at as a high (general) level as practical and proceed with detailed evaluations in areas where the analysts will be benefited without abusing inappropriately time and resources (ABS 2000).



Example Risk Matrix

	Negligible	Marginal	Critical	Catastrophic
High	A	M	U	U
Med. to High	A	M	U	U
Low to Med.	A	A	M	U
Low	A	A	A	M

Figure 4.1. *A generalized Risk Assessment process*

Source: Reproduced and edited from ABS (2000)

TABLE 4.I. *Standard elements and techniques of Risk Assessment*

Element	Examples of techniques	Implication/Level	References
Hazard Identification	What If Analysis	Feasibility study and concept analysis	Roland & Moriarty (1990) Kumamoto & Henley (1996) Bahr (1997) Kristiansen (2005), Vinnem (2007)
	Hazard and Operability Analysis (HAZOP)	Broadly focussed detailed analysis	
	Structured What if Checklist (SWIFT)	Broadly focussed detailed analysis	
	Failure mode and Effect (Criticality) Analysis (FMEA/FMECA)	Narrowly focussed detailed analysis	
Risk Analysis	Statistical analysis	Frequency assessment	Vose (2001), Bahr (1997) Roland & Moriarty (1990) Kumamoto & Henley (1996) Bedford & Cooke (2004) Kristiansen (2005), CCPS (2000) Modarres (2006), Vinnem (2007) IMO (2002b, 2007b)
	Human reliability/error analysis	Frequency assessment	
	Fault Tree Analysis	Frequency & Consequence assessment	
	Event Tree Analysis	Frequency & Consequence assessment	
	Simulation models (empirical/analytical)	Consequence assessment	
Risk reduction measures	Attribute assignment (prevention and/or mitigation)	Hierarchy of options	IMO (2002b, 2007b)
Risk acceptance criteria	Individual/Societal Risk	Decision – making	HSE (2002a), Skjong et al. (2005)
Cost – benefit aassessment	Indices for cost – effectiveness (GrossCAF/NetCAF)	Decision – making	IMO (2002b, 2007b) Kristiansen (2005)

4.4 Conclusions

It can be construed that risk assessment is a well developed field which can be used as the prime instrument in order to describe a rational, transparent and systematic *risk – informed* approach for safety assessment.

This page is intentionally left blank

This page is intentionally left blank

5 Bulk Carrier safety

“In a structured subject, it is known what is known, what is unknown, what people have already tried and doesn’t lead anywhere. There you have to work on a problem which is known to be a problem, otherwise you get lost. But a problem which is known to be a problem must be hard; otherwise it would already have been solved”

Heiz-Otto Peitgen

5.1 Preamble

BCs can be characterized as the “workhorses” of maritime commerce since a high percentage of world trade is transported by sea. Their losses during the early 1990s caused the marine industry to initiate operational measures for improving their safety. Although today the number of sunk BCs has been reduced dramatically, in order to establish the areas of concern and try to prevent the failure implications from the first place, their safety needs to be maintained and enhanced at a measurable level by adopting an integrated and holistic approach in which risk assessment and decision – making are linked. It is the purpose of this chapter to set up the informed basis upon which that approach will be formulated and be addressed in the dry bulk transport.

5.2 Origins and development of dry bulk shipping

The modern dry bulk shipping industry can be tracked back to the coal trade between the north of England and London which started in the 17th century. Until mid –

nineteenth century the standard cargo vessel was a wooden sailing collier brig. In the 1840s, however, the shipbuilders were spurred into a burst of innovation by introducing steam colliers, which were independent of weather and with much greater carrying capacity could make many more round trips than a sailing vessel. During the latter half of 19th century and the early years of 20th century, a large fleet of iron – hulled and screw – propelled "tramp" steamers known as freight vessels or tweendeckers; was grown up for carrying shiploads in unit and packaged form. The traditional "tramp" steamer lasted until the 1950s but it could not compete with the larger BCs (up to 20,000 DWT) which were entering into service that time. Whilst in 1960 only about one – quarter of bulk cargoes i.e. any commodity whose homogeneous physical character lends itself to bulk handling and transport such as coal, iron ore, grain, bauxite/alumina, phosphate rock (major bulks), industrial and agricultural materials (minor bulks) were carried in bulk; the situation was transformed by 1980 at which time, almost all bulk cargoes were transported by bulkers of up to 200,000 DWT or over. Today, BCs transport a high percentage of world trade (**Figure 5.1**) and apparently each of the major and other bulk trades followed its own distinctive growth pattern during the last three and half decades (**Figure 5.2**) (Stopford 2009).

Although the BC was developed for exploiting economies of scale, yet the size of the crew required did not increase greatly and fuel costs also rose relatively slowly, since speed is not vital. In this respect, it represents the tailored transport operation by sea in large consignments in order to reduce the unit cost, cargo handling time and the stockpiles held by importer/exporter. This can be achieved through the standard design which has been crystallized into a single hull ship with a double bottom, large cargo holds with hopper and topside tanks covered by hatches (**Figure 5.3**). Main features of this configuration include the self – trimming of cargoes for eliminating the danger of cargo movement, ensuring that cargo settles during voyage and contributing to convenience in collecting the cargoes on discharge, holds clear of any obstruction so that to facilitate rapid cargo handling, five to about nine holds depending on the vessel's size for incorporating the transport of different parcels and ballasting/de – ballasting of the vessel can be performed without interrupting the cargo operations. The engine room, navigating bridge and accommodation areas are nearly always located at the stern of the vessel (Rogers et al. 1997, Isbester 1993).

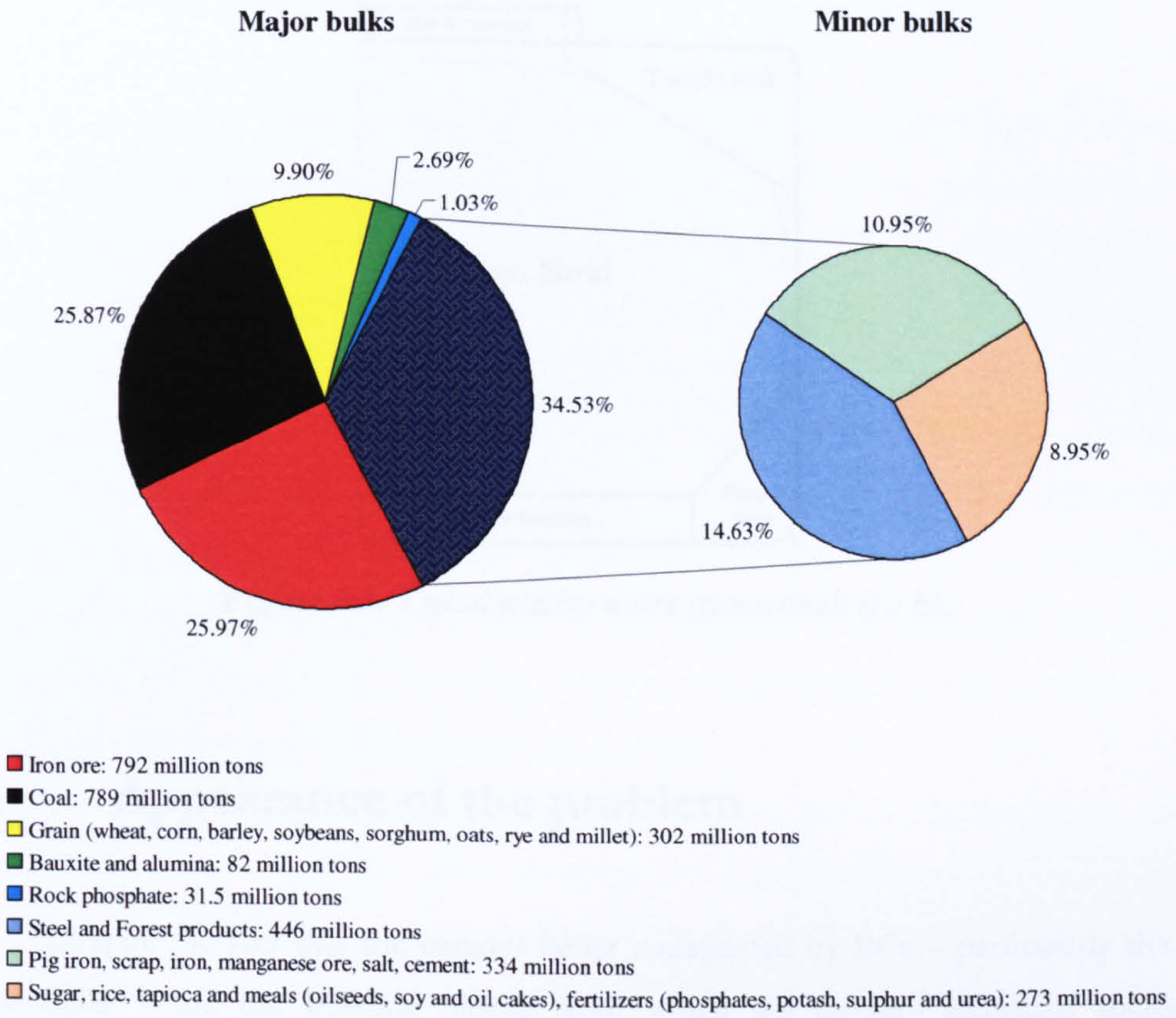


Figure 5.1. *Quantities of major and minor bulks being transported during 2007*

Source: UNCTAD (2008)

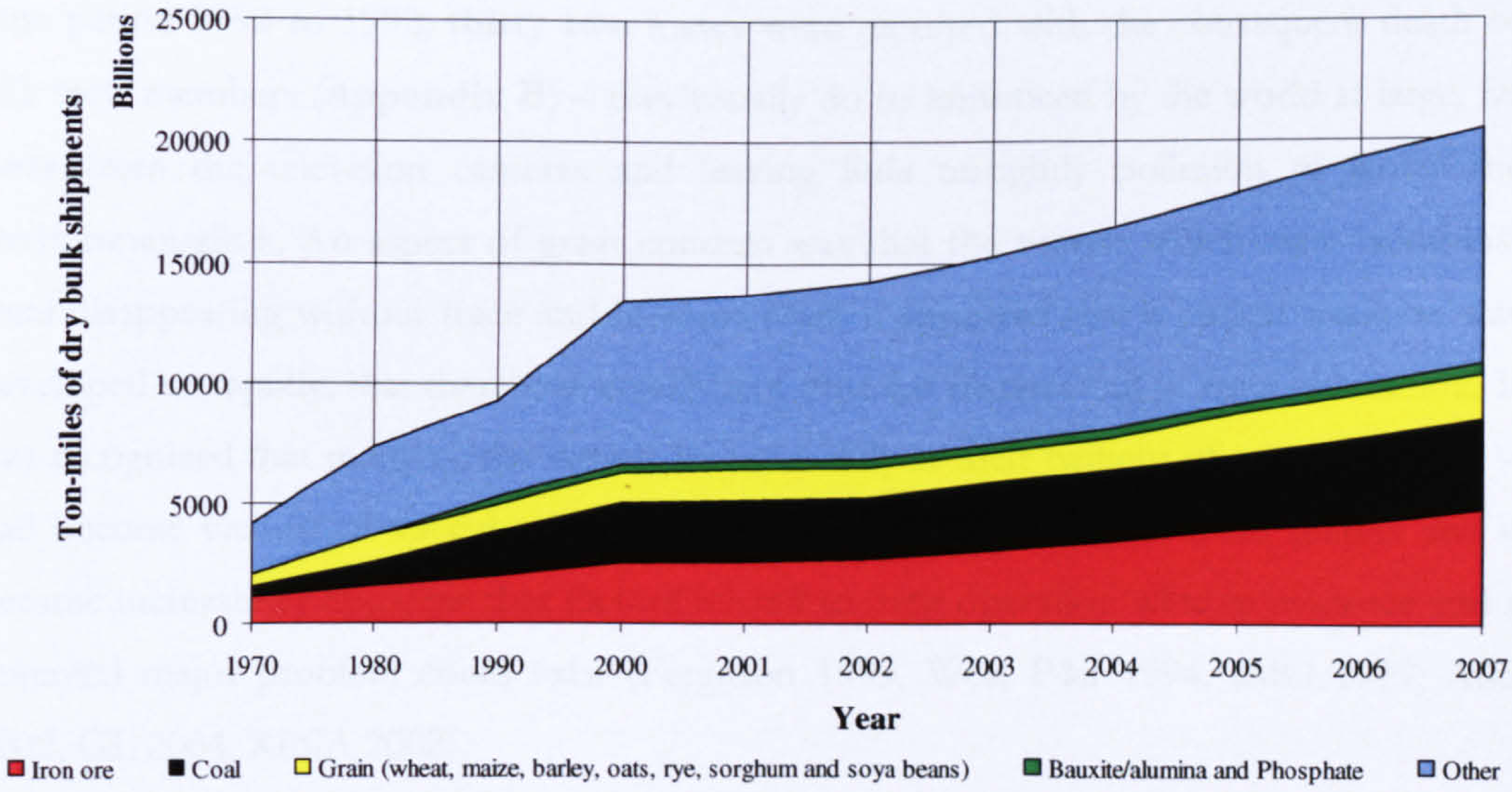


Figure 5.2. *Historic growth tonnage movement of each commodity*

Source: UNCTAD (2008)

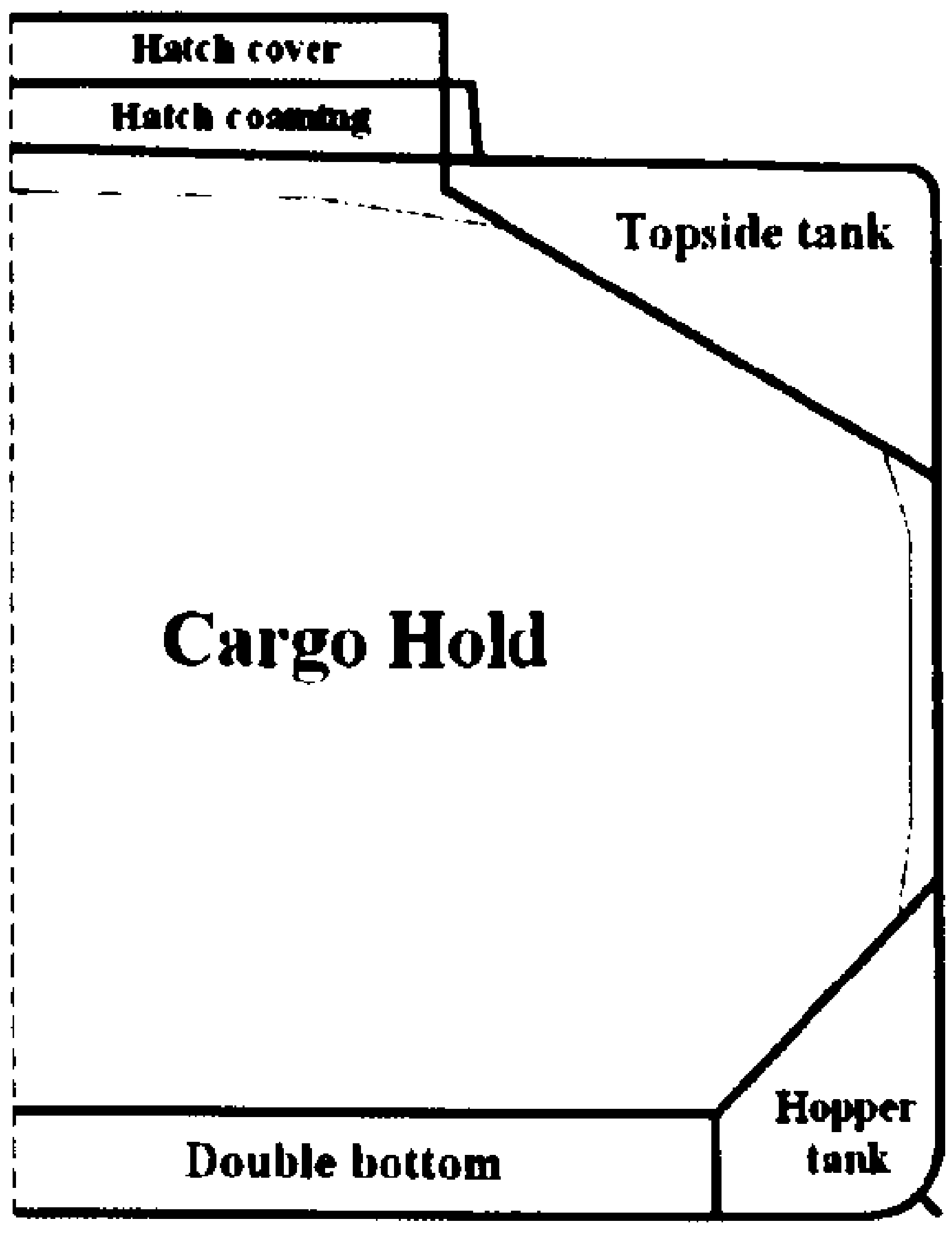


Figure 5.3. *Typical midship section (symmetrical) of a BC*

5.3 Appearance of the problem

Despite the fact that the cargoes being transported by BCs – particularly the five major bulks – are the building blocks from which the modern industrial society is constructed, yet are among the most anonymous of ships. In essence, it is generally claimed that when they sink; which they did too often in the early 1990s – for instance, over the time period 1990 to 1992, **thirty two** losses were reported with the consequent death of 321 crew members (**Appendix B**) – they usually do so unnoticed by the world at large, far away from the television cameras and leaving little unsightly pollution to worry the environmentalists. An aspect of great concern was that the vessels which were being lost were disappearing without trace and in some cases it appeared that a critical situation was developed so rapidly, that there was insufficient time for distress call or even evacuation. It was recognized that many of the vessels lost – usually at their twilight of operational life – had become victims of speculative buying and selling on the second hand market and it became increasingly apparent that factors related to their operation were in evidence and a potential major problem could exist (Ferguson 1993, West P&I 1994, IMO 1999, ABS 2002, GL 2004, RINA 2002).

5.4 Dealing with the problem

In recent years, the number of lost BCs has caused understandable concern for issuing safety initiatives urgently, accompanied with a greater sense of liability within the marine industry. In the wake of these events, the operational measures that have been introduced (BLU Code; SOLAS Ch. VI – B Reg. 7, ESP; SOLAS Ch. XI – 1, Reg. 2, ISM Code; SOLAS Ch. IX, PSC; SOLAS Ch. I, Part B) (IMO 2004a), the International Load Lines Convention (IMO 2005c) in an attempt to identify and correct the encountered situation; are aimed at *mitigating the consequences of an accident* rather than prevention in contrast to rational decision – making. As an exception, consideration can be given to SOLAS Ch. IX, Reg. 3.1 (IMO 2004a) where attention is concentrated on **internal** management and organization for safety, with the company and vessel personnel being encouraged to set the targets for (safety) performance.

It needs to be recognized that the majority of current regulations are indeed implemented following the *"re – active approach"*, thus a great deal of experience and best practice is represented which cannot be disregarded since the majority of ships has been trading on safely for many years. However, although tangible evidence of compliance is provided (prescription), there is therefore potential concern that with the increasing market demand for better service, proof quality and increased competitiveness moving faster than the gained experience, the provisions of regulations will not be updated to meet the new expectations, so that in time their original goal – ***the reassurance of a reasonable and acceptable safety level with regard to human life, property and the environment*** – is forgotten (Vassalos 2005). This can be illustrated by considering the traditional decision – making process which is focused primarily on the consequences of accidents resulting from failures made in relation to safety and the adopted measures – usually in the aftermath of accidents – intended on either reducing the occurrence or mitigating the outcome of such circumstances in the future. Furthermore, it is widely accepted that the root causes of accidents might never be uncovered precisely due to the many complex sources involved. It would be more reasonable though, to identify all the relevant sources by analysing performance observations and concurrently consider the possible failure cases that could occur (Kristiansen 2005, Mikelis 2005).

In the course of improving BC operational safety, planned action in anticipation of potential events or circumstances that could have negative effects on their performance, which may eventually lead to accidents, is considered necessary. In doing so, the factors that affect BC safe operation can be identified and prioritized at an *early stage* for establishing the areas of concern and contributing to the eradication of failure implications. Hence, by adopting an integrated and holistic approach in which risk assessment and decision – making are linked, for instance *ORM*, the rationale of decision – making is encompassed through performance observations, so that safety can be treated as a lifecycle issue and optimal solutions can be attained. Furthermore, the particular solution is open to differing approaches, innovation, flexible enough for continuous improvement, without adhering the prescriptive approach to anyone. It is therefore implied, that the resulting solutions are linked to decision – making through the modelling of pertinent failure cases in terms of ensuing probability and associated consequences for the early identification of the factors that may adversely affect safety. Similar trends have been expressed by other research works using the terms "risk – based design", "pro – active" or "safety level" approach (Vassalos 1999, 2005, Psaraftis 2006, Japan 2006b, Denmark et al. 2006, IMO 2007a).

Notwithstanding the above, the recognition of the need for a fair balance and protection between the various interests and positions of those who will be affected by any changes to the regulatory regime is important. Since the stakeholders (parties investing in shipping) are either exposed to risk or incur cost – benefit from the shipping enterprise, the final recommendations for decision – making are entitled to redress any imbalance between those who impose risk and those who carry disproportionate risk in relation to the return they receive i.e. those imposing – voluntarily or not – risks on others should be expected to pay for that privilege (UK 2004). Although this could be a prescriptive approach, the safety of dry bulk cargo transportation shall be measured since a significant financial risk is carried by the industry. To this end, through *ORM* it would be ensured that the underlying risks are addressed in a manner which is *cost* and *safety – effective* and agreed by the stakeholders affected (ALARP Principle) in parallel with what commented by Vassalos (1999, 2005) and RINA (2001).

TABLE 5.I. *Example of stakeholders accompanied with their balance concept and the principal ones highlighted*

Stakeholder*	Incurs costs	Receives benefits	Imposes risks	Carries risks
Owner/charterer	Cost of vessel	Income	Choice of vessel specifications	Loss of vessel
Operator/manager	Running costs	Income	Operating practice	Loss of income
Crew	-	Employment	Lack of due diligence	Loss of life
Cargo owner	Pays for passage	Profit from trade	Dangerous cargoes	Loss of cargo
Flag State	Administration costs, employment	Fees	Inadequate local legislation	Reputation
Port of call	Cost of infrastructure, operating costs	Fees	Navigational control, dredging levels	Damage to infrastructure, loss of trade
Coast State	Local navigation	-	Inadequate navigation aids	Pollution and clean up
Insurer	Liability	Premiums	Liability	Claims
Classification societies	Operating costs	Fees	Lack of due diligence	Negligence claims, reputation
Designer/constructor	Materials/labour	Fees	Lack of due diligence	Reputation

* It is well respected and understood that the safety of the vessel lies with the owner, operator and her crew

Source: Kristiansen (2005), Starling and Riding (1998)

5.5 Defining the problem

Whether transport is between a coal mine and the power station, an iron ore mining area and the blast furnace, a chemical plant and the fertilizer wholesaler or a crop field and the flour mill; the BC can be characterized as part of a logistics chain that facilitates transportation of raw materials from their sources (origin) to processing plants (destination), usually located on different continents. Thus, the prime operational goal is accomplished by the **safe**, fast, economic and environmental friendly carriage of payload within the parameters defined by the owner/charterer, typically arriving on time under instructions related to fuel consumption. Bearing in mind this and the issues noted previously, it is clearly envisaged that BC performance expectations can be very demanding and in order that owners are ensured to know the commitments they are taking on, the current (operational) safety level of dry bulk cargo transportation should be determined in a holistic high level manner.

As a starting point preceding the detailed application of the *"risk – informed"* approach; it is suggested to consider the relevant type of vessel, her systems, functions and operations, external/internal influences, accident category and the risks associated with consequences such as injuries/fatalities, environmental impact, damage to the vessel or port facilities, commercial impact (Starling and Riding 1998, Japan 2002a, Kristiansen 2005, IMO 2002b, 2007b). It needs to be stressed that the previous characteristics should therefore be defined to be precise and relevant to the problem in question, broken down to an appropriate level of detail with artful simplicity and expressed in consistent terms of dimensions natural to the scope of the study.

In this respect, the following 'picture' for preparing the study is galvanized upon which the *ORM* can be applied. The study is conducted by considering ***new – building*** handysize (10,000~39,999 DWT), handymax (40,000~59,999 DWT), panamax (60,000~79,999 DWT) and capesize (80,000+ DWT) single side skin BCs[3]. For clarification purposes, *BC of single side skin construction* means a BC in which a cargo hold is bounded by the side shell (IMO 2004a – SOLAS Ch. XII, Reg. 1.2), with *BC* meaning a ship which is constructed generally with single deck, top-side tanks and hopper side tanks in cargo spaces, and is intended primarily to carry dry cargo in bulk, and includes such types as ore carriers and combination carriers (IMO 2004a – SOLAS Ch. IX, Reg. 1.6). Furthermore, the term dry cargo in bulk i.e. *solid bulk cargo*, is referred to any material, other than liquid or gas, consisting of a combination of particles, granules or any larger pieces of material, generally uniform in composition, which is loaded directly into the cargo spaces of a ship without any intermediate form of containment (IMO 2004a – SOLAS Ch. XII, Reg. 1.4).

---

[3] The reasons for preferring single side skin vessels are addressed in Guarin and Vassalos (2004) where it was concluded that ***"the introduction of double side skin would certainly improve maintenance of the inner skin, but it would also exacerbate problems of inspection, maintenance and repairs of the internal spaces. It is a case of reducing a risk and creating another and therefore it is uncertain whether there will be a risk reduction at all"***. In other words, ships should be maintenance friendly and not a challenge to maintain.

The considered aspects focus on the carriage of payload (vessel's function) during ocean transit (operational phase – loaded and ballast passage) interacting with the operational and management infrastructure (vessel's systems). These systems are related to the outer environmental context such as financial (freight market) and commercial realities (charterers) , which is governed by pressures and influences of all parties (stakeholders) interested in shipping (**Table 5.I**) and each of these is dynamically affected by the others (Kristiansen 2005, HORSCTCI 1995a, 1995b). Moreover, the defined function is fulfilled by ensuring the **safe** carriage of payload (performance). Obviously, the transported cargoes are internal influences, while since the majority of foundering/disappearance casualties (accident category) occurred during bad weather (**Appendix B**), external influences on the vessel such as weather conditions and routeing are also included. In connection with the previously noted issues, the risks associated with consequences to human life (crew fatalities) will be evaluated through a quantitative model and concurrently be compared with the acceptance criteria proposed by Skjong et al. (2007). The environmental risk is not considered since an oil pollution incident with a BC is very remote (oil spills due to bunkering are not counted) and the financial risk will not be dealt with.

5.6 Conclusions

This chapter wished to contribute to the understanding of applying a *risk – informed* approach for measuring the operational safety of BCs and respectfully, the boundary limits of performing the study were addressed.

This page is intentionally left blank

6 Identification and Screening of Hazards

> "If hazards are dealt with one at a time, many must be neglected. The instinctive response to this problem is to deal with problems in order of importance. Unfortunately, the information needed to establish priorities is not available; the collection of such data might itself swamp the system"
>
> Baruch Fischhoff, Paul Slovic and Sarah Lichtenstein

6.1 Preamble

The aim of this chapter is to address the hazards associated with the dry bulk cargo transportation in relation to the problem under consideration and information retrieved from existing HAZID studies. The safety performance of BCs is influenced by hazardous substances onboard such as corrosive cargoes while weather conditions and the company's management with regard to the commercial pressure represent external hazards.

6.2 Introduction

The operational profile of a BC can be grouped into three mission segments: provision of transportation (loaded/unloaded passage), port operations (loading/ discharging) and planning of service life (maintenance, inspection, lay – up). The first two are identified as operations during which the majority of accidents occur, while the last one is considered to be the mission where deficiencies allow the causes of BC casualties to go uncorrected (Van Roon 2001). Since the BC can be identified as part of a logistics chain that facilitates transportation of raw materials from their sources to processing plants, usually located on different continents, the prime operational goal is accomplished by the **safe**, fast and economic carriage of payload within the parameters defined by the owner/charterer, typically arriving on time under instructions related to fuel consumption. In this context, each action affecting safety is based on understanding the relation between causes and effects and an attempt will be made through a qualitative risk assessment (HSE 2002a).

6.3 Hazard Review

The purpose of a qualitative risk assessment is the identification of hazards and associated scenarios prioritized by risk level specific to the problem under review. The essence of a hazard is that it has a potential for causing harm to human life, impact in the environment and property loss, regardless of how likely or unlikely such an occurrence might be. Generally speaking, the term "hazard" is used for the combination of a physical situation with particular circumstances that might lead to harm, i.e. the ocean transportation of dry bulk cargoes. Since the study is carried out by a single analyst and existing experience from a wide range of sources is being used, the hazard review is preferred, which is a qualitative review to identify the hazards that are present and to gain qualitative understanding of their significance. To this end, the addressed issues are existing HAZID studies, previous experience/accidents (**Appendices B** and **C**), hazardous influences and Regulations, Guidelines and Codes of Practice (IMO 2004a), that should be complied with (HSE 2002a).

According to Packard (1985) the dry bulk cargoes are grouped into 8 families as follows: ***ferrous ores – FE*** (iron, chrome, manganese, nickel ore, – ore concentrates), ***coal – CO*** (coke, petcoke, anthracite, steam coal), ***cement – CE*** (clinker, cement), ***mineral – MI*** (alumina, bauxite, copper, zinc and lead concentrates, sands, salt), ***agricultural and food products – AF*** (wheat, corn, barley, maize, soybean meal (SBM), sugar, tapioca), ***fertiliser and chemicals – FC*** (sulphur, rock phosphates, soda ash, muriate of potash, di – ammonium phosphate, urea), ***metal – ME*** (steel products, copper cathodes, pig iron, direct reduced iron (DRI), iron pellets, scrap metal), ***timber – TI*** (logs, sawn timber, wood – pulp). The main hazards associated with transported cargoes are liquefaction (FE and MI concentrates), cargo shift (AF, ME, TI), structural damage due to improper distribution (FE, ME, high density MI), chemical hazards due to corrosion and fire/explosion (CO, FC, scrap metal and DRI, MI, SBM), health hazards due to dust, poisoning and asphyxiation (CO, CE, FC, scrap metal) (Swadi 2005, IMO 2005a, Rankin 2002, Rogers et al. 1997, Sewell 1999, Sparks 2003, Isbester 1993, House 2005). Bearing in mind that 60.7 % of the cargoes being transported are raw materials (**Figure 5.1**), hazards related to the problem under review are corrosive, aggressive and high dense cargoes such as coal, sulphur, iron ore, ore concentrates (i.e. chalcopyrite – $CuFeS_2$) the frequent changes of which, form a "deadly cocktail" for the vessel's structure. Thus, liquefaction, cargo shift, fire/explosion and health hazards are not considered to be related to the problem. It should be mentioned that the capability to manage port operations (i.e. compliance with the agreed loading plan, finding the correct sequence of loading relative to the location of the load – loader chute, spout or grab, part/multi – port loading segregation (Isbester 1993, IMO 1998, 2005b, IACS 1998) is typified by commercial realities.

Although the safe operation of ships is required under SOLAS Ch. IX with adopting ISM Code and the implementation of an SMS, the habit to cut corners for commercial expediency is not removed either from the management/shipowning company or the charterers. The creation of the SMS is not described in detail, but it is stated that some areas of measures (responsibility and authority, supply of resources and support, procedures for checking competence and operational readiness, training, shipboard operations[4], minimum standards of the maintenance system[5]) have to be addressed through the company's safety management objectives and it is assumed that through the company's SMS compliance with regulations, codes, procedures, practices, routines should be ensured (IMO 2004a, 2002a). In this sense, ISM Code is considered to be a *self – regulation* culture, in which regulations go beyond the setting of externally imposed compliance criteria (prescriptive regulations) and safety is organised and managed by those who are directly affected by the implications of failure, meaning the company and vessel's crew (Kristiansen 2005). Consequently, this freedom is enjoyed by shipowners in

---

[4] For instance the preparation of holds described in Isbester (1993) and the hold cleaning guidance prepared by UK P&I (2005).

[5] For instance the guide to managing maintenance prepared by IACS (2001b).

determining different vessel operating policies (**Table 6.I**), depicting maximum (ceiling) and minimum (floor) levels of expenditure in relation to "good" and "common" (or average) practice within the shipping industry (OECD 1996). To this end, through the standard or minimum level, the compliance with basic standards of safe operation is ensured, while below this level a margin of substandard operation is identified within which a shipowner is able to operate a vessel not subject to detection by one or a number of regulatory authorities (flag states and classification societies acting on their behalf, port states) or the imposition of penalties which effectively reduce the margin. Unfortunately, the owners who operate their vessels at the last two levels of expenditure are far too difficult to be detected for the simple reason that they know perfectly how to survive. It should be stressed that this attitude is governed by the freight market's volatility because substandard charterers can find sufficiently low – quality ships to meet their requirements (OECD 1996, 2001)

TABLE 6.I. *Vessel operating levels*

Ceiling	Level of maximum expenditure (influenced by financial revenue, earning potential of the vessel in the freight market and financial costs of owner)
Good Practice	High level of expenditure adopted by minority of shipowners
Common Practice	Average level of expenditure adopted by majority of shipowners
Standard Practice	Minimum level of expenditure to ensure owner's compliance with basic standards o safety
Shaded Area	Margin of substandard operation within which the shipowner is able to operate a vessel subject to non – detection by regulatory authorities (flag states and classification societies acting on behalf of flag states, port states) or the imposition of penalties which effectively reduce the margin
Floor	Level of minimum expenditure (still keeping the vessel "operational")

Source: OECD (1996)

The safe operation of the vessel(s) is determined through the company's SMS, thus, it can be squeezed by charter party restrictions on the choice of route. Fundamentally, the choice is laid down by the shortest, the fastest and the simplest way (Alderton 2004). The shortest way is known as the great circle route and appears on the Mercator chart (the standard navigational chart) as a curved line. In the northern hemisphere, i.e. on a North Atlantic passage, the curve takes the vessel into higher latitudes than necessary (or the Aleutian route for North Pacific), and possibly in winter into worse weather than the vessel might be expected to encounter if she was kept further south, consensus, the shortest way may not be the quickest. Thus, a longer route might be accepted in preference to a shorter more hazardous route. Least – time, weather or optimum routeing is a relatively modern technique and is only as good as the accuracy of long – term weather forecasts. According to Alderton (2004), savings of up to 14 hours can be claimed on a North Atlantic crossing, but far more important than this is the reduction in damage to the hull, engine and cargo and perhaps the major use of weather routeing services is in settling disputes after the voyage has been completed. Safer use of Weather Routeing Services can be achieved by increased dialogue between vessels' masters and their weather routeing service providers and through a continuous review of the information that is provided by them (IMO 2002c). The simplest route is chosen for the ease of navigation. One of the reasons why mandatory routeing in the English Channel was introduced was that the majority of ships preferred coming along the English rather than the French coast. Hence, this led to heavy congestion and high collision risk in the region. Because of this, mandatory ships' routeing in converging areas of the world was introduced (IMO 2003), but if routeing measures can be extended to oceans is far too difficult to be determined since the master has (or supposed to have) the freedom to choose the appropriate ocean route as defined by SOLAS Ch. V Reg. 34/3 (IMO 2004a).

Although rough weather management is not outlined at the IMO Guidelines for voyage planning (IMO 2000), it is acknowledged that safe speed and necessary speed alterations en route having regard to the proximity of navigational hazards along the intended route or track should be maintained, so that the safety of life at sea is ensured. When the weather is bad it would not be reasonable the vessel to be expected to keep her full speed and even if she had sufficient power eligible for all weathers, she would suffer considerable damage. One of the most fundamental obligations of an owner is that the vessel's seaworthiness is ensured, meaning that the vessel has the fitness to withstand the expected hazards of the contemplated voyage laden with cargo[6] (Hill 2003). From the reviewed references (Rogers et al. 1997, Sparks 2003, Hill 2003, BIMCO n.d.) not all charters mentioned about weather conditions (i.e. in the paramount clause "Deviation" it was rarely stated that the vessel will be "on – hire" when altering course due to severe

---

[6] The "unofficial" concept of "cargo worthiness" is also included which reflects the fitness of the vessel in those parts which have direct reference to and direct contact with cargo, i.e. the holds being clean and generally fit to receive the chartered cargo (Hill 2003).

weather) and also in some cases the master had to comply with the charterers' weather routeing service. There was no clause or sub – clause exclusively about weather conditions determining the monitoring of the vessel's performance, for instance time should not count when the wind speed exceeds say, Beaufort force 5. It should be born in mind that due to strict commercial confidentiality it is not possible to have actual contracts and view how the arrangements are performed.

6.4 Setting and identifying priorities

Having in mind the aforementioned issues and the information retrieved from existing HAZID studies (Guarin and Vassalos 2004, UK 2001a, b, c, Republic of Korea 2001, IACS 2001a, Japan 2002b), the hazard register in **Appendix A** is constructed, where the causal factors are grouped into the following categories (HORSCTCI 1995b) bearing in mind the highlighted stakeholders from **Table 5.I** (first three lines i.e. owner/charterer, operator/manager and crew):

- ***Human/Crew (H)***, it is acknowledged as the most common cause for every incident/accident.
- ***Management/Ownership (M)***, it is accepted to be important while the age of the vessel does not seem to be that significant as long as she is well maintained. Hence, maintenance comes within this category since it **is** a Management aspect.
- ***Financial (Market) (F)***, if the market conditions were improved, this would not necessarily get rid of the bad operators since it is statistically proven that freight rates tend to rise concurrently with world trade and as world trade increases, there is a requirement for more tonnage capacity, including regrettably those of the bad operator.
- ***Commercial realities (Charterers) (C)***, although it is believed that they have to operate in a very competitive environment, quality and compliance should be maintained.

A total of 54 causal factors related to internal hazards (cargoes) and external (weather) are identified and categorized depending on their effect in **Table 6.II**. It is remarkable that all hazards are related to the management and operational infrastructure (software issues) which influence hardware issues (structural integrity) and furthermore in most cases is difficult to distinguish them in one category. **It is evident that the effect of corrosive/abrasive cargoes has bigger influence in an incident's progression, compared to those of passage planning, decision making, mechanical damage and alternate/block loading respectively.** However, this influence (highlighted green) needs to be proved by the ranking of hazards and relevant scenarios as will be shown in the subsequent paragraphs.

TABLE 6.II. *Causal factors' categorization depending on their effect*

Internal Hazards (Cargoes)		
Effect	**Category**	**No**
Chemical Hazards – corrosive/abrasive cargoes	H, M, C	3
	H, M	3
	M, C	4
	M	1
	C	7
	F	1
SUBTOTAL		**19**
Mechanical damage – poor stevedoring techniques (crab damage, bulldozers), coating damage	M, C	3
	M	1
	C	2
SUBTOTAL		**6**
TOTAL (INTERNAL)		**25**
External Hazards (Weather)		
Effect	**Category**	**No**
Inadequate passage planning, no response on changing weather/sea conditions	H, M, C	2
	M, C, F	2
	H, M	3
	M, C	1
	C	4
	Weather	2
SUBTOTAL		**14**
Uninformed decisions onboard and ashore	H, M, C	1
	H, M	4
	M, C	2
	M, F	1
	C, F	1
	M	1
SUBTOTAL		**10**
Problem of alternate/block loading is not appreciated	M, C, F	1
	M, C	2
	C, F	1
	C	1
SUBTOTAL		**5**
TOTAL (EXTERNAL)		**29**
GRAND TOTAL		**54**

6.4.1 Broad Analysis

The IMO FSA Guidelines are followed for the hazard ranking and the relevant risk matrix (**Appendix A**) is advised (IMO 2002b, 2007b), where the levels to each of the combinations of probability of occurrence (likelihood) and consequence of events are assigned and measured on a logarithmic scale[7]. It should be noted that since all causal factors are mutually dependent of each other, it is necessary to establish a priority level based on their likelihood/severity perspective and the possibility of finding effective risk reduction measures (RCOs). In this respect, the "top cases" are recognized in **Figure 6.1**, where the dashed – dotted line is added for the easiness of identification and their numbering is determined in **Appendix A**.

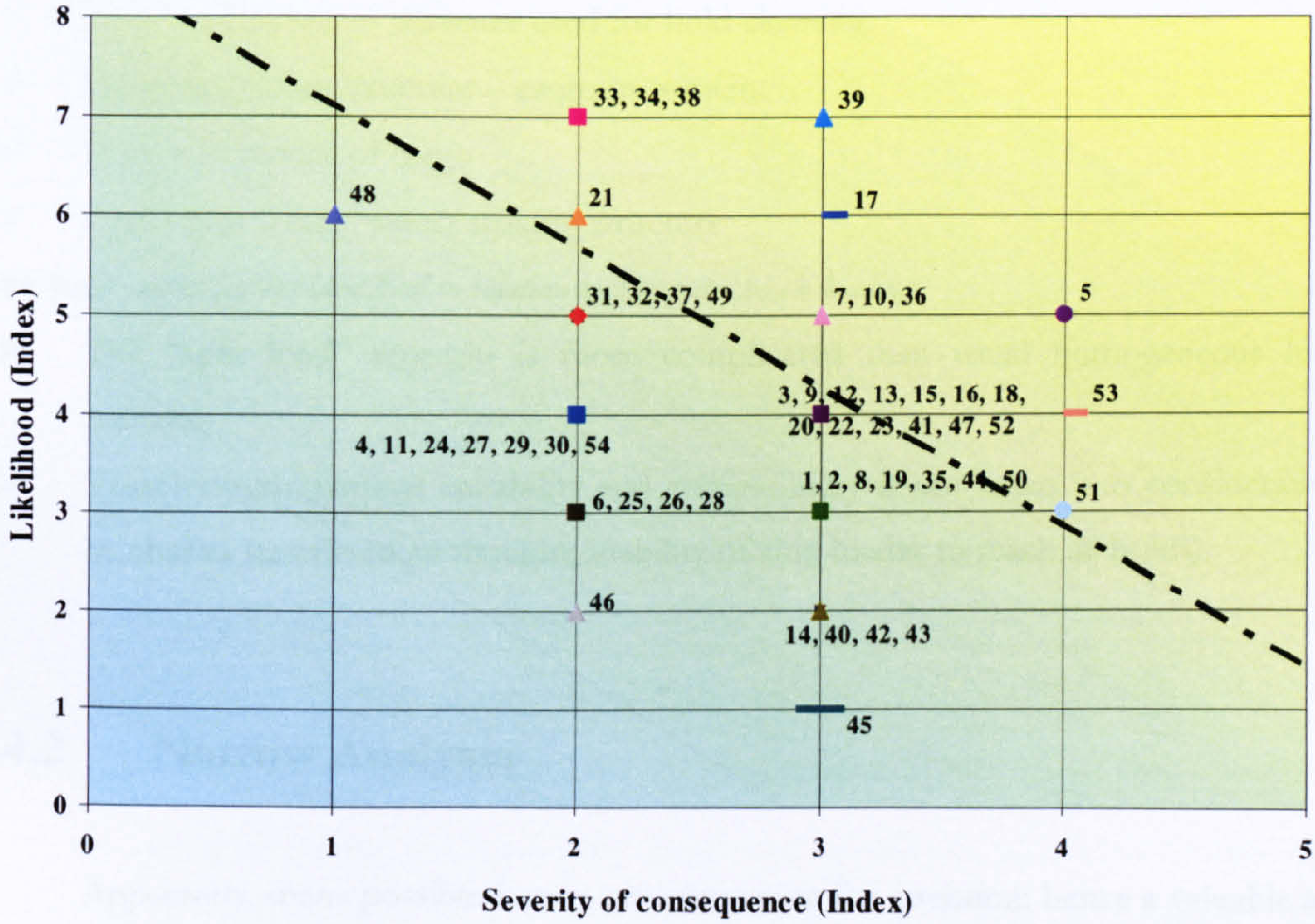


Figure 6.1. *Risk area priority level for the identified causal factors*

---

[7] Risk = Probability × Consequence ⇒ log(Risk) = log(Probability)+log(Consequence) or Risk Index (RI) = Likelihood Index (LI) + Severity Index (SI) (IMO 2002b, 2007b)

As illustrated, 12 of 54 causal factors are prioritized based on their high likelihood and high severity level as follows:

The three major causal factors related to corrosive/abrasive cargoes are:

- High loading rates – reduced No of shiftings/pours
- Corrosive nature of cargo
- Commercial pressure – requirement to retain bilge water on board to conserve deadweight where draught survey is used to check cargo weight at discharge port

Three major causal factors related to passage planning are identified:

- Encountering heavy weather in condition of loading high density cargo
- Inappropriate speed, heading and draft
- Failure of ship operator to modify speed/heading in line with weather condition

The four major causal factors in relation to mechanical damage:

- Corrosive nature of seawater used for hold cleaning
- Working of ship structure – cargo movement
- Corrosive nature of cargo
- Cargo gear (crabs, wires) striking structure

Two major causal factors identified in relation to alternate/block loading:

- The "split load" scenario is more complicated than usual homogeneous load scenario
- Vessel/cargo/terminal suitability and compatibility is not taken into consideration by charter (restricted air draught, inability of ship loader to reach all holds).

6.4.2 Narrow Analysis

Apparently, many possible factors are competing for attention; hence a valuable aid used to establish priorities is the Pareto diagram (Pareto principle) which may simply be described as a bar chart that ranks related contributors to the total effect in decreasing occurrence frequency accompanied with their cumulative percent of total effect. According to this principle, is stated that in any population that contributes to a common effect, a relative few of the contributors – the vital few (20%) – account for the bulk of the effect

(80%) (Juran 2000b, Dhillon 2007). The application of Pareto principle is shown in **Figure 6.2**, where *corrosion* is selected and identified as the main contributor (causal factors 39, 33, 34, 38).

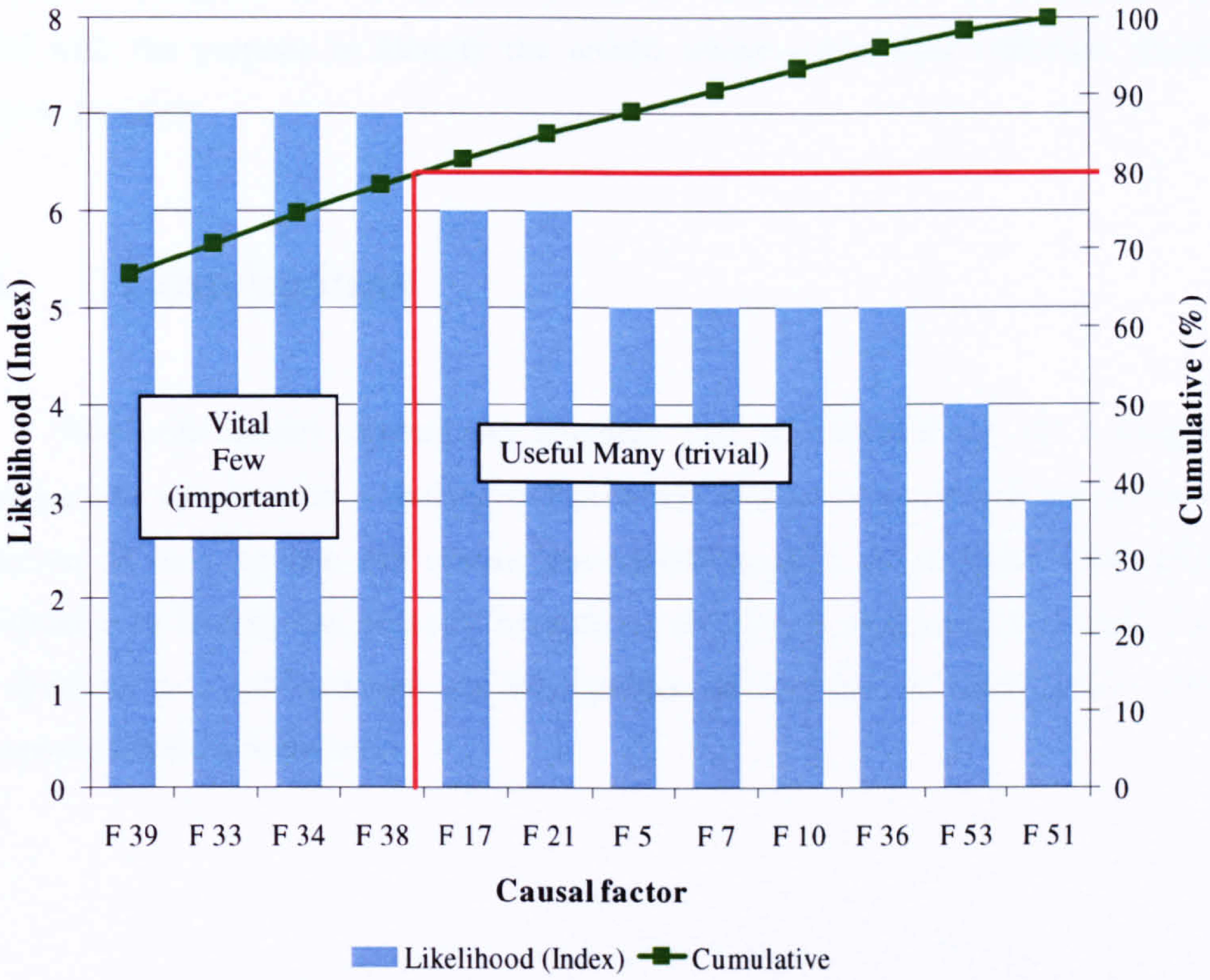


Figure 6.2. *Pareto diagram for the 12 identified causal factors*

6.5 Next stage preparation

In connection with the previously mentioned issues, the risk can be controlled (minimised) by reducing either the likelihood (frequency) which is associated with preventive (passive, built – in, design) measures or the consequences of an effect which are associated with mitigating (active, operational) measures, or both. Bearing in mind that software and hardware issues cannot be isolated, it needs to be emphasized that by reducing either the likelihood or the consequence of effects alone will not suffice, making also necessary to address the preventive **and** mitigating nature of RCMs during the vessel's lifecycle. However, it should be stressed that the previous prioritization precedes the risk analysis (following Chapter) where the causal factors are investigated in more detail. It should be also pointed out that the aim of a qualitative risk assessment (HAZID) is to prioritise the causal factors in order to provide guidance where attention needs to be given when constructing the risk model. Hence, only the 12 causal factors will be included in the model with the purpose to identify the area(s) where action (risk reduction measures) needs to be taken.

6.6 Conclusions

Safe bulk carrier operational practices can be affected by the management infrastructure and decision – making onboard and ashore. It is required shipowners and charterers to co – operate and ensure that vessels' masters are provided with sufficient information to identify the potential hazards of the carried cargoes i.e. corrosion, vessels are operated in a safe manner and the commercial pressure on masters and terminal operators should be removed.

This page is intentionally left blank

7 Risk Analysis

"The only certainty in life is death; uncertainty lies in when and how death occurs, and whether it is final"

William D. Rowe

7.1 Preamble

The aim of the current chapter is to develop a probabilistic model for estimating the uncertainty of the dry bulk transportation. The DOOBNs technology is used to model the uncertainties of the aforementioned operational domain. A methodology is proposed for estimating the current risk level of dry bulk cargo transport and concurrently measuring its safety with the use of RSM CCD.

7.2 Introduction

Risk analysis is considered to be more appropriate in identifying the factors that may adversely affect safety and a good understanding is provided of the mechanisms of accidents and the role of safeguards in terminating accident sequences. Hence, the underlying causes and progression of the most important scenarios (previous chapter) are identified by a quantitative model involving simultaneous examination of their likelihood and consequences (IMO 2002b, 2007b, HSE 2002a). The developed risk model incorporates the most important contributors (including stakeholders) involved in a foundering scenario and quantifies the risk level to life and property during the dry bulk cargo transportation using the BN technology. This model may be used as a tool where the factors influencing the safe operation of a ship can be identified at an *early stage* and for establishing the areas of concern to *prevent* undesirable events (safety performance prediction).

7.3 BNs background (Jensen 1996, 2001, Pearl 1988, Koller and Pfeffer 1997, Neapolitan 2004, Sanghai et al. 2005)

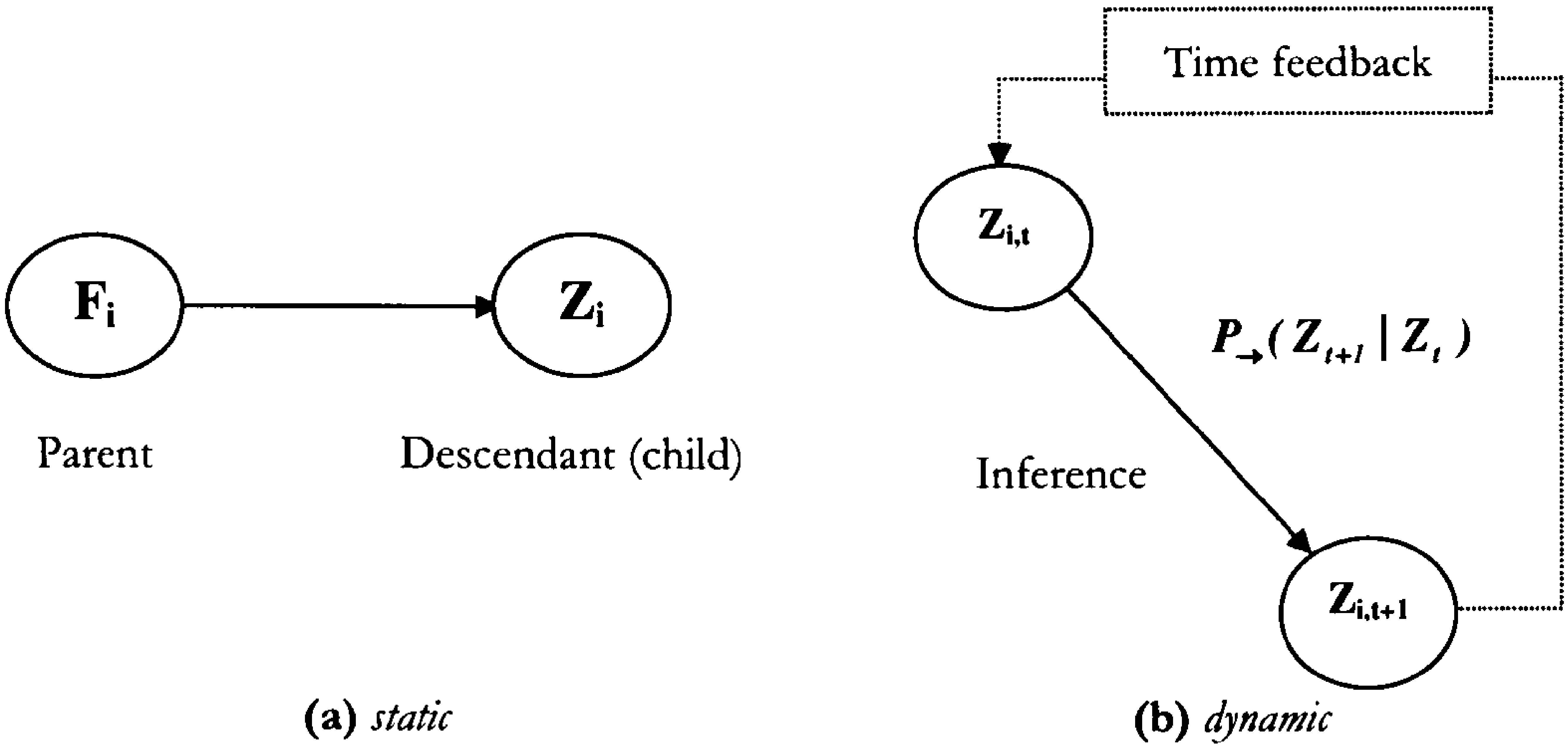
A BN (**Figure 7.1(a)**) (a.k.a. Bayes Net, Causal Probabilistic Network, Bayesian Belief Network or simple Belief Network) is a probability model expressed in graphical terms, enabling the use of statistically acceptable and mathematically rigorous techniques – such as Bayes' theorem[8] – for reasoning under uncertainty. Through a BN the joint probability distribution of a set of variables $\{Z_1,\ldots,Z_d\}$ is encoded as a DAG[9] and a set of CPTs. Each variable is corresponded to a node and the table associated with it allows to compute the probability of a state of the variable given the state of its parents (unconditional or marginal probability distribution). The set of parents of Z_i, denoted $Pa(Z_i)$, is the set of nodes with an arc to Z_i in the graph where each edge is interpreted as causal relationship and ***not*** flow of information. The assertion that each node is conditionally independent of its non – descendants given its parents is encoded through the network's structure (*Markov Condition*). So, the joint probability of an arbitrary event $Z = (Z_1,\ldots, Z_d)$ can then be computed as:

---

[8] Given two events Z and F, the formula $P(Z\,|\,F) = \frac{P(F\,|\,Z)P(Z)}{P(F)}$, where $P(Z/F)$ the ***posterior*** (joint or conditional) probability distribution, $P(F/Z)$ the ***likelihood*** of the data and $P(Z)$ the ***prior*** probability distribution, $P(F)$ the unconditional probability distribution, was originally developed by Thomas Bayes (published in 1763), is called ***Bayes' theorem*** and so that is explained the denomination ***"Bayesian Networks"***.

[9] A directed graph is acyclic if there is no directed path $Z_1 \rightarrow \cdots \rightarrow Z_n$ subject to $Z_1 = Z_n$.

$$P(Z)=\prod_{i=1}^{d}P(Z_i\mid Pa(Z_i)) \tag{7.1}$$



(a) *static* **(b)** *dynamic*

Figure 7.1. *A simple network for the random variable Z_i.*

DBNs (**Figure 7.1(b)**) are an extension of BNs for modelling dynamic systems. In a DBN, the state at time t is represented by a set of random variables $Z_t = (Z_{1,t},\ldots, Z_{d,t})$. The state at time t is dependent on the states at previous time steps. Typically it is assumed that each state only depends on the immediately preceding state (*Markov Condition*) and thus, the transition distribution $P_{\rightarrow}(Z_{t+1}\mid Z_t)$ needs to be represented. This can be done with time – slice fragments and since for all t each Z_i (parents and descendants) has the same space, the vectors $z_{i,t+1}$ and $z_{i,t}$ both represent values from the same set of spaces. Hence, a DBN is defined as a network containing the variables that constitute the T random vectors consisting of:

(a) the DAG composed of the DAG G_0 and for $0\le t\le T-1$ the DAG $G_{\rightarrow}$ evaluated at t; and

(b) the following joint probability distribution:

$$P(Z_t)=P_0(Z_0)\prod_{t=0}^{T-1}P_{\rightarrow}(Z_{t+1}\mid Z_t) \tag{7.2}$$

An object – oriented probabilistic graphical model can be defined as a network (i.e. BN) that, in addition to the usual nodes instance nodes are contained and the fundamental unit is an object. An object represents either a node (i.e. a variable) or an instantiation of a network class (called an instance node). An instance node is an abstraction of a network fragment into a single unit. The OOBNs' modelling is based on the decomposition of the global network into hierarchical levels. This representation method allows to decentralise and to structure the knowledge within BNs of reduced size. Two organizational hierarchies are provided in OOBNs, the *part – of hierarchy* corresponding to the inclusion of one object within another (iconization – no hidden variables within a probabilistic interface) and the *is – a hierarchy* over classes. Noting that iconization is fitted naturally into the *is – a hierarchy*, a network class is a named and self – contained representation of a network fragment with a set of interface and hidden nodes (**Figure 7.2**).

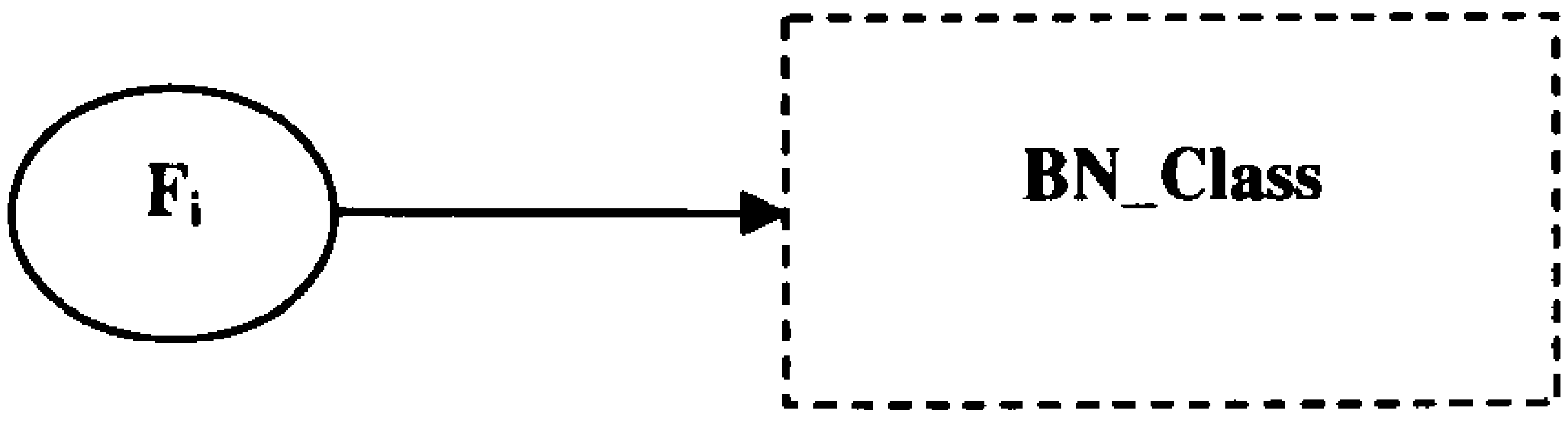


Figure 7.2. *A simplified network class where Z_i are hidden nodes included in BN_Class*

7.4 Modelling risk through the BN

The current model has been developed behind the thought that an accident can be viewed as a process where contributing and interacting factors of operational, environmental and technological aspects constitute its causal network. Furthermore, the system's frequent behaviour (i.e. dry bulk cargo transportation) is considered to be at risk when through that causal influence, an enumeration process is generated resulting to various consequences (i.e. loss of life/property). This can be expressed mathematically by the equation: Risk = Likelihood × Consequence, whereas the first part represents uncertainty in the system's operational profile (variability of transported cargoes, trade routes and weather conditions) and the second part is the interaction between causes and effects (accident statistics, investigation reports) as shown in **Figure 7.3**.

All three indices are defined as objects and the nodes' states of Likelihood and Consequence Indices are named according to the IMO risk matrix (IMO 2002b, 2007b). The Likelihood Index is consisted of $N = 2\times\{1,\ldots,6\}$ DBNs depending on the time slice for transported cargoes and trade routes and concurrently the market structure (financial) is represented (**Figure 7.4**). This index is related to the frequency of an accident as defined at the IMO Guidelines on FSA (IMO 2002b, 2007b) and it can be calculated as:

$$\boldsymbol{Likelihood := \frac{No\ of\ accidents}{Fleet\ population} \times 1{,}000\ vessels} \tag{7.3}$$

The Consequence Index is related to the severity of an accident determined by the number of injuries or fatalities for each incident as defined at the IMO Guidelines on FSA (IMO 2002b, 2007b) and it can be calculated as:

$$\boldsymbol{Consequence := \frac{No\ of\ injuries\ /\ fatalities}{Fleet\ population} \times 1{,}000\ vessels} \tag{7.4}$$

The basis for constructing this OOBN is provided through the information found at Japan (2002c), whereas the fault tree has been converted into a BN augmented with the operating and shore management levels (see § **E.5** and **C.3** respectively, with the latter one being important for understanding the development of this network). The Risk Index is interpreted as the potential for realization of unwanted, negative outcomes of an event (vessel en voyage) and thus uncertainty of the performance of a system (vessel) (Rowe 1988, Aven 2003). Therefore, it should be associated with all the possible negative outcomes, i.e. low likelihood/consequence, low likelihood – high consequence, high likelihood – low consequence and high likelihood – high consequence. It can be represented by considering four levels of the IMO Risk Matrix (IMO 2002b, IMO 2007b):

$$\boldsymbol{Risk := \bigcap_{n=1}^{4} \begin{pmatrix} Low \\ High \end{pmatrix} \{Likelihood, Consequece\}} \tag{7.5}$$

Input data for completing the conditional or marginal probability tables was achieved from accident statistics (**Appendix B**), casualty information (**Appendix C**), actual voyage data (**Appendix D**), Port State Control detention lists (**Appendix E**) and wave statistics (Hogben et al. 1986), whilst for any unavailable data, the hazard register (**Appendix A**) was advised. The software used for developing the model is the HUGIN tool (Hugin Expert A/S 2006) and bearing in mind that the BN can be extended to an ID (which cannot contain continuous nodes), the network is discrete. It should be mentioned that the nodes in **Figures 7.3** and **7.4** are only illustrative and not the ones used in the actual model which has a higher level of detail and are enclosed in **Appendix E**.

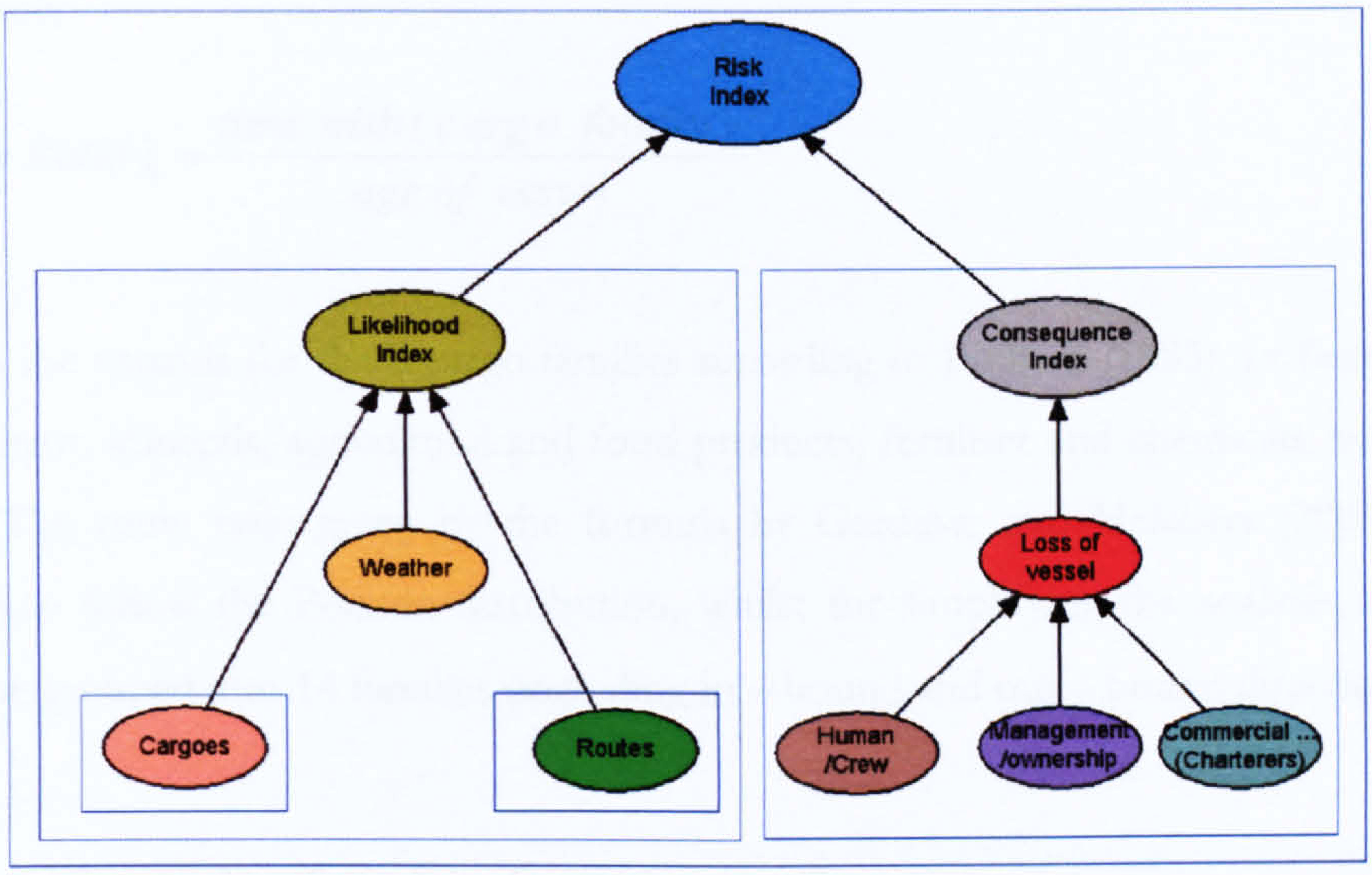


Figure 7.3. *Overview of the BN modelling with the rectangular lines indicating objects*

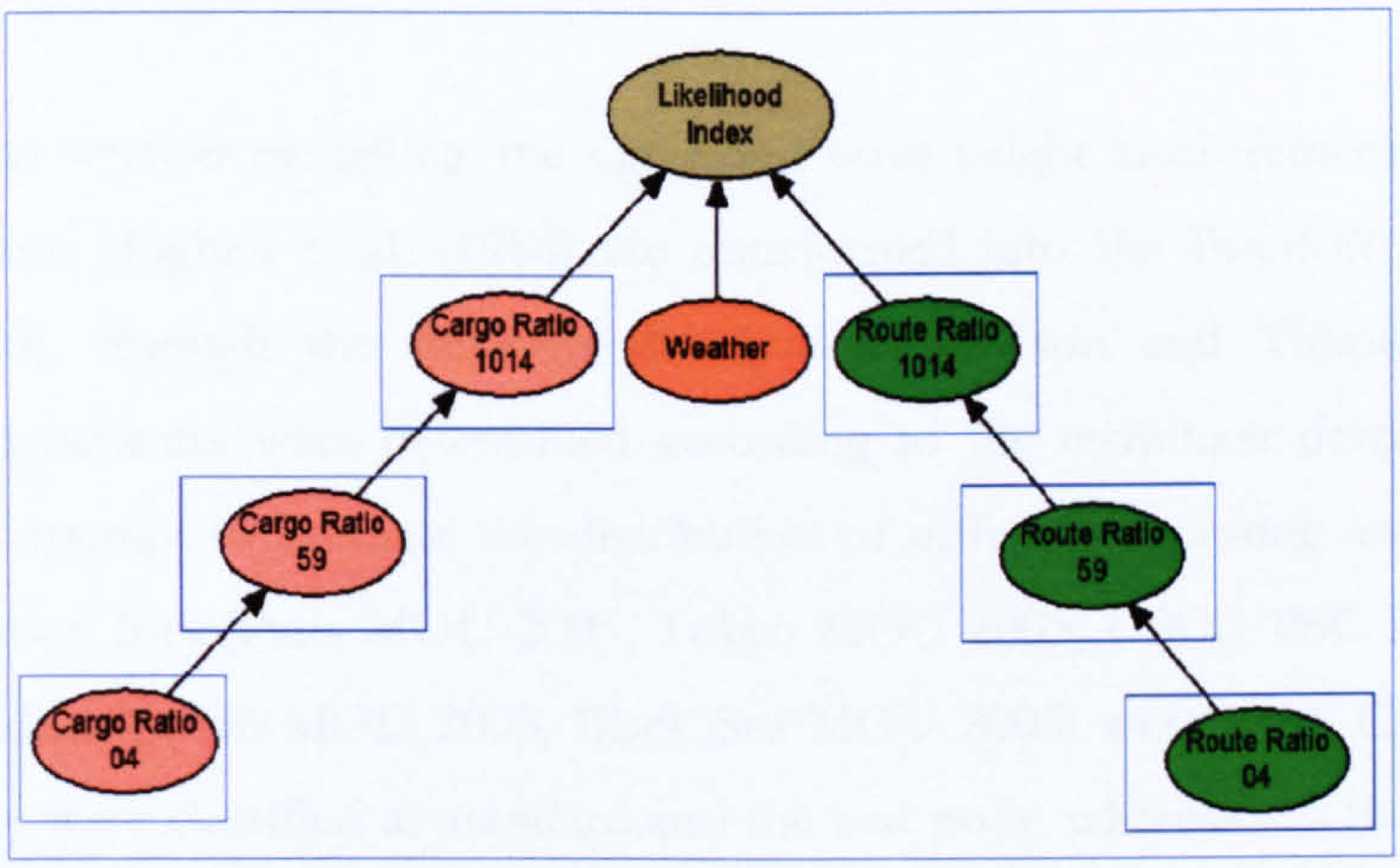


Figure 7.4. *Example of likelihood index for three time slices with the rectangular lines indicating objects*

It needs to be stressed that the lack of information and knowledge is driven by the fact of how much resources are or might be available to the analyst to obtain it. In this sense, data is transformed into knowledge by the usage of probabilities whilst for any unknowns the estimation is based on subjective interpretations of probability. Hence, the cargo changes are assumed to follow the Poisson process meaning that there is a random occurrence of states during an extended window of observation as a function of time which in this case is one (1) year (Evans et al. 2000, Bury 1999). The cargo ratio is given by the formula found in Gardiner and Melchers (2003) and is assumed to follow the Poisson distribution:

$$(\mathbf{\textit{Cargo Ratio}})_i = \frac{\mathbf{\textit{time with}}\,(\mathbf{\textit{cargo family}})_i}{\mathbf{\textit{age of vessel}}} \tag{7.6}$$

Whereas the *i* stands for the 8 cargo families according to Packard (1985), i.e ferrous ores, coal, cement, minerals, agricultural and food products, fertiliser and chemicals, metals and timber. The route ratio given by the formula by Gardiner and Melchers (2003) and is assumed to follow the Poisson distribution, whilst for simplifying the analysis, the trade routes are grouped into 14 families (including in – bound and out – bound directions, see **§ E.3.3**):

$$(\mathbf{\textit{Route Ratio}})_i = \frac{\mathbf{\textit{time in}}\,(\mathbf{\textit{route family}})_i}{\mathbf{\textit{age of vessel}}} \tag{7.7}$$

For the weather modelling, the significant wave height measurements (annual – all directions) from Hogben et al. (1986) are transformed into the Beaufort scale of wind (UKHO 2004), through the Rayleigh distribution (Rawson and Tupper 2001). The distribution parameters were determined according to the technique described in Vose (2001). In an attempt to estimate the distribution of different operating levels, port state control detention lists (Paris MOU 2005, Tokyo MOU 2005, USCG PSC 2005, Viña del Mar 2005, Indian Ocean MOU 2005, Black Sea MOU 2005) were used. Cases with only one deficiency were classified as standard and the rest poor, whereas for the ceiling, good and common and practice, shaded area and floor conditional to the shore management, the Pareto Principle (Dhillon 2007) was applied. By way of reference, the frequencies were estimated by the equation:

$$\mathbf{\textit{Frequency}} = \frac{\mathbf{\textit{No of detentions}}}{\mathbf{\textit{2005 fleet population}}} \tag{7.8}$$

Fore more details the reader should be referred to **§ E.5.20** and **E.5.21** of **Appendix E.**

7.5 Verifying the previous prioritization

Before proceeding to the results, some missing points need to be cleared out. From the screening of hazards, corrosion (internal hazards – cargoes) and turn – around times (external hazards – weather) were identified as main situations for causing harm and concurrently corrosion was **qualitatively** prioritized (see **§ 6.4.2**). Furthermore, The output from **§ 6.4** (Setting and identifying priorities) is used in combination with appropriate techniques (BNs technology, see **§ 7.4**) for constructing a quantitative model where the causes and consequences of the most important situations are investigated in detail. This allows attention to be focused upon high risk areas and to identify and evaluate the factors which influence the level of risk. Consequently, by running the BN (Hugin Expert A/S 2006), i.e. the program calculates automatically equations (7.1) and (7.2), the following probability (risk) values are obtained and presented at **Table 7.I**. Again, it should be noted that these values are defined by Rowe (1988) and Aven (2003) as the potential for realization of unwanted, negative outcomes of an event and thus uncertainty in the performance of a system quantified by probabilities. Hence, given that an accident has occurred, the **Table 7.I** values quantify the probability of possible hazards. It is far from obvious that **corrosion wastage is identified as an area which needs to be addressed further**, without meaning that fatigue (other factor – cracks/dents) is insignificant, but this boundary is set for the current study.

TABLE 7.I. *Prioritization of high risk areas*

Influence area	**Vessel size**			
	Handysize	**Handymax**	**Panamax**	**Capesize**
Corrosion wastage	0.8889	0.8621	0.7668	0.8387
Other factor (cracks, dents)	0.7778	0.3448	0.5882	0.4194
Weather routine failure	0.1905	0.1500	0.2353	0.2581

Apparently, the low values of weather routine failure are due to the fact that weather routeing had been introduced as an RCO (UK 2002b), work had been already done and no further actions are required (IMO 2002c). Furthermore, parameters with regards to the transit performance (seakeeping and seaworthiness) such as assignment of freeboard (vertical distance from the upper edge of the deck line to the upper edge of the related load line), design of hatchways, hatchcovers and deck openings to withstand green seas loading including provisions against flooding due to water on deck (weather and water tightness), minimum bow height and reserve buoyancy of the fore end structure and protection of the crew (satisfactory means for the passage of crew on deck/accommodation) have been ensured through the revised Load Lines Convention (IMO 2005c). Moreover, any other regulatory attempt could be addressed through the definition of charter – party arrangements, but this is beyond the scope of the current research.

7.6 Sensitivity analysis of the risk index

By running the BN, the nominal values of the states of the Risk Index ($\mathrm{RI}_{\mathrm{Nom}}$) were obtained and are shown at **Table 7.II**. Recalling the essence of risk, the meaning of the five states is to what extent the risk can be avoided or not in conjunction with that given at the IMO Risk matrix used for the initial ranking of hazards (IMO 2002b, 2007b). More specifically, it is shown that the majority of dry bulk transport operational risk is ALARP.

TABLE 7.II. *Risk Index nominal values*

Risk Index state	Vessel size			
	Capesize	Panamax	Handymax	Handysize
Intolerable	25.24	26.62	26.34	26.28
ALARP High	22.62	23.31	23.17	23.14
ALARP Medium	20.00	20.00	20.00	20.00
ALARP Low	17.39	16.71	16.84	16.87
Negligible	14.77	13.39	13.67	13.73

The distinction of ALARP area within three categories is for determining the effectiveness of risk reduction measures, since through the dry bulk shipping is entailed such a low level of residual risk whilst benefits are also brought that contribute to lowering the background level of (intolerable) risks. The residual risks are not unduly high and are kept ALARP by ascertaining whether further or new control measures need to be introduced to take into account changes over time such as new knowledge about the risks or the availability of new techniques for reducing or eliminating risks (HSE 2001). As it has been demonstrated that the majority of vessels lies within the ALARP area (Skjong et al. 2007), it could be argued that for the current risk level of for instance capesize vessels, there is rougly 25% probability of something going wrong (uncertainty) during transit, 60% is ALARP and the remaining 15% is acceptable. Of course, no risk is acceptable, but the bebeficial importance of dry bulk transport is justified since the majority of risk is within the ALARP area.

Before going any further and in order to check how reliable these values might be, their sensitivity will be investigated by changing critical parameters. As shown from **Figure 7.3**, a critical parameter is the loss of the ship, with the probability of structural failure being a tangible indicator (see **§ E.5.2**). Hence, the probabilities of structural failure are compared with those calculated at Guarin and Vassalos (2004) from the structural reliability assessment during the lifetime of single hull vessels given the effects of ESP and SOLAS Ch. XII (**Appendix B**) and are presented at **Table 7.III**. It should be pointed out that the first three records describe the probability of structural failure during a foundering scenario, whilst the other records are defined in the same way as in **Table 7.II**.

TABLE 7.III. *Probabilities of structural failure and their influence at risk index*

Vessel size	**Reliability Assessment**	**Bayesian Network**
Capesize	0.6009	0.6339
Panamax	0.5314	0.6674
Handymax	0.6257	0.7036

Risk Index state	**Vessel size**					
	Capesize		Panamax		Handymax	
	RI'	ΔR (%)	RI'	ΔR (%)	RI'	ΔR (%)
Intolerable	25.12	0.48	26.22	1.51	26.05	1.11
ALARP High	22.56	0.27	23.11	0.86	23.02	0.65
ALARP Medium	20.00	0.00	20.00	0.00	20.00	0.00
ALARP Low	17.44	-0.29	16.89	-1.08	16.98	-0.84
Negligible	14.88	-0.75	13.79	-2.99	13.96	-2.12

Although the probability of structural failure is overestimated by the BN, the level of influence to the index is shown at **Table 7.III**. It is obvious that although with the probability calculated by the reliability assessment the extent of avoidable risk is slightly increased, it is better to "err" from the side of unavoidable risk. Moreover, the risk difference ranges between 0.3 ~ 3.0 % which can be considered reasonable based on the assumption that it is better to "err" from the side of unavoidable risk.

7.7 Current risk estimation

Based on the developed model, it would be appropriate to establish a general function Y (refined risk) so that for some observable quantities $X_1, X_2, X_3, \ldots, X_n$ can be written $Y = f(X_1, X_2, X_3, \ldots, X_n)$, where in the current study $n = 2$ reflects the vessel's age and DWT respectively. This function is considered necessary for the CEA calculations. As shown earlier, since some risk is unavoidable and is generally related to the negative outcomes of an event, this potential needs to be quantified and calibrated (bench – marking) by weighting factors which will be determined by input (evidence) from accident investigation reports as outlined at **Appendix C**. Therefore, from the known narrations of accidents, evidence was put to each of the BN's nodes and the results are recorded at **Table 7.IV**. Furthermore, by applying multivariate regression of the five risk states with response the covariance, it is easy to estimate the current risk Y:

$$Cov\left[\vec{RI}_{Nom}, \vec{RI}\right] \equiv \overline{RI_{Nom,i} \cdot RI_i} - \overline{RI_{Nom,i}} \cdot \overline{RI_i} \tag{7.9}$$

Hence, the weighting factors are calculated (**Appendix G**) and their values are as follows:

Risk Index state (RI_i)	**Weighting factor (w_i)**
1. Intolerable	: 0.0008
2. ALARP High	: 0.7525
3. ALARP Medium	: N/A
4. ALARP Low	: 0.1853
5. Negligible	: 0.0614

Finally, the "refined" values:

$$Risk_{Ref} = RI_1 \cdot w_1 + RI_2 \cdot w_2 + RI_4 \cdot w_4 + RI_5 \cdot w_5 \tag{7.10}$$

are presented at **Table 7.IV** together with the five risk states and the equivalent covariance from the nominal values for each investigated accident. From the same table it is observed that the refined risk (residual) is marginally reduced compared to the intolerable risk, explaining the effects of the ALARP region as commented by HSE (2001).

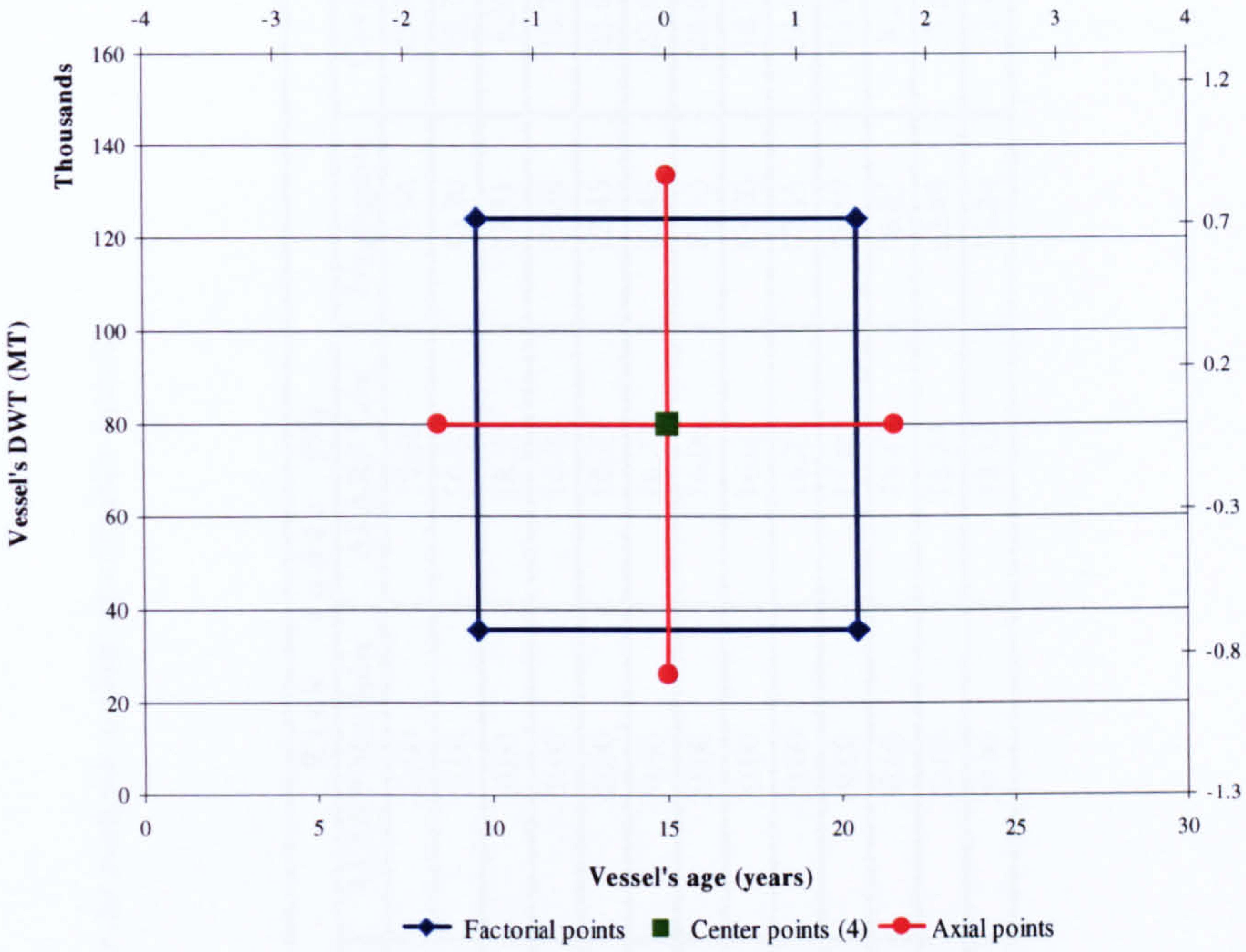


Figure 7.5. *CCD for the refined risk*

As mentioned at § **3.4**, the function $Y = f(X_1, X_2, X_3, ..., X_n)$ can be estimated by applying RSM CCD experiments for the cases at **Table 7.IV**. Thus, a two – factor (k = 2), five – level CCD was used (Montgomery 2005) and is comprised of 12 points (runs). The orthogonal CCD (a unique class of designs that minimize the variance of the regression coefficients $\beta_{i,j}$), is made up of a $n_f = 4$ point two – level full factorial $2^{k=2}$ design augmented with $n_{cf} = 4$ centre points with an additional axial block consisting of $n_a = 2$ points per factor at a distance:

$$\alpha = \left[\frac{\left(\sqrt{2^{n_f} + 2 \cdot n_f + n_{cf}} - \sqrt{2^{n_f}} \right)^2 \cdot 2^{n_f}}{4} \right]^{\frac{1}{4}} = 1.21 \qquad (7.11)$$

from the design centre (**Figure 7.5**).

TABLE 7.IV. *Results of risk index for the available accident investigation reports*

Name	Age	DWT	Risk Index (%)						
			Intolerable	**ALARP High**	**ALARP Medium**	**ALARP Low**	**Negligible**	**Cov[R]**	**Risk_{Ref}**
Adamandas	17	22580	26.64	23.32	20.00	16.68	13.36	20.83	21.49
Alexadre-P	23	94532	26.80	23.40	20.00	16.60	13.20	18.78	21.41
Daeyang Honey	22	123745	22.49	21.25	20.00	18.75	17.51	6.53	20.56
Derbyshire	4	172200	26.80	23.40	20.00	16.60	13.20	18.78	21.41
Edmund Fitzerald	17	27460	27.55	23.77	20.00	16.23	12.45	23.68	21.69
Flare	26	28761	27.55	23.77	20.00	16.23	12.45	23.68	21.69
Leader L	23	69120	27.87	23.94	20.00	16.06	12.13	26.03	21.76
Manila Transporter	15	115960	26.80	23.40	20.00	16.60	13.20	18.78	21.41
Marine Electric	31	25575	27.55	23.77	20.00	16.23	12.45	23.68	21.69
Melete	16	72060	24.81	22.40	20.00	17.60	15.19	15.91	21.07
Mineral Diamond	9	141028	23.15	21.57	20.00	18.43	16.85	8.24	20.71
Singa Sea	12	26586	27.55	23.77	20.00	16.23	12.45	23.68	21.69
Starfish	21	56277	23.76	21.88	20.00	18.12	16.24	12.44	20.84

Although the levels in design factors are inaccurate ($\neq \pm 1.414$) the result will not be seriously affected by not achieving the desired factor levels exactly (Montgomery 2005). Details of the CCD are enclosed at **Appendix G**. The analysis was carried out on the coded data sets so that the magnitude of the model coefficients is directly comparable. The coding was as follows:

$$X_i = \alpha \cdot \frac{\xi_i - \frac{\xi_{i,max} + \xi_{i,min}}{2}}{\frac{\xi_{i,max} - \xi_{i,min}}{2}} \tag{7.12}$$

where ξ_i are the natural variables. Therefore, the fitted model is:

$$\hat{Y} = 21.53 - 0.06 \cdot X_1 - 0.52 \cdot X_2 - 0.14 \cdot X_1^2 - 0.27 \cdot X_2^2 - 0.21 \cdot X_1 \cdot X_2 \tag{7.13}$$

Bringing in mind the essence of safety and applying the same methodology, the fitted (complement) model is:

$$\hat{Y}_{com} = 78.47 + 0.06 \cdot X_1 + 0.52 \cdot X_2 + 0.14 \cdot X_1^2 + 0.27 \cdot X_2^2 + 0.21 \cdot X_1 \cdot X_2 \tag{7.14}$$

The ordinary R^2 is close to the adjusted R^2 (**Appendix G**) and hence both linear and quadratic terms contribute significantly to the model.

By plotting the contours (**Figure 7.6**) and the response surface (**Figure 7.7**) the system's performance can be characterized and is noted that is more sensitive as the age increases (as expected). It is observed that when the vessels enter service, there is 19.5 % uncertainty of something that might go wrong which is increased up to 21.5 % until their 20 – year anniversary while is decreased afterwards (in accordance with § **B.6.5** and **B.6.8**). It is also revealed that the estimated current safety level of bulk carriers is around 80 % with the minimum appearing between the ages of 17 – 19 years. The acceptability or not of these values can be defined by determining the current levels of individual and societal risk[10] (F – N diagram). It is obvious (**Figure 7.8**) that the current risk level for capesize, panamax and handymax vessels is ALARP Low while for handysize vessels and all bulk carriers is ALARP High. It is remarkable that the current individual risk (**Figure 7.9**) is below the target value. The question that arises here i.e. how safe is safe enough, will be attempted to be answered at the subsequent Chapter since the aim of this chapter was just to assign a risk value. Speaking coarsely, from the screening of hazards and risk analysis, corrosion was prioritized as main situation for causing harm and the evaluation of measures for controlling it will be investigated in the following Chapter.

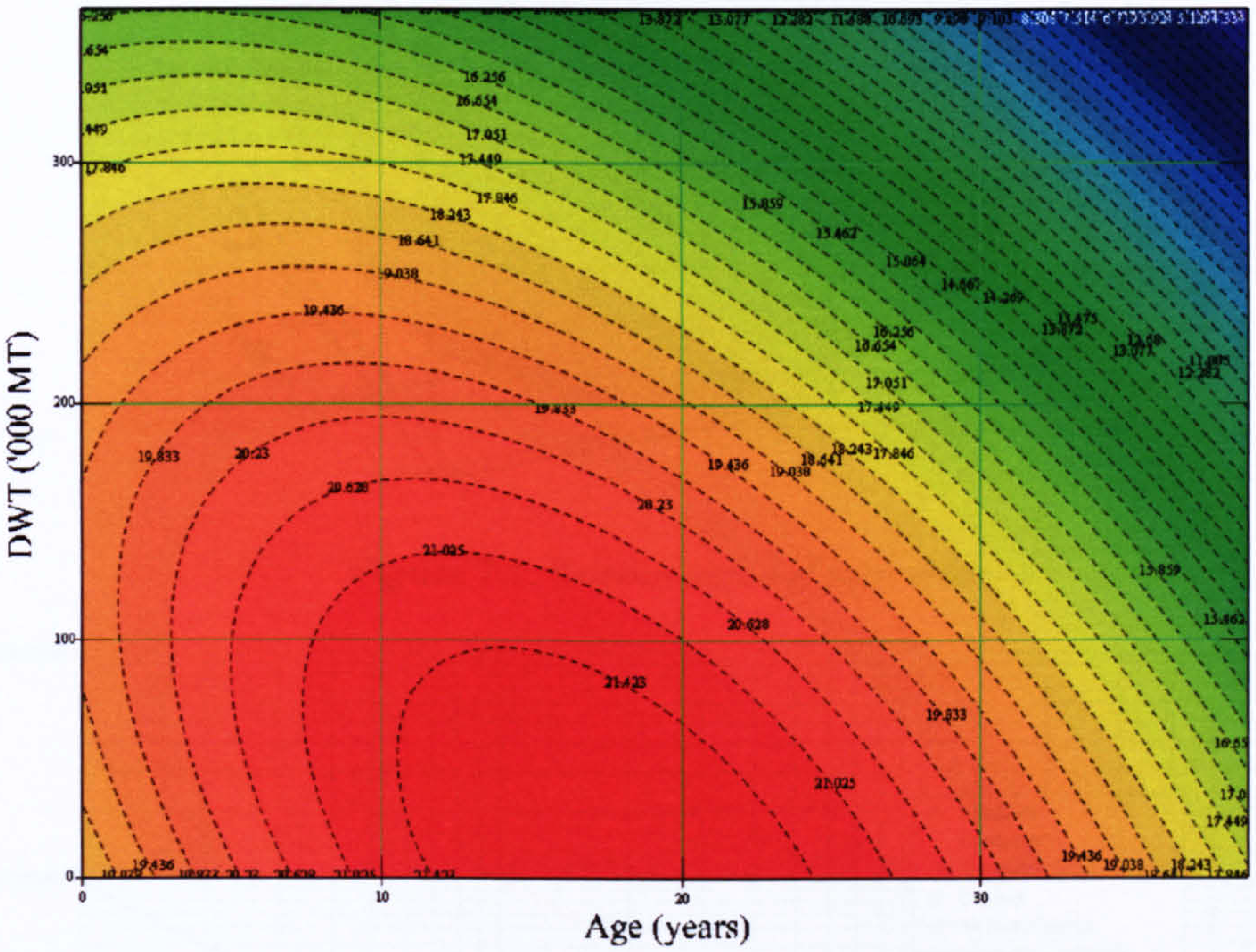


Figure 7.6. *Contour plots for the refined risk*

---

[10] The reader should be referred to **§ B.6.12** (**Appendix B**) for more information.

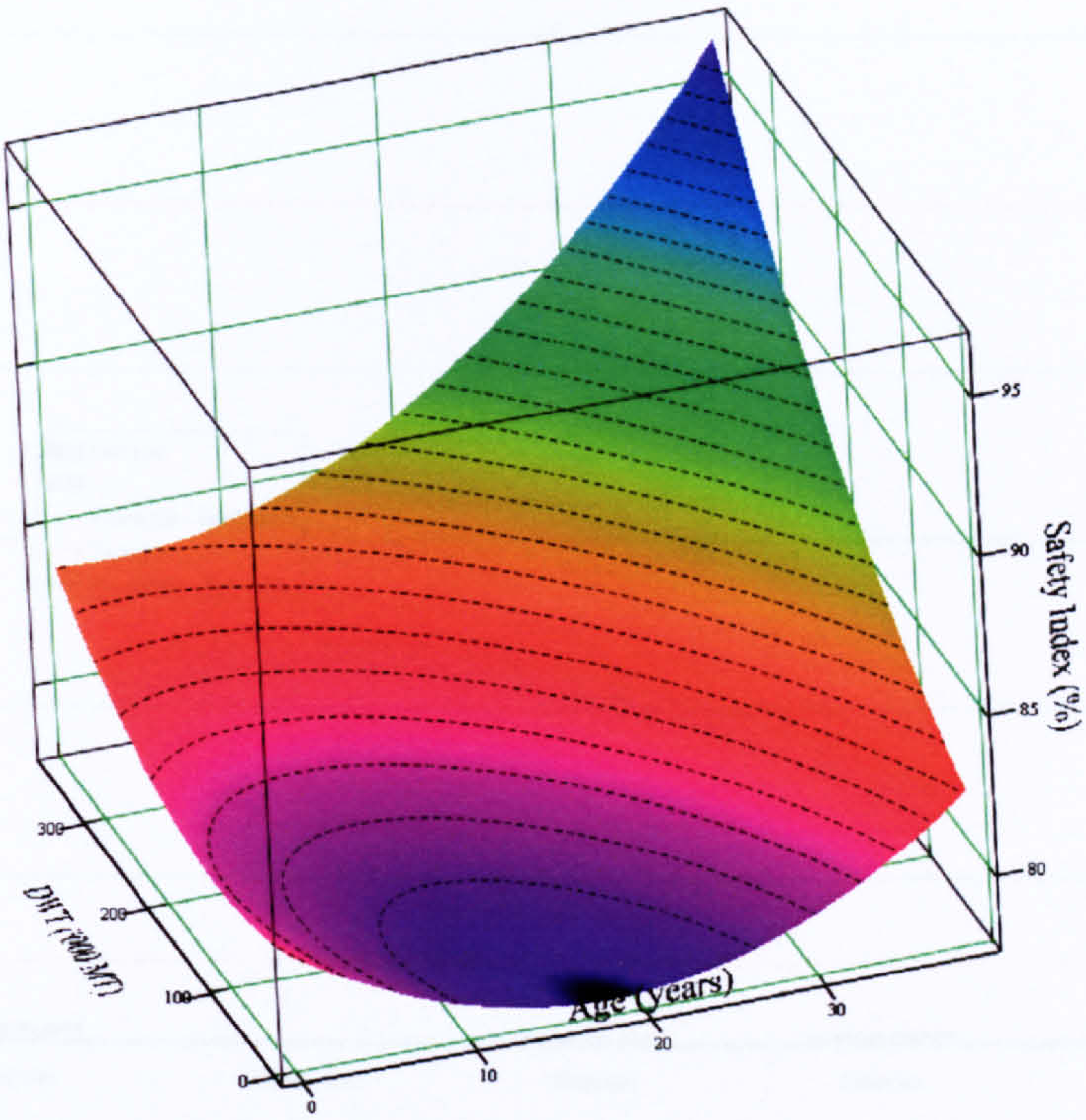


Figure 7.7. *Response surface of safety index*

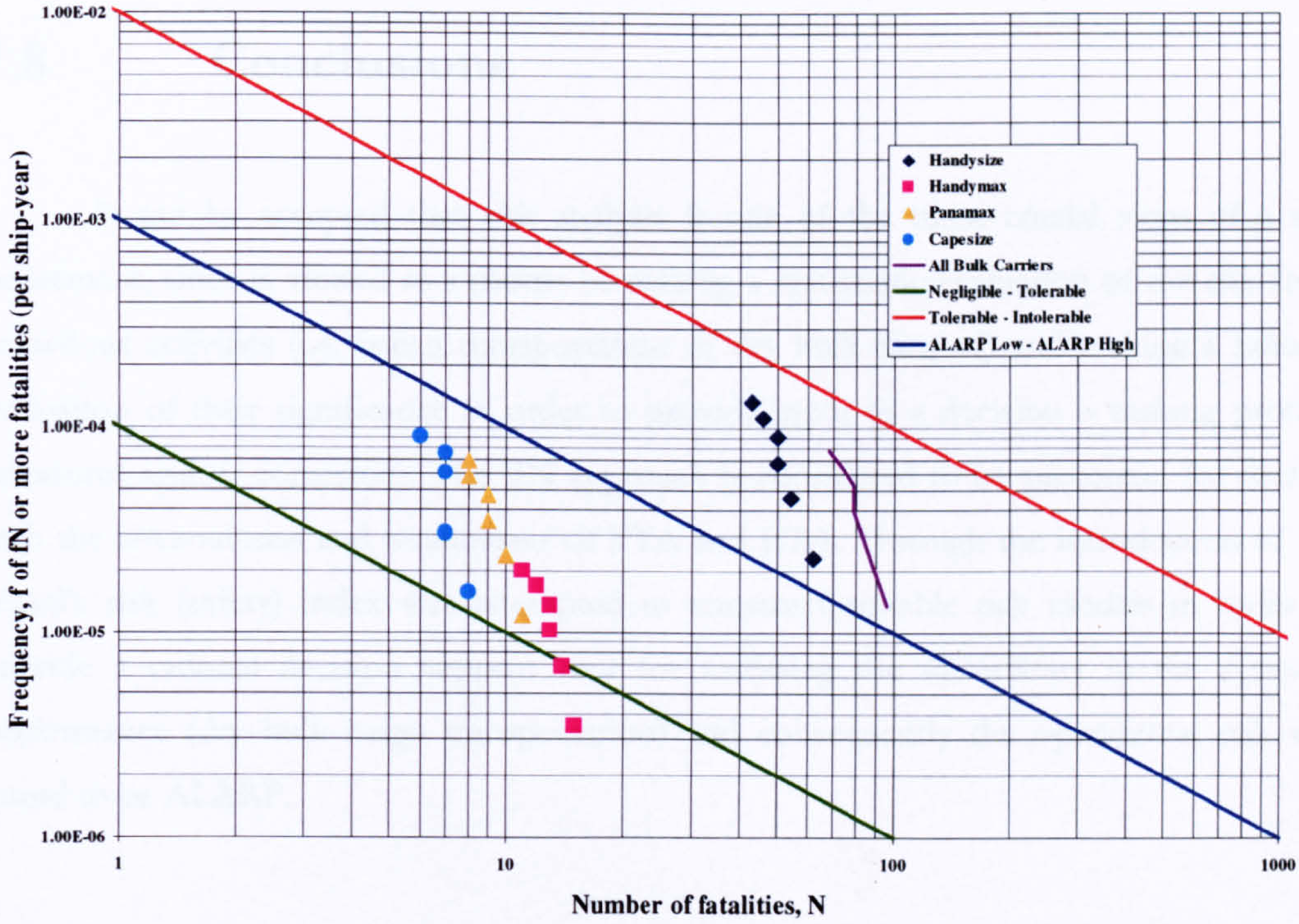


Figure 7.8. *F-N diagram of BC current risk level*

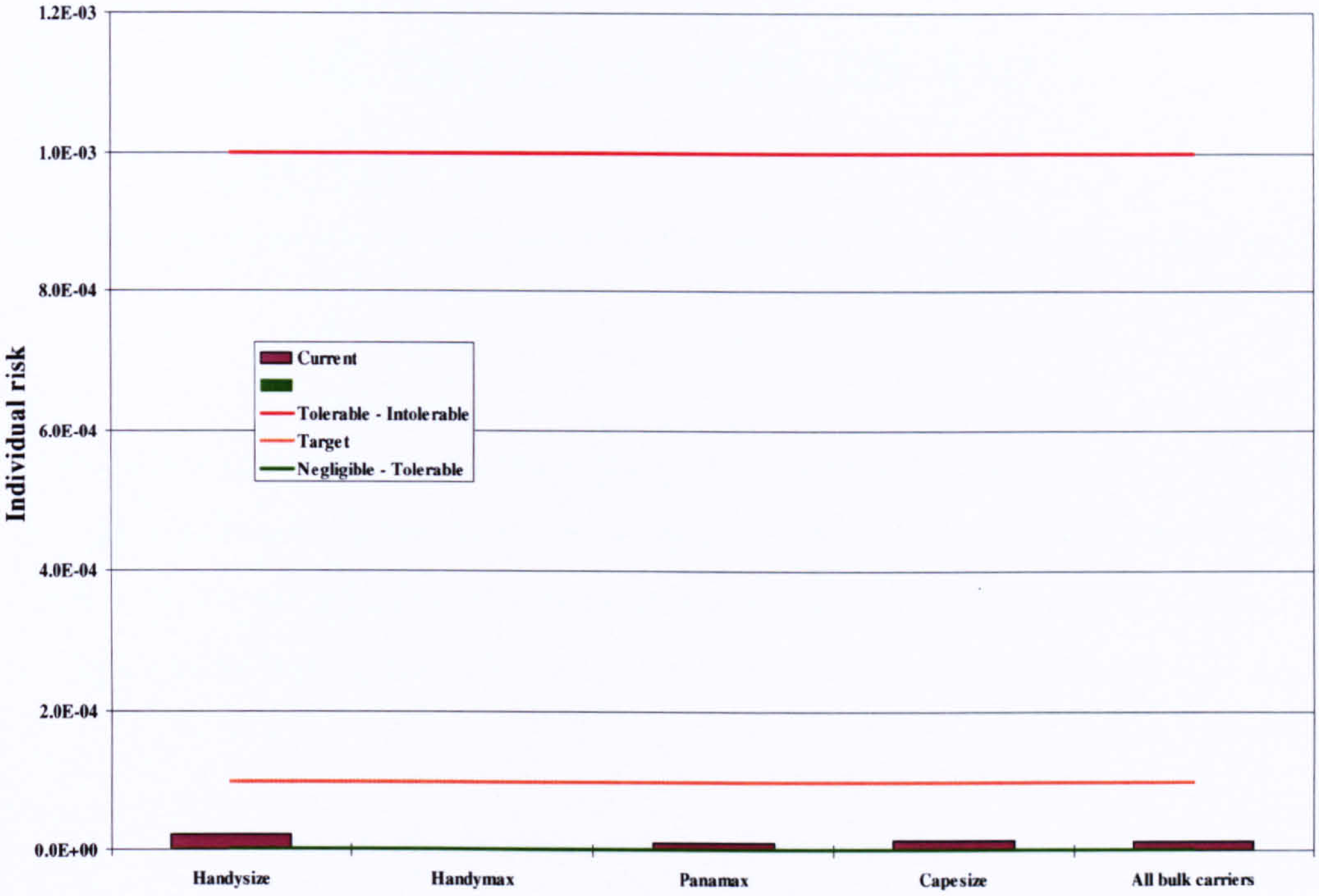


Figure 7.9. *Current individual risk (annual) for BC crew members*

7.8 Conclusions

It can be accepted that risk analysis is one of the most crucial steps of a risk assessment, since is viewed as a means of making a systematic evaluation of the risk from hazardous activities (i.e. ocean transportation of dry bulk cargoes) and making a rational evaluation of their significance in order to provide input to a decision – making process (measures against corrosion). The BN approach is considered to be successful for dealing with the uncertainties and weaknesses of FTA and ETA. Through the introduction of the vessel's risk (safety) index was attempted to construct suitable risk models in order to provide a rational decision support tool for assessing the uncertainty in the system's performance (dry bulk cargo transportation) and consequently the operational risk was found to be ALARP.

This page is intentionally left blank

8 The elusive art of risk control

> "Risks are conceptually uncontrollable; one can never know whether one is doing enough to prevent a hazard from occurring. Even after a hazard has occurred, one is still left with the question of how much more action would have been necessary to have prevented it, and whether such action would have been with the bounds of reasonable behaviour"
>
> Jerome R. Ravetz

8.1 Preamble

The BN developed as a high level risk model is extended to an ID where different design (passive) and operational (active) measures addressing corrosion are evaluated as an action implementing risk management decision. Moreover, their effectiveness as an option for accident prevention is illustrated by employing LCCA in the risk assessment process.

8.2 Introduction

Through risk assessment, a structured basis is provided for any analyst to identify hazards and to ensure that the risks have been reduced to appropriate levels in a cost – effective manner. It has been accepted that the purpose behind almost any risk assessment is to support some form of decision – making on safety matters. Decisions may be needed on issues such as (HSE 2002a):

1. Whether or not an activity should be permitted.
2. Whether measures are necessary to reduce its risks.
3. Which of various options, involving different combinations of safety and expenditure, should be selected.
4. How much should be invested in enhancing the safety of an installation.

In fact, to answer questions such as these, it needs to be decided when the activity or the installation is *safe enough*, i.e. there is a willingness to live with risk(s) so as to secure certain benefits and in the confidence that it is/they are being properly controlled (HSE 2002a). In this respect, ORM can be used as a tool to evaluate the costs and benefits of decisions regarding options to reduce those risks. In particular, the proposed solutions focus on the high risk areas identified in Chapter 7 (Risk analysis) and CBA aims at identifying benefits and costs associated with implementing the various identified options.

8.3 Managing and enhancing BC safety

By general consensus, the proposed solutions (RCOs) need to be effective, practical and comprised of the following stages (IMO 2002b, 2007b):

A.1. Focusing on risk areas needing control.
A.2. Identifying potential RCMs.
A.3. Evaluating the effectiveness of the RCMs in reducing risk by re – evaluating the quantitative assessment (Risk Analysis).
A.4. Grouping RCMs into practical regulatory options.

In general, RCMs should be aimed at one or more of the following (IMO 2002b, 2007b):

B.1. Reducing the frequency of failures through better design, procedures, organizational polices, training.
B.2. Mitigating the effect of failures, in order to prevent accidents.
B.3. Alleviating the circumstances in which failures may occur.
B.4. Mitigating the consequences of accidents.

New RCMs can be identified by engaging appropriate techniques such as risk attributes and developing causal chains, where the latter have been already included when developing the risk model. The prime purpose of attributes is to facilitate a structured thought process to understand how an RCM works, how it is applied and how it would operate. By way of reference, the attributes can be categorized as (IMO 2002b, 2007b):

- ***Passive*** where there is no action required to deliver the RCM, whilst ***active*** where the risk control is provided by the action of safety equipment or operators.
- ***Engineering*** where safety features are included (either built in or added on) within a design, whilst ***procedural*** where the operators are relied upon to control the risk by behaving in accordance with defined procedures.
- ***Preventive*** where the probability of the event is reduced, whilst ***mitigating*** where the severity of the outcome of the event or subsequent events is reduced.

As stated previously, corrosion wastage[11] needs to be addressed further (A.1) and potential RCMs together with their attributes are identified at **Table 8.I** (A.2). More precisely, these attributes aim at the establishment of adequate corrosion allowance where extensive steel renewals will not be deemed necessary before specified time intervals. The latter is addressed explicitly through ESP (SOLAS Ch. XI – 1, Reg. 2) and ISM Code (SOLAS Ch. IX) (IMO 2004a, IMO 2002a). For illustrative purposes, in **Figure 8.1** the use of the BN is shown for estimating the effect of RCMs (A.3).

A noteworthy comment can be the fact that the RCMs are applied to the Consequence Index Object only. From a first point of view, it could be argued that emphasis has been placed on reducing the consequences, whereas this paradox cannot be justified since through the Consequence Index (OOBN), the accident's (foundering) causal network is represented. Furthermore, the Likelihood Index (OOBN) is developed in a sense that the Market structure of dry bulk cargo transportation can be described and although two – tier market proposals already exist (Tamvakis and Thanopoulou 2000), the financial risk will not be dealt with. Moreover, any attempt for proposing trade discrimination will be opponent to common sense as this would impose the introduction of age limits and hence a race could be induced to build the cheapest and shortest life vessels (Donaldson of Lymington 1994).

---

[11] The reader should be referred to **Appendix F** for information regarding corrosion and its modelling.

TABLE 8.I. *Attribute assignment to the RCMs regarding corrosion wastage*

Risk Control Option: Corrosion Margin		
Attribute	**Risk Control Measure**	
	Corrosion addition	Enhanced replacement programme
Passive	X	
Active		X
Engineering	X	
Procedural		X
Preventive	X	
Mitigating		X

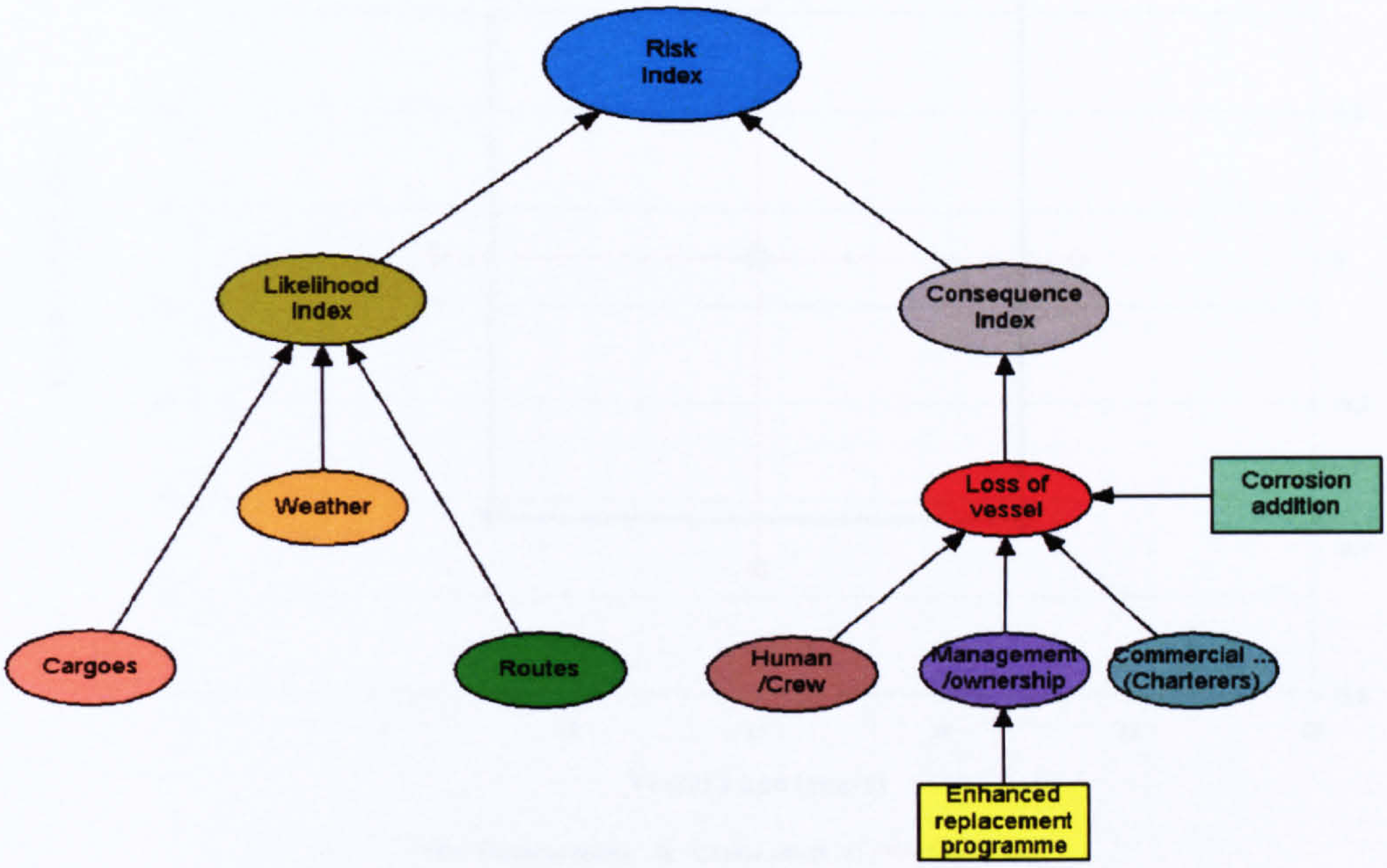


Figure 8.1. *Usage of ID to estimate the effect of RCMs*

8.3.1 Future risk prediction

The effectiveness of the RCMs is quantified by re – evaluating Risk Analysis (previous Chapter) and concurrently the results are presented at **Table 8.II** (prediction of future risk level). Since the original OOBN (consequence index) is augmented with decision nodes; the resulting model (Risk Index OOBN) is called an ID. The two – factor, five – level CCD was used (details are enclosed at **Appendix G**) and is shown at **Figure**

8.2, whereas for any comments regarding the RSM, the previous Chapter should be referred to. Again, in **Table 8.II**, the risk index values for each investigated accident are recorded by running the ID this time, since the decision nodes have been added as proposed risk reduction measures. Additionally, the nominal values of risk index together with the weighting factors from the multivariate analysis are recorded.

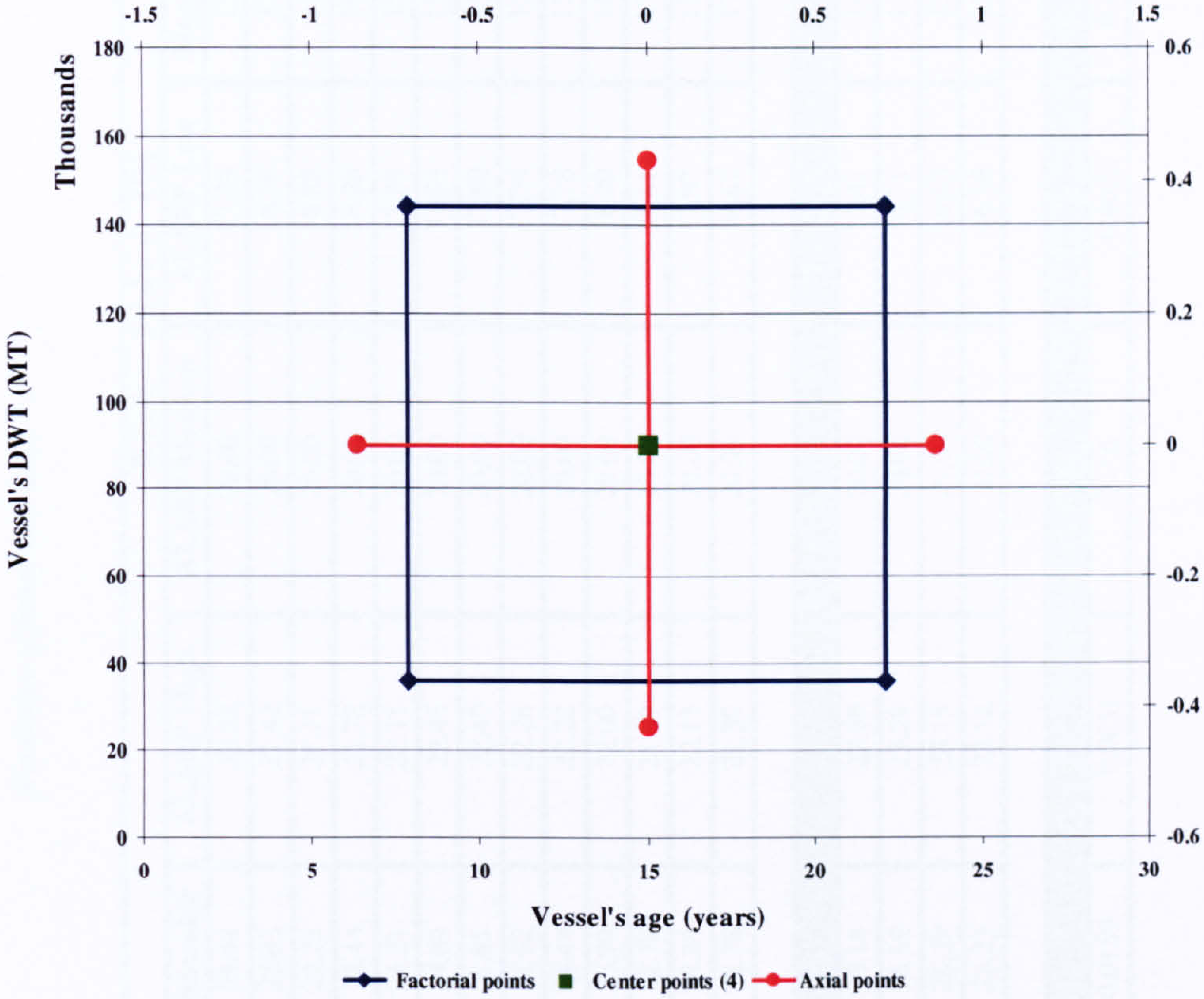


Figure 8.2. *CCD for the refined risk (prediction of future risk level)*

Bringing in mind what was mentioned in the previous Chapter, the fitted models for the refined risk and safety index are respectively:

$$\hat{Y} = 17.72 - 0.13 \cdot X_1 - 1.17 \cdot X_2 - 0.45 \cdot X_1^2 - 0.54 \cdot X_2^2 - 0.34 \cdot X_1 \cdot X_2 \qquad (8.1)$$

$$\hat{Y}_{com} = 82.28 + 0.13 \cdot X_1 + 1.17 \cdot X_2 + 0.45 \cdot X_1^2 + 0.54 \cdot X_2^2 + 0.34 \cdot X_1 \cdot X_2 \qquad (8.2)$$

TABLE 8.II. *Effect of RCMs on the risk index for the available accident investigation reports, nominal values of Risk Index and weighting factors*

(Prediction of future risk level)

Name	Age	DWT	Risk Index (%)						
			Intolerable	ALARP High	ALARP Medium	ALARP Low	Negligible	Cov[R]	$Risk_{Ref}$
Adamandas	17	22580	24.44	22.22	20.00	17.78	15.56	13.84	17.15
Alexadre-P	23	94532	22.83	21.42	20.00	18.58	17.17	7.34	18.19
Daeyang Honey	22	123745	22.23	21.11	20.00	18.89	17.77	5.78	18.58
Derbyshire	4	172200	23.44	21.72	20.00	18.28	16.56	8.91	17.81
Edmund Fitzerald	17	27460	24.21	22.11	20.00	17.89	15.79	13.13	17.31
Flare	26	28761	24.89	22.45	20.00	17.55	15.11	15.25	16.86
Leader L	23	69120	24.81	22.40	20.00	17.60	15.19	15.84	16.92
Manila Transporter	15	115960	24.52	22.26	20.00	17.74	15.48	11.71	17.11
Marine Electric	31	25575	24.44	22.22	20.00	17.78	15.56	13.84	17.15
Melete	16	72060	23.99	22.00	20.00	18.00	16.01	13.15	17.44
Mineral Diamond	9	141028	22.78	21.39	20.00	18.61	17.22	7.21	18.22
Singa Sea	12	26586	24.26	22.13	20.00	17.87	15.74	13.28	17.27
Starfish	21	56277	22.78	21.39	20.00	18.61	17.22	9.16	18.22
	Vessel size		**Nominal values**						
	Capesize		25.18	22.59	20.00	17.41	14.82		
	Panamax		26.59	23.29	20.00	16.71	13.41		
	Handymax		26.29	23.15	20.00	16.85	13.71		
	Handysize		26.23	23.12	20.00	16.88	13.77		
			Weighting factor (w_i)						
			0.0159	0.0631	N/A	0.4632	0.4578		

By plotting the contours (**Figure 8.3**) and the response surface (**Figure 8.4**) the system's performance could be characterized as similar as the one without the RCMs. It can be observed that when the vessels enter service, there would be 17.5 % uncertainty (19.5 % before) of something that might go wrong which would be increased up to 18 % (21.5 % before) until their 20 – year anniversary, decreasing afterwards. It is also revealed that the predicted future safety level of BCs would be around 82 % (80 % before) with the minimum appearing between the ages of 17 – 19 years. Apparently, the improvements after the proposed solution will be introduced are obvious (B.1 – B.4). The current risk level was identified to be ALARP Low for capesize, panamax and handymax whilst for handysize vessels and all bulk carriers was ALARP High. From **Figures 8.5** and **8.6** can be seen that the future risk level for handysize vessels and all bulk carriers would still be ALARP High, but slightly decreased whereas for the other types would be ALARP Low with minor decreases, whilst the individual risk would be tolerable and slightly decreased. This downward trend is illustrated clearly at **Figure 8.7** for the PLL. Despite the fact that the risk level would be slightly reduced, the importance of introducing the proposed solution is associated with maintaining the tolerability level of risks. Hence, the two proposed RCMs can be effectively grouped into regulatory option (adequate corrosion margin) regarding protection against corrosion (A.4).

8.3.2 Decision – making

Technical standards are issued by IMO, classification societies, national authorities (flag administrations) and industry bodies but the adoption is agreed through IMO. It is expected that the performance of any vessel will be underpinned under the compliance of existing and new regulations which the latter are justified through risk assessment and the risks are ensured to be ALARP (HSE 2002a). Obviously, the purpose of ORM is to contribute to solutions that might affect the routine operations by using an integrated and holistic approach where risk assessment and decision – making are linked. Hence, by adopting that *risk – informed* approach, performance observations are included in the risk assessment as a basis for attaining optimal solutions whilst safety is treated as an objective and not as a constraint (see § **5.4**).

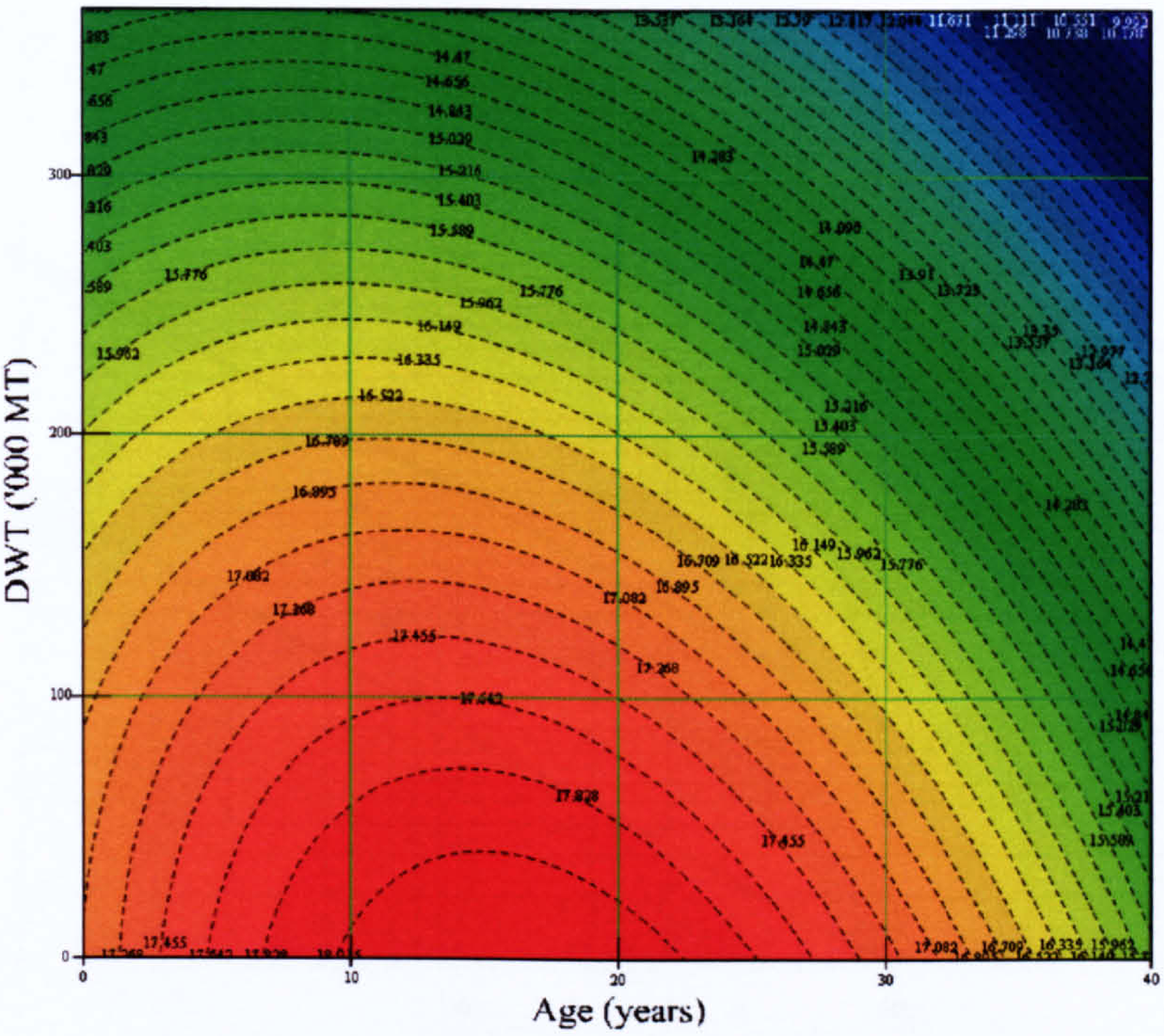


Figure 8.3. *Contour plots for the refined risk (future prediction)*

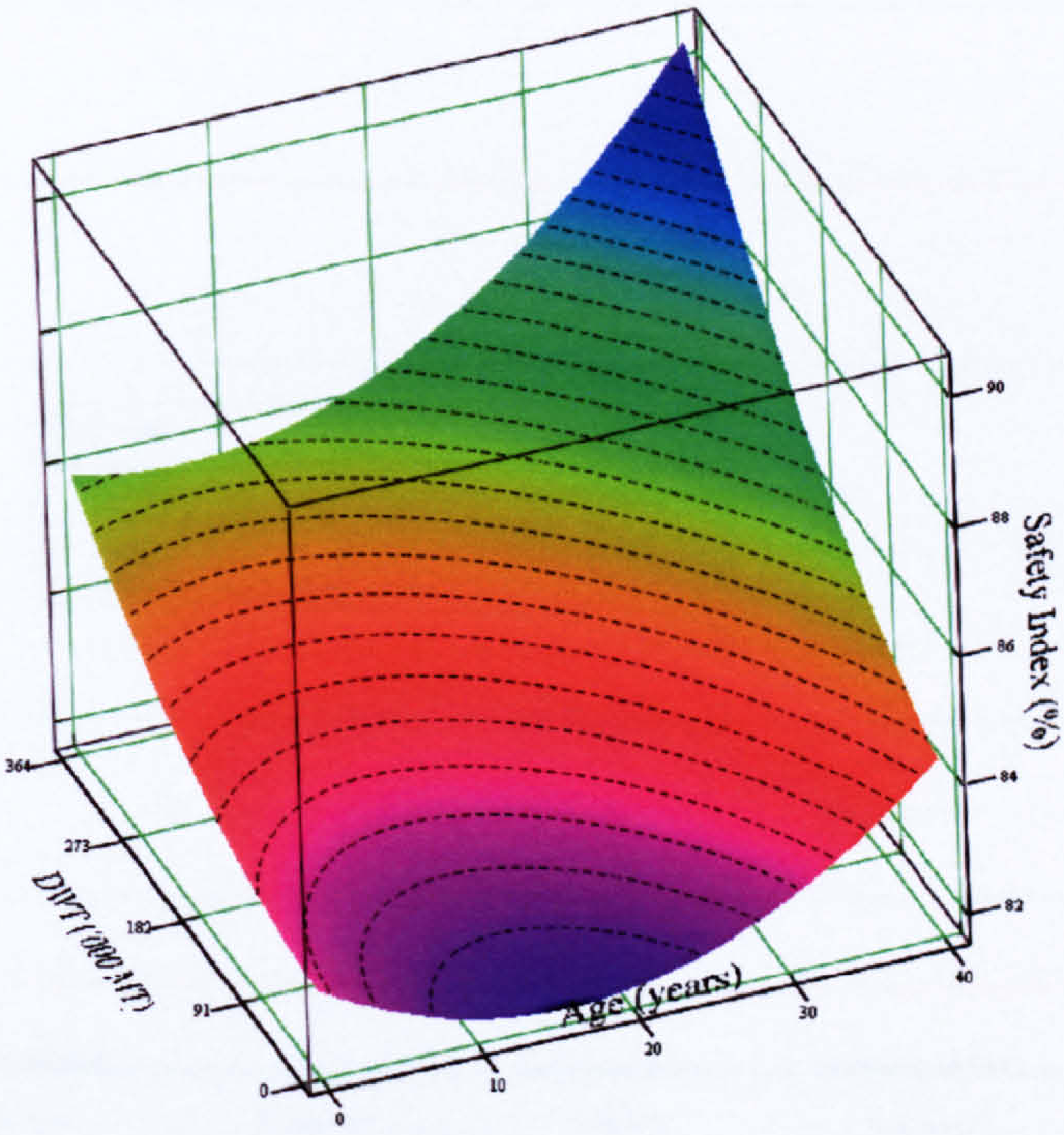


Figure 8.4. *Response surface of safety index (future prediction)*

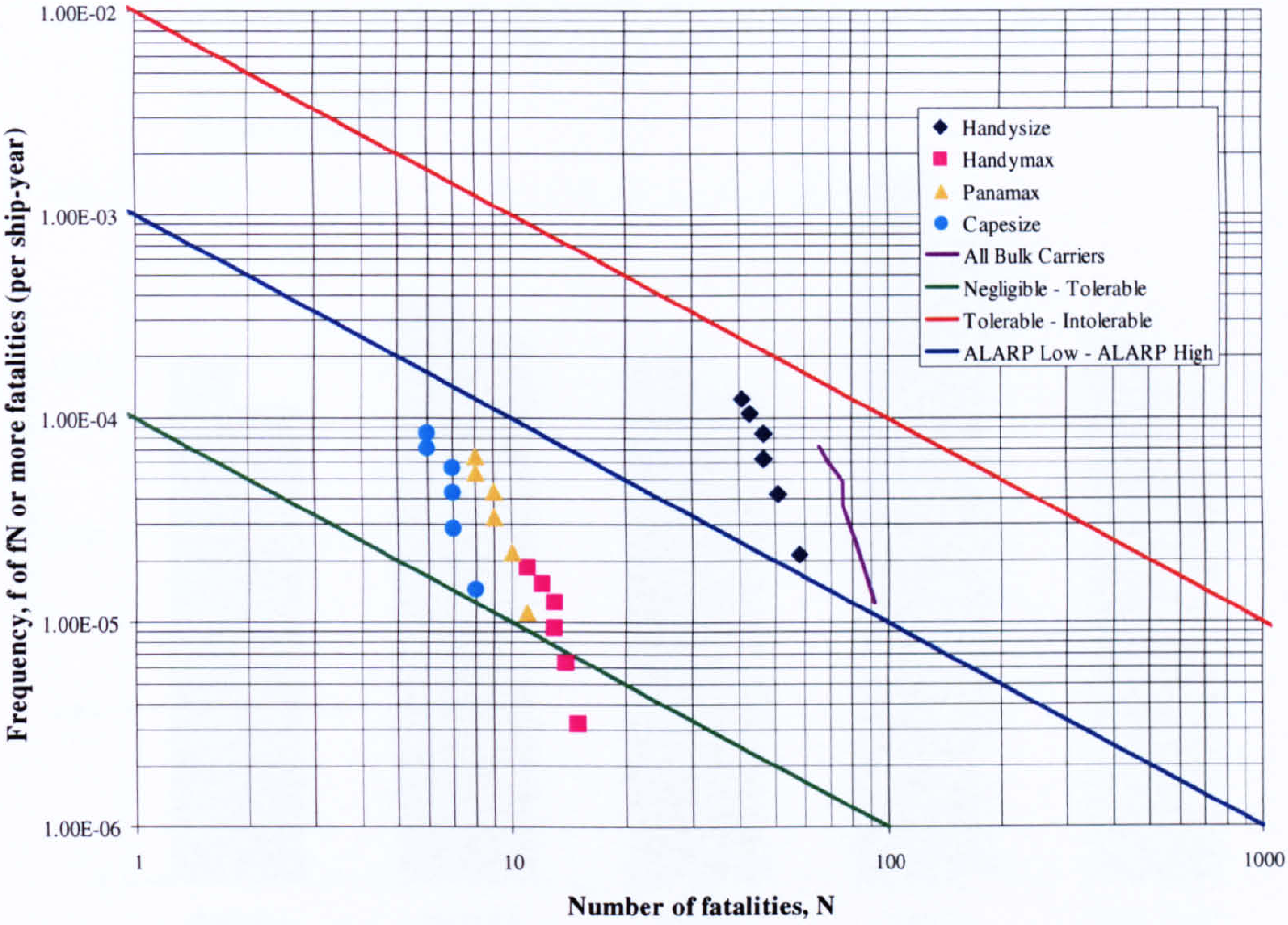


Figure 8.5. *F-N diagram of BC future risk level (predicted)*

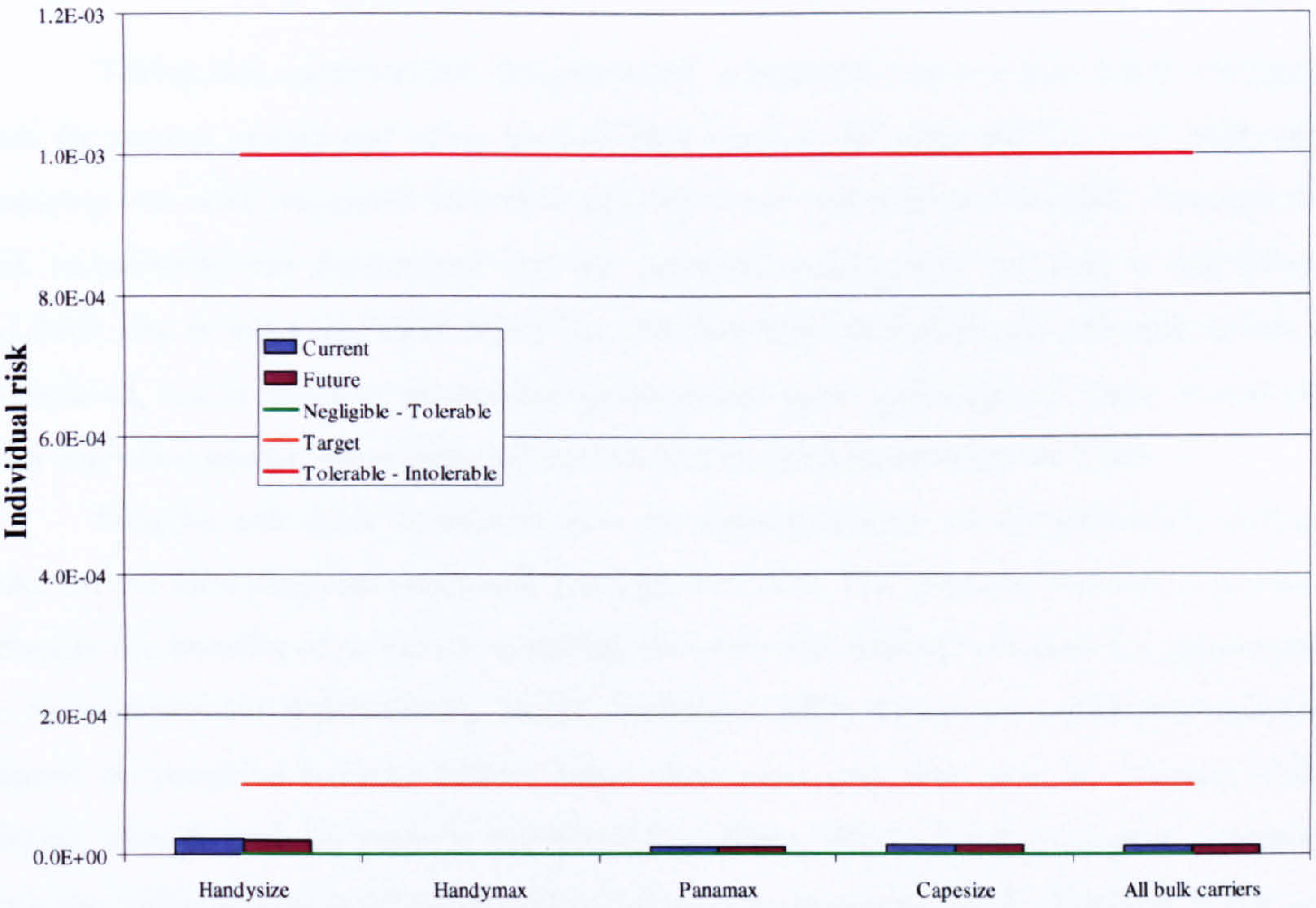


Figure 8.6. *Future individual risk (annual) for BC crew members (predicted)*

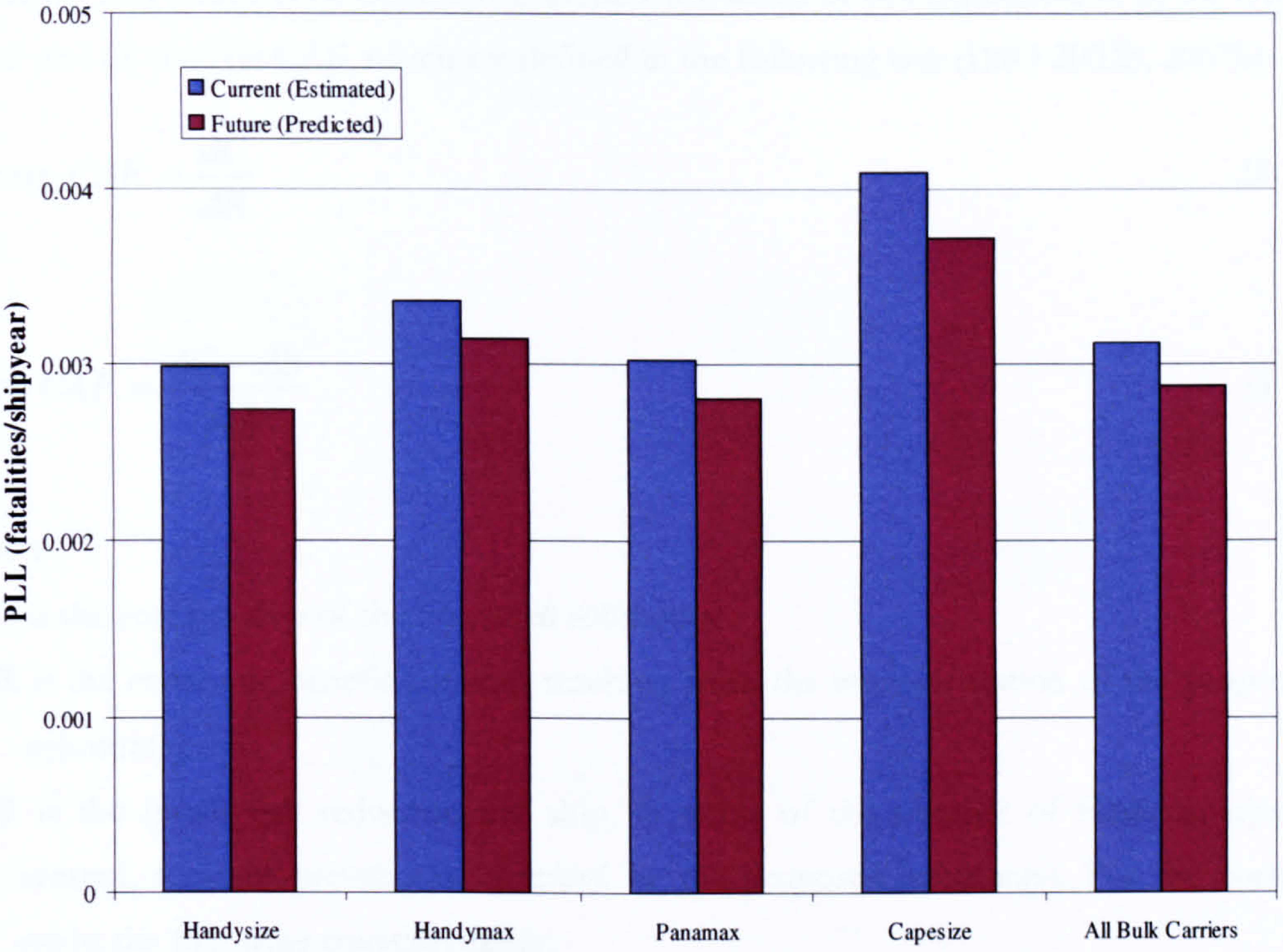


Figure 8.7. *Effect of the proposed RCO in PLL*

Taking into consideration the previously mentioned matters, it is clearly envisaged that the current operational safety level of BCs needs to be maintained or even improved, implying that risks associated with their operations are tolerable and ALARP. Through the risk assessment, was determined that the predicted safety level not only is maintained ALARP, but is improved also. Since the risk has been evaluated; the risk assessment is completed, but in order to answer the question *how safe is safe enough*, i.e. does it worth to turn corrosion margin into regulatory option, will be demonstrated by the CBA.

Benefits and costs associated with the implementation of the previously defined solution are identified and compared through the CBA. The purpose of CBA is to show whether the benefits of an option outweigh its costs, thus indicate whether it is appropriate to be implemented (IMO 2002b, 2007b, Mathiesen 1997). However, a definitive decision cannot be provided because factors other than costs and risks may be relevant (HSE 2002a), though a useful guide is provided. The direct effect of risk reduction associated with the implementation of the proposed solution is accounted for in the CEA. There are currently two measures of CEA in use within the context of risk management: (i) the Gross CAF and (ii) the Net CAF, which are defined in the following way (IMO 2002b, 2007b):

$$\textit{Gross CAF} = \frac{\Delta C}{\Delta R} \tag{8.3}$$

$$\textit{Net CAF} = \frac{\Delta C - \Delta B}{\Delta R} \tag{8.4}$$

where:

ΔC: is the cost per ship of the proposed solution(s).

ΔB: is the economic benefit per ship resulting from the implementation of the proposed solution(s).

ΔR: is the (total) risk reduction per ship, in terms of the number of fatalities/injuries averted, accident prevention, implied by the proposed solution(s). For the current study, the following equation exists:

$$\Delta R = \int_0^t \left(\int_0^{DWT} \Delta f(X_1, X_2)\, dDWT \right) dt \tag{8.5}$$

with $\Delta f(X_1, X_2)$ the risk index difference defined by the CCD.

In principle, all applicable costs over the whole life cycle of the proposed solution(s) should be accounted for, i.e. initial, operating, training, inspection, certification, decommissioning. Concurrently, all benefits that apply should be taken into consideration, i.e. reduction in fatalities/injuries, environmental damage as well as increase in average vessel's life, operating margins (IMO 2002b, 2007b).

The ID previously developed is extended with the utility node (**Figure 8.8**) considering four different alternatives (**newbuilding vessels**):

- **Alternative A:** 0.5 mm increase.
- **Alternative B:** 1.0 mm increase.
- **Alternative C:** 1.5 mm increase.
- **Alternative D:** 2.0 mm increase.

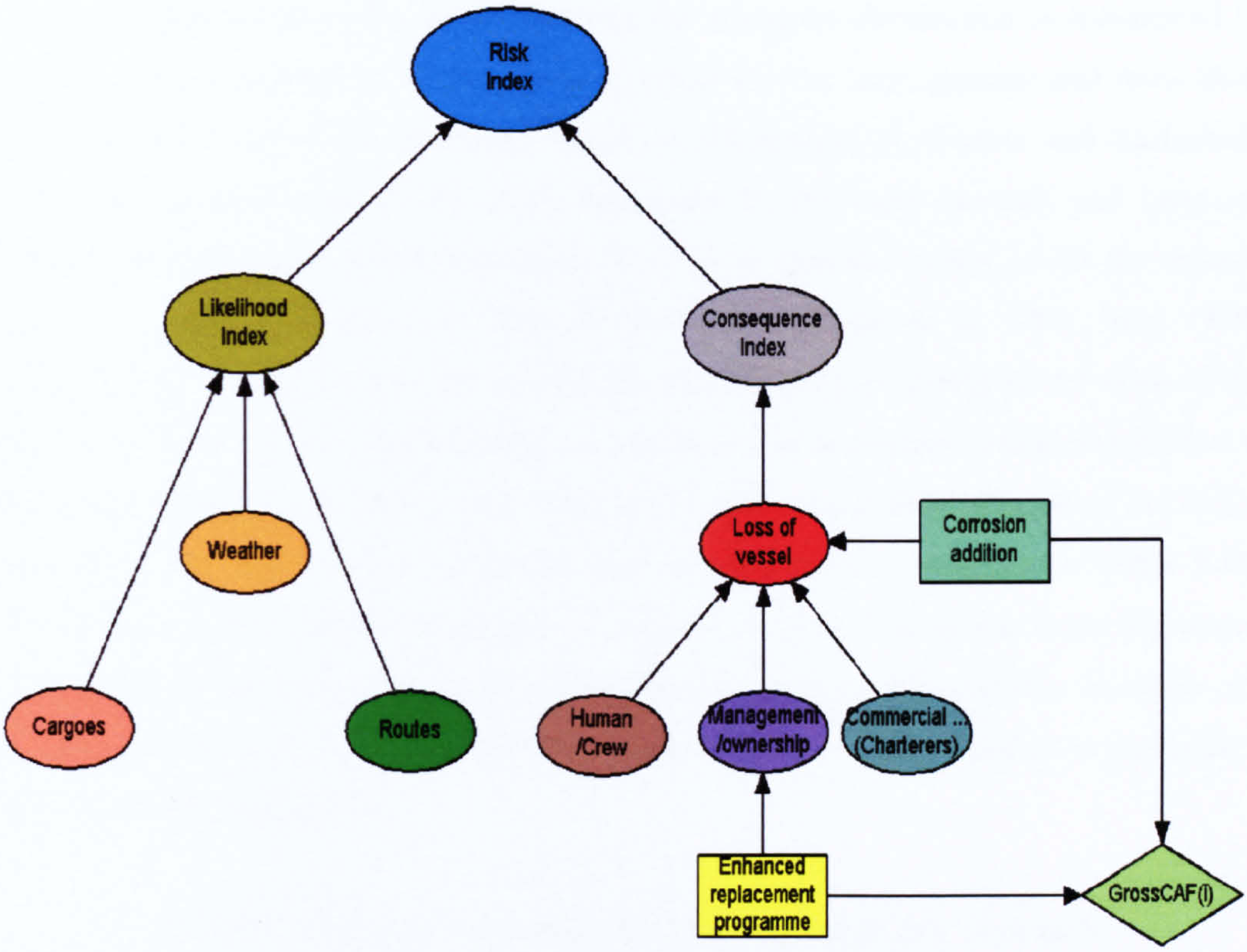


Figure 8.8. *Usage of ID to estimate the effect of RCM alternatives*

The evaluation of the four alternatives is performed using LCCA with the NPV as the final indicator whereas the resulting Gross CAF is used for filling the ID's CPTs. Only the differential costs that are anticipated are included in the analysis whilst operating (excluding repairs and maintenance) and voyage costs[12] are assumed to be equal for all alternatives and accordingly are excluded. The probabilistic approach is preferred by employing Monte Carlo simulation which is also extended to perform sensitivity analysis for different inflation environments, i.e. the proportionate rate of change in the general price level, as opposed to the proportionate increase in a specific price.

Most cost – related items (Gratsos and Zachariadis 2005, Løseth et al. 1994, Japan 2002d, UK 2002a, Guarin and Vassalos 2004) are usually a speculative estimate of the costs or benefits anticipated throughout the vessel's life – cycle. Thus, this uncertainty is

---

[12]

Operating costs	:	manning, stores and lubricants, repairs and maintenance, insurance, administration
Voyage costs	:	fuel and diesel oil, port fees

Source: Stopford (2009)

considered appropriate to be modelled using the triangular distribution as manifested by Osman (2005) and Back et al. (2000), since values for the least, greatest and most likely costs are rather easy to be estimated. Based on information by Gratsos and Zachariadis (2005) incorporated with results from **Appendix F**, the steel renewals and increased lightship are assumed to follow lognormal distribution (positive values) whilst the reduced off – hire time is modelled by Weibull distribution (Evans et al. 2000, Bury 1999). Furthermore, the variability in the vessel's life and the percent change in the value of the dollar per period of time (discounting) are considered by using the normal distribution in consistency with Greece (2005) and Ozbay et al. (2003) respectively. Details of the LCCA parameters and their corresponding statistical distributions are provided in **Table 8.III.** Exactly what (cost) components should be included in the LCCA exercise is not the subject of total agreement and it is probable very valid that opinions should differ. However, the list that is developed needs to be adequate to identify the potential interaction and trade – off between the alternatives.

TABLE 8.III. *Statistical distributions and parameters for LCCA variables*

Category	Variable	Distribution	Parameters
Environment – related	Reduction ratio (5% Inflation)	Normal	$(0.048, 0.012^2)$
	Reduction ratio (10% Inflation)	Normal	$(0.091, 0.016^2)$
	Reduction ratio (15% Inflation)	Normal	$(0.1304, 0.022^2)$
Performance – related	Vessel's lifetime (years)	Normal	$(27, 4^2)$
	Reduced off – hire time A (days)	Weibull	(92, 183)
	Reduced off – hire time B (days)	Weibull	(92, 457)
	Reduced off – hire time C (days)	Weibull	(274, 639)
	Reduced off – hire time D (days)	Weibull	(365, 822)
Cost – related	Recycle (scrap) value (USD/t)	Triangular	(110, 190, 390)
	Initial construction (USD/t)	Triangular	(1500, 2250, 3000)
	Rehabilitation activities[13] (USD/t)	Triangular	(2500, 5000, 8500)
	Handysize loss of income (USD/d/t)	Triangular	(7200, 8450, 13000)
	Handymax loss of income (USD/d/t)	Triangular	(9300, 10888, 16750)
	Panamax loss of income (USD/d/t)	Triangular	(10400, 13000, 20000)
	Capesize loss of income (USD/d/t)	Triangular	(17500, 27625, 42500)
	Handysize benefit light (USD/d/t)	Triangular	(11232, 14040, 21622)
	Handysize benefit heavy (USD/d/t)	Triangular	(7488, 9360, 14415)
	Handymax benefit light (USD/d/t)	Triangular	(17760, 22200, 34188)

---

[13] Periodic maintenance every 5 years including survey (Special Survey – SS) and repair costs (Løseth et al. 1994).

TABLE 8.III (continued). *Statistical distributions and parameters LCCA variables*

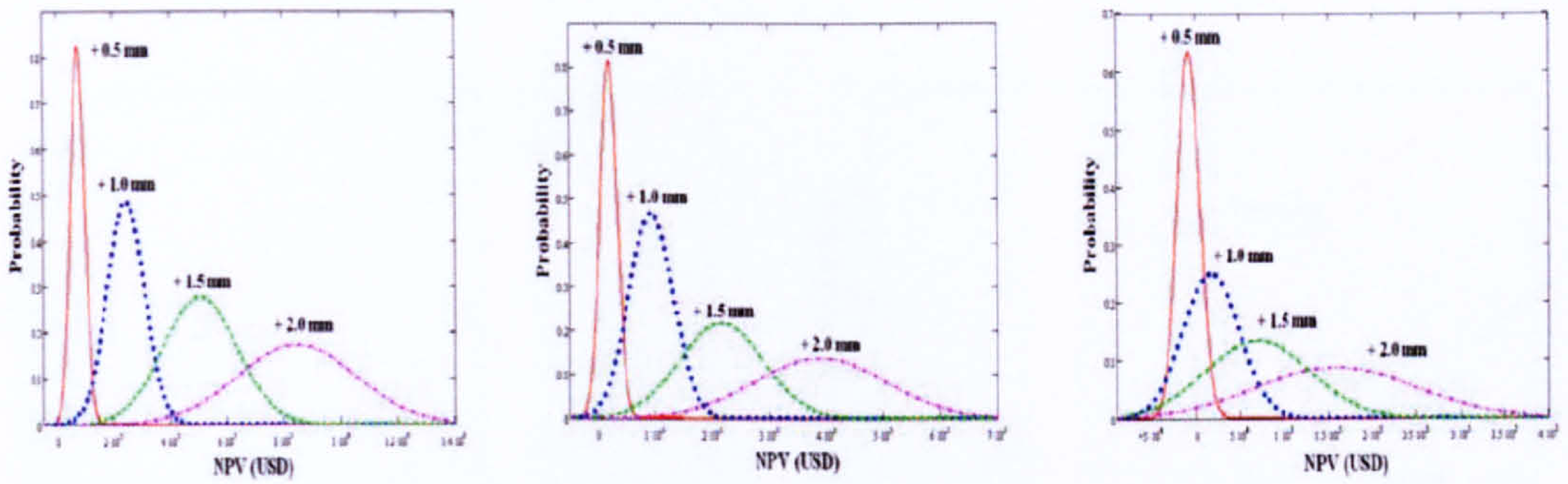
Category	Variable	Distribution	Parameters
Cost – related	Handymax benefit heavy (USD/d/t)	Triangular	(10656, 13320, 20513)
	Panamax benefit light (USD/d/t)	Triangular	(22592, 28240, 43490)
	Panamax benefit heavy (USD/d/t)	Triangular	(11296, 14120, 21745)
	Capesize benefit light (USD/d/t)	Triangular	(57920, 72400, 111496)
	Capesize benefit heavy (USD/d/t)	Triangular	(28960, 36200, 55748)
Function – related	Handysize increased Lightship A (t)	Lognormal	(41, 1.03^2)
	Handysize increased Lightship B (t)	Lognormal	(93, 2.33^2)
	Handysize increased Lightship C (t)	Lognormal	(161, 4.03^2)
	Handysize increased Lightship D (t)	Lognormal	(232, 5.80^2)
	Handymax increased Lightship A (t)	Lognormal	(86, 2.15^2)
	Handymax increased Lightship B (t)	Lognormal	(171, 4.28^2)
	Handymax increased Lightship C (t)	Lognormal	(256, 6.40^2)
	Handymax increased Lightship D (t)	Lognormal	(341, 8.53^2)
	Panamax increased Lightship A (t)	Lognormal	(196, 4.90^2)
	Panamax increased Lightship B (t)	Lognormal	(308, 7.70^2)
	Panamax increased Lightship C (t)	Lognormal	(419, 10.48^2)
	Panamax increased Lightship D (t)	Lognormal	(531, 13.28^2)
	Capesize increased Lightship A (t)	Lognormal	(213, 5.33^2)
	Capesize increased Lightship B (t)	Lognormal	(425, 10.63^2)
	Capesize increased Lightship C (t)	Lognormal	(638, 15.95^2)
	Capesize increased Lightship D (t)	Lognormal	(851, 21.28^2)
	Handysize rehabilitation A/3SS	Lognormal	(24, 1.20^2)
	Handysize rehabilitation A/4SS	Lognormal	(110, 5.50^2)
	Handysize rehabilitation A/5SS	Lognormal	(184, 9.20^2)
	Handysize rehabilitation B/3SS	Lognormal	(16, 0.80^2)
	Handysize rehabilitation B/4SS	Lognormal	(71, 3.55^2)
	Handysize rehabilitation B/5SS	Lognormal	(117, 5.85^2)
	Handysize rehabilitation C/3SS	Lognormal	(10, 0.50^2)
	Handysize rehabilitation C/4SS	Lognormal	(46, 2.30^2)
	Handysize rehabilitation C/5SS	Lognormal	(76, 3.80^2)
	Handysize rehabilitation D/3SS	Lognormal	(5, 0.25^2)
	Handysize rehabilitation D/4SS	Lognormal	(23, 1.15^2)
	Handysize rehabilitation D/5SS	Lognormal	(38, 1.90^2)
	Handymax rehabilitation A/3SS	Lognormal	(37, 1.85^2)
	Handymax rehabilitation A/4SS	Lognormal	(169, 8.45^2)
	Handymax rehabilitation A/5SS	Lognormal	(282, 14.10^2)
	Handymax rehabilitation B/3SS	Lognormal	(24, 1.20^2)
	Handymax rehabilitation B/4SS	Lognormal	(108, 5.40^2)
	Handymax rehabilitation B/5SS	Lognormal	(180, 9.00^2)
	Handymax rehabilitation C/3SS	Lognormal	(15, 0.75^2)
	Handymax rehabilitation C/4SS	Lognormal	(70, 3.50^2)
	Handymax rehabilitation C/5SS	Lognormal	(116, 5.80^2)
	Handymax rehabilitation D/3SS	Lognormal	(8, 0.40^2)
	Handymax rehabilitation D/4SS	Lognormal	(35, 1.75^2)

TABLE 8.III (continued). *Statistical distributions and parameters LCCA variables*

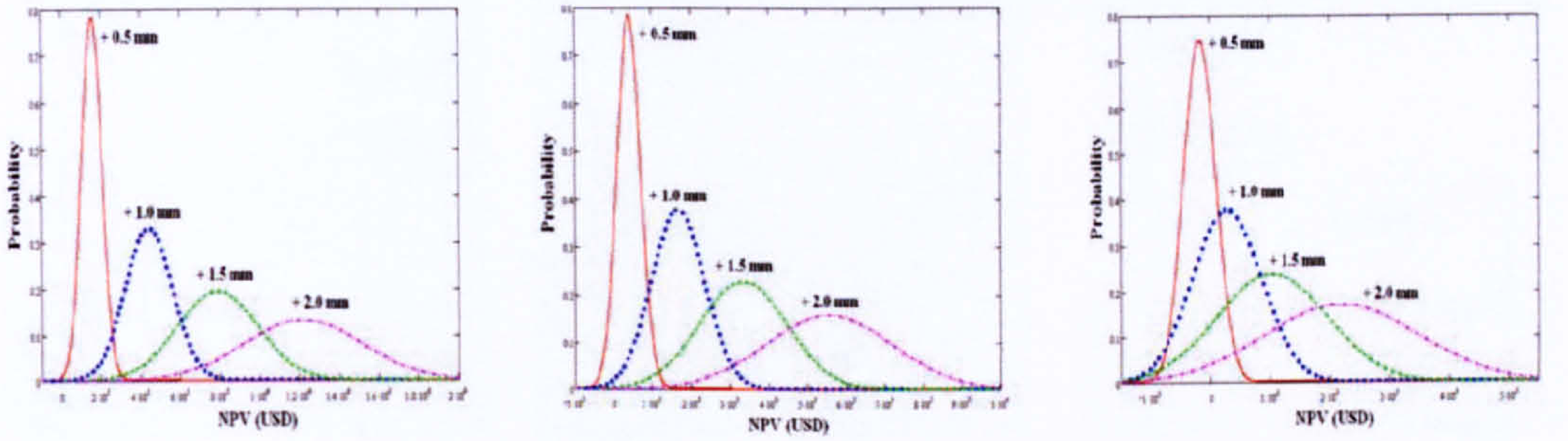
Category	Variable	Distribution	Parameters
Function – related	Handymax rehabilitation D/5SS	Lognormal	$(58, 2.90^2)$
	Panamax rehabilitation A/3SS	Lognormal	$(44, 2.20^2)$
	Panamax rehabilitation A/4SS	Lognormal	$(204, 10.20^2)$
	Panamax rehabilitation A/5SS	Lognormal	$(340, 17.00^2)$
	Panamax rehabilitation B/3SS	Lognormal	$(28, 1.40^2)$
	Panamax rehabilitation B/4SS	Lognormal	$(130, 6.50^2)$
	Panamax rehabilitation B/5SS	Lognormal	$(217, 10.85^2)$
	Panamax rehabilitation C/3SS	Lognormal	$(18, 0.90^2)$
	Panamax rehabilitation C/4SS	Lognormal	$(84, 4.20^2)$
	Panamax rehabilitation C/5SS	Lognormal	$(140, 7.00^2)$
	Panamax rehabilitation D/3SS	Lognormal	$(9, 0.45^2)$
	Panamax rehabilitation D/4SS	Lognormal	$(42, 2.10^2)$
	Panamax rehabilitation D/5SS	Lognormal	$(70, 3.50^2)$
	Capesize rehabilitation A/3SS	Lognormal	$(88, 4.40^2)$
	Capesize rehabilitation A/4SS	Lognormal	$(408, 20.40^2)$
	Capesize rehabilitation A/5SS	Lognormal	$(680, 34.00^2)$
	Capesize rehabilitation B/3SS	Lognormal	$(56, 2.80^2)$
	Capesize rehabilitation B/4SS	Lognormal	$(260, 13.00^2)$
	Capesize rehabilitation B/5SS	Lognormal	$(434, 21.70^2)$
	Capesize rehabilitation C/3SS	Lognormal	$(36, 1.80^2)$
	Capesize rehabilitation C/4SS	Lognormal	$(168, 8.40^2)$
	Capesize rehabilitation C/5SS	Lognormal	$(280, 14.00^2)$
	Capesize rehabilitation D/3SS	Lognormal	$(18, 0.90^2)$
	Capesize rehabilitation D/4SS	Lognormal	$(84, 4.20^2)$
	Capesize rehabilitation D/5SS	Lognormal	$(140, 7.00^2)$

Monte Carlo simulation is used to generate the distribution of possible PVs. Samples are taken from the input variable distributions and the corresponding NPV that is function of these variables is evaluated. The process is repeated for 500,000 iterations and the resulting values are used to obtain the density and cumulative distributions of ΔR, PV, NPV, Gross and Net CAF (**Appendix G**). In **Figure 8.9** the NPV density functions are illustrated for different inflation environments per alternative and vessel's type. Although the mean value of NPV is increased by adding more corrosion margin, a wider distribution yields a riskier alternative in comparison to a narrower distribution. Sometimes decision – makers prefer less risky projects even if the mean of the NPV is less than the riskier alternatives. From **Appendix F** has been proved that alternatives A and B seem to be adequate in comparison to alternatives C and D, hence more evidence is needed for deriving correct decision between A and B.

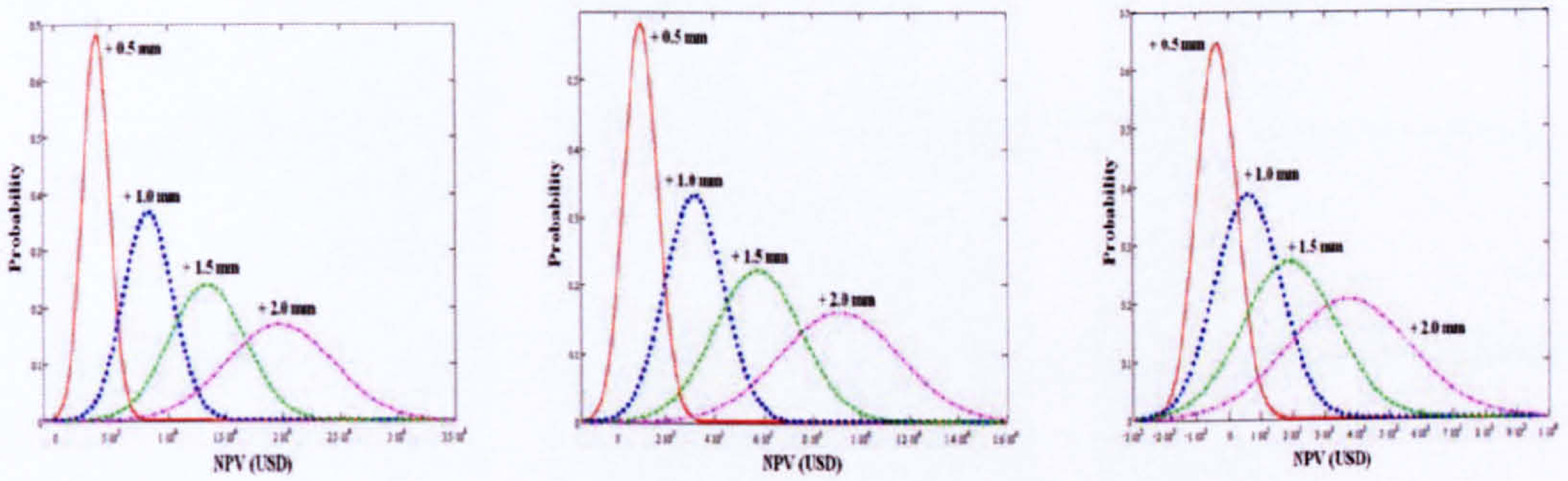
Since the probabilistic approach can also be extended to perform the sensitivity analysis, with this type of analysis any anticipated variation can be identified. The discount rate (in relation with the inflation environment) employed in the LCCA is one of the most sensitive parameters and has a great effect on the final outcome. A lower discount rate would favour projects that have larger capital investments; and conversely higher discount rates would favour projects that have higher future costs. Intuitively, it is believed that the future could be expected with 5% inflation, the past could be approximated with 10% inflation whilst the 15% inflation is considered as an extreme scenario for exploring investment opportunities. By plotting the NPV cumulative probability distribution of all alternatives on the same graph (**Figure 8.10**) the comparison can be interpreted directly. It is obvious that the probability of alternative A having a larger NPV than alternative B is less than 10% for handysize, handymax and panamax vessels whereas in the case of capesize is more than 20%. From this peculiar observation the decision – maker is driven to undertake additional result exploitation. The uncertainty in the expected profit return can be expressed by the NPV COV (**Figure 8.11**, 15% inflation curve) where it is shown that maximum is appeared by considering alternative B for handysize, handymax and panamax vessels whilst alternative C for capesize vessels. Thus, it is asserted that the corrosion margins depend on the vessel's type and should be addressed for each type separately.



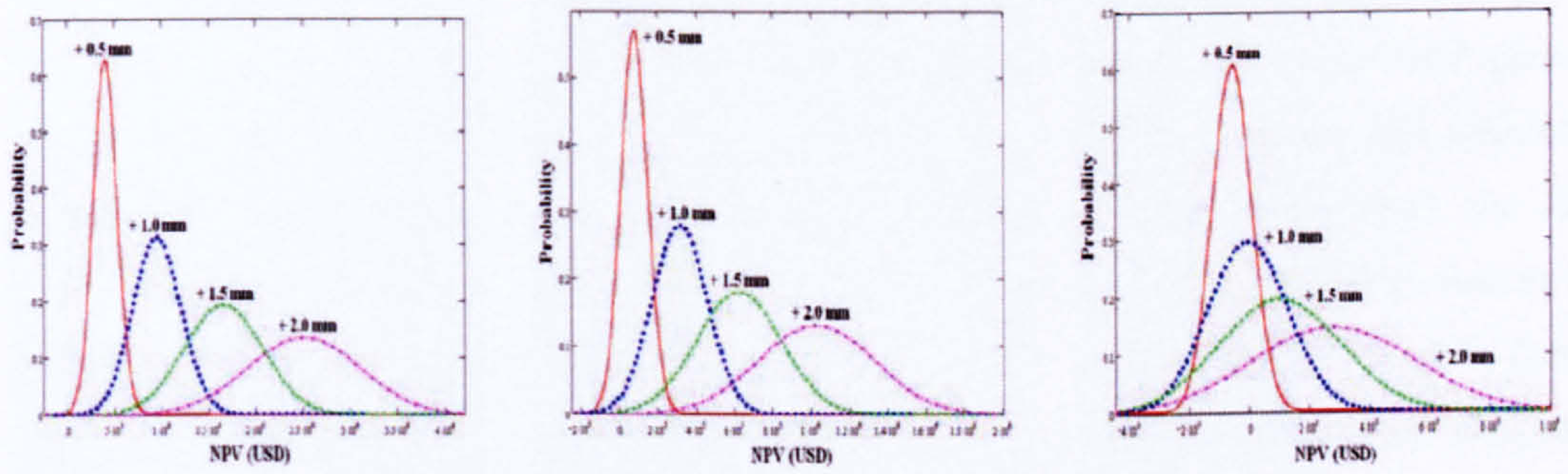
a. Handysize: 5% Inflation b. Handysize:10% Inflation c. Handysize:15% Inflation



d. Handymax: 5% Inflation e. Handymax:10%Inflation f. Handymax:15% Inflation

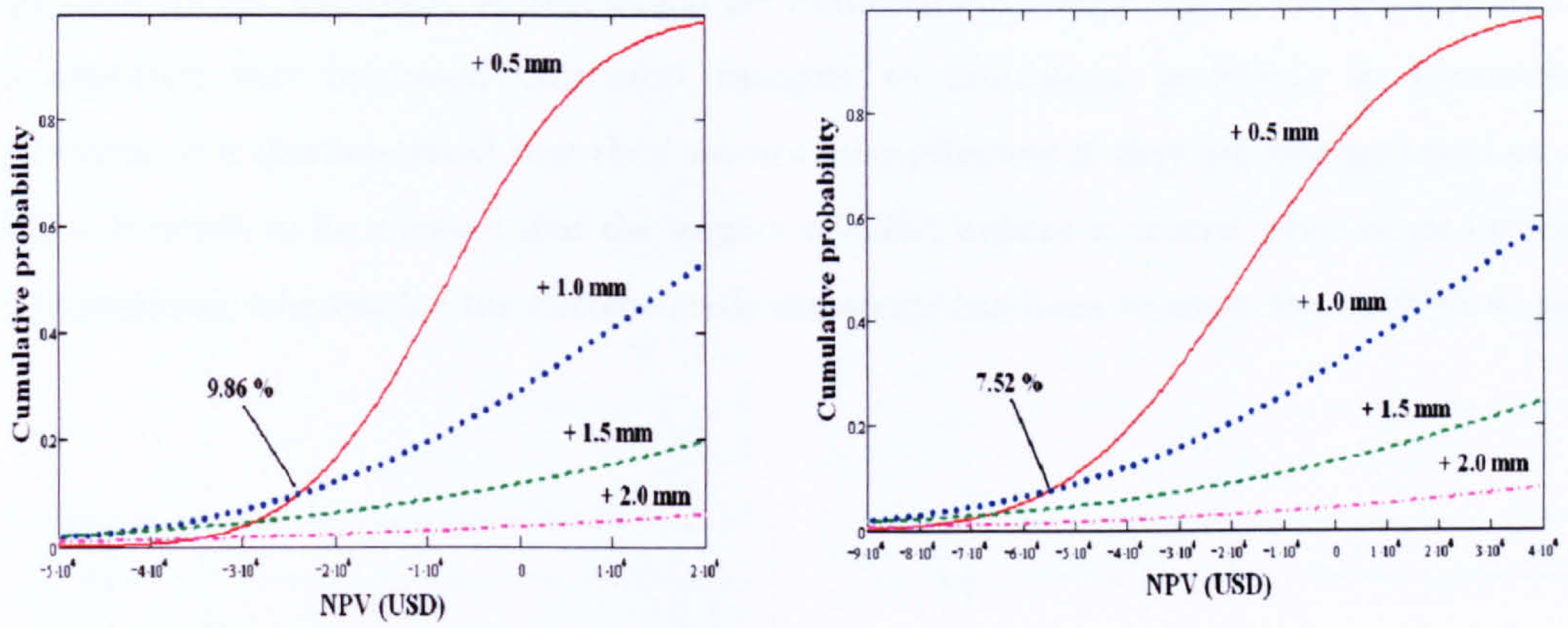


g. Panamax: 5% Inflation h. Panamax: 10% Inflation i. Panamax: 15% Inflation

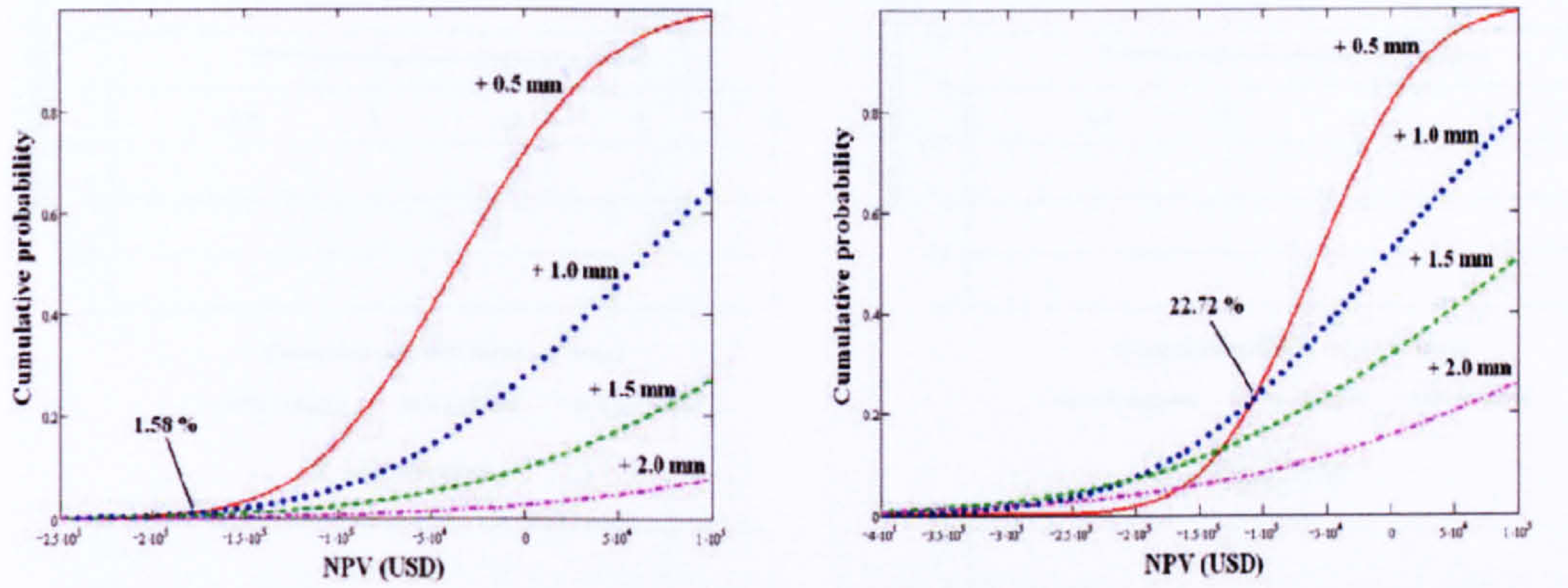


j. Capesize: 5% Inflation k. Capesize: 10% Inflation l. Capesize: 15% Inflation

Figure 8.9. *NPV PDFs per alternative and vessel type considering different inflation rates (99% confidence limits)*



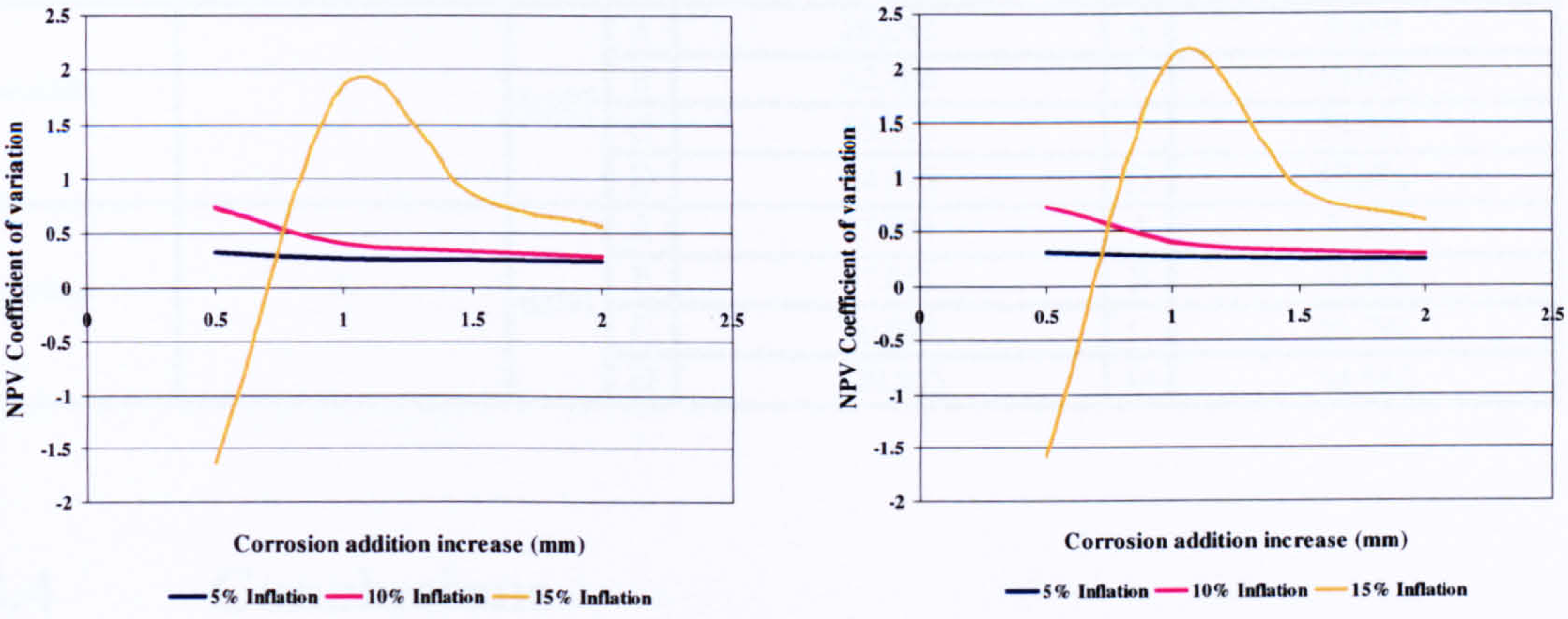
a. Handysize b. Handymax



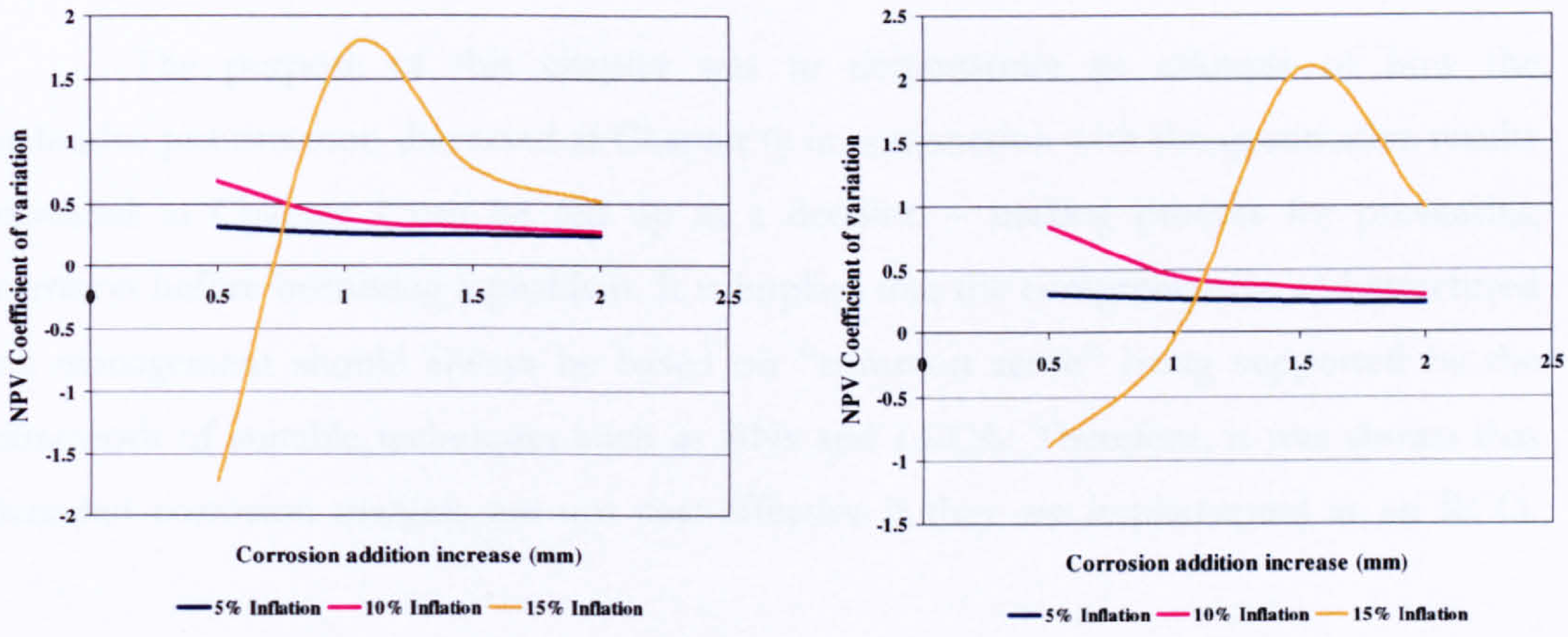
c. Panamax d. Capesize

Figure 8.10. *NPV cumulative probability per alternative and vessel type considering 15% inflation (99% confidence limits)*

In **Table 8.IV** the results of CEA are presented where it is demonstrated that due to a very small reduction of saved lives (except handysize vessels), the Gross CAF (total) values are high, which indicates that as a measure for averting fatalities and accident prevention, increased corrosion margins are not effective. Furthermore, from the ID derived Gross CAF values (fatality aversion); only the alternative B for handysize vessels is below 6 million USD as proposed by Skjong et al. (2007). Controversially, the Net CAF values (**Appendix G**) are negative which indicate that the benefits in monetary units are higher than the costs associated with the proposed solution. However, it should be considered that these high values are due to the fact that the proposed solution has a low risk reduction potential ΔR (IMO 2007b) whilst from **Figure 8.5** the effectiveness is apparent for the handysize vessels which are in the ALARP high region. Hence, although it is expected that increased corrosion margins to contribute positively in preventing accidents, it is demonstrated that they are not cost-effective if they are implemented as an RCO. It needs to be stressed that the impact of CEA indices is crucial when more options are examined, whereas for the current study the scope has been to apply the methodology.



a. Handysize   b. Handymax



c. Panamax   d. Capesize

Figure 8.11. *NPV COV per alternative and vessel type considering different inflation rates (99% confidence limits)*

TABLE 8.IV. *Descriptive results of CEA (Mean values for 5% inflation and 99% confidence limits)*

Vessel type	No of lives saved	ΔR	GrossCAF (Total)[$\$10^6$]		GrossCAF (ID) [$\$10^6$]	
Handysize	18	0.040	A	3.388	A	1.886
			B	10.749	B	5.983
			C	22.266	C	12.392
			D	37.362	D	20.794
Handymax	1	0.026	A	10.012	A	6.349
			B	26.243	B	16.641
			C	45.815	C	29.053
			D	69.695	D	44.196
Panamax	1	0.027	A	20.852	A	9.459
			B	42.106	B	19.099
			C	65.919	C	29.901
			D	94.415	D	42.826
Capesize	3	0.031	A	17.794	A	5.465
			B	47.671	B	33.428
			C	80.989	C	56.792
			D	120.563	D	84.542

8.4 Conclusions

The purpose of this chapter was to demonstrate an example of how the qualitative prioritization discussed at Chapter 6; in conjunction with the quantitative results estimated in Chapter 7 can be fed up in a decision – making process for preventing corrosion before becoming a problem. It is implied that the comprehensive and structured risk management should always be based on "common sense" being supported by the framework of suitable techniques such as BNs and LCCA. Therefore, it was shown that increased corrosion margins are not cost-effective if they are implemented as an RCO.

9 Operational Risk Management Methodology

"Our goal is to be a quality organization and do a quality job which means that we will be proud of our work and our products for years to come"

Digital Equipment Corporation

9.1 Preamble

This chapter is aimed at presenting and providing a framework for ORM in a sense that is explained how the different steps fit together and is generic enough to constitute an ORM tool for consideration by other vessel types.

9.2 Introduction

It has been accepted that the purpose of ORM is to ensure that adequate measures are taken to protect people, the environment and property from situations with a potential for causing harm of the activities being undertaken. The analysis of risks, costs and benefits is necessary for effective ORM, particularly within the complicated nature of shipping, but although the needed information for decision – making is provided, it cannot manage the risks by itself. The risks can be controlled by actions and therefore actions informed by analysis are the cornerstone of effective safety management. In this respect, it is emphasized that the controls are applied in order to prevent incidents/accidents from occurring rather just re – acting to specific events when they occur. Hence, a unifying structure should be developed as a self – evaluation resource that will encourage and guide the voluntary use of ORM by the many disparate parties involved in shipping.

9.3 A comprehensive tool for ORM

There are several important risk – related terms that are used throughout this part and the definitions are provided in the **Glossary** on the preliminary pages of this thesis. It is therefore implied that the reader should note the key distinctions between *hazard* (inherent situations/properties) and *risk* (likelihood and consequence) and between *risk assessment* (systematic and scientific process) and *risk management* (decision – making and action). In the context of this chapter, the underlying structure of an ORM methodology is meant to be flexible so that it can be adapted and be applied by various parties in a wide variety of situations. It is also recognized that this tool would not compel a mandatory way of thinking but rather a stepwise approach where the parties who choose to use it, will need to tailor it to their individual circumstances and specific applications for achieving cost – effective risk controls beyond the regulations. Hence, this generic ORM approach is comprehensive and integrative in nature, but not necessarily detailed, indicating that can be applied broadly to serve as the foundation for an organization's overall ORM programme. Alternatively, it can be applied in a more focused way to guide an ORM exercise and the implementation is targeted at a single or multiple source.

In **Figure 9.1** a generic and stepwise approach for ORM is portrayed. Even though consisting of many boxes and arrows, the flowchart is a substantial simplification of reality, especially with respect to all the possible interconnections and feedback loops among the steps. The approach can be applied generally to a wide range of risk management problems and be adapted in whole or in part and used by a shipowner, charterer, aboard and ashore personnel, consignee, classification society, regulator, or other involved party. This generic methodology is intended to serve as a model of a logical and sequential procedure for addressing risk issues effectively. While presented in the figure and being discussed below as a sequence of discrete steps, feedback, monitoring and iteration are critical throughout the procedure. Typically, analyses begin at a high level and through iteration grow into more complex and realistic forms as needed. The information gained in one iteration feeds into successive iterations, which should enhance the outcome and by monitoring it, the efficiency of ORM will be improved through the possible reviews. It should be mentioned that ORM can have at least two valuable products; the identification of critical areas either demanding greater attention and control or those where additional controls may not be necessary.

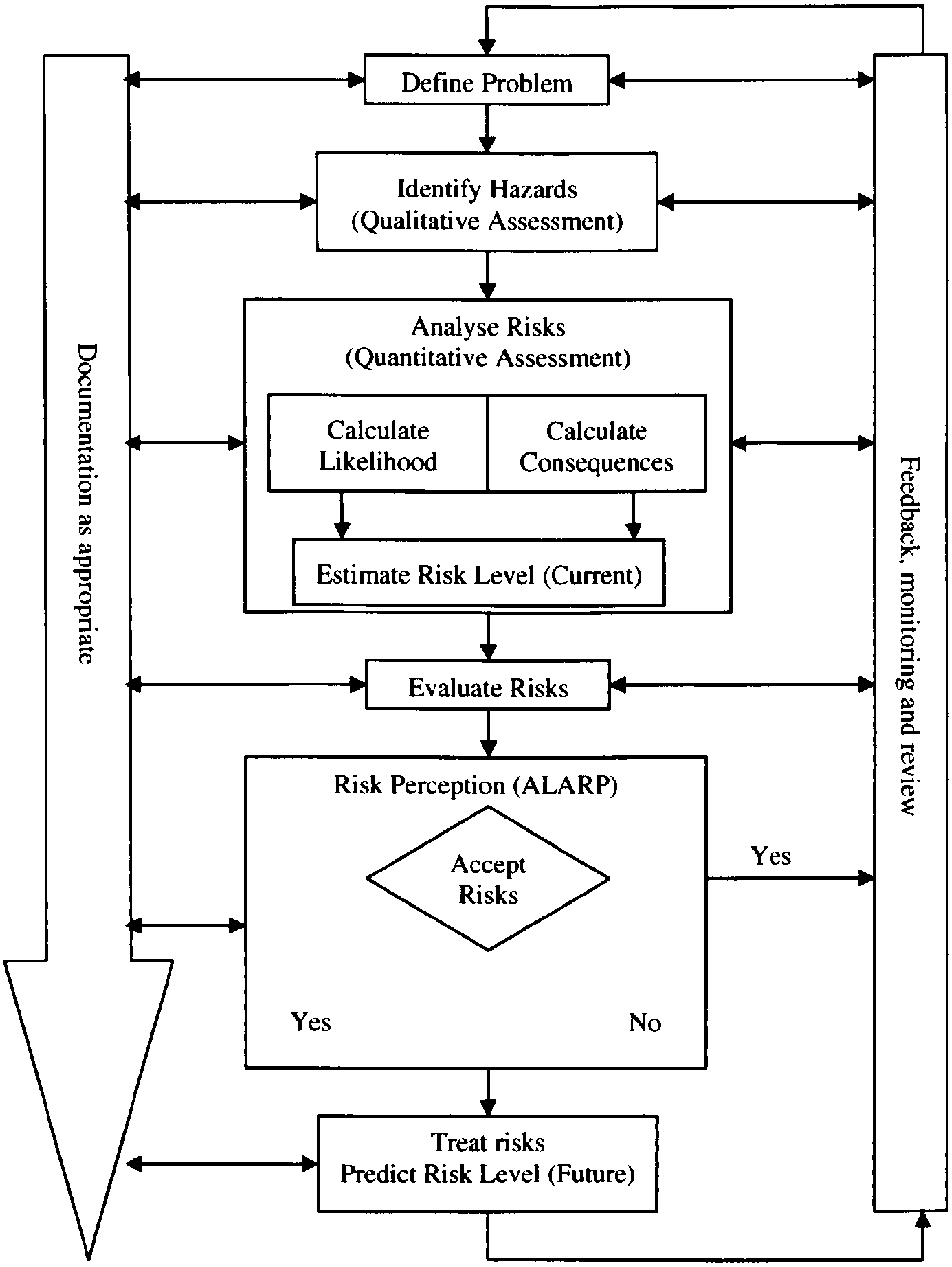


Figure 9.1. *Generic ORM methodology*

Before an ORM task is commenced, it is necessary to establish its context (*defining the problem*), which basically means deciding up the input from appropriate parties, considering the roles and responsibilities of the stakeholders involved, the goals – recognition of what is tried to be achieved – and limitations of the ORM initiative. The following specific issues need to be addressed:

Type of vessel i.e. merchant, passenger, naval

Vessel's systems i.e. organizational, management, technical, human, accommodation and hotel service, defence

Vessel's functions i.e. carriage of payload, power and propulsion, structural integrity, manoeuvrability, stability

Vessel's performance i.e. safety, speed, fuel efficiency, comfort, seakeeping

Operational phase i.e. loading, discharging, bunkering, en voyage, entering port, during combat

Accident category i.e. foundering, fire, explosion, grounding, collision

Internal influences i.e. cargo, combustible materials

External influences i.e. weather, routeing, competition, commercial pressure

Furthermore, the procedure should be applied with full consideration of the risks related to human life, environment and property which emanate from sudden and unintended departures of the normal operational phases. It is endorsed to decide the criteria against which risks are to be evaluated from the beginning. Criteria may be affected by internal/external perceptions and legal requirements, so it is imperative that appropriate acceptance criteria be determined at the outset (i.e. IMO). As more iterations of the ORM procedure are performed, these criteria may be further developed and refined subsequently as new risks realised and particular analysis techniques are chosen in order to correspond to the experienced risks.

After having understood thoroughly the problem, the aim is to generate a comprehensive list of events which might affect the referred operational phase (*hazard identification*). These are then considered in more detail to provide information on causes, scenarios, their areas of impact and existing safeguards. It is generally a qualitative assessment in the form of numerical scales to describe the magnitude of potential consequences and the likelihood that those consequences will occur. The results of the initial screening activity are recorded in the format of a table where the produced prioritization guides the person/team charged with the ORM task. For the tools and techniques used to identify hazards, **Table 4.I** should be consulted.

Consequently, the objectives of *risk analysis* are to separate the minor from the major risks and provide data to assist in the evaluation and treatment of risks (iteration). The consideration of the sources of risk, affecting factors, their consequences and the likelihood that those consequences may occur is involved. Risk is analysed by combining estimates of consequences and likelihood in the context of existing control measures. In the quantitative assessment numerical values are determined (current risk estimation) for both consequences and likelihood using information from a variety of sources (past records, industry practice and experience, published literature, economic, engineering or other models). Consequences may be estimated by modelling the outcomes of an event or set of events, or by extrapolation from experimental studies or past data. Likelihood is usually expressed as either frequency or exposure. Since some of the estimates made in the quantitative assessment are imprecise, a sensitivity analysis should be carried out to test the effect of changes in assumptions and resources. Again, the reader should be referred to **Table 4.I** for the available techniques and tools.

The comparison of the risk level found during the analysis with previously established criteria is involved through *risk evaluation*. If the resulting risks fall into the low (ALARP) or acceptable region they may be accepted with minimal further treatment (*decision – making*). Low and accepted risks should be monitored and periodically reviewed to ensure they remain acceptable. If risks are unacceptable, they should be treated (*decision – making*) using one or more of the considered options (RAE 2003):

a. Avoid the risk by deciding not to proceed with the activity likely to generate risk.
b. Reduce the likelihood of the occurrence (prevention).
c. Reduce the consequences (mitigation).
d. Transfer the risk to another party being capable to deal with it.
e. Retain the risk if nothing can be done.

It is pointed out that reduction of consequence and likelihood may be referred to as risk control which involves regulations, procedures and practices or physical changes.

The proposed options should be assessed on the basis of the extent of risk reduction (the risks are analysed again for future prediction) and any additional benefits created, taking into account the established acceptance criteria. A number of options may be considered and applied either individually or in combination where the most appropriate is selected by balancing the cost of implementing it against the benefits derived from it. In general, the adverse impact of risks should be made ALARP and decisions be based on common sense although sometimes may not be justifiable on strictly economic grounds. Of course, ORM is not a static task. Risks and the effectiveness of control measures (**Table 4.I**) need to be monitored to ensure changing circumstances do not alter the organization's daily operations. Essentially, through ongoing reviews is ensured that the ORM remains relevant and the suitability of the adopted options is checked.

As illustrated by the vertical arrow in **Figure 9.1**, the need for appropriate documentation runs throughout the ORM. Data analyses, techniques, results, decisions and other key inputs to and outputs from the ORM should be documented in a way that the organization will be benefited in the future. Documentation should have a clear purpose, need not be burdensome or bureaucratic, and a consistent record of the conducted activities should be maintained for future ORM efforts.

9.4 Conclusions

In this chapter a framework has been put forward for identifying and measuring the threats during the operational phase of any vessel and a solution has been proposed of how to handle the question of ORM. It was also targeted at enhancing the reader's understanding and providing a full realisation of the generic methodology which could be adapted to specific organizations and applications.

10 Discussion – Proposals for further research

"Although it is impossible to determine with certainty how an event shall happen yet it may be determined mathematical, what likelihood or degree of probability there is for its happening or failing; and this is all that is intended by a calculation, [...] except that there be made an infinite number of repetitions, and then one with another will always bring it to the same thing as the calculation makes it"

William Emerson

10.1 Preamble

It is probable very valid that opinions and approaches around the areas of risk management and assessment would differ among the scientific community. However, some key points are addressed below and are supported by the cited references.

10.2 Discussion

Although this research started with the intention to answer the question *"for how long BCs should trade worldwide"*, it was realised that the solution has been already provided by IACS (2005), where the decision is left to the shipowner; thus age limits would not be the objective of any self – regulatory attempt. Moreover, from the derived voyage data (**Appendix D**) is evident that shipowners operate their vessels with concern since they have gained the experience of performing that job excellently.

10.2.1 Qualitative assessment

It needs to be stressed that HAZID is usually a qualitative exercise based primarily on expert judgement. Most HAZID techniques involve a group of experts (i.e. HAZOP, for installation under operation), since few individuals have expertise on all hazards and group interactions are more likely to stimulate consideration of hazards that even well – informed individuals might overlook. By all means, it was on the author's best effort to be as creative as possible.

10.2.2 Quantitative assessment

With regard to the developed model in Chapter 7, it could be argued that the domain is modelled in a macroscopic and not in a microscopic scale, but considering the fact that models regarding the structural degradation of ships due to corrosion already exist (**Appendix F**), the aim was to model the activity (i.e. from A to B). The uncertainty in its performance is estimated by taking into account not only the past history (infrequent occurrences – accident statistics) but also usual operating conditions and the vessel's management regime. In addition, risk is confronted as a whole, a "collective construct" (Douglas and Wildavsky 1983), in a sense that its perception is substantiated from the organizational culture and sustained by the different business strategies. Moreover, safety is a dynamic product of learning from error over time, whereas the idealized, complete and integrated system for coping with the potential of an accident is (Morone and Woodhouse 1988):

1. Conservatively protection against the possible hazard.
2. Prioritized testing and monitoring of experience in order to reduce uncertainty.
3. As uncertainty is reduced and more is learned about the nature of risk, the original precautions are revised and strengthened if new risks are discovered or if appear to be worse than initially feared. It needs to be stressed that if the risks are found to be at an acceptable level, this does not mean that the initial precautions are weakened but appropriate actions are deemed necessary for maintaining that situation.

In this manner, risk assessment is a structured and systematic process aimed at enhancing maritime safety by estimating this uncertainty. As in the case of artificial intelligence, the decision support system (BN) is used in order to model the domain of uncertainty and thus support the analysts without replacing them. To this end, ORM methodology is viewed as an interactive tool aimed at aiding decision – making where the recommendations are based on common sense.

10.2.3 Risk Assessment

The results of a risk assessment are inevitably uncertain due to the attached lack of knowledge (HSE 2002a), thus this problem has been attempted to be solved by employing appropriate techniques such as BNs and LCCA. Yet, the analyst's degree of belief is reflected by the quoted probabilities where the uncertainty is inherently included. However, there is a widely held concern about the reliability of conducting a risk assessment covering safety matters and existing experience might have caused a loss of confidence on the actions implemented by risk management. In real – life facts, the stylized results of any model or technique are difficult to be believed since uncertainty is scary and human perception regularly seeks shelter from unpleasant surprises (Bernstein 1998). Yet, it needs to be understood that empirical models of probabilities don't kill; by contrast, the assumption that everything has been dealt with certainty is dangerous (Tsaraklis and Papazoglou 2001). Furthermore, with regard to the "Garbage In, Garbage Out - GIGO" principle (Bernstein 1998), the rationality mandated by risk management has been ignored by analysts who entered the consultancy market and resorted dodges to violate its rigid constraints (Waring and Glendon 1998). This rational logic can be considered as the first stage in the evolution of maritime safety regime and the creation of ***self – regulation culture*** where each player is responsible for the actions taken to improve safety and deemed relatively trust – worthy to conduct their own audits or inspections subject to verification by a governmental organization, rather than seeing them imposed from external prescriptive parties (Kristiansen 2005).

10.2.4 Decision – making

In a nutshell, the approach to safety regulations is manifested by the systematic identification of important hazards, risks or patterns of non – compliance whereas risk analysis and risk control are considered as a problem – solving strategy for focusing on the most important areas without being limited to the prospect of turning down less significant problems. It is envisaged that this *risk – informed* practice involves and requires understanding of all aspects of risks, knowledge of a wide spectrum of the influencing factors to risks and selection of appropriate methods for organizing the tools around the work rather than picking areas to fit the tools (Sparrow 2000). In this sense, ORM would provide guidance for accomplishing this goal by establishing and adapting the oversight of continuous safety performance improvement, summed up in the common phrase ***"the way we do things around here"*** (Krause 1997). Of course, it is expected that rule – making procedures are a result of negotiation processes navigating on a landscape of conflicting and shifting interests for establishing consensus. Though, one of the central challenges of regulatory art would be overemphasizing customer satisfaction – especially when regulated industry is viewed as the customer – leading those to the feeling that are entitled to be pleased by violating compliance. On the other extreme, when regulations are applied to areas that do not belong and are allocated with inflexibility (prescription), although the industry will not be opposed to these hands of protection, it would be merely frustrated at their lack of rationality and the feeling of a *culture of punishment* might have been created. It needs to be pointed out that besides the good organization/planning of prevention programmes, accidents will still happen since human behaviour will not be transformed, however this cannot be interpreted as regulatory deficiency but as a feedback for changing responses and priorities (Sparrow 2000).

Notwithstanding the above, from the governmental organization side, a structured framework needs to be supplied which should above all ensure that the self – regulation does not only obey the rule of the strongest (Blind 2004). It is believed that this optimal solution can be achieved through IMO's regulations. Furthermore, across service sectors (i.e. marine industry), standards are analyzed in the context of quality and are defined as customer expectations stated in a way that service quality is improved, thus uncertainty is reduced (Berry et al. 1992). Therefore, quality standards are more likely for technologies with a risk potential for the customers or the environment in general, because they are a sign for the safety reputation of the service. Taking into account this incentive, professional groups define minimum levels, and then there is a tendency to set the levels higher upon common agreement (harmonization) in order to achieve the desirable, effective and efficient protection of interests. It is pointed out that technical standards, particularly their drafts, contain information about the state – of – the – art technology and additionally – if publicly accessible – a good basis for innovation. Apparently, this elaboration falls into self – regulation and can attain legally binding status if they are referred concretely in the regulative framework, i.e. incorporation into SOLAS. To this end, as a recommendation, the all – purpose clause (blanket clause) method can be used for the legal provision of addressing corrosion margins for handysize, handymax, panamax and capsize BCs respectively, which is the observation of "generally acknowledged rules of technology", the consideration of the "status of science and technology" and application of the "best available techniques" (Blind 2004).

10.3 Thesis' limited scope of work

Although corrosion was prioritised as a main situation of causing harm, from the CEA it was seen that increased corrosion margins were not cost-effective. Thus, as it can be observed from **Table 7.I**, fatigue (cracks, dents) and weather routeing need to be investigated further with the potential of identifying possible risk reduction measures aiming at reducing the estimated risk. In addition, the effects of green water and damage during cargo operations need to be investigated in view of the operational risk management methodology described in the previous chapter. The critical issue of course in every risk assessment study is the establishment of suitable risk acceptance criteria where further research efforts are needed for such topic. It would be interesting also to perform the same approach for other accident categories (fire or explosions, collisions, groundings, contacts), since from **Figure B.7**, **Appendix B**, it is evident that navigation related accidents (collisions, groundings and contacts) represent also high percentage of bulk carrier losses. Furthermore, a more comprehensive study is deemed necessary by including all the involved stakeholders in dry bulk shipping (**Table 5.I**) and of course including other elements of risk such as environmental (bunker spills, lost cargo), financial (market structure) or business (flow of services). Hence, in an attempt of addressing the whole risk picture, the cooperation of different disciplines is considered more appropriate, which is a challenge, since it has never been done before.

10.4 Proposals for further research

An important aspect of the conducted research was the determination and quantification of the current operational safety level of BCs. Yet, what needs to be investigated is the acceptability and tolerability of the quoted number which is a difficult subject; addressing also political implications. Of course, this study can be considered as a "drop in the ocean" and therefore it would be interesting (as mentioned earlier) the proposed approach to be applied in the less significant areas (i.e. fatigue, weather routeing) that have been identified. Furthermore, the areas of concern should be monitored through time so that the derived decisions can be updated continuously.

11 Conclusions

"Der Herr Gott würfelt nicht - God does not play dice"

Albert Einstein

The performed study wished to contribute to the understanding of ORM and a framework has been put forward for identifying and measuring the threats during the operational phase of any vessel, i.e. BC and a solution has been proposed of how to handle the question of ORM. Its role in shipping operations has become increasingly important in recent years since it is related to the continuous improvement of safety (operational safety of BCs). It is also regarded as a systematic and documented task where the implementation of cost – effective controls is justified through the risk assessment process. It was construed that risk assessment is a well developed field which can be used as the prime instrument in order to describe a rational, transparent and systematic risk – informed approach for safety assessment. During the process, a technique was proposed for estimating/predicting the operational safety of BCs. Moreover, through the graphical representation of the whole process with the BNs technology, the attached uncertainty was considered into the model development in a consistent fashion. In essence, the BN approach was proved to be successful for dealing with the uncertainties and weaknesses of FTA and ETA. Through the introduction of the vessel's risk (safety) index was attempted to construct suitable risk models in order to provide a rational decision support tool for assessing the uncertainty in the system's performance (dry bulk cargo transportation) and consequently the operational risk was found to be ALARP. Furthermore, the factors influencing the safety performance of BCs can be identified at an *early stage* and consequently the areas of concern can be established in order to prevent accidents from happening in the first place. This uncertainty is influenced by the organizational and management infrastructure where it is therefore required that all the affected stakeholders co – operate to identify and understand the potential hazards (i.e. corrosion was identified qualitatively as a main situation of causing harm and its prioritization was verified quantitatively) in order to ensure the safe operation of the vessel. The performed risk assessment was extended into a risk management procedure since different design (passive) and operational (active) measures addressing corrosion were evaluated as an option for accident prevention and mitigation. Furthermore, it has been demonstrated that decisions should always be based on common sense and supported by the framework of suitable tools such as BNs and LCCA which are recommended to be used with greater awareness in decision – making. Finally, it was asserted that corrosion margins cannot be effectively implemented as a regulatory option. Of course, the conducted ORM is not a static but a dynamic task instead, where through future reviews will be ensured that the recommended options can be kept updated in a rational manner.

In conclusion, the following can be underlied:

- The current operational risk was estimated and predicted with the RSM CCD and was found to be within the ALARP region.
- Through the BN a suitable risk model was constructed for identifying priorities between the causes and effects.
- The whole risk assessment process was represented graphically with the ID.
- The CBA was performed by employing LCCA.
- The CEA was conducted through the ID.
- It was asserted that increased corrosion margins are not cost-effective RCO.
- A methodology was developed for how to conduct an ORM procedure.

12 References

"Knowledge is not so much like a building, eventually to be finished, but more like a many – sided conversation in which being ultimately right or wrong is not at issue. What matters is that the conversation continue with new definitions and solutions and terms made deep enough to hold the meanings being tried"

Mary Douglas and Aaron Wildavsky

[1] **ABS**, 2000, "Guidance notes on Risk Assessment: Applications for the Marine and Offshore Oil and Gas Industries", ABS Plaza, Houston, Texas, USA.

[2] **ABS**, 2002, "Bulk Carrier Solutions: Safer and Stronger Vessels", ABS Plaza, Houston, Texas, USA. [Online]. Available from (cited: 24 August 2007): www.eagle.org/news/pubs/pdfs/Bulk%20Carrier.pdf

[3] **Alderton, P., M.**, 2004, "Reeds Sea Transport: Operation and Economics", Fifth Edition, Adlard Coles Nautical, London.

[4] **Arrow, K., J.**, 1951, "Alternative Approaches to the theory of Choice in Risk – Taking Situations", Econometrica, **19**, (4), pp. 404 – 437.

[5] **ASTM International**, 2006a, "Designation G 15 – 05, Standard Terminology Relating to Corrosion and Corrosion Testing", in *Annual book of ASTM standards 2006, Section Three, Metals Test Methods and Analytical Procedures, Volume 03.02, Wear and Erosion; Metal Corrosion*, West Conshohocken, Pennsylvania, USA.

[6] **ASTM International**, 2006b, "Designation G 16 – 95 (Reapproved 2004), Standard Guide for Applying Statistics to Analysis of Corrosion Data", in *Annual book of*

ASTM standards 2006, Section Three, Metals Test Methods and Analytical Procedures, Volume 03.02, Wear and Erosion; Metal Corrosion, West Conshohocken, Pennsylvania, USA.

[7] **ATSB**, 1988, "Maritime Safety Investigation Report 22 – Final: "Singa Sea"", Canberra, Australia.

[8] **ATSB**, 1990, "Maritime Safety Investigation Report 24 – Final: "Alexandre – P"", Canberra, Australia.

[9] **ATSB**, 1991a, "Maritime Safety Investigation Report 28 – Final: "Starfish"", Canberra, Australia.

[10] **ATSB**, 1991b, "Maritime Safety Investigation Report 29 – Final: "Mineral Diamond"", Canberra, Australia.

[11] **ATSB**, 1992a, "Maritime Safety Investigation Report 32 – Final: "Manila Transporter"", Canberra, Australia.

[12] **ATSB**, 1992b, "Maritime Safety Investigation Report 34 – Final: "Melete"", Canberra, Australia.

[13] **ATSB**, 1993, "Maritime Safety Investigation Report 45 – Final: "Daeyang Honey"", Canberra, Australia.

[14] **Attikouris, K.**, 2003, "Risk Management in Shipping: Modeling, Measuring & Managing Freight Market Uncertainty", Presentation given at NTUA. [Online]. Available from (cited: 31 January 2008): http://www.freightmetrics.com/downloads/PresentationNTUA.pdf

[15] **Aury, P.**, 2007, "Demystifying Risk", Presentation given at the *Dry Freight Derivatives Forum*, Athens, Hellas. [Online]. Available from (cited 31 January 2008): http://www.balticexchange.com/media/pdf/athens/clarksons_aury.pdf

[16] **Aven, T.**, 2003, "Foundations of Risk Analysis – A Knowledge and Decision Oriented Perspective", John Wiley & Sons Ltd, Chichester, England, UK.

[17] **Aven, T., Vinnem, J., E.**, 2007, "Risk management, With Applications from the Offshore Petroleum Industry", Springer – Verlag Ltd., London, UK.

[18] **Back, W., E., Boles, W., W., Fry, G., T.**, 2000, "Defining Triangular Probability Distributions from Historical Cost Data", Journal of Construction Engineering and Management, **126**, (1), pp. 29 – 37.

[19] **Bahr, N., J.**, 1997, "System Safety Engineering and Risk Assessment: A Practical Approach", Taylor & Francis, USA.

[20] **Bailey, T., J., Capt.**, 1999, "Managing Risk On Board Ship", in *Managing Risk in Shipping: A Practical Guide*, The Nautical Institute, London.

[21] **Bakopoulos, A., Chrisovergis, J.**, 1994, "Introduction to Numerical Analysis – with Program Library and Diskette", Symeon Publishing Co., Athens. (Hellenic language)

[22] **BEAmer**, 2004, "Report on the investigation of the total loss of the Bulk Carrier "Adamandas" on 22nd September 2003 off the Island of La Reunion following the re-oxidation of a cargo of Direct Reduced Iron". [Online]. Available from (cited: 24 August 2007): http://www.beamer-france.org/english/inquieries/inquieries.htm

[23] **Bearfield, G., Marsh, W.**, 2005, "Generalising Event Trees Using Bayesian Networks with a Case Study of Train Derailment", Lecture Notes in Computer Science, **3688**, pp. 52 – 66.

[24] **Bedford, T., Cooke, R.**, 2004, "Probabilistic Risk Analysis: Foundations and Methods", Third printing, Cambridge University Press, Cambridge, UK.

[25] **Beichelt, F., E., Fatti, L., P.**, 2002, "Stochastic Processes and their Applications", Taylor & Francis, London.

[26] **Bernstein, P., L.**, 1998, "Against the Gods – The Remarkable Story of Risk", John Wiley & Sons Inc., Toronto, Canada.

[27] **Berry, L., L., Zeithaml, V., A., Parasuraman, A.**, 1992, "Five Imperatives for Improving Service Quality", in Lovelock, C., H., ed., *Managing Services – Marketing, Operations and Human Resources*, Second Edition, Prentice – Hall International Editions, Englewood Cliffs, New Jersey, USA.

[28] **BIMCO**, n.d., "Document Samples and Explanatory Examples – Voyage and Time Charter Parties", Bagsværd, Denmark. [Online]. Available from (cited: 24 August 2007):
http://www.bimco.org/Corporate%20Area/Documents/Document_samples.aspx

[29] **Bitner-Gregersen, E., M., Cramer, E., H., Løseth, R.**, 1995, "Uncertainties of Load Characteristics and Fatigue Damage of Ship Structures", Marine Structures, **8**, (2), pp. 97 – 117.

[30] **Black Sea MOU**, 2005, "Detention List for year 2005". [Online]. Available from (cited: 24 August 2007): http://www.bsmou.org/default2.htm

[31] **Blind, K.**, 2004, "The Economics of Standards, Theory, Evidence, Policy", Edward Elgar Publishing Ltd., Cheltenham, UK.

[32] **Bobbio, A., Portinale, L., Minichino, M., Ciancamerla, E.**, 2001, "Improving the analysis of dependable systems by mapping fault trees into Bayesian Networks", Reliability Engineering and System Safety, **71**, (3), pp. 249 – 260.

[33] **BOMEL Limited**, 2002, "Development and Quantification of Influence Networks", Final Report No.: C999\06\047R, Rev. C, Maidenhead, Berkshire, for Maritime and Coast Guard Agency: FSA on Bulk Carriers – WP 12.

[34] **Boussabaine, H., A., Kirkham, R., J.**, 2004, "Whole Life – cycle Costing, Risk and Risk Responses", Blackwell Publishing Ltd., Bodmin, Cornwall, UK.

[35] **Box, G., E., P., Draper, N., R.**, 1987, "Empirical Model – Building and Response Surfaces", John Wiley & Sons Inc., New York, USA.

[36] **Brown, R., H.**, 1986, "Marine Insurance Vol. 1 – Principles & Basic Practice", 5th Edition, Witherby & Co. Ltd., London.

[37] **BSI**, 1996, ***Draft for Public Comment***, "Corrosion of Metals and Alloys – Guidelines for Applying Statistics to Analysis Corrosion Data (ISO/DIS 14802)", Document No. 96/713159 DC, London.

[38] **BTCE**, 1994, "Structural Failure of Large Bulk Ships", Report 85, Australian Government Publishing Service, Canberra. [Online]. Available from (cited: 17 March 2008): http://www.bitre.gov.au/publications/72/Files/R085.pdf

[39] **Bury, K.**, 1999, "Statistical Distributions in Engineering", Cambridge University Press, Cambridge, UK.

[40] **Caridis, P.**, 2001, "Inspection, Repair and Maintenance of Ship Structures", Witherby, London.

[41] **Caridis, P., A.**, 2002, "Inspection, Repair and Maintenance of Ship Structures", (with CD – ROM), NTUA University Press, Athens. (Hellenic Edition)

[42] **CCPS**, 2000, "Guidelines for Chemical Process Quantitative Risk analysis", Second Edition, American Institute of Chemical Engineers, New York, USA.

[43] **Chandler, K., A.**, 1985, "Marine and Offshore Corrosion", Butterworth & Co. Ltd., London.

[44] **Chernov, B., B., Ponomarenko, S., A.**, 2001, "Physico – Chemical Modelling for the Prediction of Seawater Metal Corrosion", in Lewis, J., A., ed., *10th International Congress on Marine Corrosion and Fouling, University of Melbourne, February 1999 – Additional Papers*, for Australian Government, Department of Defence, Defence Science and Technology Organisation, Canberra: Pub. No.: DSTO-GD-0287. [Online]. Available from (cited: 24 August 2007): http://dspace.dsto.defence.gov.au/dspace/bitstream/1947/3822/1/DSTO-GD-0287%20PR.pdf

[45] **Clarksons**, 2004a, "Clarksons Register of Bulk Carriers: Historical Growth of World Bulk Carrier Fleet 1977 – 2004", provided by Intercargo.

[46] **Clarksons**, 2004b, "The Tramp Shipping Market", London. [Online]. Available from (cited: 24 August 2007): http://www.clarksons.net/archive/research/freestuff/tramp_shiopping_market_April_2004.pdf

[47] **Compaq**, 2001, "Compaq Visual Fortran Version 6.6", http://www.hp.com

[48] **Cooper, M., D.**, 2000, "Towards a model of safety culture", Safety Science, **36**, (2), pp. 111 – 136.

[49] **Countryman, B., E., McDaniel, M., S.**, 2007, "The Cargo Letter – Maritime Casualties", California, USA. [Online]. Available from (cited: 24 August 2007): http://www.cargolaw.com/presentations_cas.index.html

[50] **Cousteau, J-Y.**, 1963, quoted in Schwenk, T. (1996), *Sensitive Chaos: The Creation of flowing Forms in Water and Air*, Revised Second Edition, Rudolf Steiner Press, East Sussex, UK, Reprinted: 2004.

[51] **Covino, B., S., Jr., Cramer, S., D.**, 2005, "Introduction to Forms of Corrosion", in Covino, B., S., Jr., Cramer, S., D., Eds., *ASM Handbook: Vol. 13A, Corrosion: Fundamentals, Testing and Protection*, Second Printing, ASM International, Materials Park, Ohio, USA.

[52] **Cox, L., A., Jr.**, 2002, "Risk analysis: Foundations Models and Methods", Kluwer Academic Publishers (International Series in Operations Research & Management Science), Boston, Massachusetts, USA.

[53] **Deal, T., E., Kennedy, A., A.**, 2000, "Corporate Cultures: The rites and rituals of corporate life", Basic Books, New York, USA.

[54] **Denmark and Norway**, 2006, "Any Other Business – FSA Study on ECDIS/ENCs", London: IMO MSC 81/24/5.

[55] **Denmark, Germany, Norway and Sweden**, 2006, "Goal – Based New Ship Construction Standards – Safety level approach", London: IMO MSC 81/6/2.

[56] **DFT**, 2005, "M.V. Derbyshire", London, UK. [Online]. Available from (cited: 24 August 2007): http://www.dft.gov.uk/pgr/shippingports/shipping/safety/mvderbyshire/

[57] **Dhillon, B., S.**, 2007, "Applied Reliability and Quality – Fundamentals, Methods and Procedures", Springer – Verlag Limited, London, UK.

[58] **Digital Equipment Corporation**, n.d., quoted in Peters T., Waterman, R., H., Jr., *In Search of Excellence. Lessons from America's Best – Run Companies*, Profile Books Ltd., London, 2004.

[59] **DNV**, 1997, "DNV Exchange on the Web – Casualty Information: Corrosive cargo in holds", Report No. 6/97. [Online]. Available from (cited: 24 August 2007): http://exchange.dnv.com/ServiceExperience/CasualtyInformation/Documents/DocHeader.asp?DocCode=9706&Row=7&Col=6

[60] **DNV**, 2004, "Guidelines for Ultrasonic Thickness Measurements of Ships classed with Det Norske Veritas", Rep. No.: DNV-MTPNO864, Høvik, Norway. [Online]. Available from (cited: 24 August 2007): http://www.dnv.com/binaries/UTM_tcm4-77272.pdf

[61] **Donaldson of Lymington, J., F., D., B.**, 1994, "Safer ships, cleaner seas: report of Lord Donaldson's Inquiry into the prevention of pollution from merchant shipping / presented to Parliament by the Secretary of State for Transport by Command of Her Majesty", London: HMSO.

[62] **Donaldson of Lymington, J., F., D., B.**, 1995, "Lord Donaldson's assessment (Derbyshire): a report by the Rt. Hon. The Lord Donaldson of Lymington to the Secretary of State for Transport to assess what further work should be undertaken to identify the cause of the sinking of the MV Derbyshire", London: HMSO.

[63] **Douglas, M., Wildavsky, A.**, 1983, "Risk and Culture: An Essay on the Selection of Technological and Environmental Dangers", University of California Press, Published: Berkeley, California, USA, Reprinted: London, UK, 1997.

[64] **Drewry**, 1985, "The Market for Handymax Dry Bulk Carriers", London, UK.

[65] **Einstein, A.**, n.d., quoted in Vose (2001).

[66] **Eknes, M., L., Astrup, O., C., Ronold, K., Gran, S.**, 1997, "Statistical Data for Bulk Carrier Casualties where Structural May Have Been a Factor", DNV Research Report No.: 96-2042, Høvik, Norway.

[67] **Eleye-Datubo, A., G., Wall, A., Saajedi, A., Wang, J.**, 2006, "Enabling a Powerful Marine and Offshore Decision-Support Solution Through Bayesian Network Technique", Risk Analysis, **26**, (3), pp. 695 – 721.

[68] **Emerson, W.**, 1776, quoted in Hacking, I., *The Emergence of Probability, A Philosophical Study of early ideas about Probability Induction and Statistical Inference*, Second Edition, Canbridge University Press, New York, USA, 2006.

[69] **EMSA**, n.d., "Marine Accident Investigation – Contact Points". [Online]. Available from (cited: 24 August 2007): http://www.emsa.eu.int/end185d007d003d002d001.html

[70] **Equasis**, 2008, "The world merchant fleet in 2007 – Statistics from Equasis". [Online]. Available from (cited: 24 December 2008): http://www.equasis.org/EquasisWeb/public/HomePage?fs=HomePage

[71] **Evans, M., Hastings, N., Peacock, B.**, 2000, "Statistical Distributions", Third Edition, A Wiley Interscience Publication, John Wiley & Sons Inc., New York, USA.

[72] **Faber, M., H.**, 2006, "Risk and Safety in Civil, Surveying and Environmental Engineering – Lecture Notes", Swiss Federal Institute of Technology (IBK), Zurich. [Online]. Available from (cited: 24 August 2007): http://www.ibk.ethz.ch/fa/education/lecture_notes/Script_Risk_Safety_april_06_web.pdf

[73] **Fabrycky, W., J., Blanchard, B., S.**, 1991, "Life – Cycle Cost and Economic Analysis", Prentice – Hall Inc., Englewood Cliffs, New Jersey, USA.

[74] **Ferguson, J., M.**, 1993, "Bulk Carriers – The Challenge", in *Proceedings of the Third International Offshore and Polar Engineering Conference (ISOPE – 93)*, Vol. IV, Singapore.

[75] **Fischhoff, B., Slovic, P., Lichtenstein, S.**, n.d., quoted in Douglas, M. and Wildavsky, A. (1983).

[76] **Friis-Hansen, A.**, 2000, "Bayesian Networks as a Decision Support Tool in Marine Applications", Ph.D. Thesis, Department of Naval Architecture and Offshore

Engineering, Technical University of Denmark, Kgs., Lyngby. [Online]. Available from (cited: 24 August 2007): http://www.skk.mek.dtu.dk/upload/institutter/mek/skk/pdf/phd_afhandlinger/af h.pdf

[77] **Garbatov, Y., Guedes Soares, C., Wang, G.**, 2007, "Nonlinear Time Dependent Corrosion Wastage of Deck Plates of Ballast and Cargo Tanks of Tankers", Journal of Offshore Mechanics and Arctic Engineering, **129**, (1), pp. 48 – 55.

[78] **Gardiner, C., P., Melchers, R., E.**, 1998, "Aspects of Bulk Carrier Hold Corrosion", in *Proceedings of the International Conference on Design and Operation of Bulk Carriers*, RINA, London, UK.

[79] **Gardiner, C., P., Melchers, R., E.**, 2001, "Bulk Carrier Corrosion Modelling", in *Proceedings of the Eleventh International Offshore and Polar Engineering Conference (ISOPE – 2001)*, Vol. IV, Stavanger, Norway.

[80] **Gardiner, C., P., Melchers, R., E.**, 2003, "Corrosion analysis of bulk carriers, Part I: operational parameters influencing corrosion rates", Marine Structures, **16**, (8), pp. 547 – 566.

[81] **GL**, 2004, "Keep on running... The state of the art in bulk carriers", Hamburg, Germany. [Online]. Available from (cited 24 August 2007): http://www.gl-group.com/brochurepdf/0E068.pdf

[82] **Gómez, M.**, 2004, "Real – World Applications of Influence Diagrams", in Gámez, J. A., Moral, S., Salmerón, A., eds., *Advances in Bayesian Networks*, Springer – Verlag, Berlin – Heidelberg, Germany.

[83] **Gratsos, G., A., Zachariadis, P.**, 2005, "Life cycle cost of maintaining the effectiveness of a ship's structure and environmental impact of ship design parameters", in *Proceedings of the International Conference Design and Operation of Bulk Carriers*, RINA, London, UK.

[84] **Greece**, 2005, "Goal – Based New Ship Construction Standards, Definition of basic parameters for the development of GBS", London: IMO MSC 80/6/5.

[85] **Guarin, L., Drennan, T.**, 2005, "Traffic Routeing in the Minches and West of Hebrides", Report No.: CEMT01-REP-001-LG, Glasgow: Safety at Sea Ltd and Eagle Lyon Pope for Comhairle Nan Eilean Siar and The Highland Council. [Online]. Available from (cited: 24 August 2007):

http://www.w-isles.gov.uk/harbourmaster/minchtraffic.pdf

[86] **Guarin, L., Vassalos, D.**, 2004, "Comparative Study of Single and Double Side Skin Bulk Carriers", Report No.: BC01-RE-001-LG, Glasgow: Safety at Sea Ltd for Hellenic Ministry of Mercantile Marine.

[87] **Guedes Soares, C., Bitner-Gregersen, E., M., Antão, P.**, 2001, "Analysis of the frequency of ship accidents under severe North Atlantic weather conditions", in *Proceedings of the International Conference Design and Operation for Abnormal Conditions II*, RINA, London, UK.

[88] **Guedes Soares, C., Garbatov, Y.**, 1999, "Reliability of maintained, corrosion protected plates subjected to non – linear corrosion and compressive loads", Marine Structures, **12**, (6), pp. 425 – 445.

[89] **Guedes Soares, C., Garbatov, Y., Zayed, A.**, 2005, "Non-linear Corrosion Model for Immersed Steel Plates accounting for Environmental Factors", presented at the *SNAME Maritime Technology Conf and Expo*, Houston, TX, USA. [Online]. Available from (cited: 24 August 2007):
http://www.eagle.org/news/TECH/2005/Marine/19.%20Non-linear%20Corro.pdf

[90] **Heidersbach, R., H.**, 1987, "Marine Corrosion", in Korb, L., J., Olson, D., L., eds., *Metals Handbook, Ninth Edition, Volume 13*, ASM International, Metals Park, Ohio, USA.

[91] **Heinrich, H., W., Petersen, D., Roos, N.**, 1980, "Industrial accident prevention: A safety management approach", Fifth Edition, McGraw-Hill Book Company, New York, USA.

[92] **Hill, C.**, 2003, "Maritime Law – Chapter 5: Charter Parties", Sixth Edition, Informa Professional UK Ltd., London.

[93] **Hogben, N., Dacunha, N., M., C., Olliver, G., F.**, 1986, "Global Wave Statistics", Compiled and Edited by BMT Ltd., Published by BMT Ltd., Middlesex, UK, Reprinted: 2000.

[94] **Hooke, N.**, 1997, "Maritime Casualties 1963 – 1996", Second Edition, Lloyd's of London Press, LLP Limited, London.

[95] **HORSCTCI**, 1992, "Ships of Shame: An inquiry into Ship Safety", Canberra, Australia. [Online]. Available from (cited: 27 August 2007):
http://www.aph.gov.au/house/committee/trs/reports.htm

[96] **HORSCTCI**, 1995a, "Ships of Shame: A sequel – Inquiry into Ship Safety", Canberra, Australia.

[97] **HORSCTCI**, 1995b, "Review inquiry into ship standards and safety: Progress Report: Report from the House of Representatives Standing Committee on Transport, Communications and Infrastructure", Canberra, Australia.

[98] **HORSCTCI**, 1998, "Ship safe: An inquiry into Australian Maritime Safety Authority Annual Report 1996 – 97", Canberra, Australia. [Online]. Available from (cited: 27 August 2007): http://www.aph.gov.au/house/committee/trs/reports.htm

[99] **House, D., J.**, 2005, "Cargo Work for Maritime Operations", Seventh Edition, Elsevier Butterworth – Heinemann, Oxford, UK.

[100] **HSE**, 2001, "Reducing risks, protecting people: HSE's decision – making process", Norwich: HMSO, ISBN: 0 7176 2151 0.

[101] **HSE**, 2002a, "Marine Risk Assessment", Prepared by DNV for HSE, Offshore Technology Report 2001/063, UK.

[102] **HSE**, 2002b, "Guidelines for use of statistics for analysis of sample inspection of corrosion", prepared by TWI Limited, UK.

[103] **Hugin Expert A/S**, 2006, Aalborg, Denmark, http://www.hugin.com/

[104] **Hunter, S., J., Natrella, M., G., Barnett, H., Hunter, W., G., Koehler, T., L.**, 2000, "Design And Analysis of Experiments", in Juran, J., M. & Godfrey, A., B., eds., *Juran's Quality Handbook*, Fifth Edition, McGraw-Hill International Edition, Industrial/Plant Engineering Series, Singapore.

[105] **IACS**, 1998, "Bulk Carriers, Handle with care", IACS Pamphlet, London, UK.

[106] **IACS**, 2001a, "FSA of Bulk Carries: Fore – End Watertight Integrity, Annex 8, Hazard Identification of Fore – End of Bulk Carriers", London: IMO MSC 74/5. [Online]. Available from (cited: 27 August 2007): http://www.iacs.org.uk/document/public/Publications/Other_technical/PDF/FSA_Bulk_Carrier_Annex_08_pdf432.PDF

[107] **IACS**, 2001b, "Recommendation 74: A Guide to Managing Maintenance", London. [Online]. Available from (cited: 27 August 2007): http://www.iacs.org.uk/document/public/Publications/Guidelines_and_recommendations/PDF/REC_74_pdf214.pdf

[108] **IACS**, 2004a, "A Guide to Risk Assessment in Ship Operations", London. [Online]. Available from (cited: 31 January 2008) http://www.iacs.org.uk/document/public/Publications/Other_technical/PDF/Guide_to_Risk_Assessment_in_Ship_Ops_pdf421.pdf

[109] **IACS**, 2004b, "Recommendation 76: Guidelines for Surveys, Assessment and Repair of Hull Structure – Bulk Carriers", Rev. 2, London, [Online]. Available from (cited: 27 August 2007): http://www.iacs.org.uk/document/public/Publications/Guidelines_and_recommendations/PDF/REC_76_pdf216.pdf

[110] **IACS**, 2005, "Goal – Based New Ship Construction Standards – Determination of actual service life", London: IMO MSC 80/6/8.

[111] **IACS**, 2006a, "Common Structural Rules for Bulk Carriers – Chapter 13: Ships in Operation, Renewal Criteria – Section 2: Thickness Measurements and Acceptance Criteria", London. [Online]. Available from (cited: 27 August 2007): http://www.iacs.org.uk/document/public/Publications/Common_rules/PDF/CSR_Bulk_Carriers_-_Chapter_13_pdf359.pdf

[112] **IACS**, 2006b, "Summary of the Common Structural Rules", External Presentation. [Online]. Available from (cited: 27 August 2007): http://www.iacs.org.uk/publications/CommonRulesDoc.aspx?pageid=4&sectionid=2&linkid=6

[113] **IACS**, 2007a, "Requirements concerning Survey and Certification – Unified Requirement Z.10.2: Hull Surveys of Bulk Carriers", Rev. 25, London. [Online]. Available from (cited: 27 August 2007): http://www.iacs.org.uk/document/public/Publications/Unified_requirements/PDF/UR_Z_pdf160.PDF

[114] **IACS**, 2007b, "Goal – Based New Ship Construction Standards, Information submitted to the Pilot Project on Goal – Based Standards for New Ship Construction for Bulk Carriers and Oil Tankers", London: IMO MSC 83/INF.5.

[115] **IMO**, 1998, "BLU Code: Code of Practice for the Safe Loading and Unloading of Bulk Carriers", Sales number: I266E, ISBN: 92-801-1458-1, London.

[116] **IMO**, 1999, "Focus on IMO: IMO and the safety of bulk carriers", London. [Online]. Available from (cited: 27 August 2007):

http://www.imo.org/includes/blastDataOnly.asp/data_id%3D7987/BULK99.FIN.pdf

[117] **IMO**, 2000, "Resolution A.893 (21): Guidelines For Voyage Planning adopted on 25 November 1999", London. [Online]. Available from (cited: 27 August 2007): http://www.tc.gc.ca/marinesafety/oep/navigation/safety/pdf/A2Res893.pdf

[118] **IMO**, 2002a, "ISM Code: International Safety Management Code and Revised Guidelines on implementation of the ISM Code", Second Edition, Sales number: IA117E, ISBN: 92-801-5123-1, London.

[119] **IMO**, 2002b, "Guidelines for Formal Safety Assessment (FSA) for use in the IMO rule – making process", London: MSC/Circ.1023, MEPC/Circ.392. [Online]. Available from (cited: 27 August 2007): http://www.imo.org/includes/blastDataOnly.asp/data_id%3D5111/1023-MEPC392.pdf

[120] **IMO**, 2002c, "Participation of ships in weather routeing services", London: MSC/Circ.1063. [Online]. Available from (cited: 27 August 2007): http://www.imo.org/includes/blastDataOnly.asp/data_id%3D6562/1063.pdf

[121] **IMO**, 2003, "Ships' Routeing", Eighth Edition, Sales number: IB927E, ISBN: 92-801-4175-9, London.

[122] **IMO**, 2004a, "SOLAS Consolidated Edition 2004", Fourth Edition, Sales number: ID110E, ISBN: 92-801-4183-X, London.

[123] **IMO**, 2004b, "Casualty Analyses considered and approved by the Sub – Committee on Flag State Implementation at its twelfth session in 2004", London. [Online]. Available from (cited: 27 August 2007): http://www.imo.org/includes/blastDataOnly.asp/data_id%3D9803/FSI12.pdf

[124] **IMO**, 2005a, "Code of Safe Practice for Solid Bulk Cargoes, 2004: BC Code", Twelfth Edition, Sales number: ID260E, ISBN: 978-92801-4201-3, London.

[125] **IMO**, 2005b, "Manual on loading and unloading of solid bulk cargoes for terminal representatives", London: MSC/Circ.1160. [Online]. Available from (cited: 27 August 2007): http://www.imo.org/includes/blastDataOnly.asp/data_id%3D12668/1160.pdf

[126] **IMO**, 2005c, "Load Lines: International Convention on Load Lines, 1966 and Protocol of 1988, as amended in 2003 – Consolidated Edition, 2005", Third Edition, Sales number: IB701E, ISBN: 92-801-4194-5, London.

[127] **IMO**, 2006, "Casualty – Related Matters, Reports on Marine Casualties and Incidents, Revised harmonized reporting procedures - reports required under SOLAS regulation I/21 and MARPOL 73/78, articles 8 and 12", London: MSC – MEPC.3/Circ..1. [Online]. Available from (cited: 27 August 2007): http://www.imo.org/includes/blastDataOnly.asp/data_id%3D13719/1.pdf

[128] **IMO**, 2007a, "Goal – Based New Ship Construction Standards: MSC's work on goal – based new ship construction standards – an overview", London: MSC 83/5.

[129] **IMO**, 2007b, "Formal Safety Assessment – Consolidated text of the Guidelines for Formal Safety Assessment (FSA) for use in the IMO rule – making process (MSC/Circ.1023 – MEPC/Circ.392)", London: MSC 83/INF.2.

[130] **Indian Ocean MOU**, 2005, "Detention List for year 2005". [Online]. Available from (cited: 27 August 2007): http://www.iomou.org/inspmain.htm

[131] **Intercargo**, n.d., "The Dry Cargo industry". [Online]. Available from (cited: 27 August 2007): http://www.intercargo.org/bulk_trades.htm

[132] **Intercargo**, 1998, "Bulk Carrier Casualty Report, analysis of total loss and fatality statistics for dry bulk carriers 1990 – 1997", London.

[133] **Intercargo**, 1999, "Bulk Carrier Casualty Report, analysis of vessel losses and fatalities 1998, including data 1990 – 1998", London.

[134] **Intercargo**, 2003, "Bulk Carrier Casualty Report – 2002, the previous ten years (1993 – 2002) and the trends", London.

[135] **Intercargo**, 2004, "Bulk Carrier Casualty Report – 2003, the previous ten years (1994 – 2003) and the trends", London.

[136] **Intercargo**, 2006a, "Any Other Business – Bulk carrier casualty report", London: IMO MSC 81/INF.11.

[137] **Intercargo**, 2006b, "20 ships you didn't realise you used today…". [Online]. Available from (cited: 27 August 2007): http://www.intercargo.org/pdf/20ShipsleafletA5-September2006.pdf

[138] **Isbester, J., Capt.**, 1993, "Bulk Carrier Practice", The Nautical Institute, London.

[139] **ISSC**, 2000, "Specialist Committee V.1.: Risk Assessment", in Ohtsubo, H., Sumi, Y., eds. (2001), *Proceedings of the 14th International Ship and Offshore Structures Congress*, Vol. 2, Elsevier Science Ltd., Amsterdam.

[140] **ISSC**, 2003, "Specialist Committee V.1.: Risk Assessment", in Japan (2006), *Goal – Based New Ship Construction Standards: Safety Level Approach*, London: IMO MSC 81/INF.7.

[141] **ISSC**, 2006, "Specialist Committee V.6.: Condition Assessment of Aged Ships", Report of the 16th International Ship Structures Congress, Volume 2, Southampton, UK. [Online]. Available from (cited: 27 August 2007): http://www.issc.ac/committeereportspageofissc2006.htm

[142] **Ivanov, L., D.**, 1986, "Statistical Evaluation of the Ship's Hull Cross Section Geometrical Characteristics as a function of her Age", International Shipbuilding Progress, **33**, (387), pp. 198 – 203.

[143] **Ivanov, L., D.**, 2002, "A Probabilistic Assessment of all Hull Girder Geometric Properties at any Ship's Age", Technical Report R&R-2002-1, Houston, TX, USA: ABS Technology, Risk and Reliability Group.

[144] **Ivanov, L., Spencer, J., Wang, G.**, 2003, "Probabilistic evaluation of hull structure renewals for aging ships", presented at the *8th International Marine Design Conference*, Athens, Greece. [Online]. Available from (cited: 28 August 2007): http://www.eagle.org/news/TECH/Marine/lyuben%20IMDC03%20renewal.pdf

[145] **Ivanov, L., Wang, G., Seah, A., K.**, 2004, "Evaluating Corrosion Wastage and Structural Safety of Aging Ships", published at the *Pacific 2004 International Maritime Conference*, Sydney, Australia. [Online]. Available from (cited: 28 August 2007): http://www.eagle.org/news/TECH/Marine/02-IMC%20LI.pdf

[146] **Japan**, 2002a, "FSA Study on Bulk Carrier Safety, Annex 1: Problem Definition and Background Information", London: IMO MSC 75/5. [Online]. Available from (cited: 28 August 2007): http://www.mlit.go.jp/english/maritime/bcfsa/msc75/annex1.pdf

[147] **Japan**, 2002b, "FSA Study on Bulk Carrier Safety, Annex 4: Hazard Identification", London: IMO MSC 75/5. [Online]. Available from (cited: 28 August 2007): http://www.mlit.go.jp/english/maritime/bcfsa/msc75/annex4.pdf

[148] **Japan**, 2002c, "FSA Study on Bulk Carrier Safety, Annex 5: Risk Analysis", London: IMO MSC 75/5. [Online]. Available from (cited: 28 August 2007): http://www.mlit.go.jp/english/maritime/bcfsa/msc75/annex5.pdf

[149] **Japan**, 2002d, "FSA Study on Bulk Carrier Safety, Annex 7: Cost Effectiveness Analysis", London: IMO MSC 75/5. [Online]. Available from (cited: 28 August 2007): http://www.mlit.go.jp/english/maritime/bcfsa/msc75/annex7.pdf

[150] **Japan**, 2006a, "Formal Safety Assessment – Consideration on utilization of Bayesian Network at Step 3 of FSA, Evaluation of the effect of ECDIS, ENC and Track control by using Bayesian Network", London: IMO MSC 81/18/1.

[151] **Japan**, 2006b, "Goal – Based New Ship Construction Standards, Draft Guidelines on Goal – Based Standards", London: IMO MSC 82/5/8.

[152] **Jaramillo, D., Cabos, C., Renard, P.**, 2006, "Efficient Data Management for Hull Condition Assessment", International Journal of CAD/CAM, [online], **6**, (1), available from (cited: 28 August 2007): http://www.ijcc.org/sub_02_vo6.htm

[153] **Jensen, F., V.**, 1996, "An introduction to Bayesian networks", UCL Press Limited, London.

[154] **Jensen, F., V.**, 2001, "Bayesian Networks and Decision Graphs", Springer – Verlag, New York.

[155] **Johnson, J., T.**, 2001, "Cost of Corrosion – Appendix O: Ships", United States Department of Transportation, Federal Highway Administration Report FHWA-RD-01-156, Dublin, Ohio, USA. [Online]. Available from (cited: 28 August 2007): http://www.corrosioncost.com/transportation/ships/index.htm

[156] **Juran, J., M.**, 2000a, "How to think about quality", in Juran, J., M. & Godfrey, A., B., eds., *Juran's Quality Handbook*, Fifth Edition, McGraw-Hill International Edition, Industrial/Plant Engineering Series, Singapore.

[157] **Juran, J., M.**, 2000b, "The Quality Improvement Process", in Juran, J., M. & Godfrey, A., B., eds., *Juran's Quality Handbook*, Fifth Edition, McGraw-Hill International Edition, Industrial/Plant Engineering Series, Singapore.

[158] **Kattan, M., R.**, 2005, "Corrosion in ballast tanks – Is rust a must?", in *Proceedings of the International Conference Design and Operation of Bulk Carriers*, RINA, London, UK.

[159] **Kavussanos, M., G.**, 2002, "Business Risk Measurement and Management in the Cargo carrying sector of the Shipping Industry", in Grammenos, C., Th., ed., *The*

Handbook of Maritime Economics and Business, LLP Ltd, Reprinted: Informa Ptrofessional, London, 2006.

[160] **Kjeldsen, S., P.**, 2005, "Measurements of freak waves in Norway and related ship accidents", in *Proceedings of the International Conference Design and Operation for Abnormal Conditins III*, RINA, London, UK.

[161] **Kleinbaum, D., G., Klein, M.**, 2002, "Logistic Regression. A Self – Learning Text. Statistics for Biology and Health", Second Edition, Springer – Verlag, New York.

[162] **Koller, D., Pfeffer, A.**, 1997, "Object – Oriented Bayesian Networks", in *Proceedings of the Thirteenth Annual Conference on Uncertainty in Artificial Intelligence (UAI – 97)*, pp. 302 – 313, Providence, Rhode Island, USA. [Online]. Available from (cited: 28 August 2007): http://citeseer.ist.psu.edu/koller97objectoriented.html

[163] **Krause, T., R.**, 1997, "The Behavior – Based Safety Process: Managing Involvement for an Injury – Free Culture", Second Edition, John Wiley & Sons Inc., New York, USA.

[164] **Kristiansen, S.**, 2005, "Maritime Transportation, Safety Management and Risk Analysis", Elsevier Butterworth – Heinemann, Oxford, UK.

[165] **Kumamoto, H., Henley, E., J.**, 1996, "Probabilistic Risk assessment and Management for Engineers and Scientists", Second Edition, The Institute of Electrical and Electronics Engineers Inc., IEEE Press, New Jersey, USA.

[166] **La Que, F., L.**, 1975, "Marine Corrosion: Causes and Prevention", John Wiley & Sons Inc., New York, USA.

[167] **Lambeth, R., J.**, 1981, "Templeman on Marine Insurance: Its Principles and Practice", Fifth Edition, Macdonald and Evans Ltd., London.

[168] **Landsea, C.**, 2007, "Frequently Asked Questions – version 4.2", United States Department of Commerce, National Oceanic and Atmospheric Administration, Office of Oceanic and Atmospheric Research, Atlantic Oceanographic and Meteorological Laboratory, Hurricane Research Division, Miami, Florida, USA. [Online]. Available from (cited: 28 August 2007): http://www.aoml.noaa.gov/hrd/tcfaq/tcfaqHED.html

[169] **Lazos, C., E.**, 1997, "Fortran 77 – with elements of MS-DOS", Thessaloniki. (Hellenic language)

[170] **LMIU**, 2005, "Bulk Carrier Casualty Database 1999 – 2005", May 2005 Version.

[171] **Løseth, R., Sekkesæter, G., Valsgård, S.**, 1994, "Economics of High – Tensile Steel in Ship Hulls", Marine Structures, **7**, (1), pp. 31 – 50.

[172] **LR**, 2005, "Thickness Measurement and Close – up Survey Guidance", Revision 4, London. [Online]. Available from (cited: 28 August 2007): http://www.cdlive.lr.org/information/Documents/ThicknessMeasurement/TM%20Guide.pdf

[173] **MAIIF**, n.d., "Contacts". [Online]. Available from (cited: 28 August 2007): http://www.maiif.net/Contacts.htm

[174] **MARS**, 1994, "Report No. 94039: Bulk Carrier Loading – The Message has not got through", The Nautical Institute, London. [Online]. Available from (cited: 28 August 2008): http://www.nautinst.org/mars/mars94/94039.htm

[175] **MARS**, 1997, "Report No. 97011: Over Loaded and Over Stressed Bulk Carrier", The Nautical Institute, London. [Online]. Available from (cited: 28 August 2007): http://www.nautinst.org/mars/mars97/mars97011.htm

[176] **MARS**, 1999, "Report No. 99003: Bulk Cargoes Ship/Shore Check List", The Nautical Institute, London. [Online]. Available from (cited: 28 August 2007): http://www.nautinst.org/mars/mars99/99003.htm

[177] **Mathiesen, T., C.**, 1997, "Cost Benefit Analysis of Existing Bulk Carriers: A Case Study on Application of Formal Safety Assessment Techniques", DNV Paper Series No. 97-P008, Høvik, Norway.

[178] **Mathsoft**, 2007, "MathCad 14.0", http://www.ptc.com/.

[179] **Matoba, M., Yamamoto, N., Watanabe, T., Umino, M.**, 1994, "Effect of Corrosion and its Protection on Hull Strength (1st Report)", Journal of the Society of Naval Architects of Japan, **175**, pp. 271 – 280. (Japanese language)

[180] **Matsushima, I.**, 2000, "Carbon Steel – Corrosion by seawater", in Revie, R., W., ed., *Uhlig's Corrosion Handbook*, Second Edition, John Wiley & Sons Inc., New York, USA.

[181] **Melchers, R., E.**, 1994, "Modelling and prediction of seawater corrosion of steel structures", in *Proceedings of the International Conference on Marine Corrosion Prevention: A Re – Appraisal for the Next Decade*, RINA, London, UK.

[182] **Melchers, R., E.**, 1998, "Probabilistic modelling of immersion marine corrosion", in Shiraishi, N., Shinozuka, M., Wen, Y., K., eds., *Structural Safety and Reliability, Volume 2*

– *Proceedings of ICOSSAR'97: The 7th International Conference on Structural Safety and Reliability, Kyoto 24-28 November 1997*, A. A. Balkema, Rotterdam, pp. 1143 – 1149.

[183] **Melchers, R., E.**, 1999, "Corrosion uncertainty modelling for steel structures", Journal of Constructional Steel Research, **52**, (1), pp. 3 – 19.

[184] **Melchers, R., E.**, 2003a, "Probabilistic Models for Corrosion in Structural Reliability Assessment – Part 1: Empirical Models", Journal of Offshore Mechanics and Arctic Engineering, **125**, (4), pp. 264 – 271.

[185] **Melchers, R., E.**, 2003b, "Probabilistic Models for Corrosion in Structural Reliability Assessment – Part 2: Models Based on Mechanics", Journal of Offshore Mechanics and Arctic Engineering, **125**, (4), pp. 272 – 280.

[186] **Melchers, R., E.**, 2003c, "Probabilistic Model for Marine Corrosion of Steel for Structural Reliability Assessment", Journal of Structural Engineering, **129**, (11), pp. 1484 – 1493.

[187] **Melchers, R., E.**, 2006, "Recent Progress in the Modelling of Corrosion of Structural Steel Immersed in Seawaters", Journal of Infrastructure Systems, **12**, (3), pp. 154 – 162.

[188] **Merten, C.**, 2004, "Incremental Compilation of Object – Oriented Bayesian Networks. [Online]. Available from (cited: 28 August 2007): http://www.cs.ubc.ca/~murphyk/Teaching/CS532c_Fall04/Projects/merten.pdf

[189] **Mikelis, N.**, 2005, "The art of turning experience into regulations", *The Baltic*, p. 53. [Online]. Available from (cited: 17 March 2008): http://www.thebaltic.co.uk/march_2005/pdf/pp53.pdf

[190] **Modarres, M.**, 2006, "Risk Analysis in Engineering – Techniques, Tools and Trends", CRC Press – Taylor & Francis Group, Boca Raton, Florida, USA.

[191] **Montgomery, D., C.**, 2005, "Design and Analysis of Experiments", Sixth Edition, John Wiley & Sons, Inc., New York, USA.

[192] **Morone, J., G., Woodhouse, E., J.**, 1988, "Averting Catastrophe: Strategies for Regulating Risky Technologies", University of California Press, Berkeley, California, USA.

[193] **Motil, J.**, n.d., "Pareto Principle". [Online]. Available from (cited: 28 August 2007): http://www.csun.edu/~jmotil/ParetoTop.html

[194] **Myers, R., H.**, 1990, "Classical and Modern Regression with Applications", Second Edition, Duxbury – Thomson Learning, Pacific Grove, California, USA.

[195] **Myers, R., H., Montgomery, D., C.**, 1995, "Response Surface Methodology: Process and Product Optimization Using Designed Experiments", John Wiley & Sons, Inc., A Wiley – Interscience Publication, New York USA.

[196] **Nakai, T., Matsushita, H., Yamamoto, N.**, 2005, "Pitting corrosion and its influences on local strength of hull structural members", in *Proceedings of the 24th Offshore Mechanics and Arctic Engineering Conference*, (OMAE 2005-67025), Halkidiki, Greece.

[197] **Neapolitan, R., E.**, 2004, "Learning Bayesian Networks", Pearson Prentice Hall, Upper Saddle River, New Jersey, USA.

[198] **Netherlands**, 2006, "Formal Safety Assessment – Report of the correspondence group", London: IMO MSC 81/18.

[199] **Nilsen, T., Aven, T.**, 2003, "Models and model uncertainty in the context of risk analysis", Reliability Engineering & System Safety, **79**, (3), pp. 309 – 317.

[200] **Nomikos, N., K., Alizadeh, A., H.**, 2002, "Risk Management in the Shipping Industry: Theory and Practice", in Grammenos, C., Th., ed., *The Handbook of Maritime Economics and Business*, LLP Ltd, Reprinted: Informa Ptrofessional, London, 2006.

[201] **Norway**, 2005, "Passenger Ship Safety: Effective voyage planning for Passenger Ships, FSA – Large Passenger Ships – Navigational Safety", London: IMO NAV 51/10.

[202] **NTSB**, 1978, "Marine Accident Report: SS Edmund Fitzgerald Sinking in Lake Superior on November 10, 1975", Report No. NTSB-MAR-78-3, Washington, D.C., USA.

[203] **NTSB**, 1984, "Marine Accident Report: United States Bulk Carrier Marine Electric Capsizing and Sinking about 30 nautical miles east of Chincoteague, Virginia, February 12, 1983", Report No. NTSB/MAR-84/01, Washington, D.C., USA.

[204] **OECD**, 1996, "Competitive advantages obtained by some shipowners as a result of non – observance of applicable international rules and standards", OCDE/GD(96)4, Paris. [Online]. Available from (cited: 29 August 2007): http://www.oecd.org/dataoecd/10/10/2754615.pdf

[205] **OECD**, 2001, "The cost to users of substandard shipping", Prepared by SSY Consultancy & Research Ltd. for OECD Maritime Transport Committee. [Online]. Available from (cited: 29 August 2007): http://www.oecd.org/dataoecd/27/18/1827388.pdf

[206] **Olive, C., O'Connor, T., M., Mannan, M., S.**, 2006, "Relationship of safety culture and process safety", Journal of Hazardous Materials, **130**, (1-2), pp. 133 – 140.

[207] **Osman, H.**, 2005, "Risk – Based Life – Cycle Cost Analysis of Privatized Infrastructure", Transportation Research Record: Journal of the Transportation Research Board, **1924**, pp. 192 – 196.

[208] **Ott, R., L., Longnecker, M.**, 2001, "An introduction to Statistical Methods and Data Analysis", Fifth Edition, Duxbury – Thomson Learning, Pacific Grove, California, USA.

[209] **Ozbay, K., Parker, N., A., Jawad, D., Hussain, S.**, 2003, "Guidelines for Life Cycle Cost Analysis", Report No.: FHWA-NJ-2003-012, USA: Department of Civil & Environmental Engineering, Center for Advanced Infrastructure & Transportation, Rutgers, The State University of New Jersey and Department of Civil Engineering, City College of The City University of New York for New Jersey Department of Transportation, Division of Research and Technology and U.S. Department of Transportation, Federal Highway Administration. [Online]. Available from (cited: 29 August 2007): http://www.cait.rutgers.edu/finalreports/FHWA-NJ-2003-012.pdf

[210] **Packard, W., V.**, 1985, "Sea – Trading Volume 2, Cargoes", Fairplay Publications Ltd., London.

[211] **Paik, J., K., Kim, S., K., Lee, S., K.**, 1998, "Probabilistic corrosion rate estimation model for longitudinal strength members of bulk carriers", Ocean Engineering, **25**, (10), pp. 837 – 860.

[212] **Paik, J., K., Thayamballi, A., K., Park, Y., I., Hwang, J., S.**, 2003a, "A Time – Dependent Corrosion Wastage Model for Bulk Carrier Structures", International Journal of Maritime Engineering, **145**, (A2), Transactions of RINA, London, UK.

[213] **Paik, J., K., Lee, J., M., Park, Y., I., Hwang, J., S., Kim, C., W.**, 2003b, "Time – variant ultimate longitudinal strength of corroded bulk carriers", Marine Structures, **16**, (8), pp. 567 – 600.

[214] **Paik, J., K., Thayamballi, A., K., Park, Y., I., Hwang, J., S.**, 2004, "A time – dependent corrosion wastage model for seawater ballast tank structures of ships", Corrosion Science, **46**, (2), pp. 471 – 486.

[215] **Paris MOU**, 2005, "Detention List for year 2005". [Online]. Available from (cited: 29 August 2007): http://www.parismou.org/ParisMOU/Detention+Lists/xp/menu.3974/default.aspx

[216] **Parker, C., J.**, 1999, "Managing Risk in Shipping Companies", in *Managing Risk in Shipping: A Practical Guide*, The Nautical Institute, London.

[217] **Paulling, J., R.**, 1988, "Strength of Ships", in Lewis, E., V., ed., *Principles of Naval Architecture, Second Revision, Vol. I: Stability and Strength*, Published by SNAME, 601 Pavonia Avenue, Jersey City, NJ, USA.

[218] **Pearl, J.**, 1988, "Probabilistic Reasoning in Intelligent Systems: Networks of Plausible Inference", Morgan Kaufmann Publishers Inc., San Mateo, California, USA.

[219] **Peitgen, H-O.**, n.d., quoted in Gleick, J., 1998, *Chaos – The amazing science of the unpredictable*, Vintage, London, UK.

[220] **Procter & Gamble**, n.d., quoted in Deal & Kennedy (2000).

[221] **PRS**, 2000, "Report on the investigation by PRS into the loss of Bulk Carrier "Leader L"", Gdansk, Poland.

[222] **Psaraftis, H., N.**, 2006, "Maritime Safety in the Post – Prestige Era", Marine Technology, **43**, (2), pp. 85 – 90.

[223] **Psaraftis, H., N., Panagakos, G., Desypris, N., Ventikos, N.**, 1998, "An analysis of maritime transportation risk factors", presented at the *Eighth International Offshore and Polar Engineering Conference (ISOPE 98)*, Montreal, Canada. [Online]. Available from (cited: 29 August 2007): http://www.martrans.org/documents/2000/safeco/Isopepaperfinal.doc

[224] **Qin, S., P., Cui, W., C.**, 2002, "A discussion of the ultimate strength of ageing ships, with particular reference to the corrosion model", Proceedings of the Institute

of Mechanical Engineers Part M: Journal of Engineering for the Maritime Environment, **216**, (2), pp. 155 – 160.

[225] **Qin, S., Cui, W.**, 2003, "Effect of corrosion models on time – dependent reliability of steel plated elements", Marine Structures, **16**, (1), pp. 15 – 34.

[226] **RAE**, 2003, "Common Methodologies for Risk Assessment & Management", London, UK. [Online]. Available from (cited: 31 January 2008): http://www.raeng.org.uk/news/publications/list/reports/Common_Methodologies_for_Risk_Assessment.pdf

[227] **Rankin, K., S.**, 2002, "Thomas' Stowage: The Properties and Stowage of Cargoes", Fourth Edition, Brown, Son & Ferguson Ltd., Glasgow, UK.

[228] **Ravetz, J., R.**, n.d., quoted in Douglas, M. and Wildavsky, A. 1983.

[229] **Rawson, K., J., Tupper, E., C.**, 2001, "Basic Ship Theory – Volumes I & II, Fifth Edition, Butterworth – Heinemann, Oxford, UK.

[230] **Republic of Korea**, 2001, "Bulk Carrier Safety: A Trial Application of FSA Methodology to the Hatchway Watertight Integrity of Bulk Carriers", London: IMO MSC 74/INF.15.

[231] **RINA**, 2001, "Risk – based design: an integrated tool for complete ship lifecycles", in *The Future of Ship Design – Part 2*, published for Deltamarin Ltd., pp. 35 – 36.

[232] **RINA**, 2002, "Formal Safety assessment Study of Bulk Carriers", Final Report, London, UK, pp. 15 – 16.

[233] **Roberts, S., E., Marlow, P., B.**, 2002, "Casualties in dry bulk shipping (1963 – 1996)", Marine Policy, **26**, (6), pp. 437 – 450.

[234] **Rogers, P., Strange, J., Studd, B.**, 1997, "Coal: Carriage by Sea", Second Edition, LLP Limited, London, UK.

[235] **Roland, H., E., Moriarty, M.**, 1990, "System Safety Engineering and Management", A Wiley Interscience Publication, John Wiley & Sons, Inc., Toronto, Canada.

[236] **Rowe, W., D.**, 1988, "An anatomy of Risk", Reprint Edition, Robert E. Krieger Publishing Company Inc., Malabar, Florida, USA.

[237] **Ryan, T., P.**, 1997, "Modern regression Methods – Wiley series in Probability and Statistics", John Wiley & Sons Inc., New York, USA.

[238] **Saiarasamoot, S., Olson, D., L., Spencer, J., S., Wang, G.**, 2003, "Assessment of the Emerging Technologies for the Detection and Measurement of Corrosion Wastage of Coated Marine Structures", in *Proceedings of the 22nd Offshore Mechanics and Arctic Engineering Conference*, (OMAE 2003-37371), Cancun, Mexico.

[239] **Samouelides, M.**, 1999, "Strength of Ships", Lecture Notes, NTUA Publication, Athens. (Hellenic language)

[240] **Sanghai, S., Domingos, P., Weld, D.**, 2005, "Relational Dynamic Bayesian Networks", Journal of Artificial Intelligence Research, **24**, pp. 759 – 797.

[241] **Schwartz, S.**, n.d., "Steve Schwartz Wreck Listing 1996-1998". [Online]. Available from (cited: 29 August 2007): http://wrecks.softwaredoc.org/lloyddb/world.htm

[242] **Seignette, R.**, 2002, "Detailed task inventory", Report No. GM-R0342-0108-1400 Global Maritime B.V. for RINA Formal Safety Assessment of Bulk Carriers – International Collaborative Study: Work Package 9B. [Online]. Available from (cited: 29 August 2007): http://www.tripodsolutions.net/downloads/aspx

[243] **Sewell, T.**, 1999, "Grain: Carriage by Sea", LLP Limited, London, UK.

[244] **Shreir, L., L.**, 1994, "Basic concepts of corrosion", in Shreir, L., L., Jarman, R., A., Burstein, G., T., eds., *Corrosion Volume 1, Metal/Environment reactions*, Third Edition, Butterworth – Heinemann, Oxford, UK, Reprinted: 2000.

[245] **Skjong, R., Vanem, E., Endresen, Ø.**, 2007, "Risk Evaluation Criteria", SAFEDOR-D-4.5.2-2007-10-24-DNV-rev-3.0. [Online]. Available from (cited: 14 March 2009): http://www.safedor.org/resources/SAFEDOR-D-04.05.02-2005-10-21-DNV-RiskEvaluationCriteria-rev-3.pdf

[246] **Skoulikidis, T., Vassiliou, P.**, 1994, "Corrosion and Protection of Materials", Symeon Publishing Co., Athens. (Hellenic language)

[247] **Sone, H., Magaino, A., Yamamoto, N., Harada, S.**, 2003, "Evaluation of Thickness Diminution in Steel Plates for the Assessment of Structural Condition of Ships in Service", Class NK Technical Bulletin, **21**, pp. 55 – 71.

[248] **Southwell, C., R., Bultman, J., D., Hummer, C., W., Jr.**, 1979, "Estimating service life of steel in seawater", in Schumacher, M., ed., *Seawater Corrosion Handbook*, Noyes Data Corporation, Park Ridge, New Jersey, USA, pp. 374 – 384.

[249] **Sparks, A.**, 2003, "Steel: Carriage by Sea", Fourth Edition, Informa Professional UK Ltd., London.

[250] **Sparrow, M., K.**, 2000, "The Regulatory Craft – Controlling Risks, Solving Problems, and Managing Compliance", Council for Excellence in Government, Brookings Institution Press, Washington, D.C., USA.

[251] **Stambaugh, K., A., Knecht, J., C.**, 1991, "Corrosion Experience Data Requirements", Ship Structure Committee Report No. SSC – 348, Washington, D.C., USA. [Online]. Available from (cited: 29 August 2007): http://www.shipstructure.org/pdf/348.pdf

[252] **Standard-Club**, 1998, "Standard Safety Issue 1: Cargo Claims – Bulk Carriers – Side Shell Failure". [Online]. Available from (cited: 29 August 2007): http://www.standard-club.com/pdf/StandardSafety/issue1/page37.htm

[253] **Starling, M., Riding, J.**, 1998, "MCA Research Project 442: Bulk Carrier Formal Safety assessment – Preparatory Work", Report No.: 305B213/3, Fareham, Hampshire: BMT Reliability Consultants Limited for Maritime and Coastguard Agency, UK. [Online]. Available from (cited: 29 August 2007): http://www.mcga.gov.uk/c4mca/research_project_442.pdf

[254] **Stopford, M.**, 2009, "Maritime Economics", 3rd Edition, Routledge, London, UK.

[255] **Straub, D., Faber, M., H.**, 2005, "Temporal Variability in Corrosion Modeling and Reliability Updating", in *Proceedings of the 24th Offshore Mechanics and arctic Engineering Conference*, (OMAE 2005-67199), Halkidiki, Greece.

[256] **Sun, H., H., Bai, Y.**, 2003, "Time – variant reliability assessment of FPSO hull girders", Marine Structures, **16**, (3), pp. 219 – 253.

[257] **Swadi, D.**, 2005, "Cargo Notes", Seamanship International Ltd., Glasgow, UK.

[258] **Tallack, R., L.**, 1999, "Managing Risk in Trading and Transporting Cargoes", in *Managing Risk in Shipping: A Practical Guide*, The Nautical Institute, London.

[259] **Tamvakis, M., N., Thanopoulou, H., A.**, 2000, "Does quality pay? The case of the dry bulk market", Transportation Research Part E, **36**, (4), pp. 297 – 307.

[260] **Thuanboon, S., Tordonato, D., S., Navidi., Olson, D., L., Mishra, B., Wang, G.**, 2006, "A Statistical Analysis of Corrosion Wastage of Teransverse Members in Single Hull Tankers", in *Proceedings of the 25th Offshore Mechanics and Arctic Engineering Conference*, (OMAE 2006-92665), Hamburg, Germany.

[261] **Thyregod, P., Nielsen, B., F.**, 1993, "Trends in marine losses and major casualties 1984 – 1992", Technical report No.8/1993, IMSOR – The Institute of Mathematical

Statistics and Operations Research, The Technical University of Denmark, Lyngby, Denmark.

[262] **Thyregog, P., Nielsen, B., F.**, 1995, "Losses and Major Casualties 1984 – 92, Tankers and Bulkers 10,000 GT and above", Technical Report IMM-REP-1995-7, The Institute of Mathematical Modelling, Technical University of Denmark, Lyngby, Denmark. [Online]. Available from (cited: 29 August 2007): http://www2.imm.dtu.dk/documents/ftp/tr95/tr07_95.pdf

[263] **Toffoli, A., Lefèvre, J., M., Josse, P., Monbaliu**, 2004, "Investigation of Unexpected Sea – States", in *Proceedings of the 23rd International Conference on Offshore Mechanics and Arctic Engineering*, (OMAE 2004-51181), Vancouver, British Columbia, Canada.

[264] **Tokyo MOU**, 2005, "Detention List for year 2005". [Online]. Available from (cited: 29 August 2007): http://www.tokyo-mou.org/deten.htm

[265] **Tsaraklis, Z., Papazoglou, V., I.**, 2001, "Health and Safety in the Maritime Environment", Lecture Notes, NTUA Publication, Athens. (Hellenic language)

[266] **TSB**, 2000, "Marine Investigation Report: Break – Up and Sinking, The Bulk Carrier "FLARE"", Report No. M98N0001, Quebec, Canada. [Online]. Available from (cited: 29 August 2007): http://www.tsb.gc.ca/en/reports/marine/1998/m98n0001/m98n0001.asp

[267] **UK P&I Club**, 2005, "Carefully to Carry", Issue 8, London, UK.

[268] **UKHO**, 2004, "Admiralty Ocean Passages for the world", Fifth Edition, Published by UKHO, publication No. NP 136, Somerset, England, UK.

[269] **UN Ocean Atlas**, 2000, "Shipping and World Trade". [Online]. Available from (cited: 30 August 2007): http://www.oceansatlas.org/unatlas/uses/transportation_telecomm/maritime_trans/shipping/shipping.htm

[270] **UNCTAD**, 2008, "Review of Maritime Transport, 2008", Geneva, Switzerland. [Online]. Available from (cited: 30 December 2008): http://www.unctad.org/en/docs/rmt2008_en.pdf

[271] **Unisys Weather**, 2006, "Hurricane/Tropical Data", May 2006 version. [Online]. Available from (cited: 30 August 2007): http://weather.unisys.com/hurricane/index.html

[272] **UK**, 2001a, "Bulk Carrier Safety: International Collaborative FSA Study – Screening of Generic Hazards", London: IMO MSC 74/INF.4.

[273] **UK**, 2001b, "Bulk Carrier Safety: International Collaborative FSA – Hazard Identification and Screening", London: IMO MSC 74/INF.5.

[274] **UK**, 2001c, "Bulk Carrier Safety: International Collaborative FSA – Hazard Identification and Screening", London: IMO MSC 74/INF.5/Add.1.

[275] **UK**, 2002a, "Bulk Carrier Safety: International Collaborative FSA Study – FSA Step 4 (Cost Benefit Assessment)", London: IMO MSC 76/INF.7.

[276] **UK**, 2002b, "Bulk Carrier Safety: International Collaborative FSA Study – Final Report", London: IMO MSC 76/5/5.

[277] **UK**, 2003, "Role of the Human Element – Definition of the Safety Culture", London: IMO MSC 77/17.

[278] **UK**, 2004, "Goal – Based New Ship Construction Standards – Relationship between goal – based standards, prescriptive regulation and Formal safety assessment", London: IMO MSC 79/6/25.

[279] **USCG PSC**, 2005, "Detention List for year 2005". [Online]. Available from (cited: 30 August 2007): http://homeport.uscg.mil/mycg/portal/ep/contentView.do?contentTypeId=2&channelId=-18371&contentId=21901&programId=21428&programPage=%2Fep%2Fprogram%2Feditorial.jsp&pageTypeId=13489&BV_SessionID=@@@@0934203054.1188810665@@@@&BV_EngineID=cccfaddllhkdkdfcfjgcfgfdffhdghm.0

[280] **USCG**, 1977, "Marine Board of Investigation Report and Commandant's Action: SS Edmund Fitzgerald; Sinking in Lake Superior on 10 November 1975 with loss of life", Report No. USCG 16732/64216, Washington, D.C., USA. [Online]. Available from (cited: 30 August 2007): http://www.uscg.mil/hq/g-m/moa/boards/edmundfitz.pdf

[281] **USCG**, 1984, "Marine Board of Investigation Report and Commandant's Action: SS Marine Electric, O.N. 245675; Capsizing and Sinking in the Atlantic Ocean on 12 February 1983 with multiple loss of life", Report No. 16732/0001 HQS 83, Washington, D.C., USA. [Online]. Available from (cited: 30 August 2007): http://www.uscg.mil/hq/g-m/moa/boards/marineelectric.pdf

[282] **Van Roon, T.**, 2001, "High level task inventory", Report No. GM-R0315-0011-1383 Global Maritime B.V. for Formal Safety Assessment of Bulk Carriers – International Collaborative Study: Work Package 9A.

[283] **Vassalos, D.**, 1999, "Shaping Ship Safety: The Face of the Future", Marine Technology, **36**, (2), pp. 61 – 76.

[284] **Vassalos, D.**, 2005, "Risk – Based Design Concept, Methodology and Framework", Training Course on Risk – Based Ship Design, Glasgow, UK.

[285] **Viña del Mar**, 2005, "Detention List for year 2005". [Online]. Available from (cited: 30 August 2007): http://200.45.69.62/index_i.htm

[286] **Vinnem, J., E.**, 2007, "Offshore Risk Assessment: Principles, Modelling and Applications of QRA Studies", Second Edition, Springer – Verlag Ltd., London.

[287] **Visual Numerics**, 1997, "IMSL Libraries", http://www.vni.com/.

[288] **Von Neumann, J.**, n.d., quoted in Gleick, J., 1998, *Chaos – The amazing science of the unpredictable*, Vintage, London, UK.

[289] **Vose, D.**, 2001, "Risk Analysis, A Quantitative Guide", Second Edition, John Wiley & Sons Ltd., Chichester, West Sussex, England, UK.

[290] **Wang, G., Spencer, J., Sun, H.**, 2005, "Assessment of Corrosion Risks to Aging Ships Using an Experience Database", Journal of Offshore Mechanics and Arctic Engineering, **127**, (2), pp. 167 – 174.

[291] **Wang, J., Trbojevic, V.**, 2007, "Design for Safety of Marine and Offshore Systems", published by the Institute of Marine Engineering, Science and Technology (IMarEST), London, UK.

[292] **Waring, A., Glendon, A., I.**, 1998, "Managing Risk: Critical issues for survival and success into the 21st century", First Edition, Thomson Learning, Cornwall, England, Reprinted: 2006.

[293] **West P&I**, 1994, "Part 1. Structural Failure in Bulk Carriers", Loss Prevention Bulletin, London, UK. [Online]. Available from (cited: 30 August 2007): http://www.westpandi.com/WestPandI/LossPrevention/Bulletins/Part+1-+Structural+Failure+in+Bulk+Carriers.htm

[294] **Wiegmann, D., A., Zhang, H., Von Thaden, T., L., Sharma, G., Mitcell, A., A.**, 2002, "A synthesis of Safety Culture and Safety Climate Research", Technical Report ARL-02-3/FAA-0202, Savoy, Illinois, USA: University of Illinois at Urbana-

Champaign for Federal Aviation Administration, Atlantic City International Airport, NJ, USA. [Online]. Available from (cited: 30 August 2007): http://www.humanfactors.uiuc.edu/Reports&PapersPDFs/TechReport/02-03.pdf

[295] **Xerokostas, D., A.**, 1999, "Operational research II: Replacement – Maintenance – Reliability", Symmetria Publishing Co., Athens. (Hellenic language)

[296] **Yamamoto, N.**, 1997, "Probabilistic corrosion model of ship structural members", in *Proceedings of the Eleventh International Maritime and Shipping Conference: Ships – The Ageing Process*, (IMAS '97), The Institute of Marine Engineers, London, UK.

[297] **Yamamoto, N.**, 1998, "Reliability Based Criteria for Measures to Corrosion", in *Proceedings of the 17th Offshore Mechanics and Arctic Engineering International Conference*, (OMAE 1998-1243), Lisbon, Portugal.

[298] **Yamamoto, N.**, 2000, "Reliability Based Criteria For Measures Against Corrosion", Class NK Technical Bulletin, **18**, pp. 29 – 34.

[299] **Yamamoto, N., Ikegami, K.**, 1996, "A Study on the Degradation of Coating and Corrosion of Ship's Hull Based on the Probabilistic Approach", in Guedes Soares, C., Bea, R., G., Leira, B., J., Shetty, N., K., Atkins, W., S., Vinnem, J., E., eds., *Proceedings of the 15th International Conference on Offshore Mechanics and Arctic Engineering – Volume II: Safety and Reliability*, (OMAE 1996), pp. 159 – 166.

[300] **Yamamoto, N., Ikegami, K.**, 1998, "A Study on the Degradation of Coating and Corrosion of Ship's Hull Based on the Probabilistic Approach", Journal of Offshore Mechanics and Arctic Engineering, **120**, (3), pp. 121 – 128.

[301] **Yamamoto, N., Kumano, A., Matoba, M.**, 1994, "Effect of Corrosion and its Protection on Hull Strength (2nd Report)", Journal of the Society of Naval Architects of Japan, **176**, pp. 281 – 289. (Japanese language)

[302] **Yamamoto, N., Yao, T.**, 2002, "Hull Girder Strength of a Tanker under Longitudinal Bending considering Strength Diminution due to Corrosion", Class NK Technical Bulletin, **20**, pp. 103 – 109.

[303] **Yoneya, T., Shigemi, T., Yamamoto, N., Harada, S., Harada, M.**, 2003, "A Comprehensive Study on the Practical Strength assessment of Tanker and Bulk Carrier Structures", *SNAME World Maritime Technology Conference*, San Francisco, USA.

[304] **Zamiatina, O., Samoilova, O., Mayer, P.**, 2001, "Eating away at corrosion: Corrosion is more dangerous than 100 years ago", ISO Bulletin, pp. 6 – 12. [Online]. Available from (cited: 30 August 2007): http://isotc.iso.org/livelink/livelink/fetch/2000/2122/138357/138358/1068857/4390992/Corrosion.pdf?nodeid=4391852&vernum=0

This page is intentionally left blank

Appendices

> "The information you have is not the information you want;
> The information you want is not the information you need;
> The information you need is not the information you can obtain;
> The information you can obtain costs more than you want to pay"
>
> Anonymous, quoted in Bernstein (1998)

This page is intentionally left blank

A Hazard Register and Risk Matrix

TABLE A.I. *Hazard Register*

Hazard Category	Causal factors	Effect	Progression of incident	Safeguard	PI	SI	RI
1. External / C	Charter parties dictate the use of specific weather routeing services	Inadequate passage planning, no response on changing weather/sea conditions	• Vessel moved too close to tropical storm • Increased likelihood of damage • Loss of vessel	➢ SOLAS Ch. V, VI, IX, XII ➢ ISM Code ➢ BC Code ➢ BLU Code ➢ Definition of charters and contracts	3	3	6
2. External / C	Bad advice from a third party				3	3	6
3. External / C	Dominance of charterer/cargo owner over vessel owner/vessel's staff				4	3	7
4. External / M, C	Adverse weather conditions				4	2	6
5. External / M, C	Encountering heavy weather in condition of loading high density cargo				5	4	9
6. External / H, M	Poor bridge resource management				3	2	5
7. External / H, M, C	Inappropriate speed, heading and draft				5	3	8
8. External / H, M	Unawareness of navigational aids				3	3	6
9. External / H, M	Inadequate information about weather conditions				4	3	7
10. External / H, M, C	Failure of ship operator to modify speed/heading in line with weather conditions				5	3	8
11. External / M, C, F	Boost profitability – loading to tropical marks whilst carrying minimum consumables (i.e. bunkers, fresh water), effects of brackish water not taken into consideration				4	2	6
12. External / C	Lack of reliable and accurate means of determining cargo tonnages				4	3	7
13. External / M, C	Extreme loading conditions when accurate draught readings no possible				4	3	7
14. External / M, C, F	Owners over stating performance to gain charter				2	3	5

Abbreviations:

Human/Crew	:	**H**	Financial (Market)	:	**F**
Management/Ownership	:	**M**	Commercial realities (Charterers)	:	**C**

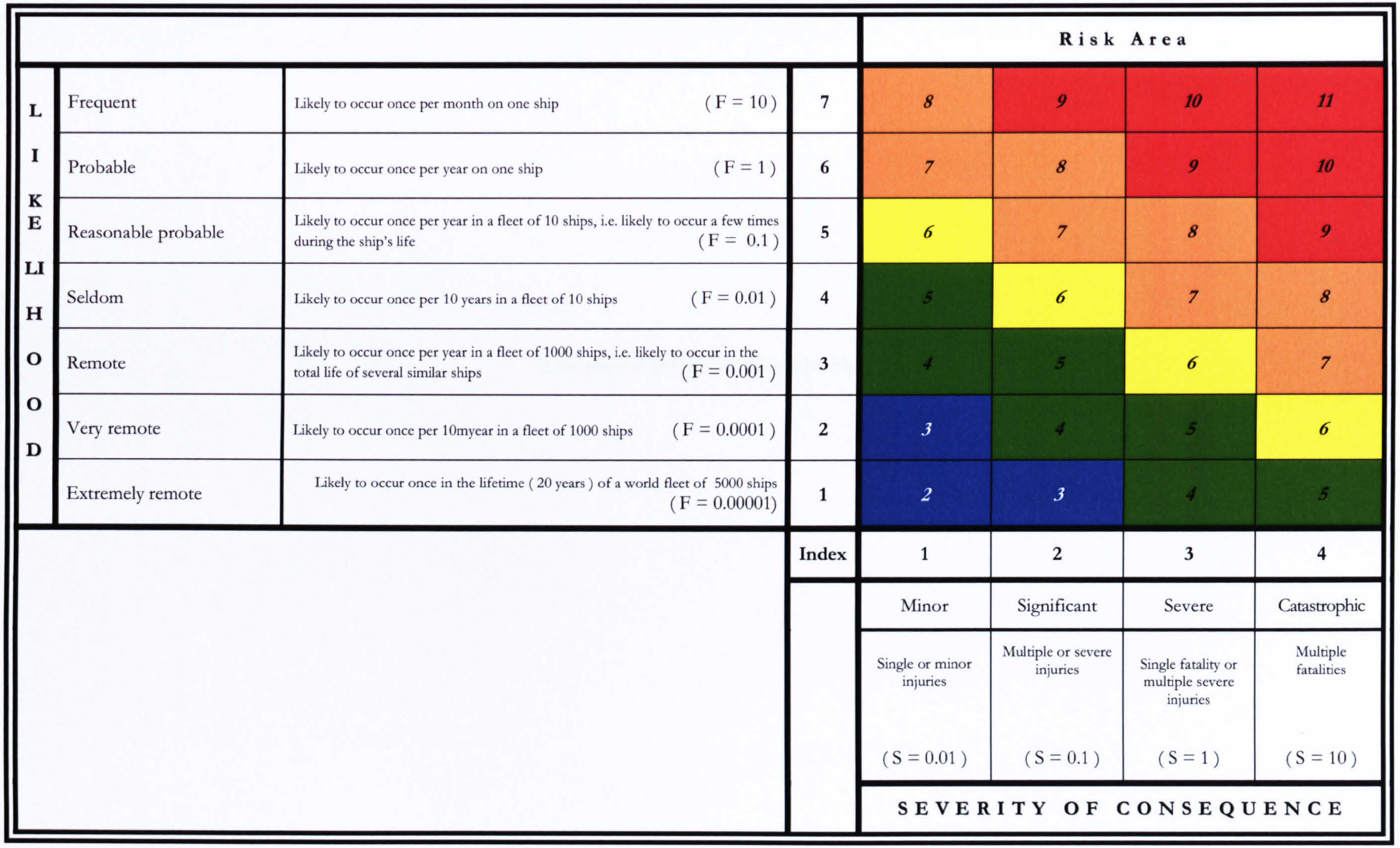
TABLE A.I (Continued). *Hazard Register*

Hazard Category	Causal factors	Effect	Progression of incident	Safeguard	PI	SI	RI
15. Cargoes / F	Commercial pressure – fluctuating/low freight indices require maximising of revenue by flexible ship operation (dangerous cargoes)	Chemical hazards – corrosive/abrasive cargoes	• Accelerated corrosion of hull structure • Increased likelihood of damage • Loss of vessel	➢ SOLAS Ch. V, VI, IX, XII ➢ ISM Code ➢ BC Code ➢ BLU Code ➢ Definition of charters and contracts	4	3	7
16. Cargoes / C	Commercial pressure – port operators				4	3	7
17. Cargoes / C	High loading rates – reduced No of shiftings/pours				6	3	9
18. Cargoes / C	Deviations from the loading plan				4	3	7
19. Cargoes / H, M, C	Ignoring procedures				3	3	6
20. Cargoes / H, M, C	Lack of effective loading/de – ballasting plan				4	3	7
21. Cargoes / M, C	Commercial pressure – requirement to retain bilge water on board to conserve deadweight where draught survey is used to check cargo weight at discharge port				6	2	8
22. Cargoes / M, C	Cargo properties different from that declared – cargo certificate are deliberately vague to prevent litigation				4	3	7
23. Cargoes / C	Incorrect naming of cargoes – trade names used rather than chemical names (difficult to be identified in BC/IMDG Codes)				4	3	7
24. Cargoes / M, C	Cargo contamination – different grades of cargoes				4	2	6
25. Cargoes / C	Carriage of cargoes with excess moisture at loading				3	2	5
26. Cargoes / C	Rain during loading – cargo stowed in the open				3	2	5
27. Cargoes / H, M	Ship disregarded cargo details				4	2	6
28. Cargoes / C	No cargo details provided				3	2	5
29. Cargoes / H, M, C	Commercial pressure – lack of time between cargoes to clean holds				4	2	6
30. Cargoes / H, M	Lack of information regarding the standard of cleanliness required and procedures applied				4	2	6
31. Cargoes / H, M	Lack of vessel's equipment to verify cargo details (e.g. moisture methane or oxygen content				5	2	7
32. Cargoes / M	Poor maintenance management – failure to provide support anc enforce the use of a planned maintenance programme				5	2	7
33. Cargoes / M, C	Corrosive nature of cargo				7	2	9

TABLE A.I (Continued). *Hazard Register*

Hazard Category	Causal factors	Effect	Progression of incident	Safeguard	PI	SI	RI
34. Cargoes / M, C	Working of ship structure – cargo movement	Mechanical damage – poor stevedoring techniques (crab damage, bulldozers), coating damage	• More rapid wastage (Corrosion) • Increased likelihood of damage • Loss of vessel	➢ SOLAS Ch. V, VI, IX, XII ➢ ISM Code ➢ BC Code ➢ BLU Code ➢ Definition of charters and contracts	7	2	9
35. Cargoes / C	Extremely heavy cargo – difficult to stow and lash				3	3	6
36. Cargoes / C	Cargo gear (crabs, wires) striking structure				5	3	8
37. Cargoes / M, C	Cargo sweat				5	2	7
38. Cargoes / M, C	Corrosive nature of cargo				7	2	9
39. Cargoes / M	Corrosive nature of seawater used for hold washing				7	3	10
40. External / M, C	Charter parties can be very complex and difficult to interpret	Uninformed decisions onboard and ashore	• Inappropriately loaded vessel • Inappropriate passage planning • Increased likelihood of damage • Loss of vessel		2	3	5
41. External / M, C	Lack of shore side back up (company/terminal)				4	3	7
42. External / H, M	Master expected to make decisions on abstract of charter and other limited information				2	3	5
43. External / C, F	Commercial pressure				2	3	5
44. External / M, F	Poor shore management				3	3	6
45. External / H, M	Inexperienced masters				1	3	4
46. External / H, M	Inappropriately trained crew				2	2	4
47. External / H, M, C	Ignoring quality shipping procedures (i.e. trimming)				4	3	7
48. External / M	Vessel's staff fear of being fired (unemployment)				6	1	7
49. External / M, H	Change of owners (sale of vessel) – unfamiliarity (company and crew)				5	2	7
50. External / C, F	Charterers interested in cost, not in safety and quality	Problem of alternate/block loading is no appreciated	• Overloaded/overstressed vessel • Increased likelihood of damage • Loss of vessel		3	3	6
51. External / M, C	Vessel/cargo/terminal suitability and compatibility is not taken into consideration by charter (restricted air draught, inability of ship loader to reach all holds)				3	4	7
52. External / M, C, F	Inappropriate charter party clause (unofficially) for size and design of vessel " Not always afloat but safely aground" (NAABSA)				4	3	7
53. External / M, C	The "split load" scenario is more complicated than usual homogeneous load scenario				4	4	8
54. External / C	Inability to redistribute or discharge cargo at loading port				4	2	6

TABLE A.II. *Risk Matrix (IMO 2002b, 2007b)*



				Risk Area			
LIKELIHOOD	Frequent	Likely to occur once per month on one ship (F = 10)	7	8	9	10	11
	Probable	Likely to occur once per year on one ship (F = 1)	6	7	8	9	10
	Reasonable probable	Likely to occur once per year in a fleet of 10 ships, i.e. likely to occur a few times during the ship's life (F = 0.1)	5	6	7	8	9
	Seldom	Likely to occur once per 10 years in a fleet of 10 ships (F = 0.01)	4	5	6	7	8
	Remote	Likely to occur once per year in a fleet of 1000 ships, i.e. likely to occur in the total life of several similar ships (F = 0.001)	3	4	5	6	7
	Very remote	Likely to occur once per 10myear in a fleet of 1000 ships (F = 0.0001)	2	3	4	5	6
	Extremely remote	Likely to occur once in the lifetime (20 years) of a world fleet of 5000 ships (F = 0.00001)	1	2	3	4	5
			Index	1	2	3	4
				Minor	Significant	Severe	Catastrophic
				Single or minor injuries (S = 0.01)	Multiple or severe injuries (S = 0.1)	Single fatality or multiple severe injuries (S = 1)	Multiple fatalities (S = 10)
				SEVERITY OF CONSEQUENCE			

This page is intentionally left blank

B Statistical Analysis of Accident Data

B.1. Introduction

The analysis of casualty and deficiency statistics is considered to be important for providing potential improvement in the specification for recording and coding relevant data including the primary causes, underlying factors and latent factors associated with a casualty. Apart from the fact that the current findings are in accordance to those of previous published studies (Roberts and Marlow 2002, Thyregod and Nielsen 1993, 1995, Eknes et al. 1997, BTCE 1994), another aim of this analysis is ***to identify a specialized categorization system for the development of a database where the analysts' requirements will be satisfied*** since many of the data resources adopt their own classification records.

B.2. Information Resources

All dry bulk cargo vessel accidents between 1963 and 2005 were identified from records published by LMIS (Hooke 1997), INTERCARGO (Intercargo 1998, 1999, 2006a), LMIU (LMIU 2005). Additional information was found in the 2002 and 2003 Casualty Reports of Intercargo (Intercargo 2003, 2004), Steve Schwartz Wreck Listing 1996 – 1998 (Schwartz n.d.) and The Cargo Letter Vessel Casualties (Countryman and McDaniel 2007). More precisely, 502 casualties were identified in LMIS, 28 in Intercargo, 95 in LMIU and 7 in Schwartz, while the rest references (Intercargo 2003, 2004, Countryman and

McDaniel 2007) were advised for any missing data. A Database was constructed regarding these 632 incidents in total, which were recorded as "Constructive Total Losses" (CTL), whereas CTL is a right of a marine assured to claim a total loss on the policy because either, (i) the property has been lost and recovery is unlikely, or (ii) an actual loss appears to be unavoidable, or (iii) to prevent an actual total loss it would be necessary to incur an expenditure which would exceed the saved value of the property or, in the case of a hull policy, the "insured" value expressed in the policy. To establish a claim for CTL the assured must abandon what remains of the property to underwriters and give his intention to do so (Hooke 1997).

B.3. Definitions

For most of the definitions, the Annexes 1 and 2 of IMO's Circular in Casualty – Related Matters were advised (IMO 2006).

B.3.1. Type of ship

The dry bulk cargo ships are grouped into the following categories:

- Bulk Dry (general, ore) Carrier
- Bulk Dry / Oil Carrier
- Self – Discharging Bulk Dry Carrier
- Other Bulk Dry (cement, woodchips, urea and other specialized) Carrier

B.3.2. Size of ship

The size – grouping of Dry Bulk Cargo ships is described in **Table B.I**, where the bold numbers in parentheses indicate the trend for maximizing capacity.

TABLE B.I. *BC size grouping*

Size	L (m)	DWT (MT)
Mini	100 – 130	< 10,000
Handysize	130 – 150	10,000 – 34,999 (~ **39,000**)
Handymax	150 – 200	35,000 – 49,999 ~ 55,000 (**40,000 – 59,999**)
Panamax	200 – 230	50,000 – 79,999 (~ **60,000 – 85,000**)
Capesize	230 – 270	> 80,000
	> 270	~ 130,000
	> 270	135,000 ~ 230,000
	343	364,000 ("Berge Stahl", the biggest BC, Intercargo n.d.)

B.3.3. Accident Category

B.3.3.1. Initial event

The accidents are divided into the following categories, where in parentheses are shown the abbreviations appeared in the Database:

- **Collision (CL):** striking or being struck by another ship (regardless of whether under way, anchored or moored).
- **Stranding or grounding (SG):** being aground, or hitting/touching shore or sea bottom or underwater objects (wrecks, etc.).
- **Contact**[14] **(CT):** striking any fixed or floating object other than those included in the previous categories.
- **Fire or explosion (FX):** the first event reported is fire/explosion, or where fire/explosion is resulted from hull/machinery damage, i.e. in this category fires due to engine damage are included, but not fires due to collision, etc.

---

[14] This is a relatively new accident category started being classified after 1980, being included in collision before that date.

- **Hull failure or failure of watertight doors, ports, etc. (HU)**: not caused by the previous categories.
- **Machinery damage (MC)**: not caused by the previous categories, and which necessitated towage or shore assistance.
- **Damages to ship or equipment (DAM):** not caused or covered by the previous categories.
- **Capsizing or listing (CAP):** not caused by the previous categories.
- **Missing (MIS):** assumed lost, i.e. vessels that disappeared without any witness knowing exactly what happened in the accident.
- **Foundered (FD):** vessels which sank as a result of heavy weather, leaks, breaking in two, etc., and not as a consequence of the previous categories.
- **War loss or hostilities (WAR):** vessels damaged from all hostile acts.
- **Towage break – up (TBU):** vessels sank during break – up voyage under tow.
- **Miscellaneous (XX):** lost or damaged vessels which cannot be classified into any of the previous categories due to not falling into any of the categories above or due to lack of information.

B.3.3.2. Subsequent event

- **Collision (CL)**
- **Stranding or grounding (SG)**
- **Contact (CT)**
- **Fire or explosion (FX)**
- **Hull failure or failure of watertight doors, ports, etc (HU)**
- **Machinery damage (MC)**
- **Damages to ship or equipment (DAM)**
- **Capsizing or listing (CAP)**
- **Missing (MIS)**
- **Miscellaneous (XX)**

B.3.4. Location

Depending on the geographical area, the aforementioned category is classified in the following:

- At berth
- Anchorage
- Port
- Port approach
- Inland waters
- Canal
- River
- Archipelagos
- Coastal waters (within 12 miles)
- Open sea

B.3.5. Internal causes (related to the vessel)

This category is grouped into the following:

- Structural failures of the vessel
- Technical failure of machinery/equipment, i.e. bilge pumping, electrical installation, propulsion/auxiliary machinery, etc.
- The vessel's cargo:
    - Cargo shifting
    - Fire or explosion in cargo
    - Improper stowage of cargo
    - Spontaneous combustion
    - Cargo liquefaction

B.3.6. External causes (outside the vessel)

This category is grouped into the following:

- Failures in aids to navigation
- The environment:
  - Heavy sea (typhoon, hurricane)
  - Wind
  - Currents or tides
  - Ice conditions/icing
  - Restricted visibility

B.4. Setting the exclusion criteria

B.4.1. Distribution of all accidents by category (Initial event)

Over the total time period, 632 accidents were recorded as CTL, distributed as follows (**Table B.II** and **Figure B.1**).

TABLE B.II. *Accident distribution by category (Initial event)*

Accident Category (Initial event)	Losses No	Percentage (%)
Collision	59	9.34
Stranding or grounding	148	23.42
Contact	8	1.27
Fire or explosion	111	17.56
Hull failure or failure of watertight doors, ports, etc.	116	18.35
Machinery damage	40	6.33
Damages to ship or equipment	5	0.79
Capsizing or listing	19	3.01
Missing	28	4.43
Foundered	40	6.33
War loss or hostilities	41	6.49
Towage break – up	9	1.42
Miscellaneous	8	1.27
Total	**632**	**100.01**

Casualties involving dry bulk cargo vessels, which were being towed away to be scrapped and other vessels which were destroyed, damaged or detained as a result of a military conflict[15] or hostility will be excluded from the analysis, since the aim of the study is to investigate the accidents under normal operation.

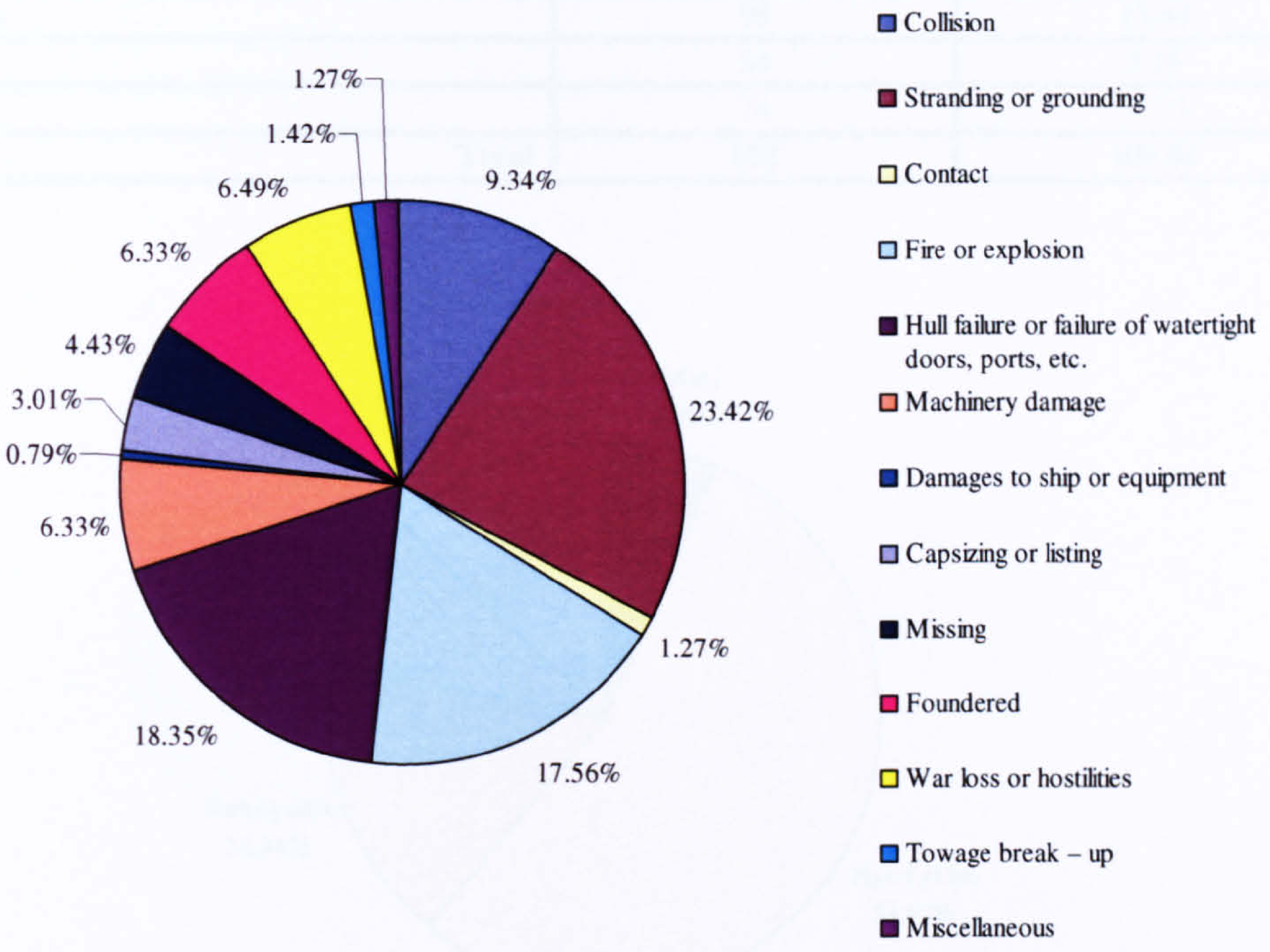


Figure B.1. *Accident distribution by category (Initial event)*

B.4.2. Distribution of accidents by vessel's size

The remaining 582 accidents are distributed as follows (**Table B.III** and **Figure B.2**). Since the aim of the study is to investigate accidents involving vessels above 10,000 DWT, the "mini" category will be excluded from the analysis.

---

[15] Most of the shipping casualties caused by military conflict occurred in the Persian Gulf during the Iraqi – Iranian war of the early and mid '80s.

TABLE B.III. *Accident distribution by vessel's size*

Vessel's size	Losses No	Percentage (%)
Mini	39	6.70
Handysize	317	54.47
Handymax	98	16.84
Panamax	54	9.28
Capesize	74	12.71
Total	**582**	**100.00**

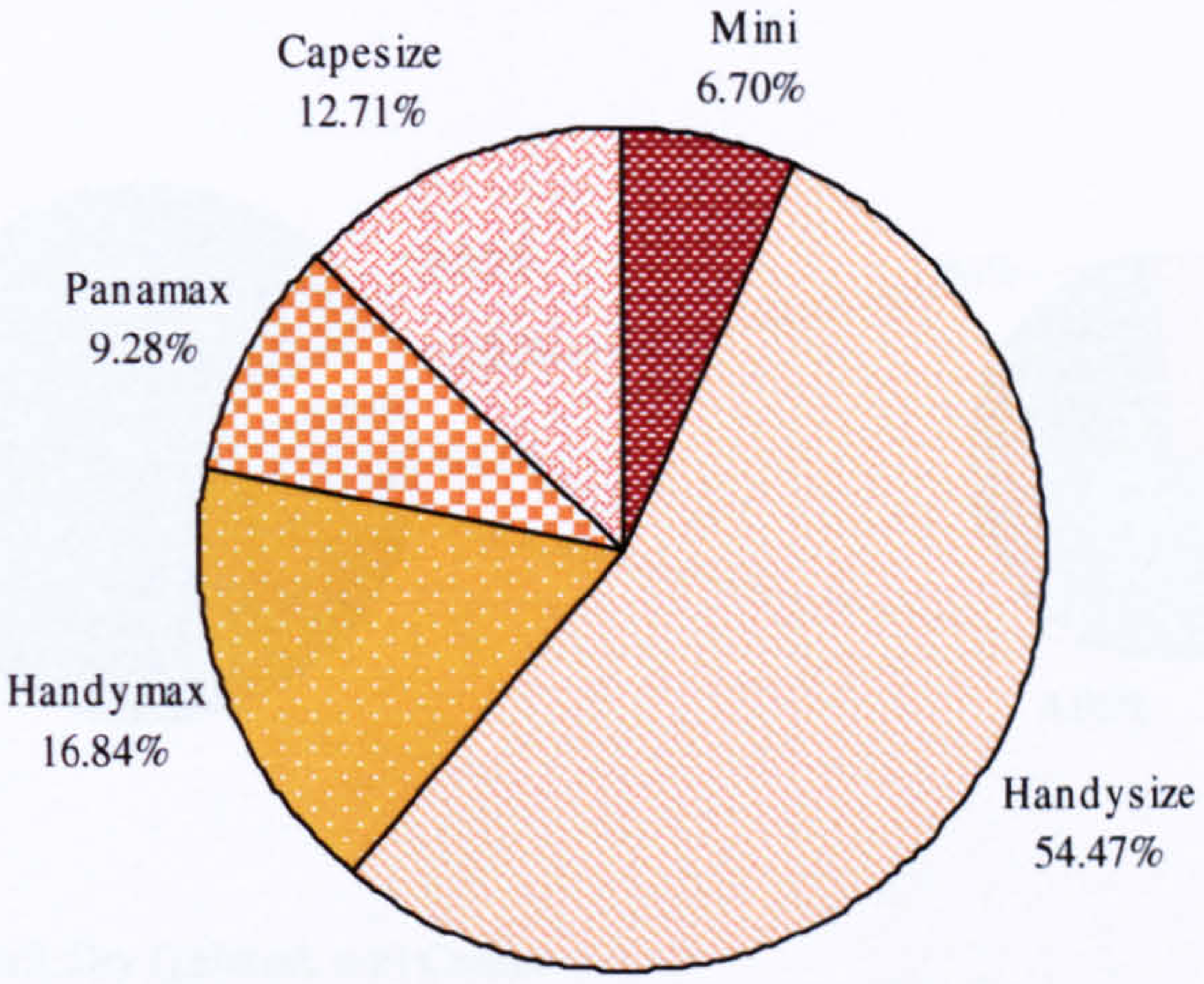


Figure B.2. *Accident distribution by vessel's size*

B.4.3. Distribution of accidents by vessel's type

Depending on the vessel's type, the remaining 543 accidents are distributed as follows (**Table B.IV** and **Figure B.3**).

TABLE B.IV. *Accident distribution by vessel's type*

Vessel's type	Losses No	Percentage (%)
Bulk Dry (general, ore) Carrier	475	87.48
Bulk Dry / Oil Carrier (Dry Cargo / Liquid Cargo / Ballast / Not known)	**46** (22/10/13/1)	8.47
Self – Discharging Bulk Dry Carrier	3	0.55
Other Bulk Dry (cement, woodchips, urea and other specialized) Carrier	19	3.50
Total	**543**	**100.00**

Ore / Oil vessels when carrying liquid bulk cargoes at the time of their loss will be excluded from the analysis, since the study is referred to vessels lost with dry bulk cargo.

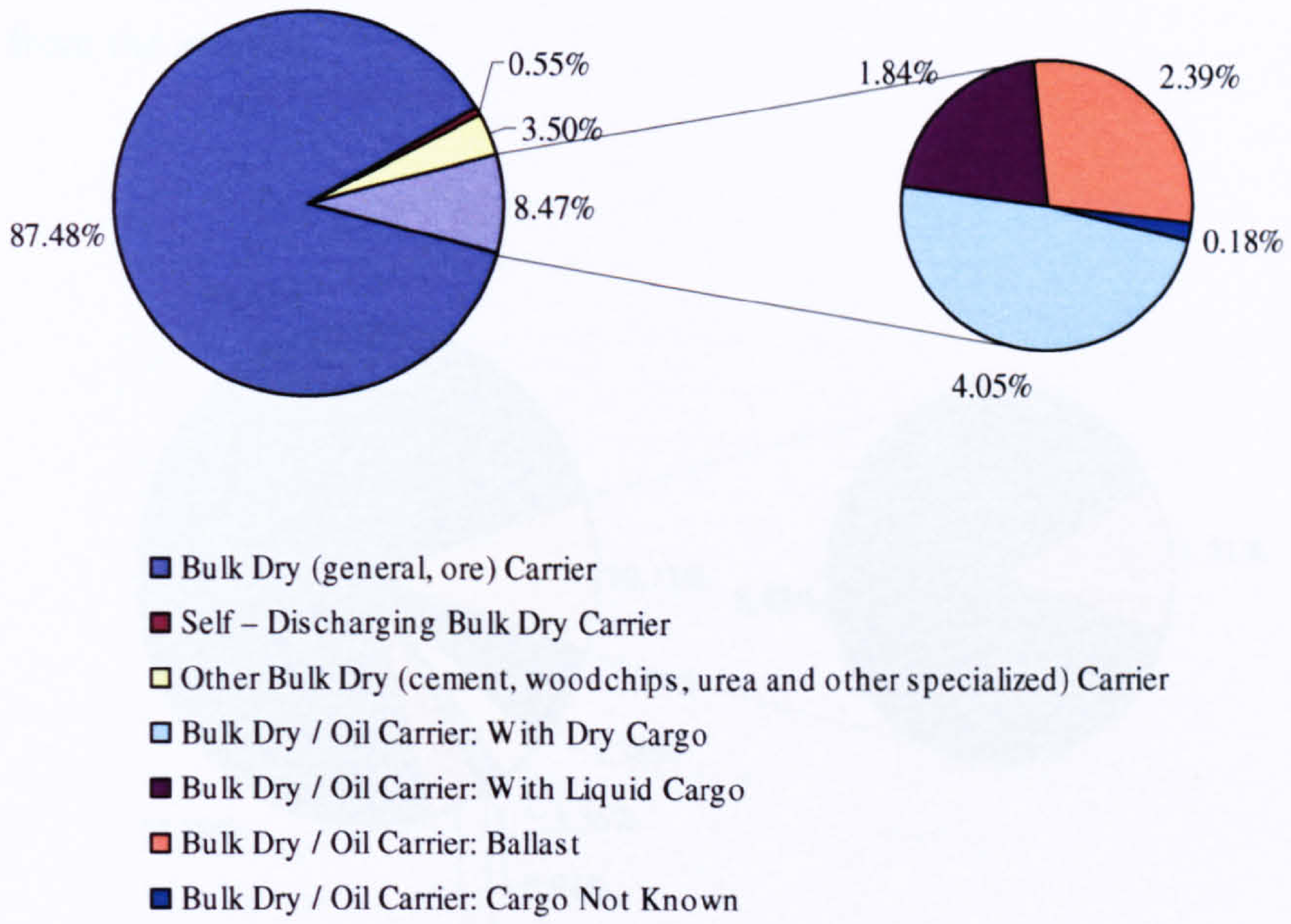


Figure B.3. *Accident distribution by vessel's type*

B.4.4. Distribution of accidents by location

Depending on the location, the remaining 533 accidents are distributed as follows (**Table B.V** and **Figure B.4**).

TABLE B.V. *Accident distribution by location*

Location	Losses No	Percentage (%)
At berth	17	3.19
Anchorage (Normal operation / Laid – up)	**54** (47 / 7)	10.13
Port	18	3.38
Port approach	19	3.56
Inland waters	5	0.94
Canal	3	0.56
River	21	3.94
Coastal waters (within 12 miles)	138	25.89
Open sea	258	48.41
Total	**533**	**100.00**

Since the study is concentrated on dry bulk vessel accidents which were *"en voyage / en route"*, accidents involving vessels at berth (dock), port or while being laid – up will be excluded from the analysis.

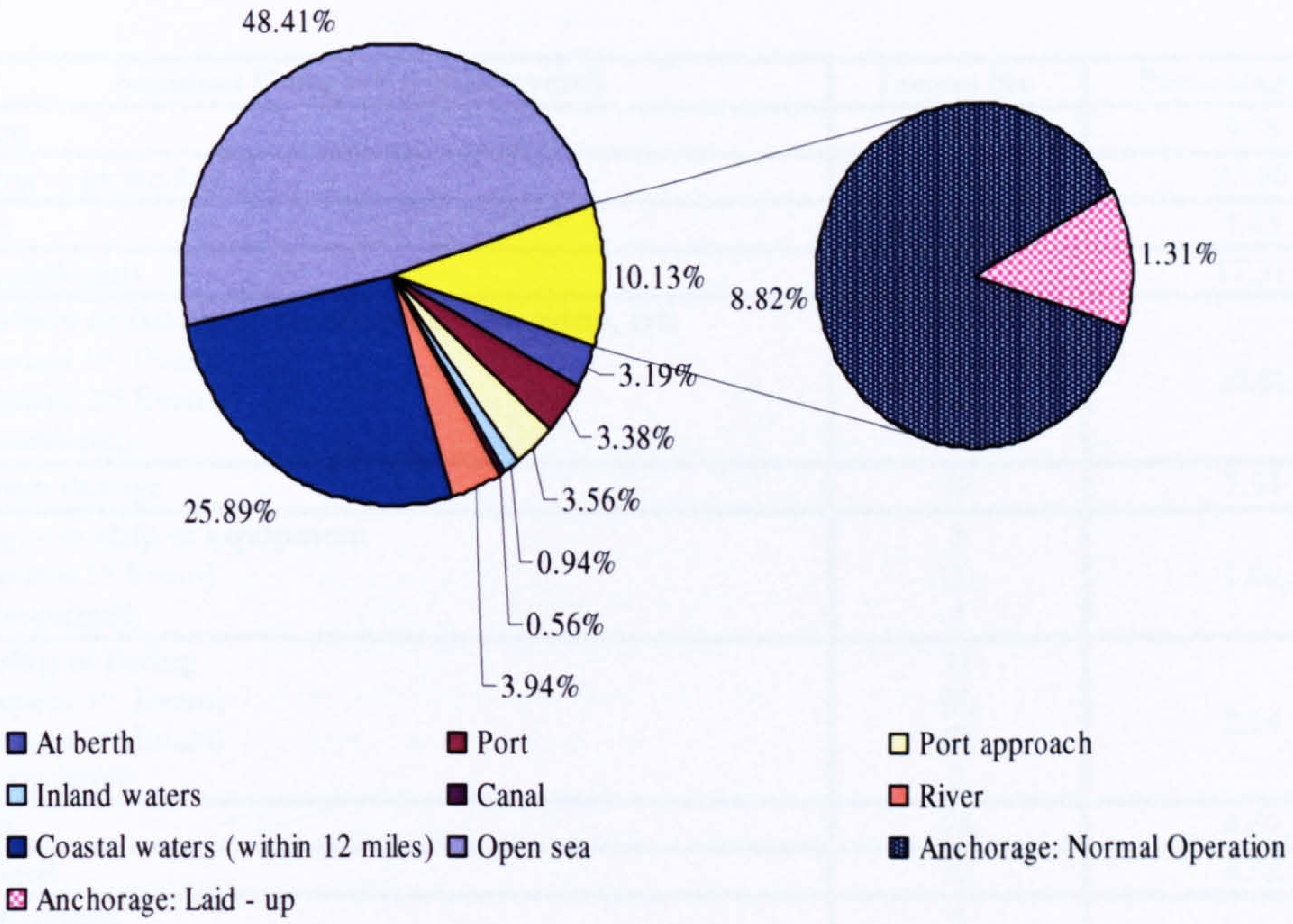


Figure B.4. *Accident distribution by location*

B.5. Actual number of accidents under consideration

Bearing in mind the above, the remaining 491 accidents, depending on their category (initial event) are distributed as follows: (See **Table B.VI** and **Figure B.5**) From the "Hull failure or failure of watertight doors, ports, etc.", "Damages to ship or equipment", "Capsizing or listing" or "Miscellaneous" Categories, the losses resulted to founderings are indicated by the numbers in parentheses (subsequent events). Although in other categories the subsequent events resulted to founderings, these accidents are not considered relevant to the problem under consideration (see **§ 5.5** and **6.3**). The basis for the following analysis on the foundering (disappearances or structural failure) of dry bulk vessels will be provided by these 167 accidents (**Table B.VII** and **Figure B.6**).

TABLE B.VI. *Accident distribution by category*

Accident Category (Initial event)	Losses No	Percentage (%)
Collision	48	9.78
Stranding or grounding	126	25.66
Contact	7	1.43
Fire or explosion	85	17.31
Hull failure or failure of watertight doors, ports, etc. (Subsequent 1st Event) (Subsequent 2nd Event) (Not foundered)	**111** (90) (10) 11	22.61
Machinery damage	37	7.54
Damages to ship or equipment (Subsequent 1st Event) (Not Foundered)	**5** (1) 4	1.02
Capsizing or listing (Subsequent 1st Event) (Subsequent 2nd Event) (Not foundered)	**11** (8) (1) 2	2.24
Missing	24	4.89
Foundered	32	6.52
Miscellaneous (Subsequent 1st Event) (Not Foundered)	**5** (1) 4	1.02
Total	**491**	**100.02**

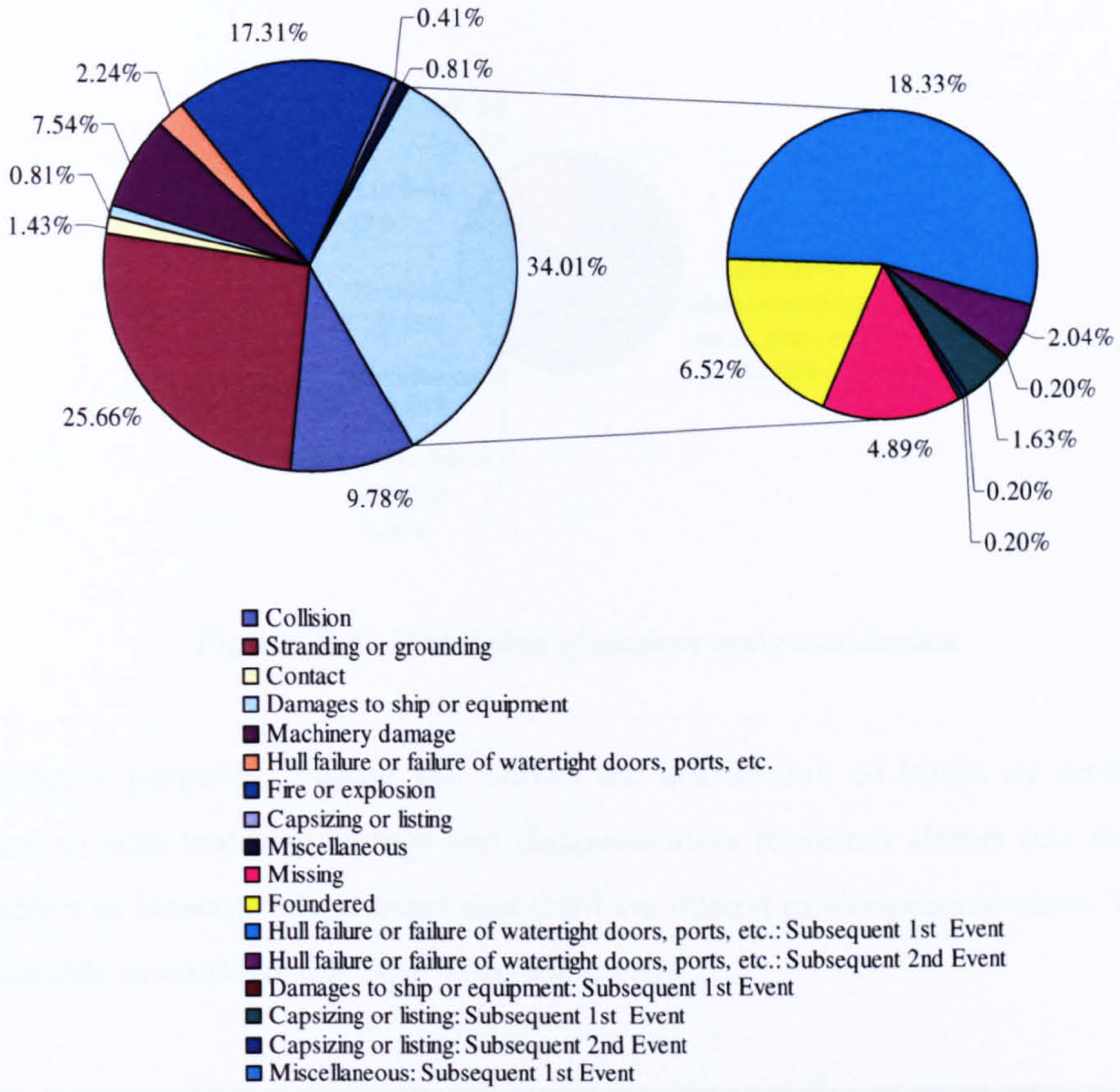


Figure B.5. *Accident distribution by category*

TABLE B.VII. *Distribution of accidents under consideration*

Accident Category	Losses No	Percentage (%)
Hull failure or failure of watertight doors, ports, etc.	100	59.88
Foundered	32	19.16
Missing	24	14.37
Capsizing or listing	9	5.39
Damages to ship or equipment	1	0.60
Miscellaneous	1	0.60
Total	**167**	**100.00**

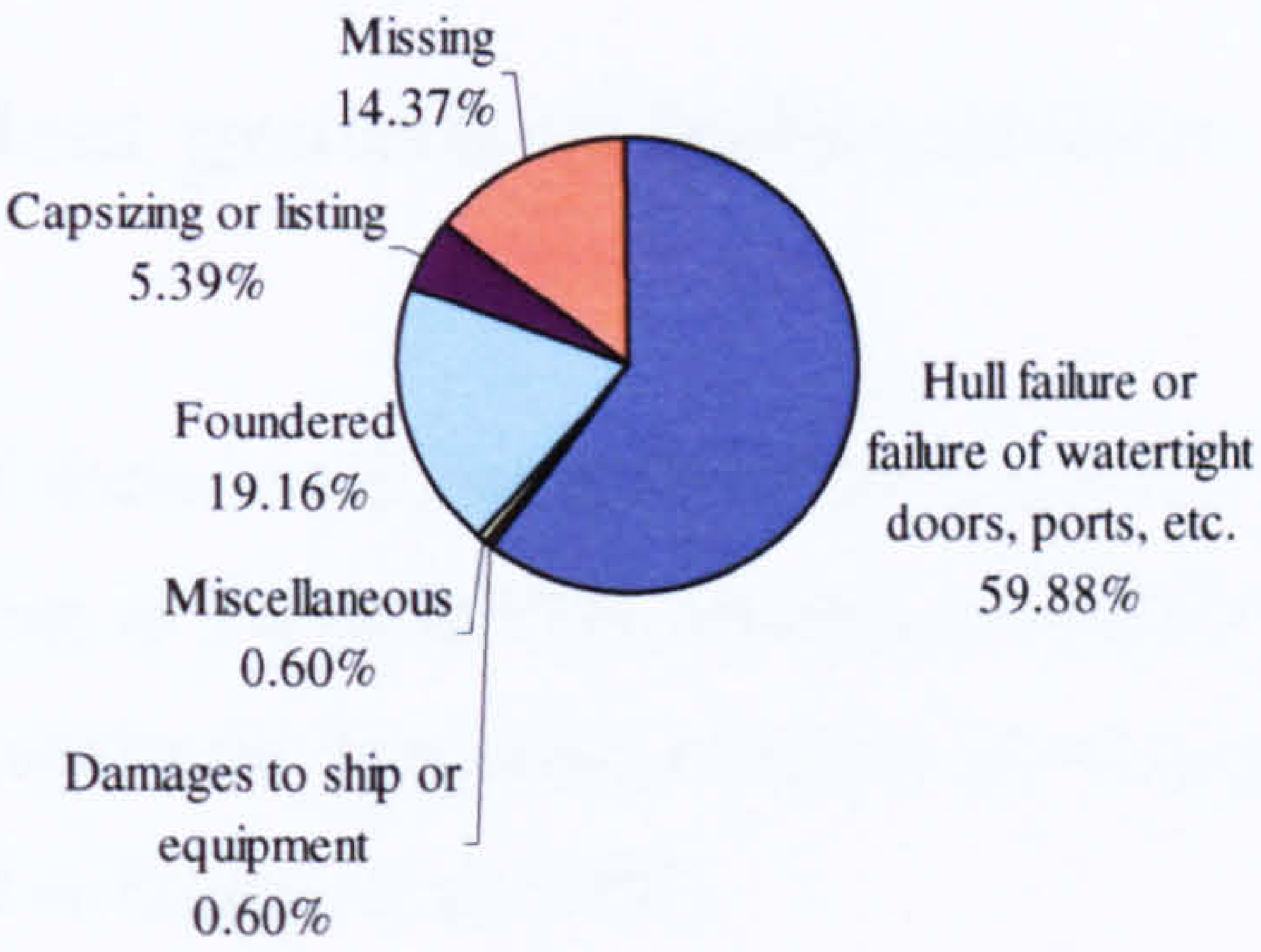


Figure B.6. *Distribution of accidents under consideration*

For illustrative purposes, **Figure B.7** shows the distribution of losses by accident. It is interesting to note that founderings and disappearances represent almost one third of the total number of losses, while another one third are related to navigational error. Therefore, it is reasonable to consider this type of accident only.

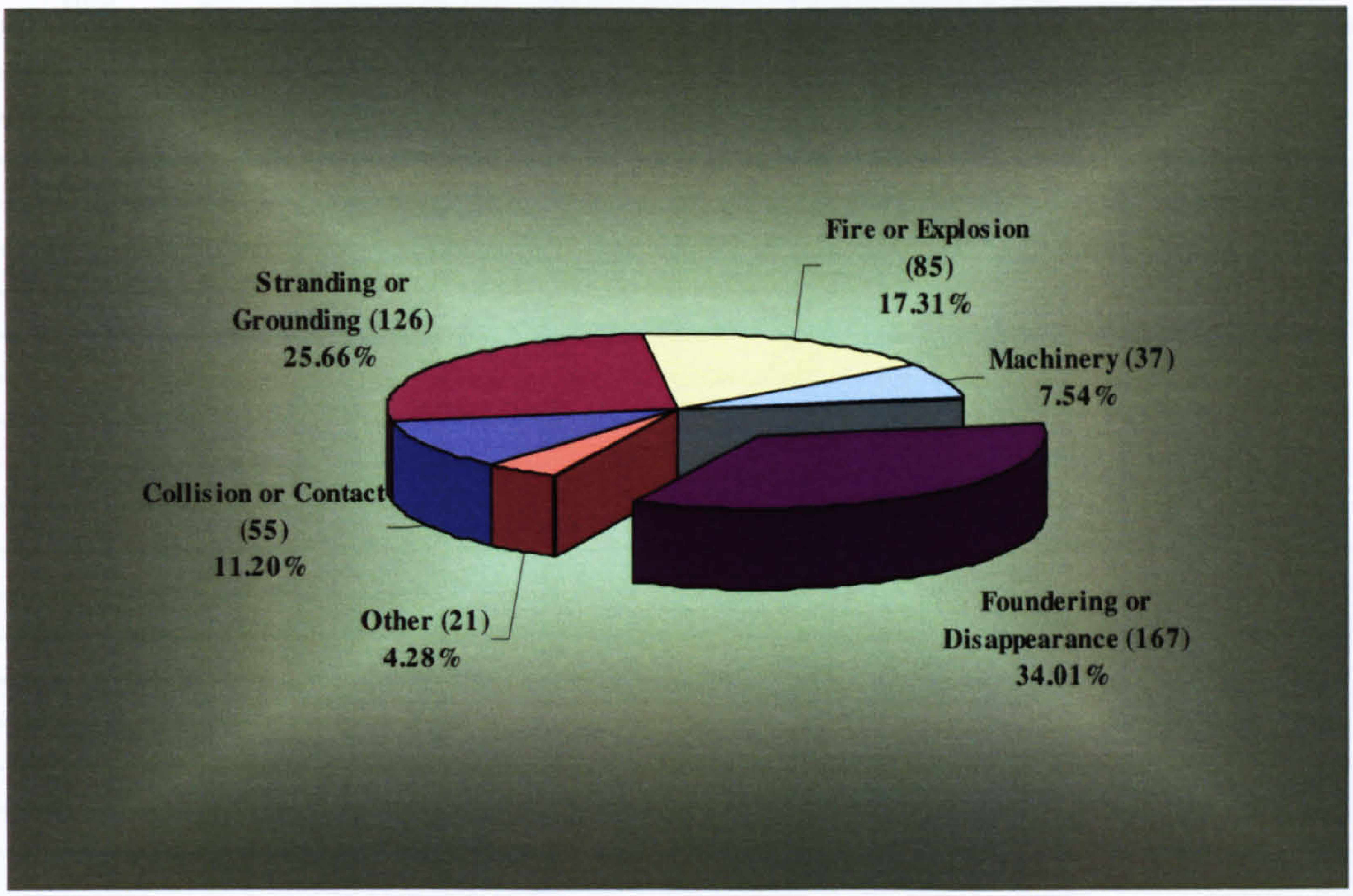


Figure B.7. *Distribution of losses by accident*

B.6. Analysis of the foundering accidents

B.6.1. Historical fleet growth of bulk carriers

The sampling window of these accidents is between 1969 and 2005. The historical bulk carrier fleet growth is shown at **Table B.VIII**, kindly provided by INTERCARGO (1977 – 2004) (Clarksons 2004a), whilst the remaining numbers are estimated by regression analysis and by information found at Rogers et al. (1997).

TABLE B.VIII. *Historical fleet growth of BCs*

Year	Handysize	Handymax	Panamax	Capesize	TOTAL
1969	625	193	34	15	867
1970	897	214	34	24	1,169
1971	1,350	237	36	39	1,662
1972	1,513	261	63	50	1,887
1973	1,822	283	89	65	2,259
1974	2,156	306	115	79	2,656
1975	2,315	329	143	91	2,878
1976	2,516	352	169	104	3,141
1977	2,620	403	195	106	3,324
1978	2,881	439	228	116	3,664
1979	3,008	457	244	125	3,834
1980	3,057	465	248	132	3,902
1981	3,109	468	267	138	3,982
1982	3,223	480	322	170	4,195
1983	3,319	511	380	203	4,413
1984	3,360	537	432	220	4,549
1985	3,425	585	479	234	4,723
1986	3,389	625	481	255	4,750
1987	3,274	619	486	275	4,654
1988	3,190	613	506	285	4,594
1989	3,156	618	518	291	4,583
1990	3,154	637	551	309	4,651
1991	3,136	658	578	345	4,717
1992	3,121	684	588	343	4,736
1993	3,117	689	585	346	4,737
1994	3,086	691	613	364	4,754
1995	3,073	739	665	386	4,863
1996	3,121	814	720	429	5,084
1997	3,116	870	750	462	5,198

TABLE B.VIII (Continued). *Historical fleet growth of bulk carriers*

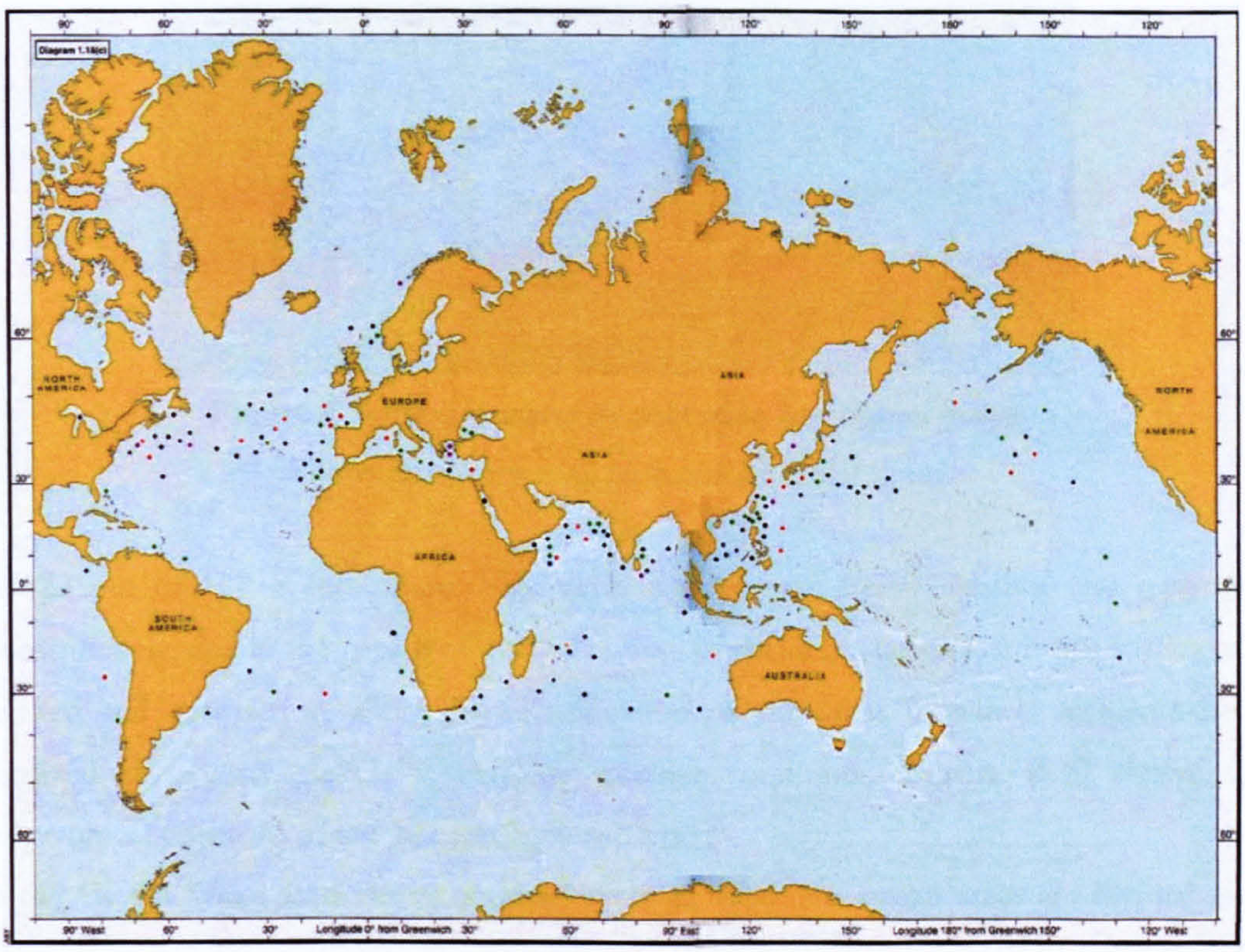
Year	Handysize	Handymax	Panamax	Capesize	TOTAL
1998	3,097	920	808	493	5,318
1999	2,995	962	837	483	5,277
2000	2,941	968	882	487	5,278
2001	2,888	985	934	519	5,326
2002	2,819	1,062	1,015	539	5,435
2003	2,778	1,139	1,052	556	5,525
2004	2,745	1,194	1,067	585	5,591
2005	2,693	1,223	1,099	603	5,618
TOTAL	**102,085**	**23,230**	**18,213**	**10,266**	**153,794**
Regression analysis (x: year, y: population)					
Handysize	$x \leq 1986 : y = -10.3057 \cdot x^2 + 40{,}919.9172 \cdot x - 40{,}615{,}866.6548$ $x \geq 1987 : y = -0.9997 \cdot x^2 + 3{,}961.0641 \cdot x - 3{,}920{,}421.5689$				
Handymax	$y = 0.3250 \cdot x^2 - 1{,}265.8064 \cdot x + 1{,}232{,}656.6317$				
Panamax	$y = 0.3026 \cdot x^2 - 1{,}171.2341 \cdot x + 1{,}132{,}963.2257$				
Capesize	$y = 0.1596 \cdot x^2 - 617.6952 \cdot x + 597{,}485.8275$				

B.6.2. Distribution of the foundering or disappearance accidents by geographical position and location

The geographical positions of the 167 bulk carriers that foundered or disappeared[16] are illustrated in **Figure B.8.** This map of the world (UKHO 2004, pp 20 – 21) shows that large numbers of bulk carriers were lost in the North Atlantic Ocean (49 or 29.34%), North Pacific (31 or 18.56%), South China Sea (20 or 11.98%), Arabian Sea and Bay of Bengal (24 or 14.37%), South Indian Ocean (20 or 11.98%).

---

[16] The positions of the bulk carriers which disappeared or foundered with no subsequent trace of the sunken wreck are based on their last reported position or the location of wreckage or debris subsequently identified from the wreck.



Notes:

- ● Hull failure (100)
- ● Capsizing (9)
- ● Foundered (32)
- ● Damages to ship (1)
- ● Missing (24)
- ● Miscellaneous (1)

Figure B.8. *World map showing the geographical positions of the 167 BCs when they foundered or disappeared (1969 – 2005)*

These areas largely refer to the regions of the world in which typhoons, hurricanes or severe tropical cyclones[17] most frequently occur[18] (UKHO 2004, Landsea 2007) (**Figure B.9**).

---

[17] The terms **"hurricane"** and **"typhoon"** are regionally specific names for a strong **"tropical cyclone"**. A tropical cyclone is the generic term for a non – frontal synoptic scale low – pressure system over tropical or sub – tropical waters with organized convection (i.e. thunderstorm activity) and definite cyclonic surface wind circulation with maximum sustained wind speeds in excess of 64 kts (74mph) (Landsea 2007), with probable/maximum wave height 14 m (UKHO 2004).

[18] During the 36 – year period 1969 – 2005 a total of 1,617 typhoons occurred worldwide. These occurred in the North West Pacific basin – from the dateline to Asia including the South China Sea – (598 or 36.98%), followed by the South Indian basin (385 or 23.81%), the North East Pacific basin – from Mexico to about the dateline – (332 or 20.53%), the Atlantic basin – including the North Atlantic Ocean, the Gulf of Mexico, and the Caribbean Sea – (229 or 14.16%), the North Indian basin – including the Bay of Bengal and the Arabian Sea – (48 or 2.97%) and the South West Pacific basin (25 or 1.55%) (Unisys Weather 2006).

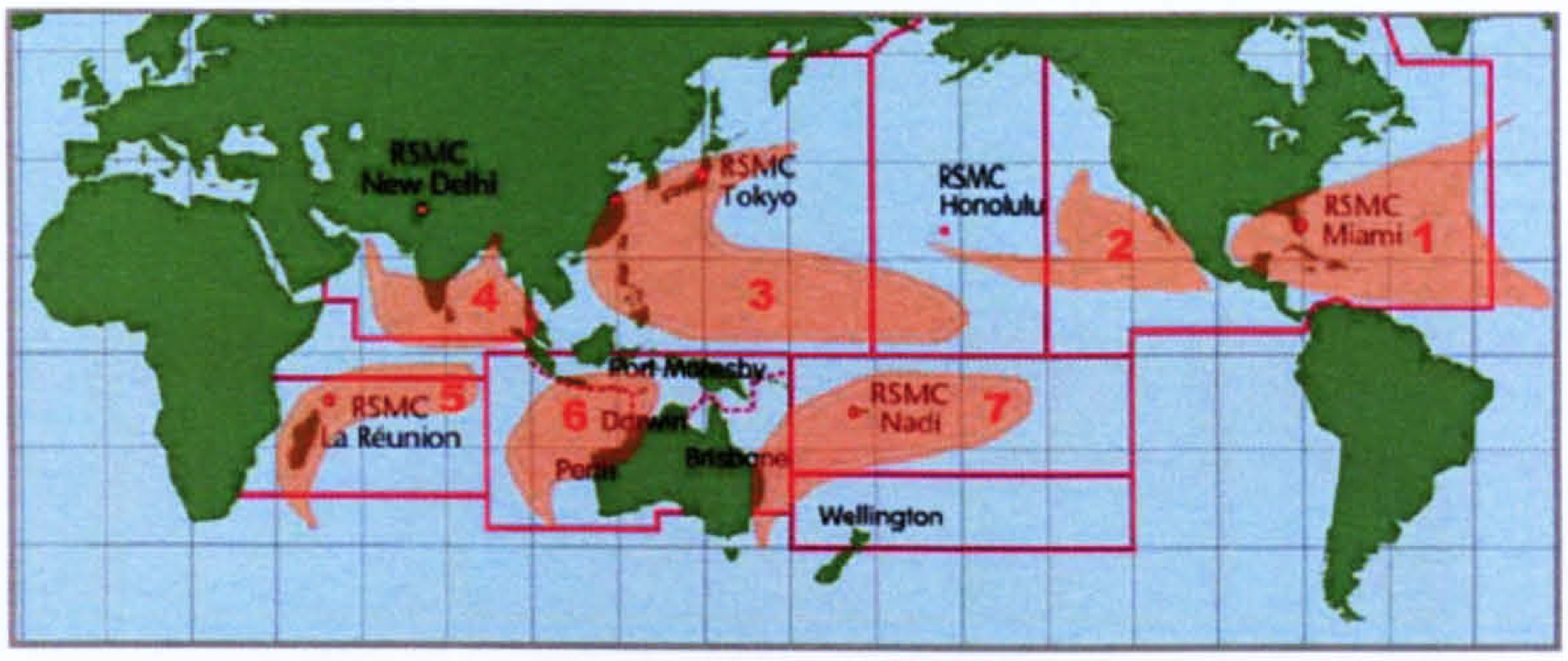


Figure B.9. *Regions around the globe which have tropical cyclones*

Source: http://www.aoml.noaa.gov/hrd/tcfaq/F1.html

In 122 out of 167 events where bulk carriers were lost, heavy weather was reported. Unfortunately, due to the nature of every database of accident statistics, it is not sufficiently detailed and accurate to allow the identification of the areas in which accidents have occurred as a consequence of extreme weather conditions. **Figure B.10** shows the geographical positions of the 122 lost bulk carriers.

In the Global Wave Statistics atlas (Hogben et al. 1986) the ocean areas are divided into 104 regions and the areas with 20 – year extreme significant wave heights[19] of more than 14 m are shown (Bitner-Gregersen et al. 1995) (**Figure B.11**).

---

[19] Significant wave height (H_S) is defined as the average height of the highest one – third waves in a wave spectrum. It is representative for determining the sea surface elevation.

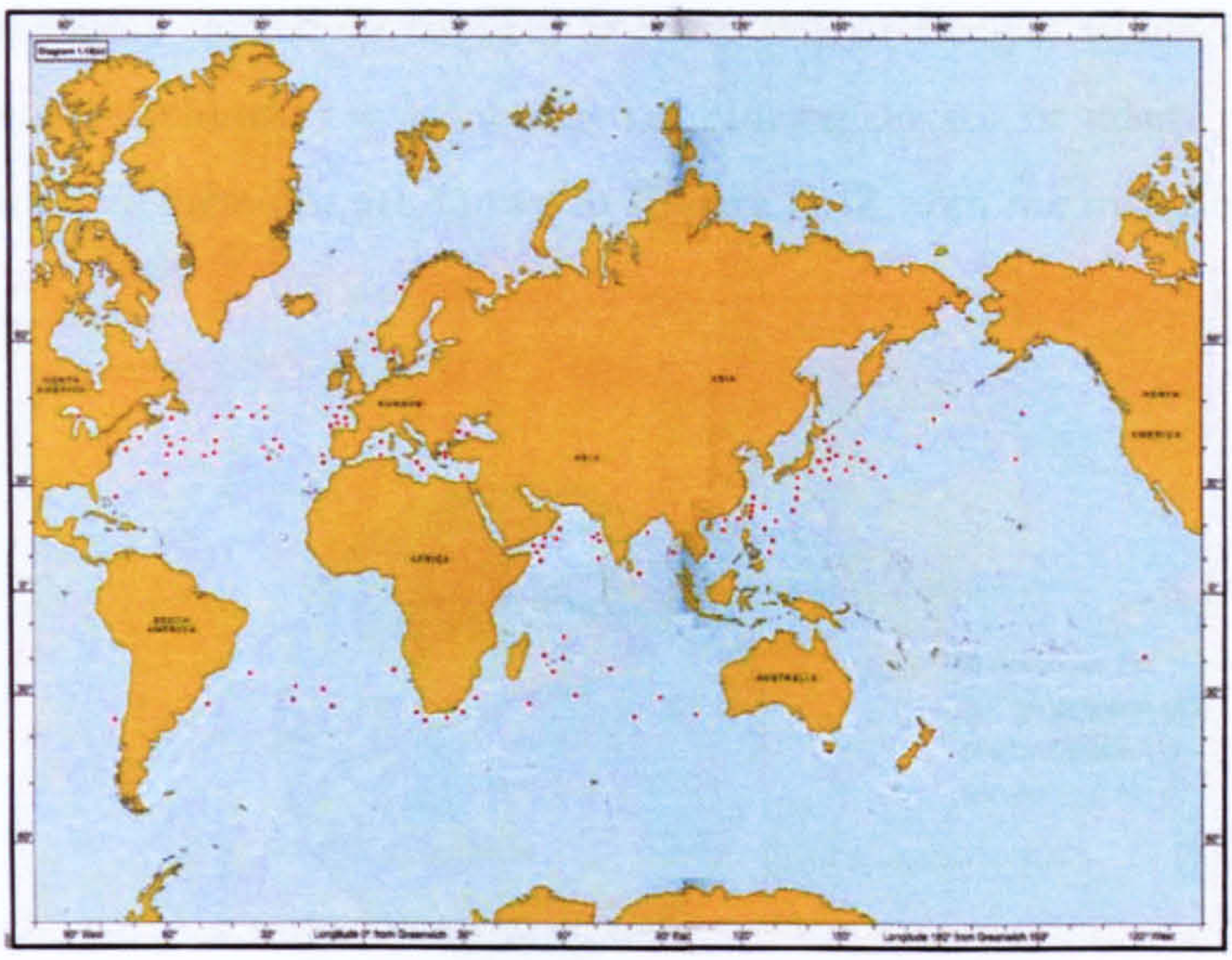


Figure B.10. *Geographical positions of the 122 BCs lost due to heavy weather*

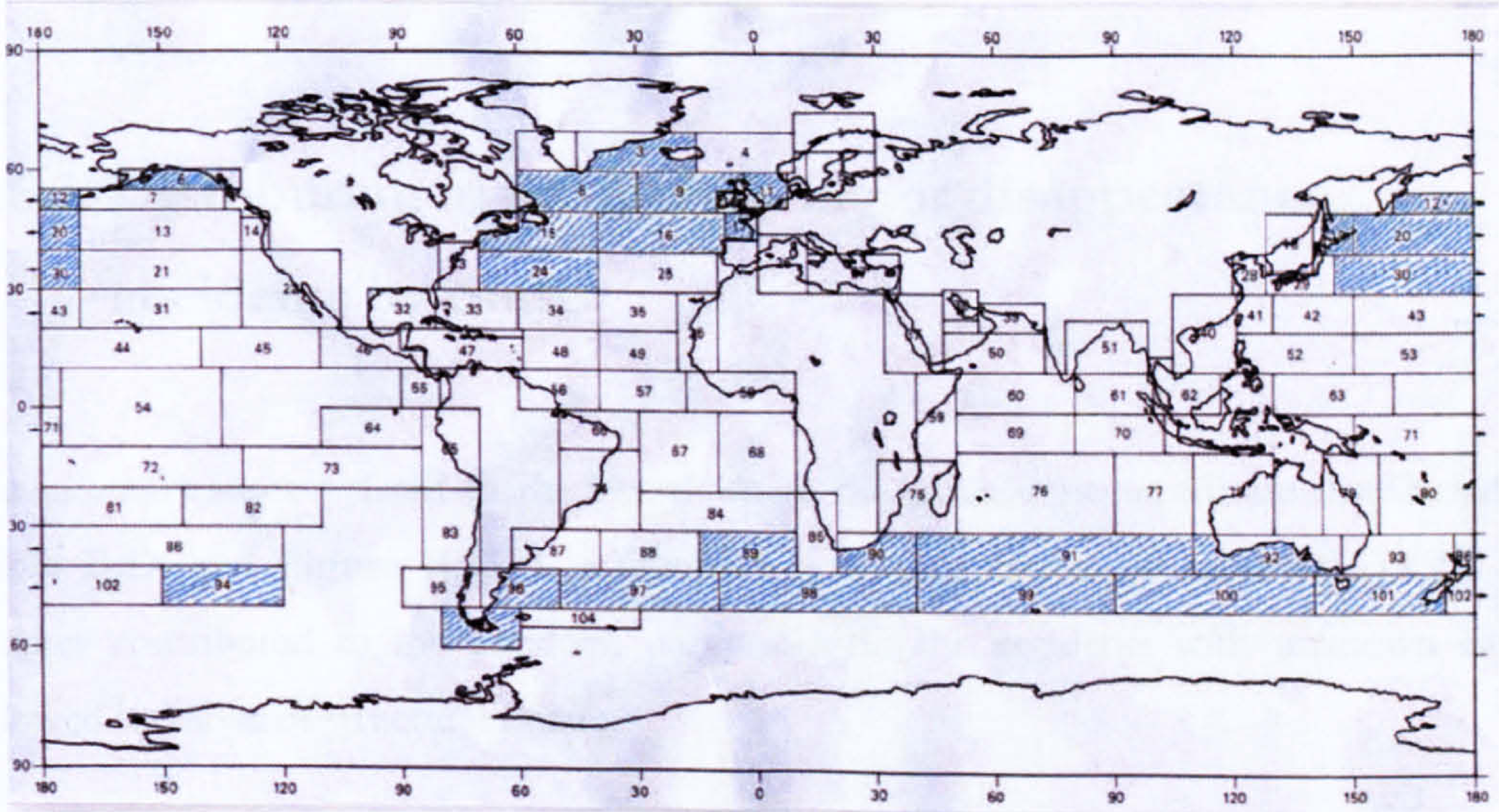


Figure B.11. *Zones with 20 – year extreme significant wave height larger than 14 m.*

It appears that some of these areas coincide well the positions where several of the bulk carriers were lost, particularly those with latitude in excess of 30^0 (North or South), i.e. North Atlantic, North Pacific – off Japan, South Indian and Atlantic. In Guedes Soares et al. (2001), Kjeldsen (2005), Toffoli (2004) was mentioned that unexpected severe sea states might occur in areas of relatively low significant wave height, for example the China Sea, North Indian Ocean (including Arabian Sea and Bay of Bengal) which are regions often prone to tropical cyclones, coastal waters i.e. Norwegian sea or inland waters i.e. Great Lakes. The accident locations are shown in **Figure B.12**, with the majority occurred in the open sea.

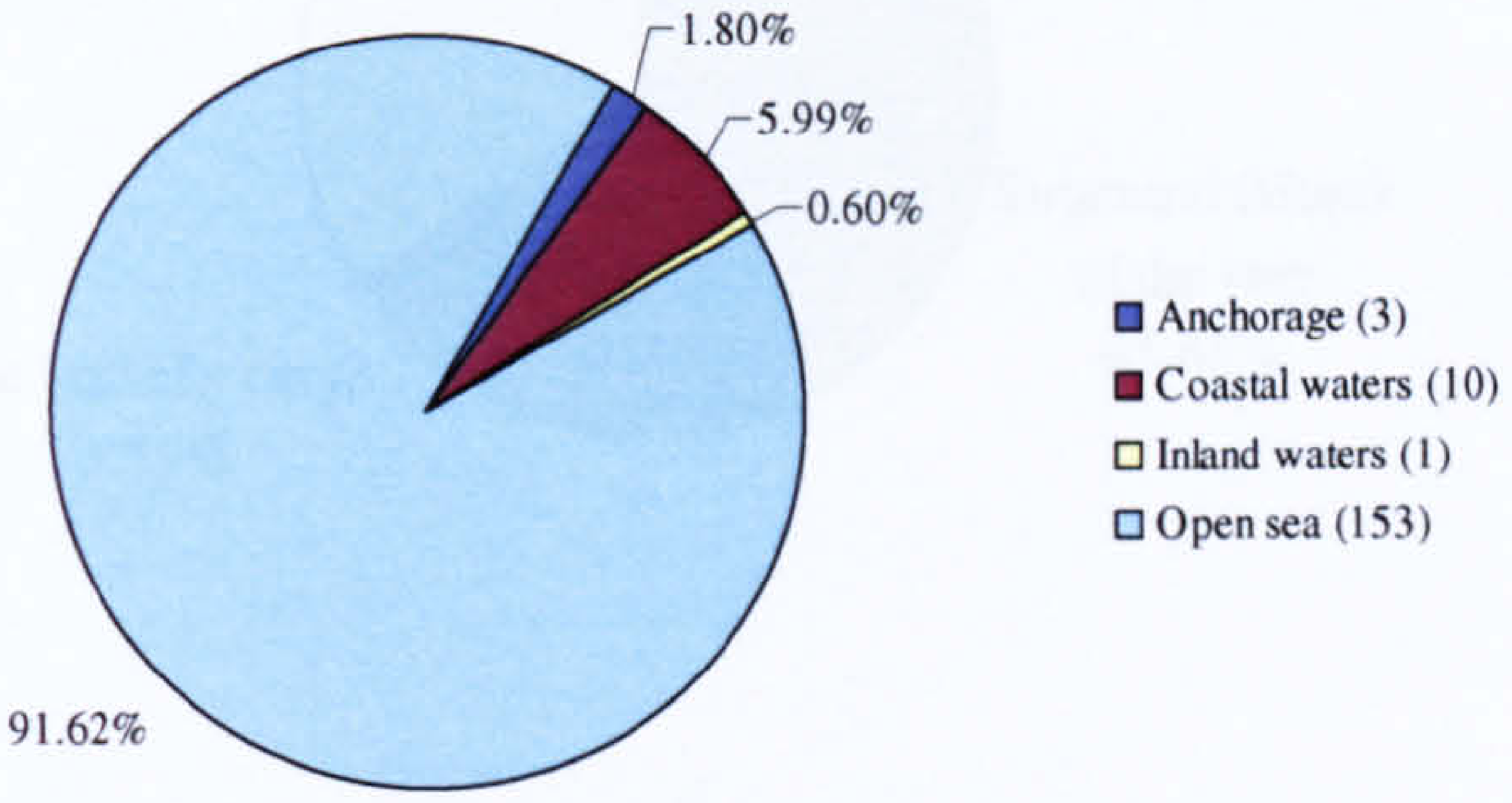


Figure B.12. *Accident distribution by location*

B.6.3. Distribution of the foundering or disappearance accidents by cause

The internal causes (related to the vessel where the casualty occurred) are distributed in **Table B.IX** and **Figure B.13**. It is interesting to note that in 96 cases or 57.49% the weather contributed to the accident, particularly in the accidents with unknown cause followed by those of structural failure.

Table B.IX. *Internal causes distribution of the accidents*

Internal Cause	**Losses**		**Percentage (%)**
	No	**Weather related (%)**	
Structural failures of the ship	103	67.96	61.68
The vessel's cargo	6	66.67	3.59
Not known	58	84.48	34.73
Total	**167**	**-**	**100.00**

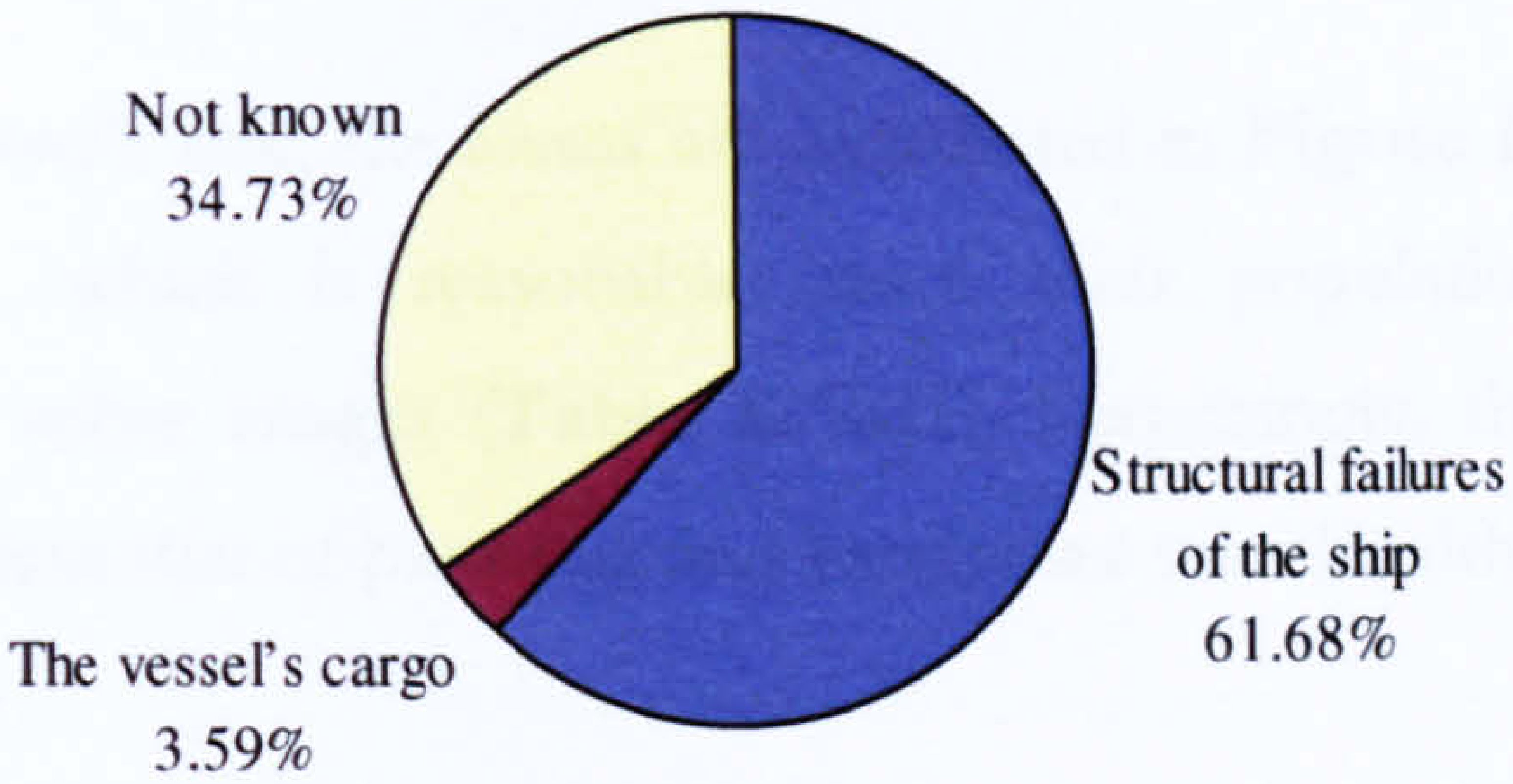


Figure B.13. *Internal causes distribution of the accidents*

The distribution of external causes (outside the vessel) is mainly correlated with weather conditions and is shown in **Figure B.14**, where almost 73% of the accidents were weather related. By contrast, roughly 7% of the accidents occurred during fine weather while for the remaining 20%, weather was unfortunately unknown.

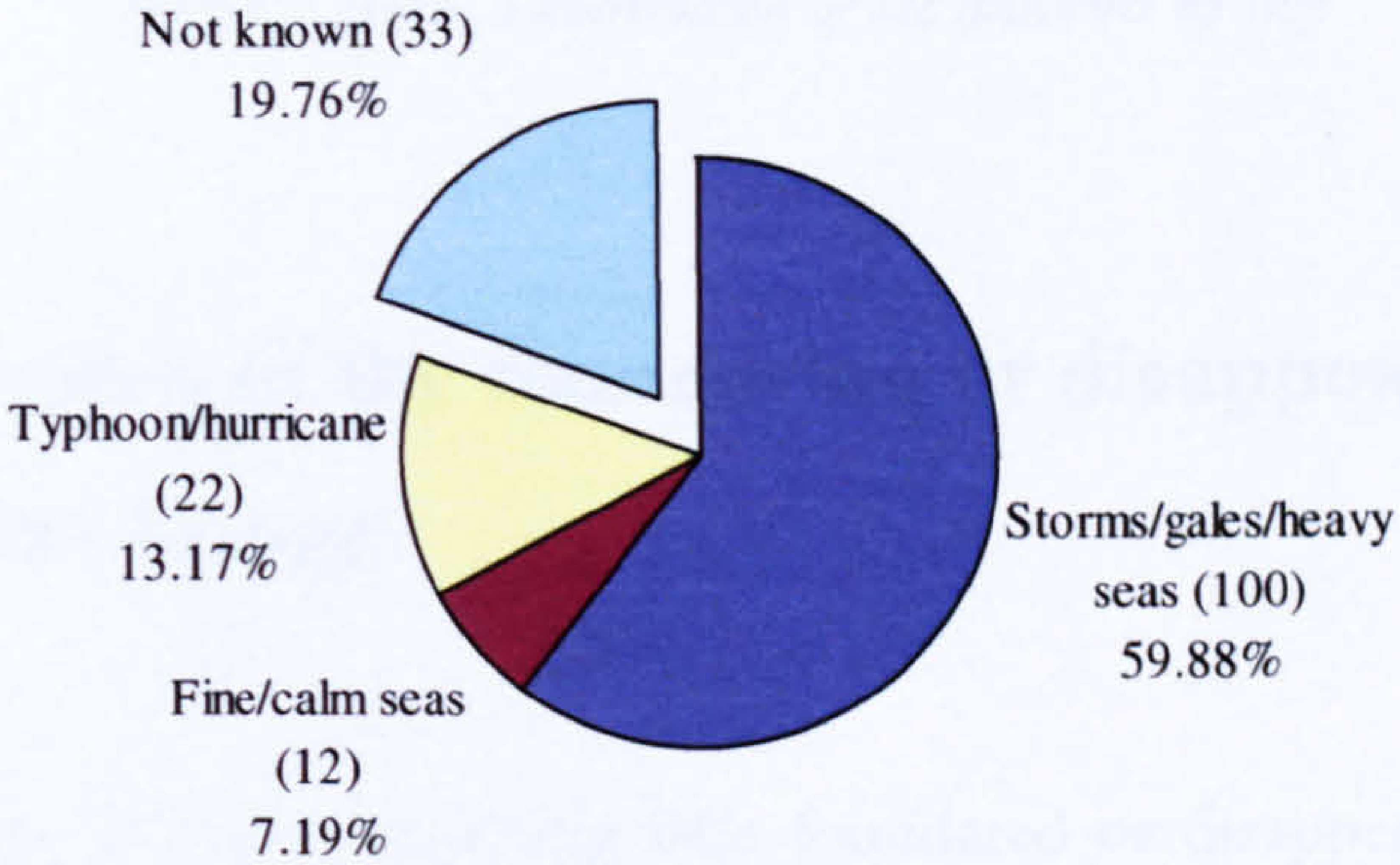


Figure B.14. *Distribution of the accidents depending on the weather conditions (external cause – environment)*

B.6.4. Distribution of the foundering or disappearance accidents by size

Depending on the vessel's size, the losses are distributed in **Figure B.15**, with dominating the handysize range, which is reasonable, since their population is the biggest in comparison with the other ranges (**Table B.VIII**). Surprisingly, the number of capsize vessels lost is bigger than that of panamax and handymax vessels, although their population is less (**Table B.VIII**).

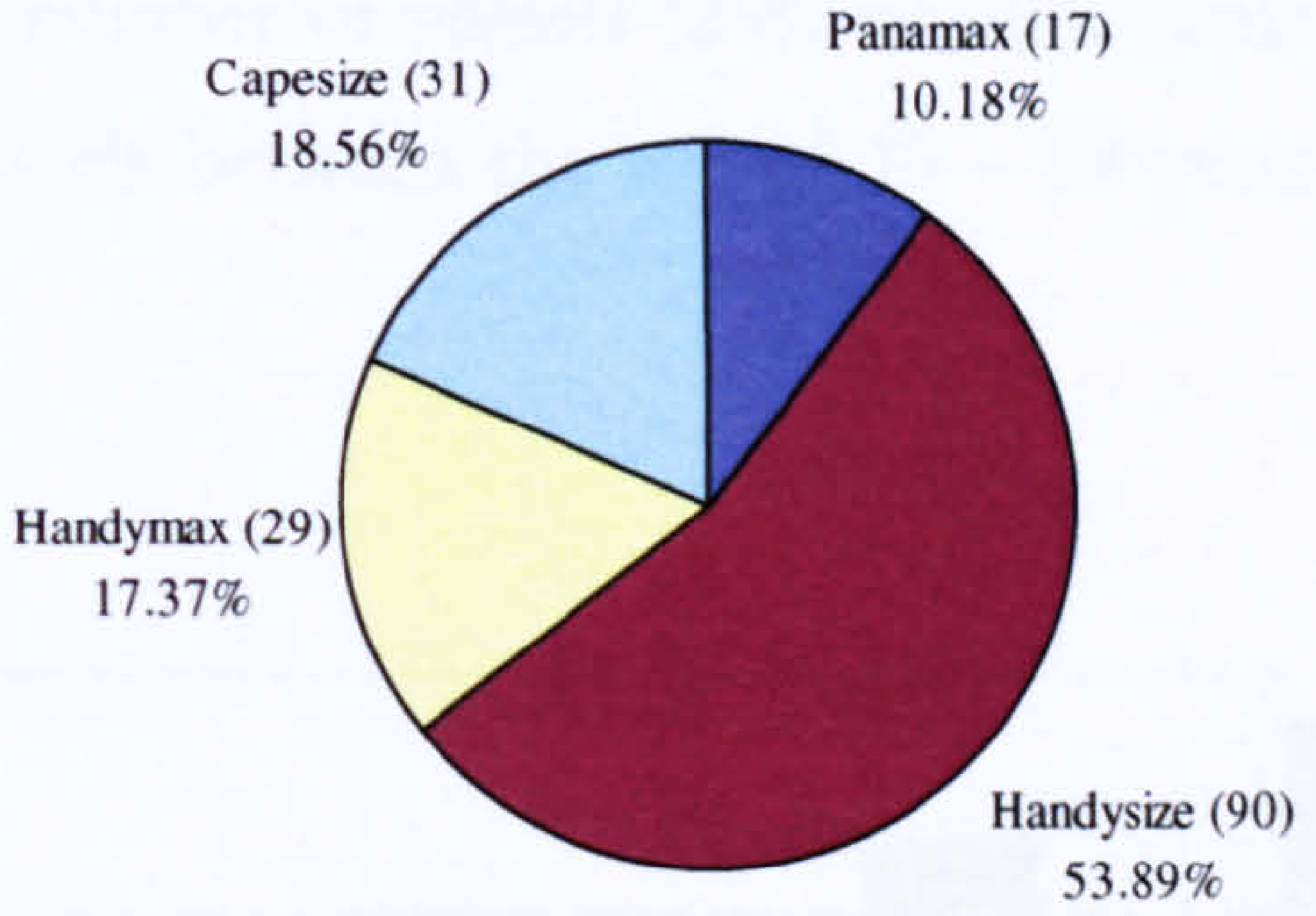


Figure B.15. *Distribution of the accidents by size*

B.6.5. Distribution of the foundering or disappearance accidents by age

The numbers of losses involving BCs foundered or disappeared from 1969 until 2005 as a function of their age range are illustrated in **Figure B.16**. It is obvious that the number of accidents is peaked at the categories 15 – 19 and 20 – 24 and possible reasons explaining that can be related to commercial considerations which may threaten safety. Some vessels as getting older are subject to speculative buying and selling in the second hand market leading to a change of ownership and perhaps vessel's management. Such changes can be assured that will accelerate the decline of the vessel's quality and her overall safety standards, unless a safety and quality culture is maintained. Also, various companies (especially those who are not interested in operating vessels, but in the financial return of investment in tonnage) have different operational standards projecting their own regulatory environment and the geographical region in which they operate (RINA 2002, Seignette 2002). However, it is interesting to note that beyond the age of 25, the number of losses is reduced. A possible explanation can be the fact that it is most likely that the structural, mechanical or other deficiencies of a vessel would have surfaced by the time she reaches this maturity level or, if the vessel has not sunk by then, most of her "bugs" have been fixed (Psaraftis et al. 1998). Furthermore, it could be argued that the downward trend might be also due to the reduced number of vessels (25% of bulk carrier fleet – Equasis 2008), although the number of vessels between the age of 15 – 24 years represents 26% of the world fleet (Equasis 2008).

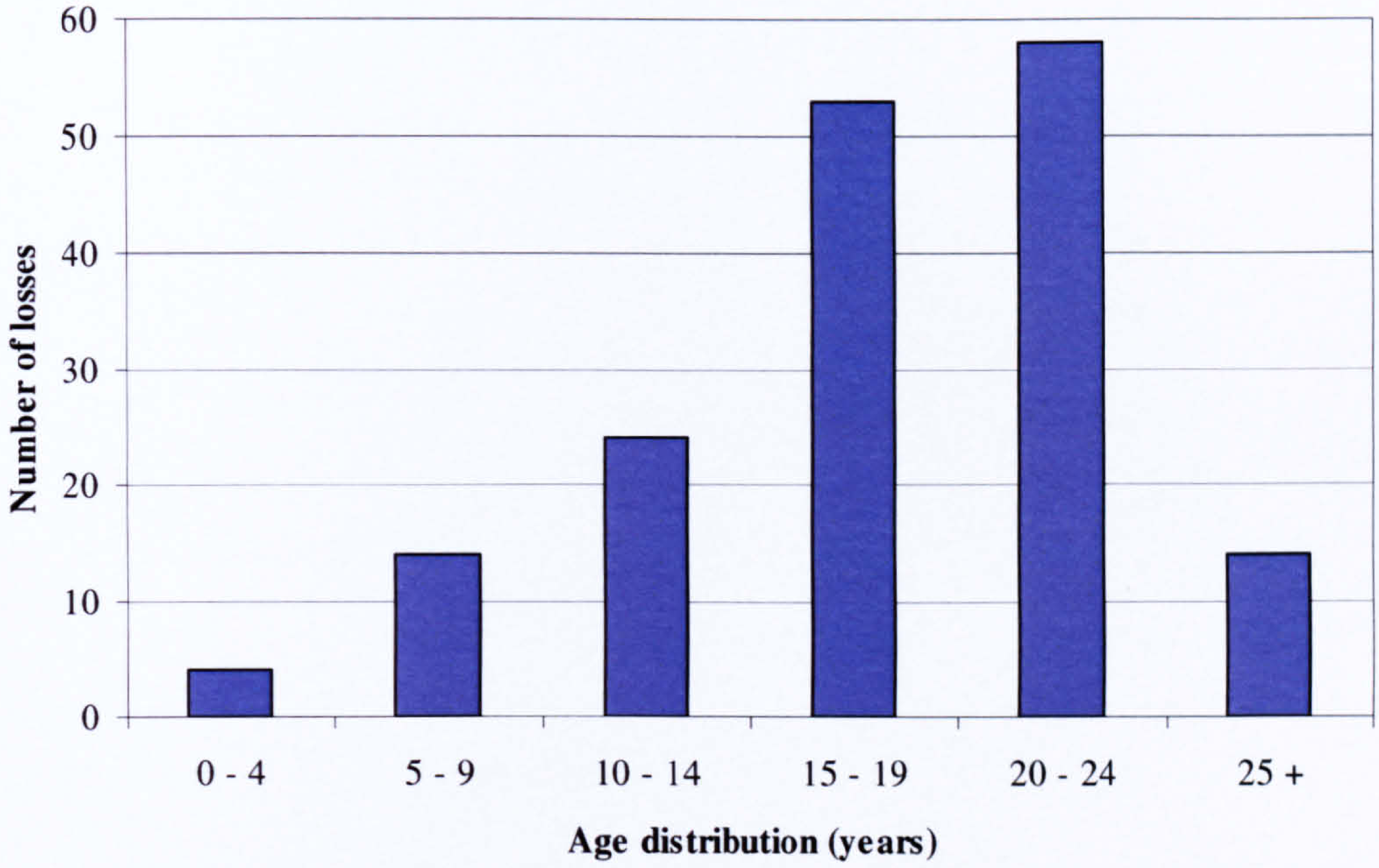


Figure B.16. *BC losses related to their age range (1969 – 2005)*

B.6.6. Distribution of the foundering or disappearance accidents by cargo

For simplifying the analysis, the various cargoes being carried were grouped in 8 families according to Packard (1985) plus the ballast condition. The 8 families are as follows: ***ferrous ores – FE*** (iron, chrome, manganese, nickel ore, – ore concentrates), ***coal – CO*** (coke, petcoke, anthracite, steam coal), ***cement – CE*** (clinker, cement), ***mineral – MI*** (alumina, bauxite, copper, zinc and lead concentrates, sands, salt), ***agricultural and food products – AF*** (wheat, corn, barley, maize, soybean meal (SBM), sugar, tapioca), ***fertiliser and chemicals – FC*** (sulphur, rock phosphates, soda ash, muriate of potash, di – ammonium phosphate, urea), ***metal – ME*** (steel products, copper cathodes, pig iron, direct reduced iron (DRI), iron pellets, scrap metal), ***timber – TI*** (logs, sawn timber, wood – pulp). **Figure B.17** illustrates the percentage losses of bulk carrier size for each of the cargo families. The capsize vessels were carrying cargoes of ferrous ores and coal family – since this type of vessels is specialized to those trades (See **Figure B.18**), while handysize and handymax vessels were carrying all types of cargoes. The panamax vessels that were involved in a foundering, were carrying cargoes of ferrous ores (in particular), coal, mineral and metal families, thus one incident occurred in ballast condition.

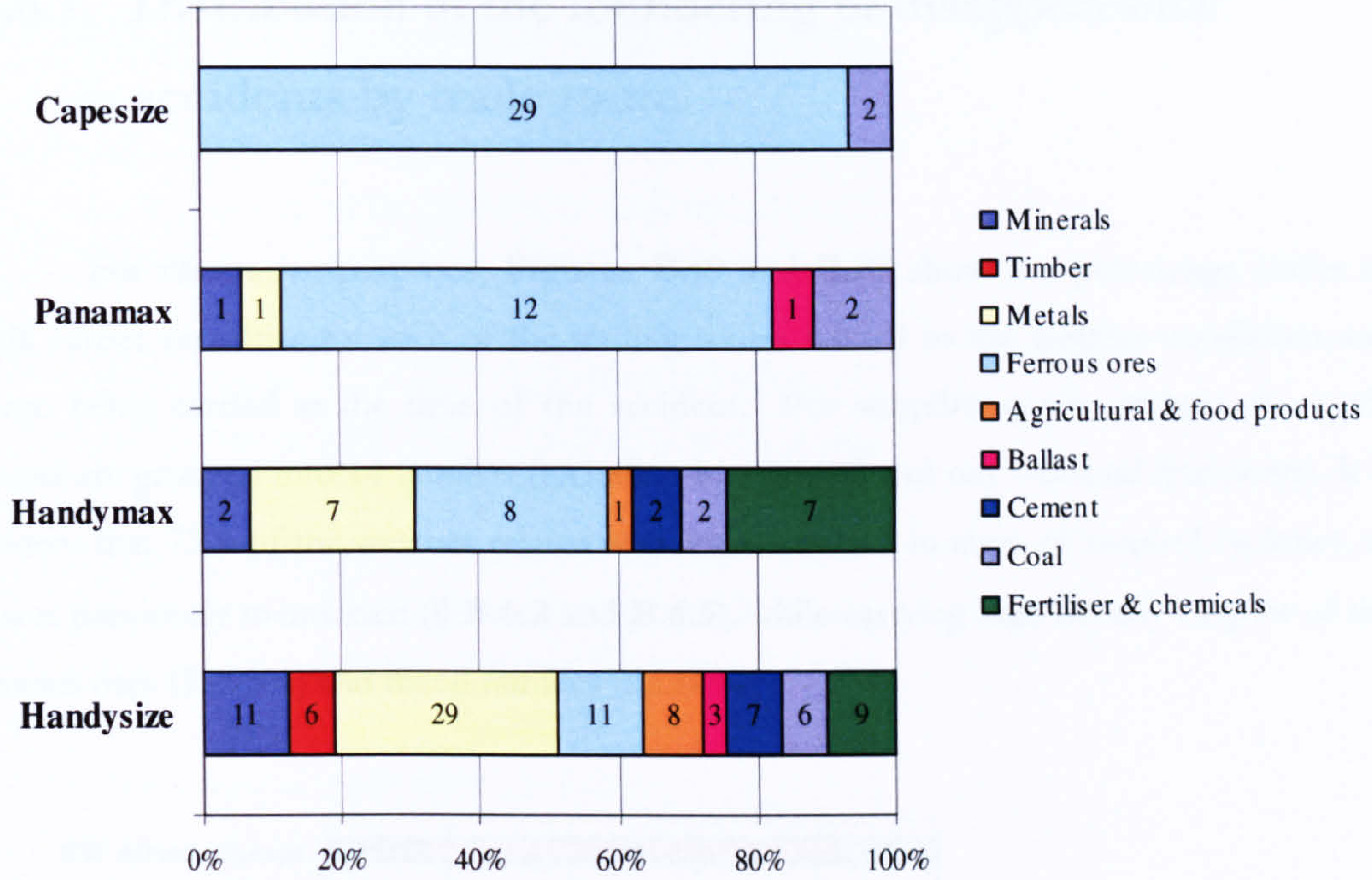
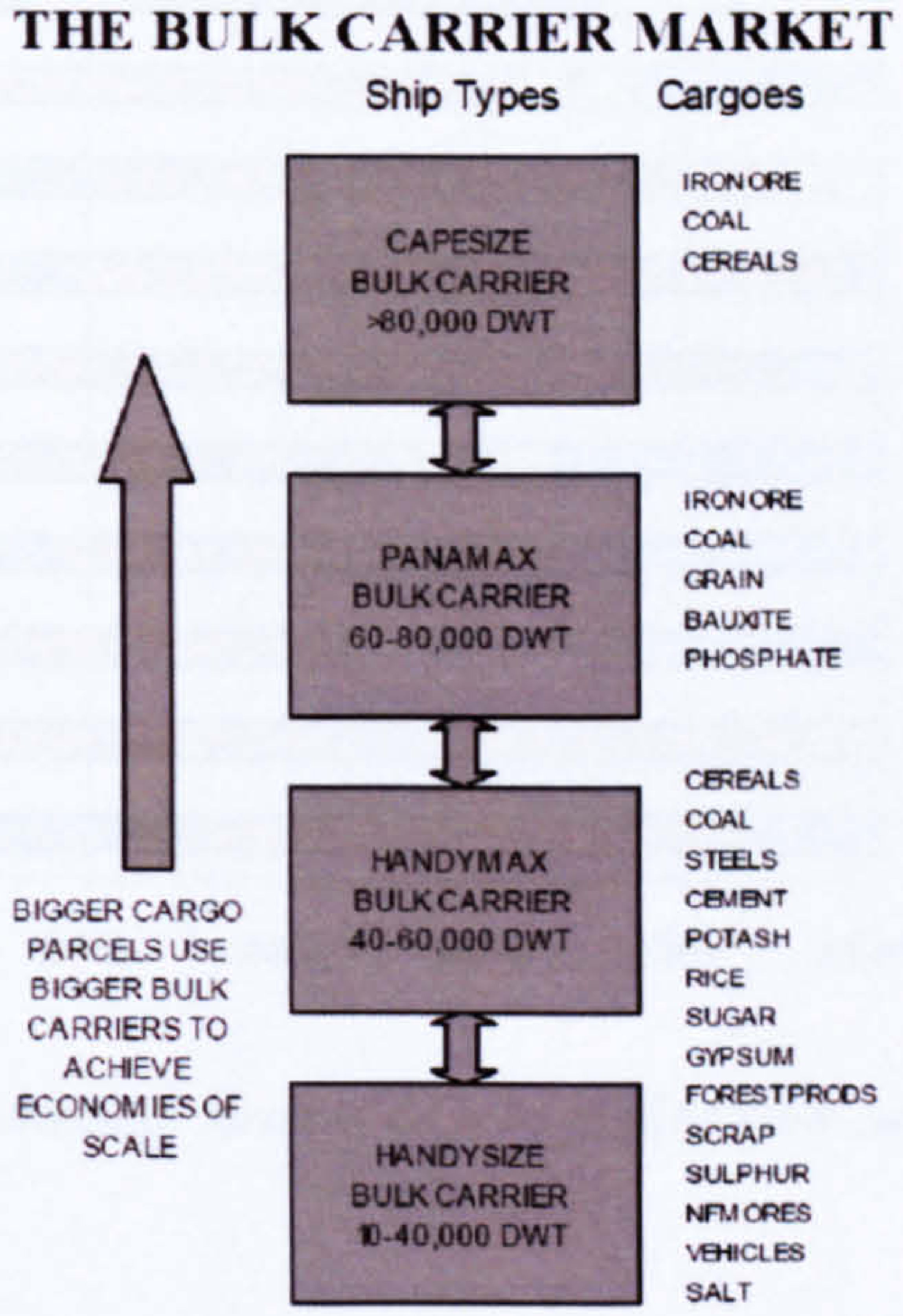


Figure B.17. *Percentage losses of BC size by cargo being transported*



Source: Clarkson Research Studies

Figure B.18. *The BC Market*

Source: Clarksons (2004b)

B.6.7. Distribution of the foundering or disappearance accidents by trade route

For illustrative purposes, **Figures B.19** and **B.20** show the percentage losses of bulk carrier casualties for each of the trading routes related to the weather conditions and cargo being carried at the time of the accident. For simplifying the analysis, the trade routes are grouped into 14 families (including in – bound and out – bound directions). It is evident that 73% of the weather related accidents occurred in areas of tropical cyclones, as it was previously mentioned (§ **B.6.2** and **B.6.3**), while carrying high density cargoes of the ferrous ores (35.93%) and metal families (22.16%).

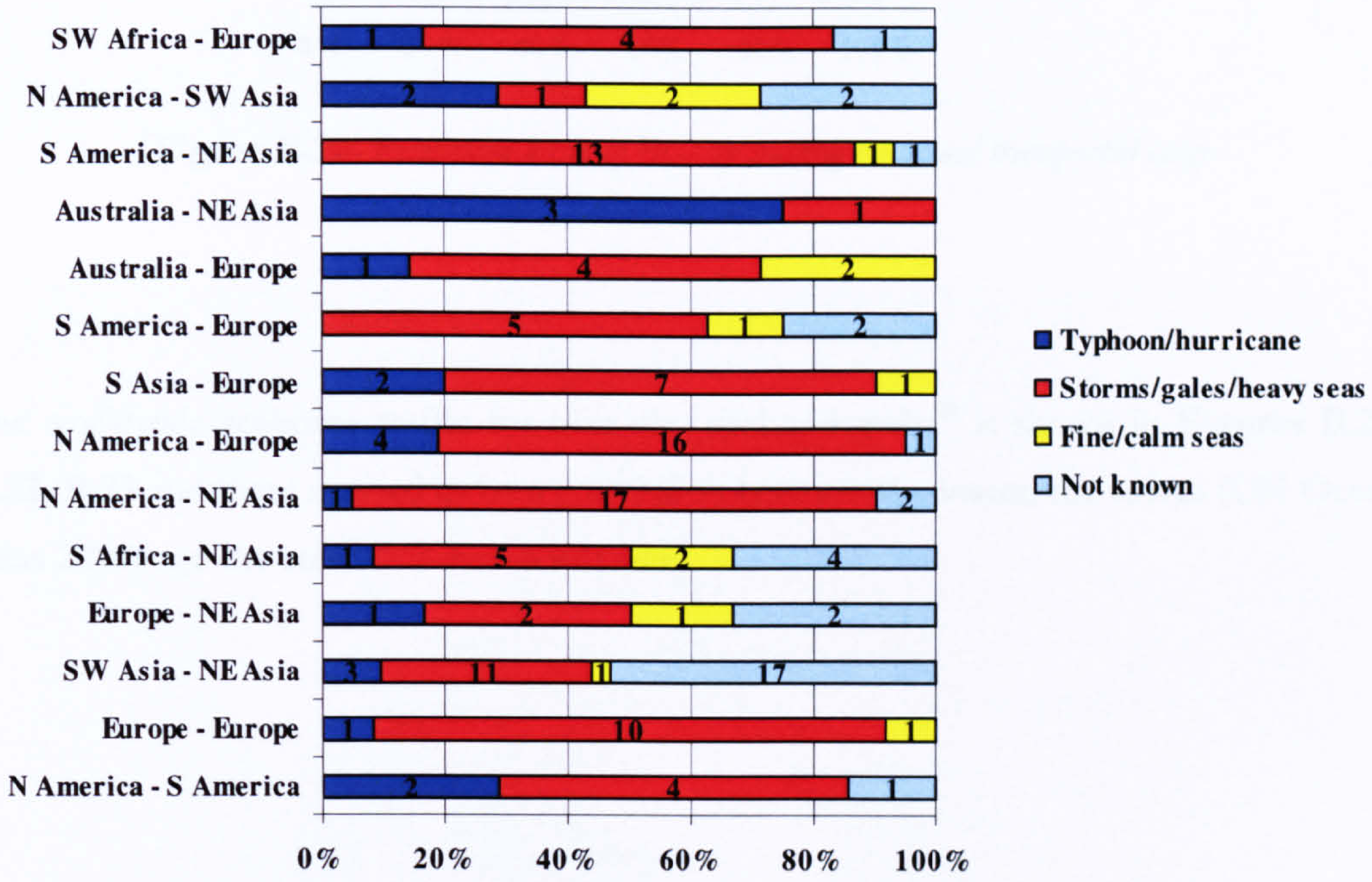


Figure B.19. *Percentage losses of BCs by trading route and weather conditions*

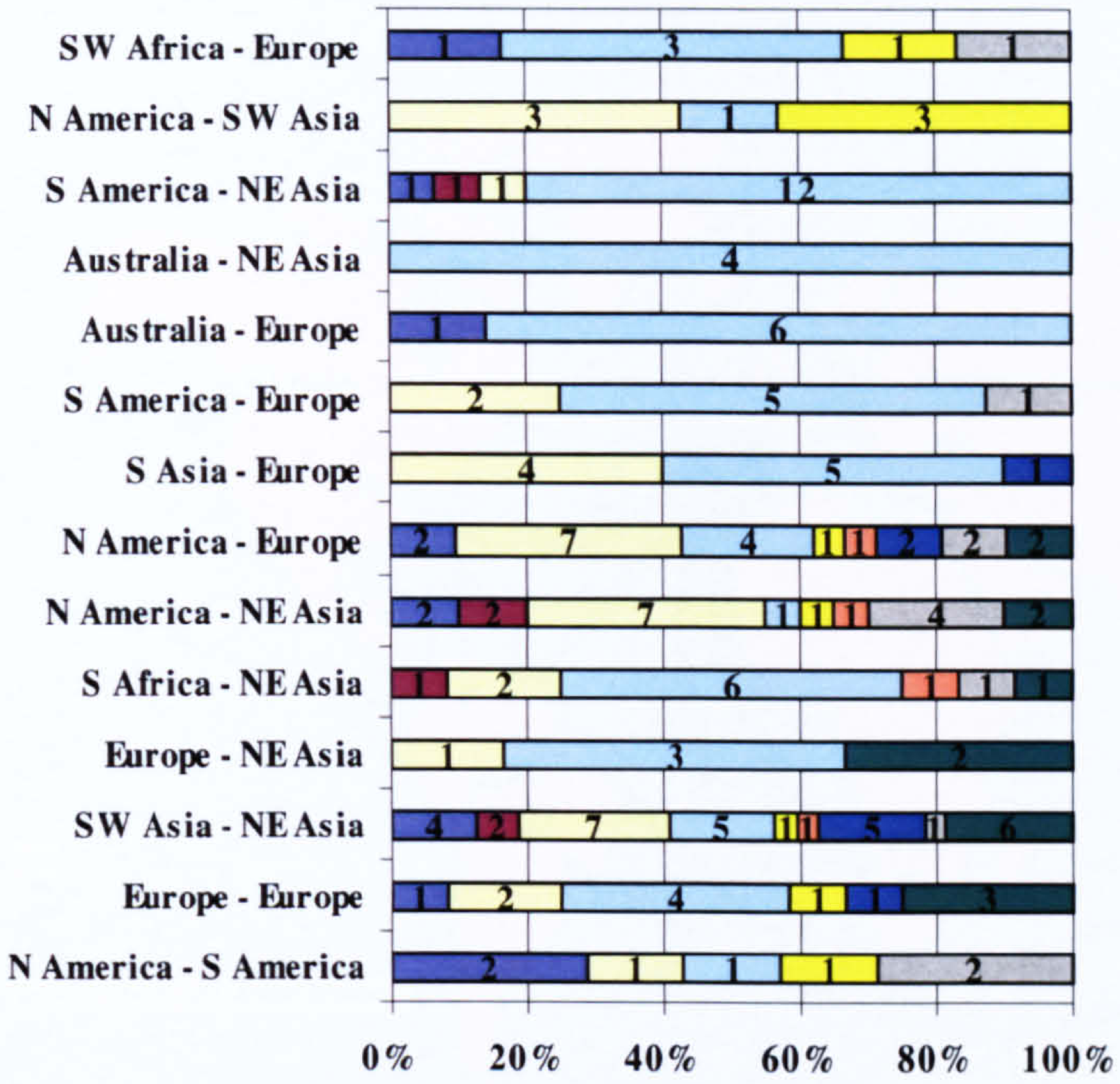


Figure B.20. *Percentage losses of BCs by trading route and transported cargo*

The worldwide seaborne traffic for iron ore, coal and grain[20] is shown in **Figures B.21, B.22, B.23** and there seemed to be a correlation between the losses, the routes (UN Ocean Atlas 2000) and the areas with heavy weather.

---

[20] Worldwide seaborne traffic for other dry bulks (Drewry 1985):

Bauxite/Alumina : (Caribbean & S America, W Africa, Australia) → (Europe, Japan, USA)
Phosphates : (USA, NW Africa, Middle East) → (Europe, Japan, Australia)
Fertilisers : (USA, Canada, NW Europe, S Europe, Japan) → (India, China, Central America)
Timber : (SE Asia, New Zealand, E Africa, Canada, USA) → (Europe, Japan)
Cement : (S Europe, Japan, Egypt, China) → (Middle East, N America W Africa)
Steels : (Europe, Japan, S America) → (NE Asia, N America, Middle East
Non–Fe ores & Minerals : (S Africa, Canada, Chile, S Asia, Australia, Mexico) → (Europe, Japan, US Gulf)

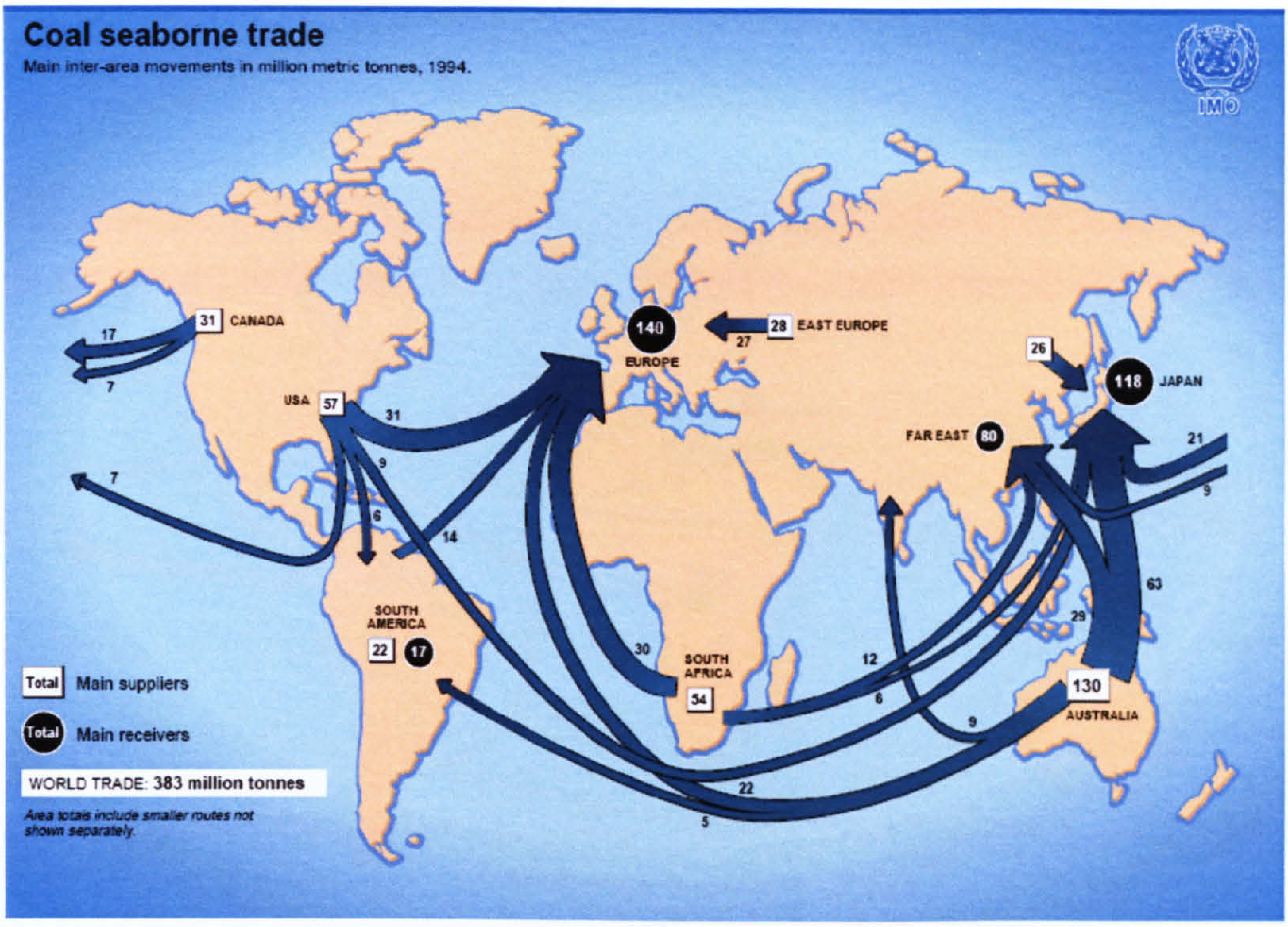


Figure B.21. *Coal seaborne trade (1994)*

Source : UN Ocean Atlas (2000)

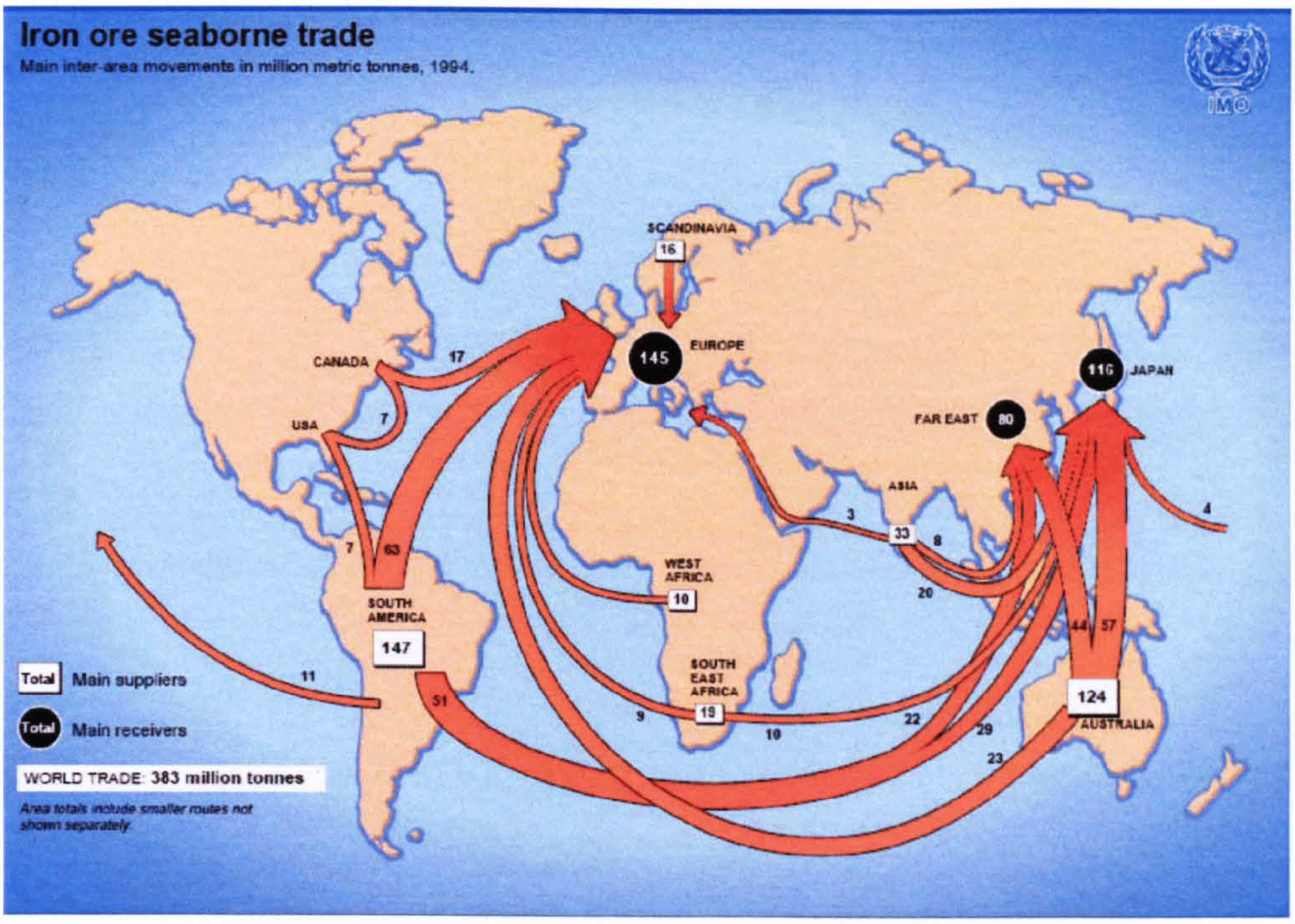


Figure B.22. *Iron Ore seaborne trade (1994)*

Source : UN Ocean Atlas (2000)

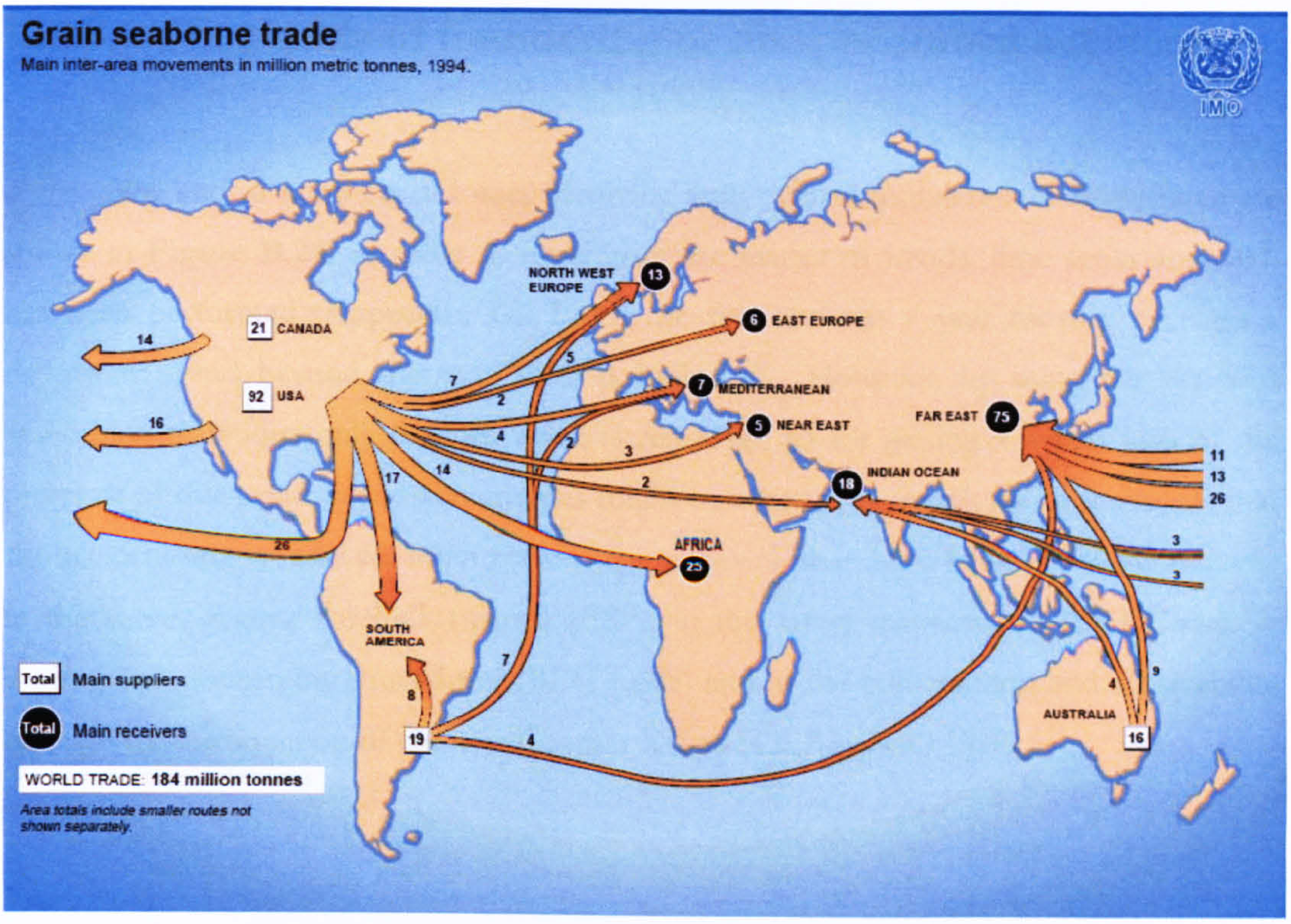


Figure B.23. *Grain seaborne trade (1994)*

Source: UN Ocean Atlas (2000)

B.6.8. The trends of foundering or disappearance accidents

The annual numbers of losses involving bulk carriers foundered or disappeared are shown in **Figure B.24**. In order to investigate the matter of trends, time series analysis[21] has been performed (**Appendix G**). From the five and ten – year moving averages a downward trend beyond the year 1995 is indicated. However, by using the previous smoothing technique only random noise is removed, so for getting a firmer idea of the presence of this trend, regression analysis might be a better approach and it is evident that the accident rate is reduced. Main reasons for achieving that, have been the improvements in the survey regime for bulk carriers (ESP), in the safety management (ISM Code), in loading and discharging procedures (BLU Code) and in the construction and survivability through the introduction of the new Chapter XII to SOLAS (IMO 1999).

---

[21] Time series modelling is based on extrapolating a set of observations from the past for clarifying possible trends. The linear moving average technique and regression analysis are forecasting methods in common use (Vose 2001). More specifically the following can be noted:
The simple linear moving average forecast F_{t+1} is calculated as:

$$F_{t+1} = \frac{X_t + X_{t-1} + X_{t-2} + \cdots + X_{t-N+1}}{N}$$

Where N is the number of the last observed data points that will be averaged to determine the forecast F_{t+1} (Vose 2001). The basic model for simple linear regression (the term ***simple*** implies a single regressor variable x and the term ***linear*** implies linear in x) for pairs of observations (x_1, y_1), (x_2, y_2), … , (x_n, y_n) is written as:

$$y_i = \beta_0 + \beta_1 x_i + \varepsilon_i \qquad (i = 1,2,\ldots,n) \qquad (1)$$

Where y is the measured response variable, β_0 and β_1 are the intercept and slope respectively, and ε is the model error. The estimation of β_0 and β_1 via the method of least squares is discussed in detail in Ryan (1997) and Myers (1990). An exact fit might be obtained when a polynomial (curvilinear) model is used instead of the previous one. In such a case, the model is described from the equation (only one regressor considered):

$$y_i = \beta_0 + \beta_1 x_i + \beta_2 x_i^2 + \cdots + \beta_k x_i^k + \varepsilon \qquad (i = 1,2,\ldots,n\,;\, n \geq k+1) \qquad (2)$$

Again the reader should advice Ryan (1997) and Myers (1990) for the least squares procedure for estimating the polynomial parameters.

It needs to be stressed that ***a linear model is defined as a model that is linear in the parameters, i.e., linear in the coefficients, the β's in equations (1) and (2)***

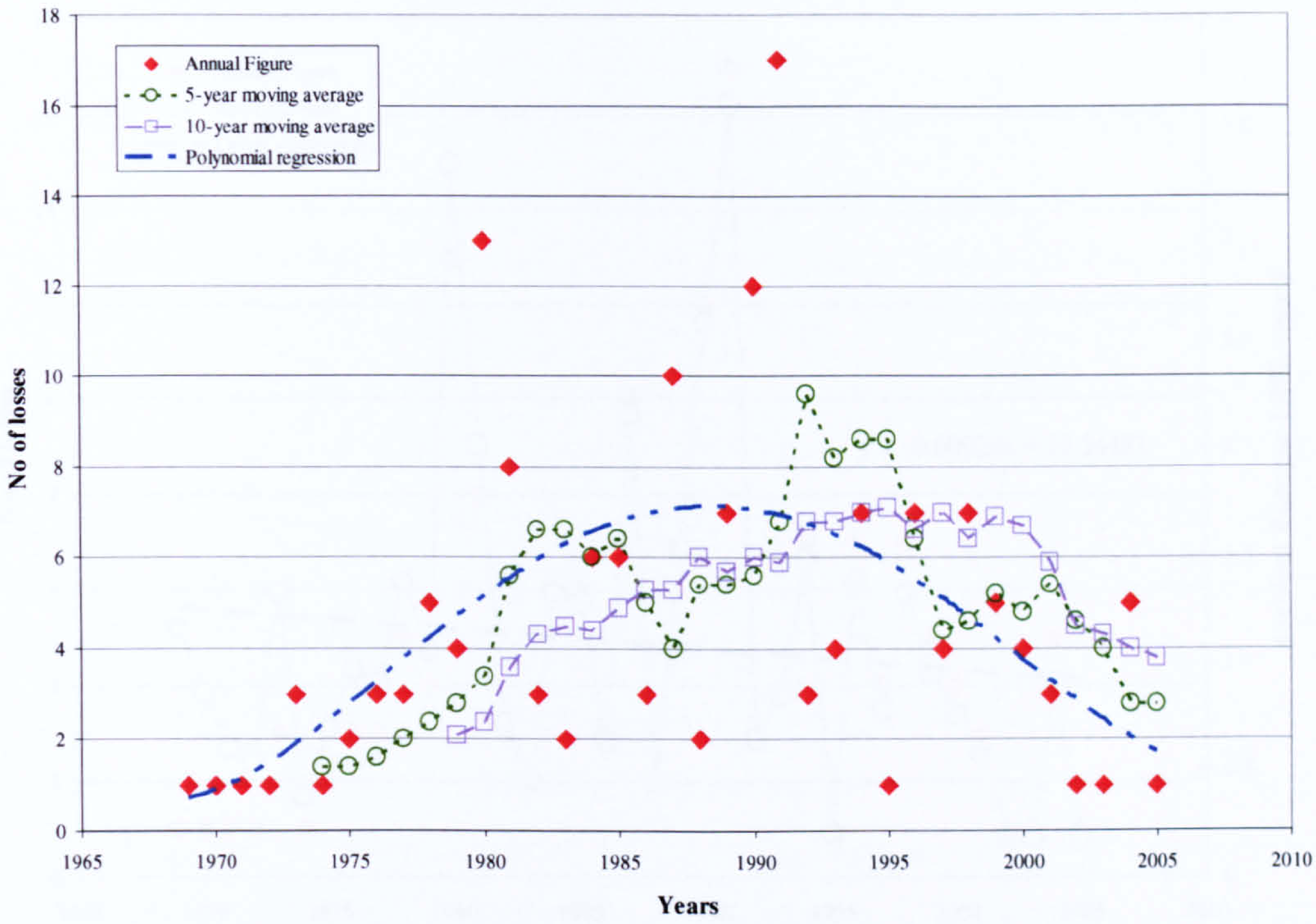


Figure B.24. *Annual number of BC losses due to foundering or disappearance (1969 – 2005)*

Similarly, the downward trend for accidents is illustrated in **Figure B.25** by the decreasing annual accident rate, which is determined by the ratio between the annual number of losses and the corresponding fleet number.

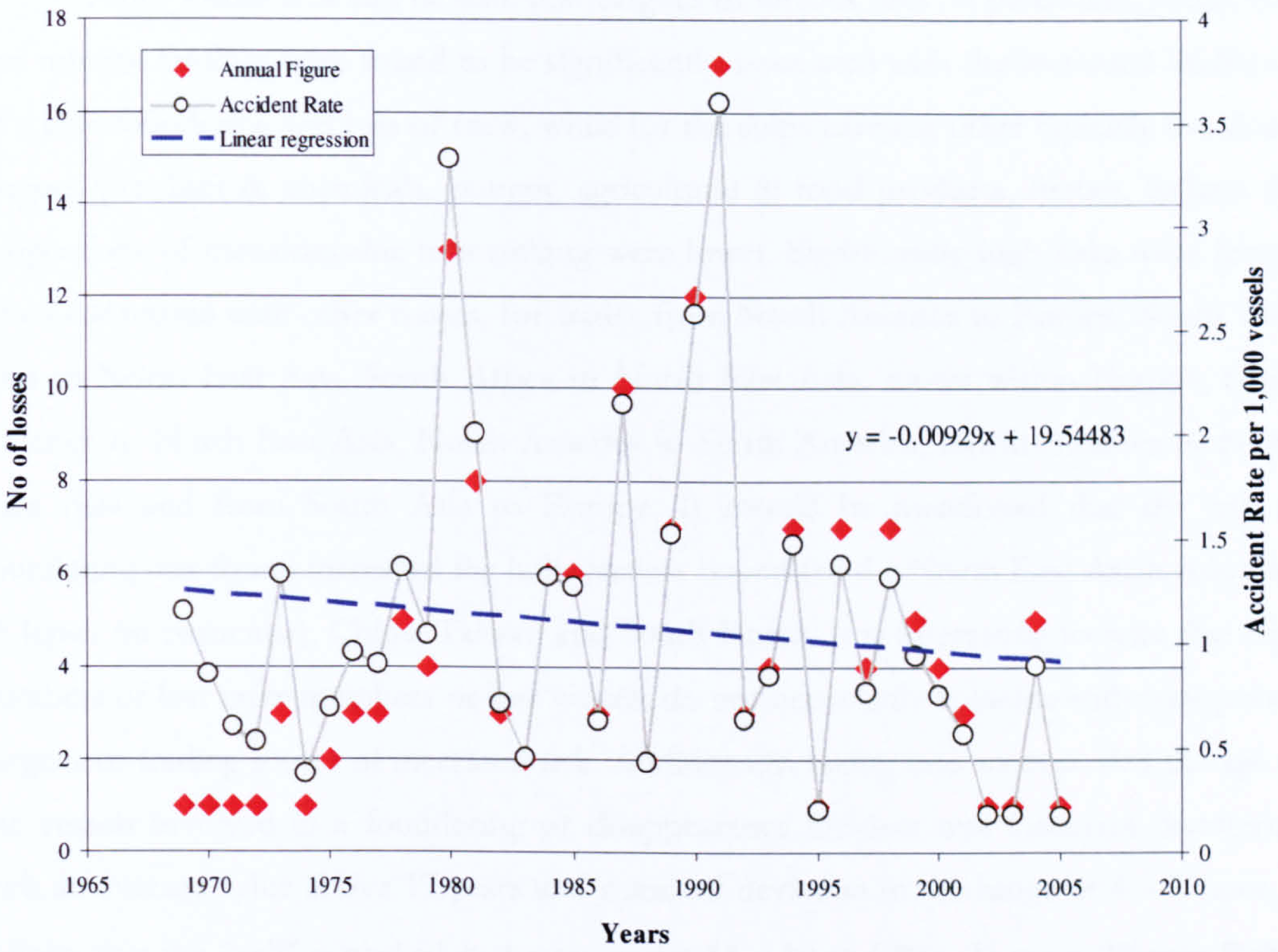


Figure B.25. *Accident rate versus calendar year for BCs foundered or disappeared (1969 – 2005)*

In order to establish the role of significance of transported cargoes and trading routes, logistic regression[22] (**Appendix G**) has been applied to assess their effects as risk factors (**Table B.X**).

---

[22] This model is often used to study the association between a binary response (accident – no accident) and a set of explanatory variables (age range – transported cargoes, age range – trading routes) and its popularity is being based on the **logistic function** $f(z) = \frac{1}{1+e^{-z}}$ where the provided estimates must lie in the range between 0 and 1. Hence, if $\pi = P(Y=1)$, it follows that $1-\pi = P(Y=0)$, and so $\frac{\pi}{1-\pi}$ is the ratio of the two probabilities, which, when stated in the form of odds (**odds ratio**), gives the odds of having $Y = 1$, for a given value of X. Regarding the above, the ***logistic regression model*** (linear) can be viewed as follows:

$$\hat{P}(X_i) = \frac{1}{1+e^{-\left(\alpha+\sum_{i=1}^{s}\beta_i X_i+\varepsilon_i\right)}} \Leftrightarrow ln\left(\frac{\hat{P}(X_i)}{1-\hat{P}(X_i)}\right) = \alpha + \sum_{i=1}^{s}\beta_i X_i + \varepsilon_i$$

For in depth analysis the reader should advice Ryan (1997), Myers (1990), Ott and Longnecker (2001), Kleinbaum and Klein (2002).

From **Table B.X** can be seen that cargoes of ferrous ores (in particular), metal, coal and mineral families were found to be significantly associated with the increased likelihood of a ship foundering and loss of crew, while for the ships carrying other typically less dense cargoes (fertiliser & chemicals, cement, agricultural & food products, timber, ballast) the proportions of casualties due to a sinking were lower. Significantly high risks were found, when contrasted with other routes, for trades from North America to Europe, South West Asia to North East Asia, South Africa to North East Asia, routes within Europe, South America to North East Asia, North America to South America, North America to North East Asia and from South Asia to Europe. It should be mentioned that the risk of foundering was found increased for bulk carriers bound for the North East Asian countries of Japan (in particular), China, Taiwan and South Korea. It is interesting to note that high numbers of lost crew members or lost vessels do not necessarily coincide with transported cargoes or trading routes of increased risk. Additionally, taking into account that the age of the vessels involved in a foundering or disappearance incident was Gaussian distributed with an average value above 17 years and standard deviation in the range of 4 – 7 years, it follows that the "bell" is peaked at the categories 15 – 19 and 20 – 24 years (**Figure B.26**), consensus with what was mentioned in **§ B.6.5**.

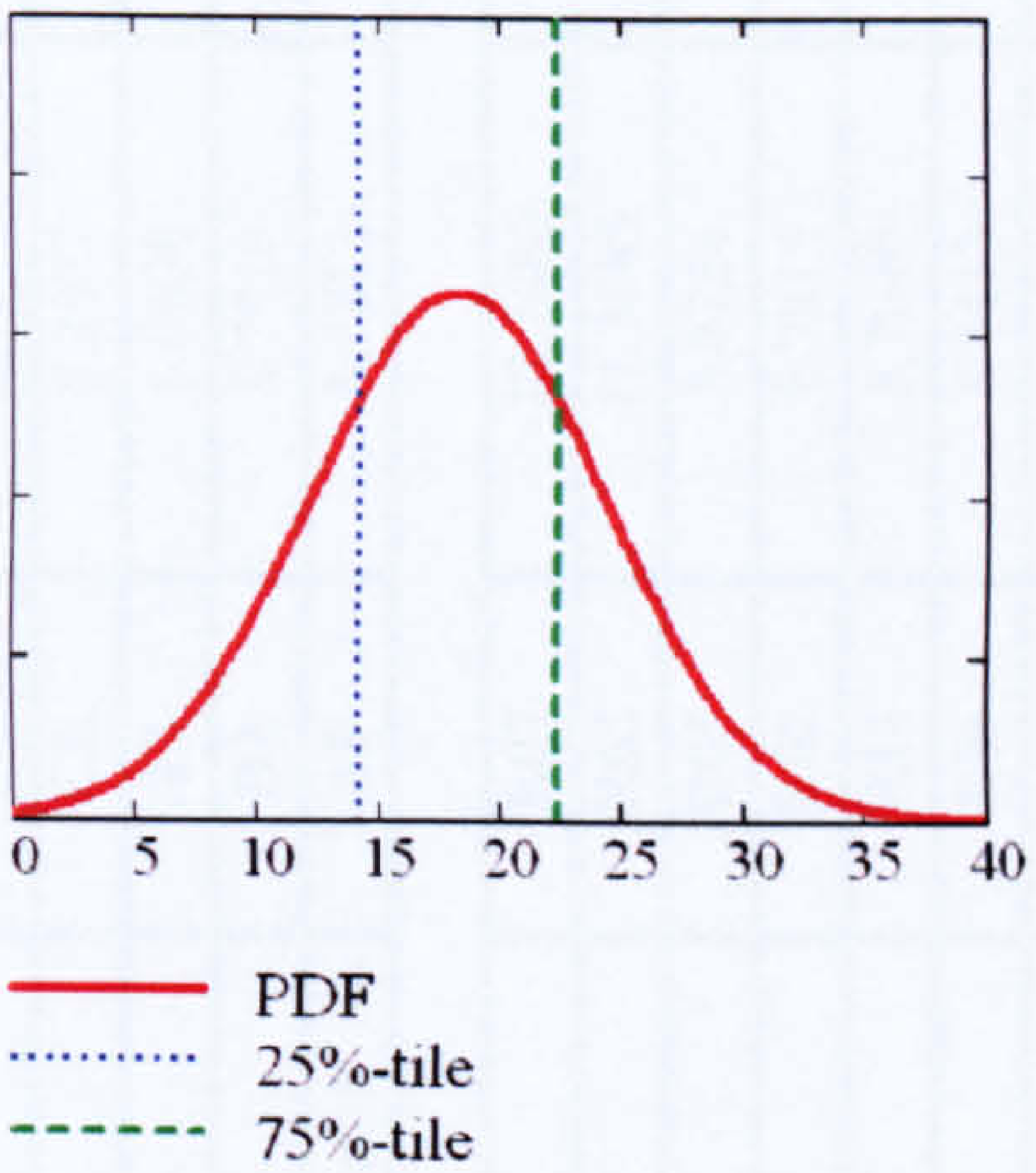


Figure B.26. *Percentiles of the Normal (Gaussian) PDF*

TABLE B.X. *Summary statistics for individual risk factors*

Risk Factors	Code	Odds Ratio	Age Modelling (Gaussian)		Crew Lost	Vessels Lost
			Mean (yrs)	St. Deviation (yrs)		
TRANSPORTED CARGOES						
Ferrous ores	**FE**	12.3937	18.46	5.77	921	60
Metals	**ME**	11.4872	17.82	6.39	417	37
Coal	**CO**	8.6727	19.65	6.58	199	12
Minerals	**MI**	8.5221	17.63	5.50	151	14
Fertiliser & chemicals	**FC**	6.7714	17.55	6.28	120	16
Cement	**CE**	6.2527	18.93	6.50	97	9
Timber	**TI**	6.0608	18.01	5.98	62	6
Ballast	**BA**	5.7919	17.13	6.20	21	4
Agricultural & food products	**AF**	5.7812	18.60	5.18	178	9
TRADING ROUTES						
N America – Europe	**R07**	12.7680	19.12	6.55	365	21
SW Asia – NE Asia	**R03**	11.3085	17.49	6.04	312	32
S Africa – NE Asia	**R05**	8.8724	18.12	6.17	84	12
Europe – Europe	**R02**	8.7913	17.63	6.10	132	12
S America – NE Asia	**R12**	8.7040	17.90	5.65	139	15
N America – S America	**R01**	8.4413	20.45	4.35	184	7
N America – NE Asia	**R06**	8.3693	17.60	5.48	272	20
S Asia – Europe	**R08**	7.9219	18.16	6.41	163	10
S America – Europe	**R09**	5.9924	18.31	6.64	106	8
Europe – NE Asia	**R04**	5.9598	18.14	6.46	27	6
N America – SW Asia	**R13**	5.8925	17.92	6.39	96	7
Australia – Europe	**R10**	5.5294	17.91	6.47	96	7
SW Africa – Europe	**R14**	5.0448	18.37	6.62	101	6
Australia – NE Asia	**R11**	4.3099	18.53	6.56	89	4

B.6.9. Calculation of foundering or disappearance likelihood

The accident likelihood $\left(:= \frac{\textbf{\textit{No of accidents}}}{\textbf{\textit{Fleet population}}} \times \textbf{\textit{1,000 vessels}} \right)$ is being calculated in the following tables[23] for the handysize, handymax, panamax and capsize vessels respectively.

A. Handysize Vessels

TABLE B.XI.A.1. *Fine/calm seas*

TRADING ROUTES	TRANSPORTED CARGOES								
	FE	CO	CE	MI	AF	FC	ME	TI	BA
R01									
R02									
R03									
R04						0.0098			
R05									
R06									
R07									
R08									
R09									
R10									
R11									
R12									
R13					0.0098		0.0098		
R14									

---

[23] The coding refers to **Table B.X.**

TABLE B.XI.A.2. *Storms/gales/heavy seas*

TRADING ROUTES	TRANSPORTED CARGOES								
	FE	CO	CE	MI	AF	FC	ME	TI	BA
R01				0.0098	0.0098				
R02	0.0098		0.0098	0.0098	0.0098	0.0196	0.0098		
R03		0.0098	0.0196	0.0098		0.0098	0.0294	0.0098	
R04	0.0098								
R05							0.0098	0.0098	
R06		0.0098		0.0196			0.0392	0.0196	
R07		0.0196		0.0098	0.0098		0.0392		0.0098
R08	0.0196						0.0294		
R09							0.0098		
R10				0.0098					
R11									
R12							0.0098	0.0098	
R13									
R14									

TABLE B.XI.A.3. *Typhoon/hurricane*

TRADING ROUTES	TRANSPORTED CARGOES								
	FE	CO	CE	MI	AF	FC	ME	TI	BA
R01		0.0098							
R02							0.0098		
R03	0.0098				0.0098	0.0098			
R04	0.0098								
R05						0.0098			
R06									
R07			0.0098				0.0098		
R08			0.0098						
R09									
R10									
R11									
R12									
R13					0.0098				
R14									

TABLE B.XI.A.4. *Not known*

TRADING ROUTES	TRANSPORTED CARGOES								
	FE	**CO**	**CE**	**MI**	**AF**	**FC**	**ME**	**TI**	**BA**
R01				0.0098					
R02									
R03	0.0098		0.0196	0.0294		0.0294	0.0392	0.0098	0.0098
R04	0.0098						0.0098		
R05	0.0098	0.0098							0.0098
R06					0.0098				
R07							0.0098		
R08									
R09	0.0098								
R10									
R11									
R12									
R13							0.0196		
R14									

B. Handymax Vessels

TABLE B.XII.B.1. *Fine/calm seas*

TRADING ROUTES	TRANSPORTED CARGOES								
	FE	**CO**	**CE**	**MI**	**AF**	**FC**	**ME**	**TI**	**BA**
R01									
R02									
R03	0.0431								
R04									
R05	0.0431								
R06									
R07									
R08							0.0431		
R09							0.0431		
R10									
R11									
R12									
R13									
R14									

TABLE B.XII.B.2. *Storms/gales/heavy seas*

TRADING ROUTES	TRANSPORTED CARGOES								
	FE	CO	CE	MI	AF	FC	ME	TI	BA
R01	0.0431	0.0431							
R02						0.0431			
R03	0.0431								
R04						0.0431			
R05									
R06		0.0431				0.0861	0.0861		
R07			0.0431			0.0861	0.0431		
R08									
R09									
R10									
R11	0.0431								
R12				0.0431					
R13	0.0431								
R14									

TABLE B.XII.B.3. *Typhoon/hurricane*

TRADING ROUTES	TRANSPORTED CARGOES								
	FE	CO	CE	MI	AF	FC	ME	TI	BA
R01							0.0431		
R02									
R03									
R04									
R05									
R06									
R07									
R08	0.0431								
R09									
R10									
R11									
R12									
R13					0.0431				
R14									

TABLE B.XII.B.4. *Not known*

TRADING ROUTES	TRANSPORTED CARGOES								
	FE	CO	CE	MI	AF	FC	ME	TI	BA
R01									
R02									
R03			0.0431			0.0431			
R04									
R05									
R06							0.0431		
R07									
R08									
R09	0.0431								
R10									
R11									
R12									
R13									
R14				0.0431					

C. Panamax vessels

TABLE B.XIII.C.1. *Fine/calm seas*

TRADING ROUTES	TRANSPORTED CARGOES								
	FE	CO	CE	MI	AF	FC	ME	TI	BA
R01									
R02									
R03									
R04									
R05	0.0550								
R06									
R07									
R08									
R09									
R10									
R11									
R12									
R13									
R14									

TABLE B.XIII.C.2. *Storms/gales/heavy seas*

TRADING ROUTES	TRANSPORTED CARGOES								
	FE	CO	CE	MI	AF	FC	ME	TI	BA
R01									
R02									
R03	0.0550								
R04									
R05	0.0550								
R06		0.1100							0.0550
R07	0.0550			0.0550					
R08	0.1100								
R09	0.0550								
R10	0.1100								
R11									
R12	0.1100								
R13									
R14	0.0550								

TABLE B.XIII.C.3. *Typhoon/hurricane*

TRADING ROUTES	TRANSPORTED CARGOES								
	FE	CO	CE	MI	AF	FC	ME	TI	BA
R01									
R02									
R03									
R04									
R05									
R06									
R07									
R08									
R09									
R10									
R11									
R12									
R13									
R14									

TABLE B.XIII.C.4. Not known

TRADING ROUTES	TRANSPORTED CARGOES								
	FE	CO	CE	MI	AF	FC	ME	TI	BA
R01									
R02									
R03									
R04									
R05							0.0550		
R06									
R07									
R08									
R09									
R10									
R11									
R12									
R13									
R14									

D. Capesize vessels

TABLE B.XIV.D.1. *Fine/calm seas*

TRADING ROUTES	TRANSPORTED CARGOES								
	FE	CO	CE	MI	AF	FC	ME	TI	BA
R01									
R02	0.0975								
R03									
R04									
R05									
R06									
R07									
R08									
R09									
R10	0.1949								
R11									
R12	0.0975								
R13									
R14									

TABLE B.XIV.D.2. *Storms/gales/heavy seas*

TRADING ROUTES	TRANSPORTED CARGOES								
	FE	CO	CE	MI	AF	FC	ME	TI	BA
R01									
R02	0.1949								
R03									
R04									
R05	0.1949								
R06									
R07	0.0975								
R08									
R09	0.1949	0.0975							
R10	0.0975								
R11									
R12	0.7793								
R13									
R14	0.0975								

TABLE B.XIV.D.3. *Typhoon/hurricane*

TRADING ROUTES	TRANSPORTED CARGOES								
	FE	CO	CE	MI	AF	FC	ME	TI	BA
R01									
R02									
R03									
R04									
R05									
R06	0.0975								
R07	0.1949								
R08									
R09									
R10	0.0975								
R11	0.2923								
R12									
R13									
R14		0.0975							

TABLE B.XIV.D.4. *Not known*

TRADING ROUTES	TRANSPORTED CARGOES								
	FE	CO	CE	MI	AF	FC	ME	TI	BA
R01									
R02									
R03									
R04									
R05									
R06									
R07									
R08									
R09									
R10									
R11									
R12	0.0975								
R13									
R14									

B.6.10. Calculation of foundering or disappearance consequences

The severity of consequence as defined at the IMO Guidelines on FSA (IMO 2002b, 2007b) is related to the determination of this probability by the number of injuries or fatalities for each incident: $\left(:= \frac{\textbf{No of injuries / fatalities}}{\textbf{Fleet population}} \times \textbf{1,000 vessels} \right)$

These values are shown in the next tables for the handysize, handymax, panamax and capsize vessels respectively.

TABLE B.XV.A. *Handysize vessels*

Severity of Consequence	Structural failure (HU[24]– Initial event)	
	Yes	**No**
Minor (Single or minor injuries)	0.3037	0.0784
Significant (Multiple or severe injuries)		
Severe (Single fatality or multiple severe injuries)		
Catastrophic (Multiple fatalities)	0.1666	0.3135

TABLE B.XV.B. *Handymax vessels*

Severity of Consequence	Structural failure (HU – Initial event)	
	Yes	**No**
Minor (Single or minor injuries)	0.5166	0.0431
Significant (Multiple or severe injuries)		
Severe (Single fatality or multiple severe injuries)	0.0431	
Catastrophic (Multiple fatalities)	0.2583	0.3875

TABLE B.XV.C. *Panamax vessels*

Severity of Consequence	Structural failure (HU– Initial event)	
	Yes	**No**
Minor (Single or minor injuries)	0.4942	0.0551
Significant (Multiple or severe injuries)		
Severe (Single fatality or multiple severe injuries)		
Catastrophic (Multiple fatalities)	0.2197	0.1648

TABLE B.XV.D. *Capesize vessels*

Severity of Consequence	Structural failure (HU – Initial event)	
	Yes	**No**
Minor (Single or minor injuries)	0.9741	
Significant (Multiple or severe injuries)		
Severe (Single fatality or multiple severe injuries)	0.1949	0.0975
Catastrophic (Multiple fatalities)	0.7793	0.9741

---

[24] Referring to the database accident code (§ **B.3.3**)

B.6.11. Hold flooding breakdown

In the following tables the likelihood $\left(:= \frac{\textbf{No of accidents}}{\textbf{Fleet population}} \times \textbf{1,000 vessels} \right)$ is calculated for the handysize, handymax, panamax and capsize vessels respectively.

TABLE B.XVI.A. *Handysize vessels*

Multiple hold flooding		**Suspected cause**			
		Bulkhead failure	Opening failure	Side failure	Unknown
No1 & No2 hold	0.0491		0.0294	0.0294	
No1 & other	0.0784			0.0392	0.0392
Other	0.2841	0.0686	0.0136	0.0812	0.1218
Unknown	0.2254				0.2254

Single hold flooding		**Suspected cause**			
		Bulkhead failure	Opening failure	Side failure	Unknown
No1 hold	0.0588			0.0294	0.0294
Other	0.0981	0.0234	0.0098	0.0281	0.0421
Unknown	0.0784				0.0784

TABLE B.XVI.B. *Handymax vessels*

Multiple hold flooding		**Suspected cause**			
		Bulkhead failure	Opening failure	Side failure	Unknown
No1 & No2 hold	0.0982			0.0431	0.0861
No1 & other	0.0431			0.0431	
Other	0.3272	0.0861		0.0861	0.1722
Unknown	0.3599				0.3599

Single hold flooding		**Suspected cause**			
		Bulkhead failure	Opening failure	Side failure	Unknown
No1 hold	0.0431			0.0431	
Other	0.1722	0.0431		0.0431	0.0861
Unknown	0.2153				0.2153

TABLE B.XVI.C. *Panamax vessels*

Multiple hold flooding		Suspected cause			
		Bulkhead failure	Opening failure	Side failure	Unknown
No1 & No2 hold	0.1648		0.0824	0.0824	
No1 & other	0.1648				0.1648
Other	0.2746			0.2746	
Unknown					

Single hold flooding		Suspected cause			
		Bulkhead failure	Opening failure	Side failure	Unknown
No1 hold	0.0551			0.0551	
Other	0.1099	0.0551		0.0551	
Unknown	0.2746				0.2746

TABLE B.XVI.D. *Capesize vessels*

Multiple hold flooding		Suspected cause			
		Bulkhead failure	Opening failure	Side failure	Unknown
No1 & No2 hold	0.1949		0.0975	0.0975	
No1 & other	0.2923	0.0975		0.1949	
Other	0.9741	0.2923	0.1949	0.2923	0.1949
Unknown	0.4871				0.4871

Single hold flooding		Suspected cause			
		Bulkhead failure	Opening failure	Side failure	Unknown
No1 hold	0.1949		0.0975	0.0975	
Other	0.5845	0.1949	0.0975	0.1949	0.0975
Unknown	0.2923				0.2923

B.6.12. Determination of the historical risk profile

In § **B.6.8** was stated that the downward trends at the accident rates were achieved due to the introduction and implementation of different RCMs and particularly the enhanced hull surveys (ESP – 1993), improvements in the loading/unloading practices (BLU Code – 1997), standards on the management for the safe operation of ships (ISM

Code – 1998), additional safety measures for bulk carriers (SOLAS Ch. XII – 1999). The effects of each measure to each vessel type separately cannot be evaluated; whilst for the whole fleet can roughly be estimated from **Table B.XVII**

$$\left(RCM_{effect} := \left| \frac{Incident\ rate_{before\ RCM} - Incident\ rate_{after\ RCM}}{Incident\ rate_{before\ RCM}} \times \alpha \right| \right)$$

where α (%) is the regression line slope (**Figure B.25**). It is remarkable that the maximum reduction is observed for the panamax vessels.

TABLE B.XVII. *Rough estimation of the effect of ESP, BLU & ISM Codes and SOLAS Ch. XII*

Period (Yrs)	No. of foundering/disappearance incidents					Risk Control
	Handysize	Handymax	Panamax	Capesize	TOTAL	
1969~1993	63	21	14	23	121	Nil
Rate/ship-year	0.000944	0.0018	0.0018	0.00528	0.00134	
1994~1997	12	1	1	5	19	ESP
Rate/ship-year	0.000968	0.000322	0.000364	0.00305	0.000955	
Effect of ESP					**26.69%**	
1998	5	2	0	0	7	ESP + BLU
Rate/ship-year	0.00162	0.00218	0.0	0.0	0.00132	
Effect of ESP + BLU					**35.51%**	
Effect of BLU Code					**6.78%**	
1999	3	1	1	0	5	ESP + BLU ISM
Rate/ship-year	0.00101	0.00104	0.001195	0.0	0.000948	
Effect of ESP + BLU + ISM					**26.18%**	
Effect of ISM Code					**9.16%**	
2000~2005	7	4	1	3	15	ESP + BLU ISM+Ch.XII
Rate/ship-year	0.000415	0.000609	0.000166	0.000913	0.000458	
Effect of ESP + BLU + ISM + SOLAS Ch. XII					**48.02%**	
Effect of SOLAS Ch. XII					**20.29%**	
1994~2005	27	8	3	8	46	ESP + BLU ISM+Ch.XII
Rate/ship-year	0.000764	0.000692	0.000288	0.001355	0.000727	
Effect	**17.72%**	**57.19%**	**78.04%**	**69.06%**	**42.50%**	

The risk (loss of life) is determined by either:

(i) Single statistics representing risk

- Individual risk – the risk experienced by crew members onboard the vessel:

$$IR_{for\ Person\ Y} = F_{of\ undesired\ Event} \cdot P_{for\ Person\ Y} \cdot E_{of\ Person\ Y}$$

Whereas: F = frequency

P = resulting casualty probability

E = fractional exposure to that risk

- Activity specific period mortality rate (Societal Risk: PLL) – the risk experienced by the whole crew exposed to the foundering/disappearance incident:

$$PLL_{Foundering\,/\,Disappearance} = \frac{No\ of\ fatalities}{Fleet\ population} \quad \text{or}$$

(ii) Frequency vs. consequence lines (Societal Risk) – F-N diagram, which is a continuous graph representing the cumulative distribution of multiple fatality events in a logarithmic scale.

The different representations of risk in the first category have in common that the consequences (number of deaths) have been averaged. In fact, the assessment of risk in a particular activity depends also on the balance between low probability/high casualty incidents on the one hand and high probability/low casualty incidents on the other. In this sense, through the F-N diagram is assessed not only the average number of fatalities but also the risk of catastrophic accidents killing many people at once. It needs to be emphasized that for achieving a full risk picture it is adequate to look for both individual and societal risk (Bedford and Cooke 2004, Netherlands 2006).

The effects in PLL of the introduced RCMs are obvious from **Figure B.27**, while in **Figure B.28** is observed that although the individual risk is in the ALARP region (the limits are those proposed by Skjong et al. 2007) , is far from the target value (as proposed by Skjong et al. 2007), apart from the panamax vessels. The F-N diagrams before and after the implementation of RCMs are shown in **Figures B.29.a** and **b** respectively together with the proposed acceptance criteria (as proposed by Skjong et al. 2007). The methodology for calculating the cumulative frequencies is outlined at HSE (2002a). Despite the improvements, the capsize (particular) and handysize vessels are in the intolerable region. The high societal risk aversion to this type of accident is considered from the F-N curve for all bulk carriers (total losses – foundering/disappearance incidents only).

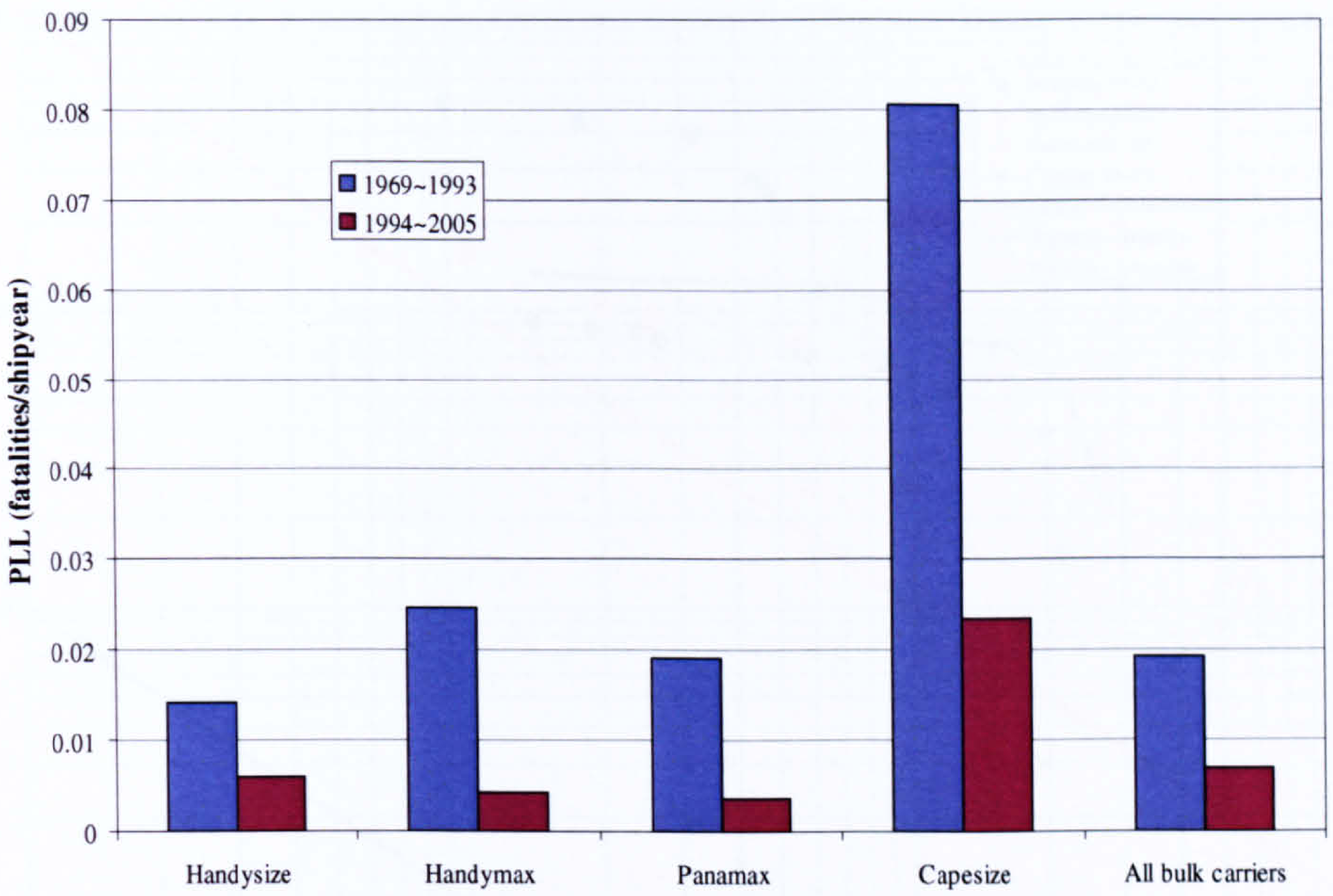


Figure B.27. *Effect of ESP, BLU & ISM Codes and SOLAS Ch. XII in PLL of BC foundering/ disappearance accidents (total losses)*

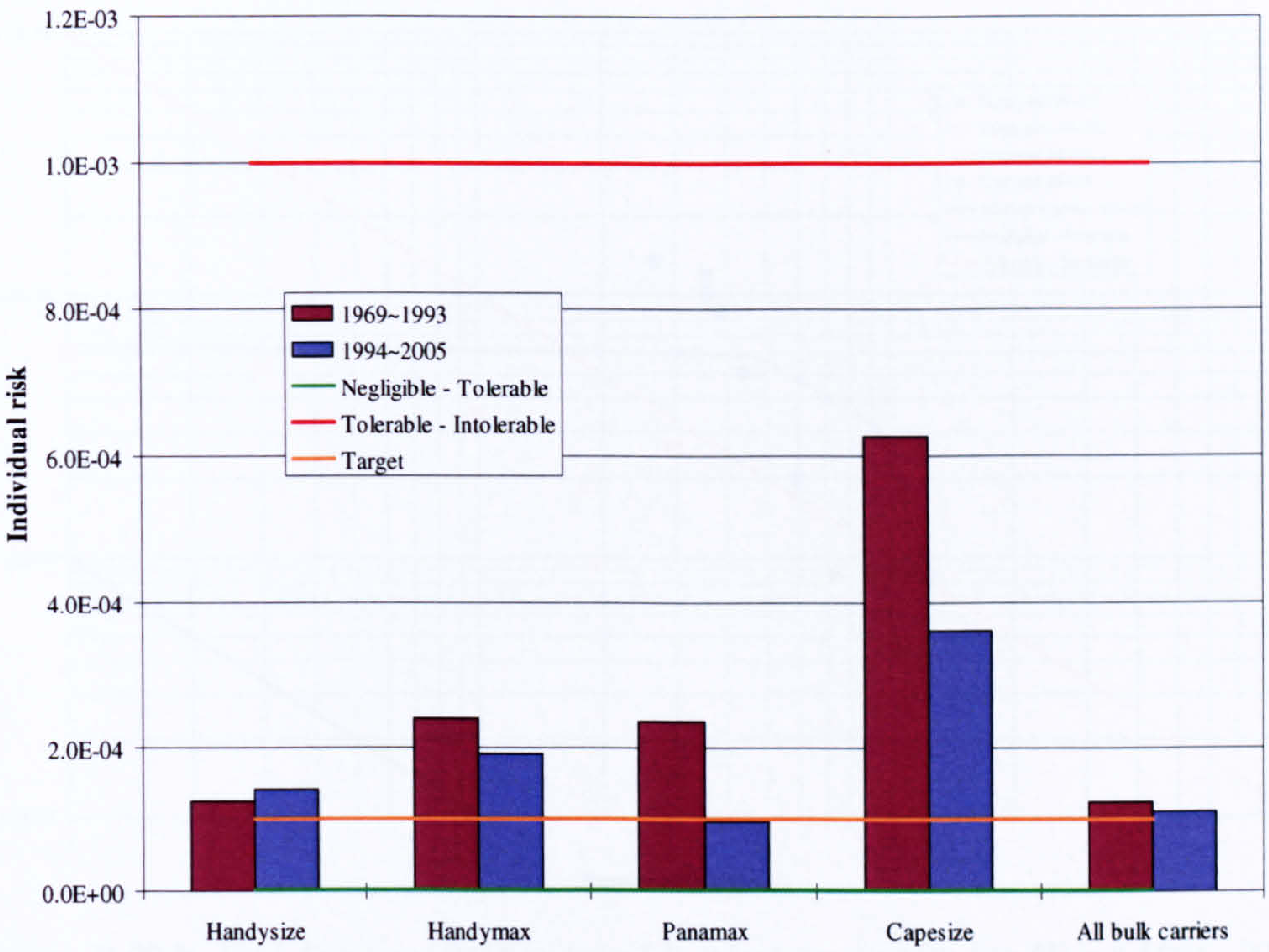


Figure B.28. *Effect of ESP, BLU & ISM Codes and SOLAS Ch. XII in the individual risk (annual) for crew of BC foundering/ disappearance accidents (total losses)*

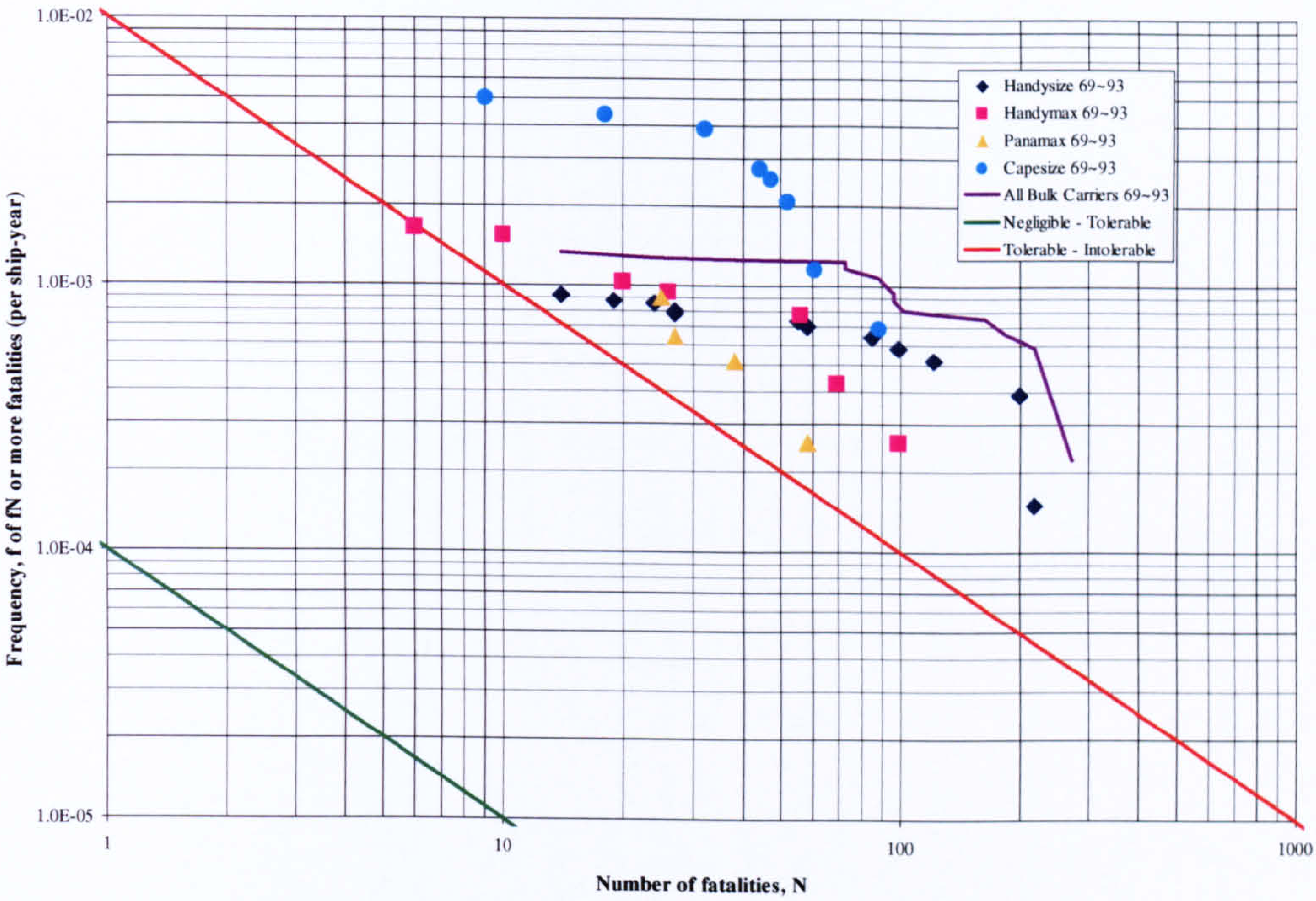


Figure B.29.a. *F-N diagram of BC foundering/ disappearance accidents (total losses) 1969~1993*

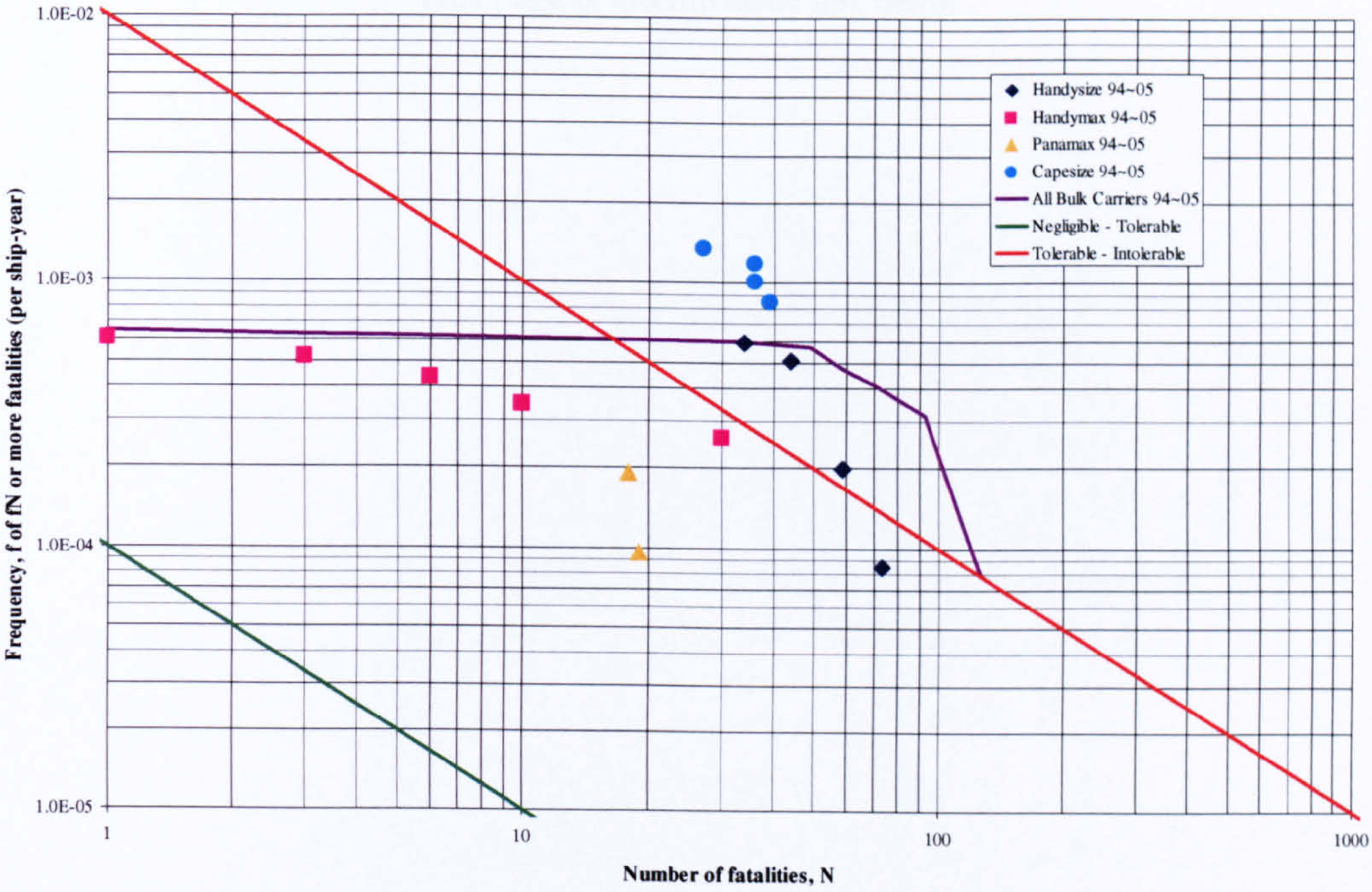


Figure B.29.b. *F-N diagram of BC foundering/ disappearance accidents (total losses) 1994~2005*

This page is intentionally left blank

ANNEX 1

Table B.Ax.I. *Identified foundering/ disappearance accidents (total losses)*

Source: LMIS, LMIU, INTERCARGO

VESSEL'S NAME	VESSEL SIZE	YEAR BUILT	CAS. YEAR	TRADE ROUTE & CARGO FAMILY	INITIAL EVENT	No DEAD	INTERNAL CAUSES	WEATHER
ACADEMY STAR	panamax	1968	1982	N America – NE Asia / Coal	hull failure		Bottom failure	storms/gales/heavy seas
ADAMANDAS	handysize	1986	2003	N America – SW Asia / Metals	miscellaneous		Cargo overheating	fine/calm seas
AEGIS DUTY	handysize	1958	1973	N America – S America / Minerals	hull failure			
AGIOS GIORGIS	handysize	1962	1980	N America – NE Asia / Metals	hull failure	29	Hull cracking	storms/gales/heavy seas
AL HADI	handysize	1968	1996	SW Asia – NE Asia / Fertiliser & chemicals	hull failure		Crack in shell plate	
ALBION TWO	handysize	1976	1997	N America – Europe / Metals	missing/assumed lost	25		storms/gales/heavy seas
ALBORADA	handysize	1969	1987	N America – S America / Coal	foundered	30		typhoon/hurricane
ALEXANDRE P.	Capesize	1967	1990	Australia – Europe / Ferrous ores	missing/assumed lost	25		fine/calm seas
ALGARROBO	capesize	1973	1990	S America – NE Asia / Ferrous ores	missing/assumed lost	32		fine/calm seas
ANDERSON	handysize	1975	1993	Europe – NE Asia / Ferrous ores	foundered	24		typhoon/hurricane
ANITA	handysize	1966	1973	N America – Europe / Coal	missing/assumed lost	32		storms/gales/heavy seas
ANTACUS	handysize	1973	1984	N America – Europe / Metals	hull failure		Bottom failure	
ANTIPAROS	handysize	1963	1981	N America – NE Asia / Metals	missing/assumed lost	35		storms/gales/heavy seas
ANTONIOS DEMADES	handymax	1963	1970	N America – NE Asia / Metals	hull failure	10	Sprang a leak	
APOLLO SEA	capesize	1973	1994	S Africa – NE Asia / Ferrous ores	foundered	36		storms/gales/heavy seas
ARCTIC CAREER	panamax	1966	1985	S America – NE Asia / Ferrous ores	missing/assumed lost	27		storms/gales/heavy seas
ARTEMIS	handysize	1973	1980	S America – NE Asia / Timber	hull failure			storms/gales/heavy seas
ASEAN CARRIER	handysize	1968	1998	SW Asia – NE Asia / Cement	hull failure		Took water in 2 cargo holds	storms/gales/heavy seas
ASIAN NOBLE	handysize	1986	2004	SW Asia – NE Asia / Coal	capsizing/listing	1		storms/gales/heavy seas

Table B.Ax.I (Continued). *Identified foundering/ disappearance accidents (total losses)*

AURELIA	handymax	1981	2005	S America – NE Asia / Minerals	foundered	10		storms/gales/heavy seas
AZALEA	capesize	1969	1990	Europe – Europe / Ferrous ores	hull failure		Shell cracked	fine/calm seas
BANALUNA	handysize	1961	1971	SW Asia – NE Asia / Ferrous ores	missing/assumed lost	35		typhoon/hurricane
BLACK SEA T	handysize	1969	1997	Europe – Europe / Agricultural & food pr.	Capsizing/listing	1		storms/gales/heavy seas
BOLIVAR MARU	panamax	1965	1969	S America – NE Asia / Ferrous ores	hull failure	31		storms/gales/heavy seas
BRAUT TEAM	handysize	1976	1991	Europe – NE Asia / Ferrous ores	hull failure		Shell cracked	
BRAVE THEMIS	handysize	1973	1986	Europe – NE Asia / Metals	hull failure			
CATHAY SEATRADE	panamax	1973	1987	SW Africa – Europe / Ferrous ores	foundered	27		storms/gales/heavy seas
CHANDRAGUPTA	handymax	1963	1978	N America – SW Asia / Agricultural & food	foundered	69		typhoon/hurricane
CHAR YE	handysize	1976	1984	SW Asia – NE Asia / Metals	foundered			storms/gales/heavy seas
CHARLIE	handysize	1975	1990	N America – SW Asia / Agricultural & food	foundered	27		typhoon/hurricane
CHIAN MARINER	handymax	1974	1998	S Africa – NE Asia / Ferrous ores	hull failure			fine/calm seas
CHOBA	handysize	1969	1991	SW Asia – NE Asia / Fertiliser & chemicals	foundered	9		
CHRISTINAKI	handysize	1973	1994	N America – Europe / Metals	hull failure	27		typhoon/hurricane
CHRISTOPHER	capesize	1983	2001	S America – Europe / Coal	hull failure	27	No1 hat. Open /taking water	storms/gales/heavy seas
CONTINENTAL LOTUS	panamax	1967	1991	S Asia – Europe / Ferrous ores	hull failure	38	Shell cracked at No5 hold	storms/gales/heavy seas
CORAZON	handysize	1972	1990	N America – Europe / Cement	hull failure	6	Broken keel water in No2	typhoon/hurricane
CUMBERLANDE	handymax	1973	1987	N America – SW Asia / Ferrous ores	hull failure		No1 & No2 holds holed	storms/gales/heavy seas
DAEYANG HONEY	capesize	1970	1992	Australia – NE Asia / Ferrous ores	foundered	28		typhoon/hurricane
DAYSPRING	handysize	1970	1987	Europe – NE Asia / Ferrous ores	capsizing/listing			storms/gales/heavy seas
DEIFOVOS	capesize	1964	1981	Europe – Europe / Ferrous ores	capsizing/listing	9		storms/gales/heavy seas
DERBYSHIRE	capesize	1976	1980	N America – NE Asia	hull failure	44		typhoon/hurricane
DON AURELIO	handysize	1976	1981	SW Asia – NE Asia / Metals	missing/assumed lost	31		
DUNAV	handysize	1973	1980	N America – NE Asia / Timber	missing/assumed lost	31	Took water in a cargo hold	storms/gales/heavy seas
DYSTOS	handysize	1972	1996	Europe – Europe / Cement	capsizing/listing	20		storms/gales/heavy seas

Table B.Ax.I (Continued). *Identified foundering/ disappearance accidents (total losses)*

EDMUND FITZGERALD	handymax	1958	1975	N America – S America / Metals	hull failure	29		typhoon/hurricane
ELENA	handymax	1966	1983	SW Africa – Europe / Minerals	hull failure		Broken keel	
ELOUNDA DAY	handymax	1973	1990	N America – NE Asia / Fertiliser & chem.	Hull failure		Cracks in No2 hold	storms/gales/heavy seas
ENTRUST FAITH	panamax	1973	1991	S America – Europe / Ferrous ores	damages to ship/eq.		Cracks shell plate	storms/gales/heavy seas
ERATO	handymax	1968	1991	Europe – Europe / Fertiliser & chemicals	foundered	6		storms/gales/heavy seas
EUROBULKER	handysize	1963	1977	S Asia – Europe / Cement	missing/assumed lost	29		typhoon/hurricane
EVELPIDIS ERA	handysize	1962	1978	N America – NE Asia / Minerals	hull failure		No3 hold flooded	storms/gales/heavy seas
FEI CUI HAI	handymax	1973	1998	SW Asia – NE Asia / Ferrous ores	hull failure	30		fine/calm seas
FLARE	handysize	1972	1998	N America – Europe / Ballast	hull failure	21	Bottom failure	storms/gales/heavy seas
FREIGHTS QUEEN	handysize	1961	1975	S America – Europe / Ferrous ores	hull failure	25	Bottom failure	
GERANIUM	handysize	1968	1974	N America – NE Asia / Metals	missing/assumed lost	29		storms/gales/heavy seas
GOLD B. CONVEYOR	handysize	1974	1993	N America – S America / Minerals	hull failure	33	Took in water	storms/gales/heavy seas
GOLDEN CHARIOT	handysize	1972	1994	N America – SW Asia / Agricultural & food	foundered			fine/calm seas
GOLDEN HARVEST	handysize	1975	1998	S Africa – NE Asia / Fertiliser & chemicals	missing/assumed lost	24	Was listing 30 degrees	typhoon/hurricane
GOLDEN PINE	handysize	1968	1981	N America – NE Asia / Minerals	hull failure	25	Flooded holds	storms/gales/heavy seas
GREAT EAGLE	panamax	1968	1992	S Africa – NE Asia / Ferrous ores	hull failure		Cracked shell plate No7 CH	storms/gales/heavy seas
HAE DANG WHA	capesize	1968	1980	Australia – NE Asia / Ferrous ores	missing/assumed lost	29		typhoon/hurricane
HANJIN KARACHI	handysize	1973	1991	S Africa – NE Asia / Ballast	hull failure		Ingress of water into E/R	
HENNIGSDORF	handymax	1966	1984	S America – Europe / Ferrous ores	hull failure		Springing a leak in a hold	
HIDIR BEY	handymax	1984	2002	SW Asia – NE Asia / Fertiliser & chemicals	foundered			
HONGHAE SANYO	handysize	1976	2001	SW Asia – NE Asia / Minerals	missing/assumed lost	28		
HONGJIN	panamax	1968	1979	N America – NE Asia / Ballast	hull failure			storms/gales/heavy seas
HOPE STAR	capesize	1970	1985	Australia – Europe / Ferrous ores	hull failure		Broken keel	fine/calm seas
HURON	handysize	1972	1989	S Africa – NE Asia / Metals	hull failure	14	No 1 hold flooded	storms/gales/heavy seas
INNOVATOR	handysize	1973	1996	SW Asia – NE Asia	foundered			storms/gales/heavy seas
IOLCOS VICTORY	capesize	1980	1996	S America – NE Asia / Minerals	hull failure	5	Taking water in Holds 1 to 3	storms/gales/heavy seas

Table B.Ax.I (Continued). *Identified foundering/ disappearance accidents (total losses)*

IRON ANTONIS	capesize	1968	1994	S America – NE Asia / Ferrous ores	hull failure	24	Crack in her Sbd side	storms/gales/heavy seas
JAG SHANTI	handysize	1972	1994	S Asia – Europe / Metals	hull failure		Leak in the E/R pipeline	storms/gales/heavy seas
JIN YANG NO. 11	handysize	1958	1980	SW Asia – NE Asia / Metals	hull failure		Cracks in No 2 hold shell	
KAIRALI	handysize	1967	1979	S Asia – Europe / Ferrous ores	missing/assumed lost	51		storms/gales/heavy seas
KALLIOPI A.	Handysize	1969	1984	N America – NE Asia Agricultural & food	hull failure		No 2 hold flooded	
KAMARI	capesize	1973	1994	S America – NE Asia / Ferrous ores	hull failure		Flooding in her holds	storms/gales/heavy seas
KAMIKAWA MARU	capesize	1986	2001	S America – NE Asia / Ferrous ores	foundered	10	Cover broken & CH flooded	storms/gales/heavy seas
KARADENIZ S.	Capesize	1969	1992	S America – Europe / Ferrous ores	hull failure		Broken keel & shell	storms/gales/heavy seas
KARIN VATIS	handymax	1973	1985	S Asia – Europe / Metals	hull failure		E/R flooded	fine/calm seas
KASTOR TOO	handysize	1977	2000	SW Asia – NE Asia / Fertiliser & chemicals	foundered			
KEN LUNG	handysize	1949	1977	SW Asia – NE Asia / Metals	hull failure		Hull leakage	storms/gales/heavy seas
KRONOS	handysize	1973	1989	Europe – Europe / Metals	foundered	20		typhoon/hurricane
LEADER L.	Panamax	1977	2000	N America – Europe / Minerals	hull failure	18	Shell No4 hold cracked	storms/gales/heavy seas
LEROS STRENGTH	handysize	1977	1997	Europe – Europe / Fertiliser & chemicals	hull failure	20	Leakage of the bow plate	storms/gales/heavy seas
LESLIE	handysize	1965	1981	S Asia – Europe / Ferrous ores	missing/assumed lost	19		storms/gales/heavy seas
LUCHANA	handysize	1964	1986	Europe – Europe / Ferrous ores	hull failure	4	Broken keel	storms/gales/heavy seas
MADONA	handymax	1982	2000	SW Asia – NE Asia / Cement	hull failure		Taking water in cargo hold	
MANIL TRANSPORTER	capesize	1976	1991	Australia – Europe / Ferrous ores	hull failure		Crack in her port side	storms/gales/heavy seas
MARIA BACOLITSA	handysize	1962	1980	S America – Europe / Metals	foundered	30		storms/gales/heavy seas
MARIKA	capesize	1973	1994	N America – Europe / Ferrous ores	hull failure	36	Cracked hull	typhoon/hurricane
MARINA DI EQUA	handymax	1972	1981	N America – Europe / Metals	hull failure	30	Serious leakage in a hold	storms/gales/heavy seas
MARINE ELECTRIC	handymax	1944	1983	N America – S America / Coal	capsizing/listing	33		storms/gales/heavy seas
MEGA TAURUS	handymax	1980	1988	SW Asia – NE Asia / Ferrous ores	foundered	20		storms/gales/heavy seas
MELETE	panamax	1975	1991	Australia – Europe / Ferrous ores	hull failure	25	Crack in No1 hold	storms/gales/heavy seas
MELIKSAH	handysize	1977	1999	Europe – NE Asia / Fertiliser & chemicals	hull failure			fine/calm seas
MEMED ABASHIDZE	handymax	1978	1995	Europe – NE Asia / Fertiliser & chemicals	hull failure	3	Cracks in her No ¾/5 CH	storms/gales/heavy seas

Table B.Ax.I (Continued). *Identified foundering/ disappearance accidents (total losses)*

MEZADA	handymax	1960	1981	N America – Europe / Fertiliser & chem.	Hull failure	24		storms/gales/heavy seas
MINERAL DIAMOND	capesize	1982	1991	Australia – Europe / Ferrous ores	foundered	27		typhoon/hurricane
MITSOS	handysize	1960	1979	N America – Europe / Metals	hull failure		Severe leakage	storms/gales/heavy seas
MORNING PARK	handysize	1971	1986	SW Asia – NE Asia / Timber	foundered		Cargo shift	storms/gales/heavy seas
MOUNT HORIZON	handysize	1970	1980	N America – S America / Agricultural & f.	Foundered	22		storms/gales/heavy seas
MUNCHEN	capesize	1972	1978	N America – Europe / Ferrous ores	missing/assumed lost	28		storms/gales/heavy seas
MYRINA	handysize	1971	1979	N America – Europe / Metals	missing/assumed lost	21		storms/gales/heavy seas
NAGOS	capesize	1969	1993	SW Africa – Europe / Coal	hull failure	17	A hatch cover was ripped off	typhoon/hurricane
NORSE VARIANT	handysize	1965	1973	N America – Europe / Coal	hull failure	29	Crack in a cargo hold	storms/gales/heavy seas
ONOMICHI MARU	panamax	1965	1980	N America – NE Asia / Coal	hull failure		Huge cracks in her hull	storms/gales/heavy seas
ORIENT PIONEER	capesize	1971	1990	S America – NE Asia / Ferrous ores	hull failure		Damaged keel	storms/gales/heavy seas
ORIENT TREASURY	handymax	1966	1982	S Asia – Europe / Ferrous ores	missing/assumed lost	26		typhoon/hurricane
OSOOL	handysize	1974	1998	SW Asia – NE Asia / Metals	hull failure			storms/gales/heavy seas
PAB	handysize	1962	1985	S America – NE Asia / Metals	hull failure		Leakage	storms/gales/heavy seas
PACROVER	handysize	1945	1972	N America – NE Asia / Coal	foundered	30		storms/gales/heavy seas
PAN DYNASTY	handymax	1968	1989	N America – NE Asia / Fertiliser & chem.	Hull failure		Hull damage	storms/gales/heavy seas
PASITHEA	capesize	1971	1990	Australia – NE Asia / Ferrous ores	foundered	31		typhoon/hurricane
PEACE	panamax	1971	1999	S Africa – NE Asia / Metals	hull failure		Leak through a cracked hull	
PETCHOMPHOO	handysize	1969	1991	SW Asia – NE Asia / Metals	hull failure	24	Flooded FPT No 1 hatch	
PETINGO	capesize	1967	1990	S Africa – NE Asia / Ferrous ores	hull failure		Broken keel	storms/gales/heavy seas
POET	handysize	1944	1980	N America – Europe / Agricultural & food	missing/assumed lost	33		storms/gales/heavy seas
PORN UDOM	handysize	1969	1989	SW Asia – NE Asia / Agricultural & food	hull failure	26	A crack in her bow	typhoon/hurricane
PROMEX CITA	handysize	1975	1997	SW Asia – NE Asia / Minerals	hull failure			
PROTEKTOR	capesize	1967	1991	N America – Europe / Ferrous ores	hull failure	33	Water in Nos 2 & 4 hold	typhoon/hurricane
PROTOKLITOS 4	capesize	1974	1993	S America – NE Asia / Ferrous ores	hull failure		Damaged frames of No3 CH	storms/gales/heavy seas
QUEEN JANE	handysize	1968	1987	SW Asia – NE Asia / Fertiliser & chemicals	foundered	24		storms/gales/heavy seas

Table B.Ax.I (Continued). *Identified foundering/ disappearance accidents (total losses)*

RHODIAN SAILOR	handysize	1962	1982	SW Asia – NE Asia / Cement	hull failure	25		
RIO BRAVO	handysize	1960	1981	N America – SW Asia / Metals	hull failure		Hull fracture and took water.	
ROCKNES	handysize	2001	2004	Europe – Europe / Minerals	foundered	18		storms/gales/heavy seas
ROSE S.	Handysize	1967	1977	N America – NE Asia / Timber	hull failure	31	Water in a hold during swell	storms/gales/heavy seas
SALVIA	capesize	1970	1991	S America – NE Asia / Ferrous ores	hull failure		Crack in No1 port shell plate	
SAM KWANG	handysize	1970	1980	SW Asia – NE Asia / Metals	missing/assumed lost	25		
SANAGA	handysize	1979	1999	S Africa – NE Asia / Coal	hull failure			
SANDALION	handymax	1963	1980	N America – NE Asia / Coal	hull failure		Water in No 1 & 2 holds	storms/gales/heavy seas
SCAIENI	handysize	1980	1991	Europe – Europe / Fertiliser & chemicals	foundered	10		storms/gales/heavy seas
SEA PROSPECT	handysize	1996	1998	S Africa – NE Asia / Ferrous ores	capsizing/listing	10		
SEAFAITH	panamax	1973	1996	SW Asia – NE Asia / Ferrous ores	foundered	19		storms/gales/heavy seas
SEVASTI	handysize	1971	1989	S Africa – NE Asia / Timber	foundered		Cargo shift	storms/gales/heavy seas
SILIMNA	panamax	1978	1990	S Asia – Europe / Ferrous ores	hull failure		A crack in way of No 3 hold	storms/gales/heavy seas
SINAR ANDALAS	handysize	1998	2004	SW Asia – NE Asia / Cement	capsizing/listing	15		storms/gales/heavy seas
SINGA SEA	handysize	1976	1988	Australia – Europe / Minerals	hull failure	19	Broken keel	storms/gales/heavy seas
SKIPPER I	handysize	1973	1987	N America – Europe / Metals	hull failure		Flooded by No1 broken h.c.	storms/gales/heavy seas
SONATA	capesize	1969	1991	Europe – Europe / Ferrous ores	hull failure		Sprang a leak	storms/gales/heavy seas
STAR CARRIER	handymax	1967	1987	N America – NE Asia / Metals	hull failure		E/R flooding	storms/gales/heavy seas
STAR OF ALEXANDRIA	handymax	1966	1989	N America – Europe / Cement	capsizing/listing	2	A loud crack was heard	storms/gales/heavy seas
STARFISH	panamax	1970	1991	Australia – Europe / Ferrous ores	hull failure		A crack in No 4 hold	storms/gales/heavy seas
SUNSET	handysize	1970	1991	S Asia – Europe / Metals	hull failure			storms/gales/heavy seas
SYLVIA L. OSSA	handymax	1943	1976	N America – S America / Ferrous ores	missing/assumed lost	37		storms/gales/heavy seas
TANFORY	handysize	1962	1985	SW Asia – NE Asia / Minerals	hull failure		Flooding of No3 hold	
TAO YUAN HAI	capesize	1977	1990	S America – NE Asia / Ferrous ores	hull failure		A crack in her hull	storms/gales/heavy seas
TESTAROSSA	capesize	1970	1987	SW Africa – Europe / Ferrous ores	hull failure	30	Hull leakage	storms/gales/heavy seas
THEOMITOR	panamax	1967	1980	N America – Europe / Ferrous ores	hull failure		Cracked hull	storms/gales/heavy seas

Table B.Ax.I (Continued). *Identified foundering/ disappearance accidents (total losses)*

THOMAS K.	Handysize	1961	1984	N America – NE Asia / Metals	hull failure	8	Shell plate cracked	storms/gales/heavy seas
TINA	handysize	1974	1987	N America – SW Asia / Metals	hull failure		E/R & No5 hold flooded	
TITO CAMPANELLA	handysize	1962	1984	Europe – Europe / Metals	missing/assumed lost	24	Improper stowage of cargo	storms/gales/heavy seas
TOPKAPI S.	Capesize	1966	1987	S America – Europe / Ferrous ores	foundered	18		storms/gales/heavy seas
TRANS SAPPHIRE	handysize	1952	1978	SW Asia – NE Asia / Fertiliser & chemicals	hull failure		E/R flooding	typhoon/hurricane
TREASURE	capesize	1983	2000	S America – NE Asia / Ferrous ores	hull failure		No4 hatch covers were gone	storms/gales/heavy seas
VASSO	panamax	1967	1991	S Africa – NE Asia / Ferrous ores	hull failure		Cracked No1 shell plate	fine/calm seas
VITASEA	handysize	1958	1978	SW Africa – Europe / Ferrous ores	missing/assumed lost	27		storms/gales/heavy seas
VULCA	handymax	1968	1989	N America – NE Asia / Metals	hull failure		No1 & 2 holds flooded	storms/gales/heavy seas
WALTER LEONHARDT	handymax	1966	1990	N America – Europe / Fertiliser & chem.	Hull failure		No 2 hold flooding	storms/gales/heavy seas
WAN LI DA	handysize	1977	1996	SW Asia – NE Asia / Timber	hull failure		Leakage in No 1 hold	
WELL SPEEDER	handysize	1976	1999	SW Africa – Europe / Agricultural & food	hull failure		Holds Nos.1&2 flooded	storms/gales/heavy seas
WILL. SHAKESPEARE	handysize	1978	1996	S Asia – Europe / Metals	hull failure		No 4 hold flooded	storms/gales/heavy seas
WIN GRAND	handysize	1986	2004	SW Asia – NE Asia / Ferrous ores	hull failure			
WINNERS BEE	handysize	1969	1985	SW Asia – NE Asia / Ballast	foundered			
WOKAM	handysize	1952	1976	SW Asia – NE Asia / Cement	hull failure		Hull fracture & leakage	
XIN ZHU JIANG	handymax	1976	1999	Australia – NE Asia / Ferrous ores	hull failure	1	A cargo hold flooded	storms/gales/heavy seas
YTHAN	handymax	1984	2004	S America – Europe / Metals	foundered	6	Cargo hold explosion	fine/calm seas
ZEKI	handysize	1966	1976	N America – Europe / Minerals	hull failure		Springing a leak	storms/gales/heavy seas

This page is intentionally left blank

C Review of accident investigation reports

C.1. Preamble

Data concerning incident reports may be very important for the purpose of making more balanced, proactive and cost – effective legislation. A judgement on the value of data which can be collected (i.e. through the contacts of EMSA (n.d.) and MAIIF (n.d.) websites) should be carried out in order to identify uncertainties and limitations and to assess the degree of reliance that should be placed on the available data. Only reports within the public domain are mentioned whilst the reports and the data obtained from independent investigation units will be kept confidential.

C.2. Information Resources

Publicly available sources include literature from appropriate representative and legislative bodies and information obtained from the internet (Classification Societies, the Nautical Institute). By conducting a search of the World Wide Web, such official investigations of 13 bulk carrier foundering accidents and reports on casualty information have been identified. In particular, the governmental bodies include:

1) The Australian Transport Safety Bureau (7 reports)
   (ATSB, www.atsb.gov.au/marine/marine.aspx)
2) The United States Coastguard Office of Investigations and Analysis (2 reports)
   (USCG, www.uscg.mil/hq/g-m/moa/safea.htm)

3) The United States National Transportation Safety Board (2 reports, same as 2))
   (US NTSB, www.ntsb.gov/Surface/marine/marine.htm)
4) The Transportation Safety Board of Canada (1 report)
   (TSB, www.tsb.gc.ca/en/marine/index.asp)
5) The French Marine Accident Investigation Office (1 report)
   (BEAmer, www.beamer-france.org/english/)
6) The United Kingdom Department for Transport (1 report)
   (UK DFT, www.dft.gov.uk, www.mv-derbyshire.org.uk/)
7) The International Maritime Organization's Sub – Committee on Flag State Implementation (1 report)
   (IMO FSI, www.imo.org/Safety/mainframe.asp?topic_id=156)

Casualty information available from other bodies includes:

8) The Det Norske Veritas (DNV) Exchange on the Web
   (http://exchange.dnv.com/ExchangeMenu/TaskManager.ASP)
9) The Polish Register of Shipping (1 report, same as 7))
   (PRS, www.prs.gda.pl/dir53.html)
10) The International Marine Accident Reporting Scheme, run by the Nautical Institute
   (MARS, www.nautinst.org/MARS/index.htm)

A list of the available investigation reports is given in **Table C.I.**

C.3. Factual evidence

The investigated incidents were governed by uncertainties and assumptions in their findings, leading in some cases to proximate causes of the loss. It can be claimed that the most probable scenario of such a catastrophic event would be progressive flooding of one or more compartments due to structural failure. Possible causes of flooding might be assumed to be one or a combination of the following:

- Failure of hull girder (i.e. bottom failure – breaking in two)
- Failure of deck opening/closing appliances (i.e. hatch covers)
- Side shell failure

- Collapse of bulkhead
- Cargo shift/liquefaction

Although the majority of foundering/disappearance incidents is associated with any weaknesses affecting the vessel's structural integrity (hardware issue), contributing factors for their escalation can be related to software issues such as: human resources (management, responsibilities, working practices, manning, communication), organisational level (safety, technical, commercial, management) and environmental aspects (commercial, social, political, regulatory, weather, cargoes and cargo handling). It should be noted that all the previous mentioned influencing factors are interfered between them through commercial considerations and a better understanding of these issues is derived inertly by reviewing previous safety inquiries.

It is generally accepted that the dry bulk shipping industry is fiercely competitive and it has to be, because there is vast over – capacity. Furthermore, low or negative profit margins and a strong temptation to cut corners are produced by market shortfalls creating a pressure on owners and operators to maximise efficiency and reduce overhead outgoings. To this end, safe BC operational practices can be squeezed by commercial pressures and it is likely that the vessel's management will be concentrated on immediate and short – term financial gain. In some cases, the solution of the arisen problems will be focused on cost, rather than quality and safety and as a result, any business available will be sought to keep the vessel trading, for example a move to sell on some of the tonnage or to cut back on maintenance may be considered appropriate. Conversely, however, when markets subsequently rise, the irresponsible owners are too concerned about keeping their vessels trading, rather than undertaking any backlog of repairs. Through this, the particular owners are not interested in operating ships, but are interested in the financial return of investment in ship tonnage, so that the safety of operational practice is left to the management company. In this respect, the occurred cycle in ship management is described by the manager's behaviour to impress the owner with how well the job can be done, so, either the manager will pull out if there is not enough funding from the owner or cost cutting will take place as becomes aware to the manager that the owner may find an alternative manager to do the job more economically. Fortunately, as it is acknowledged, there are far too few shipowners of this type. (BOMEL Limited 2002, Van Roon 2001, Seignette 2002, OECD 2001, Donaldson of Lymington 1994, HORSCTCI 1998)

Such kind of pressures which are keenly felt in the BC industry, are considered to impede routine violations contrasting the safe common practice. In order to maximise speed and boost profitability the vessel is operated within minimal profit margins. This was considered a key issue in the losses of Edmund Fitzgerald and Marine Electric (USCG 1977, NTSB 1978, USCG 1984, NTSB 1984), as the poorly managed and horribly maintained vessels' structures in combination with the effects of heavy boarding seas contributed significantly to the casualties. It is the responsibility of the master to ensure that the vessel is safely operated. However, due to lack of seagoing employment and the desirable nature of the coastwise voyages being made by the vessels, the crew were content to sail them without further complaints. In the report of M/V Flare sinking (TSB 2000), it was concluded that the ballasting arrangements were in contravention to the vessel's loading manual. The combination of the vessel's shallow forward draught (due to ballasting) and the rough seas pounding and slamming the vessel, in conjunction with the BC's already stressed and purely maintained structure, resulted into her break – up. Details of the deep ballast loading condition were included in the loading manual and if adopted they would have markedly reduced the vessel's vulnerability to pounding and slamming during the winter – North Atlantic crossing. This is tempered by the knowledge that deeper ballasting arrangements impede a vessel's speed considerably and are regularly flouted in order to achieve improved voyage cycle times and remain competitive (BOMEL Limited 2002).

Having in mind that a ship has a job to do, namely to get to destination, though this cannot be allowed to compromise safety, it is not reasonable to expect to avoid all bad weather. The weather conditions that may be anticipated for any given voyage are relevant to the planning and actions of any master. On board, decisions are taken by the master and by senior officers, based on reasoned professional judgement, experience and training. However, the rapidly increasing quality and availability of radio communications has meant that masters are more and more likely to contact shore – based managers before reaching decisions. Increasingly, the master is seen as one of a chain of managers in an organisation, yet a master's responsibility for the vessel's safety and of those on board has not in any way been reduced by the greater ease of communication. This involvement of on – shore management in the day – to – day running of a ship has resulted in an erosion of the traditional view of the master as sole commander. This is particularly dangerous in a crisis, where valuable time may be wasted while a master seeks authority for a necessary action. Masters should not have their freedom constrained by an owner insisting that a particular route or speed should be maintained despite bad weather (Donaldson of Lymington 1994).

In the case of M/V Derbyshire (DFT 2005), the master had to make decisions under uncertainty such as the inherent uncertainties of the behaviour of tropical storms, the conflicts between the track forecast for the typhoon and the track it actually followed and the conflicts between the forecasts of Japan Radio and Guam. Since the charter party arrangements are not known, it is far too difficult to identify if the information/advice provided by the weather routeing agency had to be followed strictly. The master was unfortunate enough to have chosen a course of action which resulted in the vessel being caught in the worst sector of the typhoon – with the benefit of hindsight; it can be observed that had the master acted differently it is likely that the vessel would have avoided the severe weather. From the submitted evidence (Donaldson of Lymington 1995), is not stated how often the weather forecasts were taken and it is believed that the captain was a good master and regarding the context of what he knew that time, the action he took was justifiable and prudent.

In the report of M/V Singa Sea sinking (ATSB 1988), assuming that the earlier forecasts had been received, which showed the worsening weather conditions, it would appear that the master elected to put the sea on the vessel's starboard quarter rather than alter course. Although the decided course was not in accordance with either the British Admiralty's "Ocean Passages of the World" or the United States equivalent, a number of ships were known to have followed the same course. Given the heavy weather experienced, it was questionable whether the chosen speed reduction was sufficient to reduce the effects of slamming and pounding to a significant degree. A noteworthy comment is that during the holds' inspection, a concern was expressed by the assistant harbour master about a heavy buckle on the aft bulkhead of No 1 Hold, which he thought could have been caused by the vessel working very heavily in a seaway. Unfortunately, with the presumed death of the master it was not possible to comment fully on the conduct of the vessel between sailing and the loss of the vessel.

Safe operations can be influenced by the appropriate information which is communicated and provided to the intended recipients (owner – operator – ship – terminal interface). It was acknowledged (BOMEL Limited 2002, Van Roon 2001, Seignette 2002, HORSCTCI 1992) that bulk loading terminals adhere to the loading plans submitted by the vessel. It was stated that terminals may alter loading plans to better accommodate their own operational requirements or some problem with the vessel. An issue with loading rates is the number of passes[25] made during loading operations. The number of passes to be employed in the loading process is outlined in the loading plan. It is accepted that the responsibility for the safe loading of a ship rests with the master and is up to the master to determine that the stresses placed upon the hull during loading operations are acceptable and do not overstress the ship. The possibility of overstressing the ship and overloading the individual holds is minimised by a large number of passes, but then the required time for loading is increased. It was also suggested that masters are under considerable pressure from owners to perform and that if they do not, they can be replaced.

Safety can be also compromised by the manner in which the cargo for the vessel is fixed by the bulk carrier operating company, for instance by a charter – party that does not take full account of the suitability and compatibility of both ship and cargo. However, little consideration is given to the circumstances that occur at terminals, particularly when cargo owner, charterer and terminal are represented by the same company. This can be a potential cause for concern and hazardous practices can be introduced. It was agreed that charterers are limited by port constraints, if a cargo has to be delivered to a certain port, the vessel must cope with the conditions at that port and by time requirements, if some of the vessel's holds are not ready for loading, the loading sequence will be changed in order to take advantage of the empty quay. This could result in dangerous occurrences, for example if a apsize vessel attempted to load at a completely inappropriate terminal, the result could be an unevenly loaded cargo. If this vessel then sailed, it would be less stable and it would increase the likelihood of incidents.

The previous mentioned matters were identified from the reviewed reports (ATSB 1991b, 1992a, 1992b, 1993, 1990, 1991a) where in the first four the weather conditions were considered to have contributed to the losses. In the cases of "Mineral Diamond" (ATSB 1991b) and "Starfish" (ATSB 1991a) the chosen pour quantities could be appropriate for larger vessels while in the last incident the loading sequence was amended.

---

[25] Pour or pass means the quantity of cargo poured through one hatch opening as one step in the loading plan, i.e. from the time the spout is positioned over a hatch opening until it is moved to another hatch opening (IMO 1998).

In order to assist loading, the submitted sequence by the "Daeyang Honey" (ATSB 1993) and "Alexandre – P" (ATSB 1990) was also changed where in the last one due to the cargo peaking in some holds, the hatches could not be closed contrasting the requirements of BC Code (IMO 2005a) for the trimming[26] procedures. Although agreement to the loading plan should be indicated by the master and terminal representative in compliance with SOLAS Ch. VI Reg. 7 (IMO 2004a) and the BLU Code (IMO 1998), from received evidence (MARS 1994, MARS 1997, MARS 1999) plans were not always followed and speed of loading was the only priority. It is interesting to note that the last incident was reported in 1999 and in spite of amendments to SOLAS Ch. VI; it is difficult to determine if these regulations are complied by all loading terminals around the world. In order to control that, an attempt has been done by the recent adoption of the BLU Manual for terminal representatives (IMO 2005b). It should be mentioned that very often the vessel's staff and particularly the master are put under tremendous pressure to ignore these regulations and surrender to the demands of the loading terminal and the shipper (i.e. blacklisted vessel).

In the cases of "Manila Transporter" (ATSB 1992a) and "Melete" (ATSB 1992b) operators, charterers and cargo owners requested all hold loading but the master proposed alternate loading for raising the centre of gravity so that the accelerations and resulting stresses involved in the vessel's movement in a seaway are reduced and also making the vessel's response more comfortable for the crew. It was stated (owners) that the purpose of the requested all hold loading was to expedite discharge and not for safety considerations. A noteworthy comment about the "Manila Transporter" incident was the received message from the owners regarding the losses of "Mineral Diamond" (alternate loading) and "Alexandre – P" which would appear to have created some doubt in the master's mind with regard to the suitability of the original all hold loading plan and resulted in him changing to alternate loading. It was not known whether this matter was discussed further between the master and the owner either by telephone or telex. Also, the master's decision was endorsed by the operators who stated that from a safety point of view all hold loading was better and an urgent message was sent by them requesting from the master to load all holds. There was a series of delays with important facsimile messages related to the recommended distribution of the cargo, but no attempts appeared to have been made to

---

[26] Trimming (loading cargo) is the partial or total levelling of the cargo within the holds, by means offloading spouts or chutes, portable machinery, equipment or manual labour (IMO 1998, 2005a).

pass the message by telephone through the terminal operators and by the time the message was delivered on board it was too late to change the plan. Unfortunately, due to assumptions and uncertainties it was not possible to determine whether the proposed all hold would have prevented the losses.

The safe operation of a vessel is determined by the company's safety culture[27], where safety issues are given high priority in the office as well as in the ship consensus with sensitive management and routeing. Standards for the safe management of shipping are set out in the IMO's ISM Code (IMO 2002a) where the roles, responsibilities and accountability and comprehensiveness of procedures (emergency preparedness, pollution prevention, maintenance) are defined for each element of the SMS. Although safety management is now compulsory under ISM and a document of compliance is required, many companies meet the imposed standard by buying a ready SMS off the self. In doing this, the company's procedures are certified that comply the Code's requirements and the law is not broken. However, in this case, the SMS would not be specific and its worth would be reduced, there would not be ownership of the system, resulting to an access to charterers and trade routes (BOMEL Limited 2002, OECD 2001, OECD 1996). In BOMEL Limited (2002) was concluded that the actual worth of safety management – especially compliance with procedures – was not widely understood in the industry. The survival attitude of irresponsible owners characterised by cost saving initiatives with the risk of violating international rules and standards is governed by transferring their vessels from one classification society to another for avoiding essential maintenance (HORSCTCI 1995a). In this sense, a class surveyor would be unlikely to stop a vessel on an ISM

---

[27] Safety culture is generally referred to as ***"the way we do things around here"*** and can be viewed as the over – arching policies and goals set by an organization relating to the overall safety of their facility or environment. This goal – setting concept is revealed in an organization's general patterns of attitudes and actions (socio – anthropological) and defined as the values and beliefs that its members come to share through symbolic means such as myths, rituals, stories, legends (organizational psychology). A strong safety culture is characterized by several traits:

- A definite ***commitment*** to the improvement of safety behaviours and attitudes at all organizational levels;
- An organizational structure and atmosphere that promotes open and clear ***communication*** in which people feel free from intimidation or retribution in raising issues;
- A propensity for ***resilience*** and ***flexibility*** to adapt effectively and safely to new situations;
- A prevailing attitude of constant ***vigilance*** for preparedness and prevention of accidents.

In this sense, safety awareness is strived to be made a priority for all stakeholders and a foundation will be created upon which good safety culture can grow (Olive et al. 2006, Cooper 2000, Wiegmann et al. 2002).

In conjunction with the above, the key elements for achieving a proactive maritime safety culture are: stakeholder participation, commitment and visibility, productivity/safety relationship, trust, shared perceptions, communication, organizational learning, safety resources, industrial relations and job satisfaction, training (UK 2003).

infringement, as there should be concern over the vessel changing class society (BOMEL Limited 2002).

In the sinking of M/V Leader L (IMO 2004b, PRS 2000) was concluded that the vessel was poorly managed and the survey carried out by the classification society was insufficient. Poor management was also stated in the report of the loss of M/V Adamandas (BEAmer 2004), where the dry – docking was postponed for six months, most probably so that annual and intermediate surveys would be due on the same month. Insufficient water tightness of the weather deck led to the ingress of seawater into Hold No 2 and the loss of the inert condition of the hold resulted to rapidly increased heat release. It is interesting to note that during the last PSC Inspection deficiencies were observed concerning safety issues and ISM. Regarding compliance with procedures, in DNV (1997) was mentioned that prior to taking corrosive cargoes, in order to avoid serious corrosion, the coating in cargo holds should be dealt with as necessary, the cargo should be kept as dry as possible during loading and transit, the hatches should be confirmed weather tight and holds adequately ventilated and the cleaning after discharging should be carried out properly.

C.4. Integration

The addressed and identified possible causal factors that can influence the operational integrity of a BC will be used as an input for the construction of a quantitative risk model (Chapter 7).

TABLE C.I. *List of the available individual accident investigation reports*

Name	Age	Date	Size	Cargo	Route	Source	Remarks				
Edmund Fitzgerald	17	November 1975	Handysize	Ferrous ores	N America – S America	USCG, NTSB	1	2	3		5
Derbyshire	4	September 1980	Capesize	Ferrous ores	N America – NE Asia	UK DFT		2			5
Alexandre – P	23	March 1990	Capesize	Ferrous ores	Australia – Europe	ATSB	1			4	5
Starfish	21	March 1991	Panamax	Ferrous ores	Australia – Europe	ATSB	1				5
Mineral Diamond	9	April 1991	Capesize	Ferrous ores	Australia – Europe	ATSB		2		4	
Manila Transporter	15	July 1991	Capesize	Ferrous ores	Australia – Europe	ATSB		2		4	5
Melete	16	August 1991	Panamax	Ferrous ores	Australia – Europe	ATSB		2		4	5
Daeyang Honey	22	October 1992	Capesize	Ferrous ores	Australia – NE Asia	ATSB	1	2		4	
Adamandas (+)	17	September 2003	Handysize	Metals	N America – SW Asia	BEAmer	1				5
Marine Electric	31	February 1983	Handysize	Coal	N America – S America	USCG, NTSB	1	2	3		5
Singa Sea	12	July 1988	Handysize	Minerals	Australia – Europe	ATSB	1	2			5
Leader L	23	March 2000	Panamax	Minerals	N America – Europe	IMO FSI, PRS	1				5
Flare	26	January 1998	Handysize	Ballast	N America – Europe	TSB	1	2	3		5

Remarks

1.	Poor management
2.	Weather conditions
3.	Reduced turn around times
4.	Terminal operational requirements
5.	The pressure from owners and operators
(+)	Although the vessel was scuttled by the French Navy, it was the only available report regarding an incident from the metal family. Also, the risk of the vessel's hull structure weakening was high due to the thermal stresses caused by the hot spots at the bottom of the hold resulting from the heat given off by the reaction.

D The bulk carrier actual operating profile

D.1. General

The demand for raw materials continues to sustain a major sector of the shipping industry and BCs are often described as the "workhorses" of the world merchant fleet. There are more than 7,000 of them operating in the world today forming about 30% of the world fleet in tonnage terms (Equasis 2008). Yet, for all their importance to modern life, BCs are among the most anonymous of ships, since they usually operate between terminals situated well away from cities and traditional port areas and are rarely noticed by the general public (Intercargo 2006b). Dry bulk shipping refers to the movement of significant commodities carried in bulk; the so – called major bulks – iron ore, coal, grain, bauxite/alumina and phosphate rock – together with other raw materials and semi – manufactures referred to the minor bulk trades: steel products (coils, plates and rods), forest products, sugar, cement, minerals, non – ferrous metal ores, fertilizers and various industrial materials such as scrap, pig iron (Intercargo n.d., Stopford 1997).

D.2. Database development

Having in mind that the BCs are grouped into four sizes (handysize, handymax, panamax, capesize) and the shipped cargoes' variability, the determination of the time being transported as an annual percentage might be difficult to be obtained, although their market share is more or less known (Clarksons 2004b). In fact, this dead-end may be solved by requesting data from shipping companies and in this sense; voyage reports can be very useful. A questionnaire was constructed, but due to its complexity and the very few responses received, a simplified version was developed which increased the possibilities of getting the requested information (**Figures D.1.a** and **b**).

Data regarding voyage reports was requested from almost 100 shipping companies worldwide[28] but only 15 responded whilst few replied that the information could not be provided either due to commercial confidentiality or a lot of work was required and there was lack of personnel, or surprisingly, voyage reports didn't exist. Despite the difficulties, a total number of 1,862 voyages from 185 vessels were gathered (**Table D.I**). Although it can be claimed that the sample reflects only 3% from the world fleet, this would be unreasonable, since ***a good geographic spread from around the world*** is represented. In fact, the quantitative assessment of the vessel's operating profile in terms of annual percentage of transported cargoes and trade routes as a function of vessel's size and age can be performed (**Figures D.2.a**, **b**, **c** and **d**), whilst any missing data is assumed to follow the previous category (panamax and capsize 25+).

TABLE D.I. *Total number of vessels and voyages in the database*

SIZE	Age category (years)						TOTAL
	0 – 4	5 – 9	10 – 14	15 – 19	20 – 24	25+	
Handysize							
Vessels	25	23	16	10	9	6	**89**
Voyages	287	276	152	112	93	75	**995**
Handymax							
Vessels	19	7	6	1	9	1	**43**
Voyages	174	69	56	8	89	7	**403**
Panamax							
Vessels	18	6	3	1	8	-	**36**
Voyages	160	52	21	16	62	-	**311**
Capesize							
Vessels	7	3	1	1	5	-	**17**
Voyages	75	26	8	7	37	-	**153**
TOTAL							
Vessels	**69**	**39**	**26**	**13**	**31**	**7**	**185**
Voyages	**696**	**423**	**237**	**143**	**281**	**82**	**1,862**

---

[28] Belgium, Canada, Cyprus, China, Denmark, Finland, France, Germany, Greece, Hong Kong, Italy, Japan, Norway, Singapore, S Korea, UK, USA, Switzerland.

Dry Bulk Cargo Vessel's operating profile

Please photocopy and complete the questionnaire and tick relevant boxes for <u>each vessel</u> in your fleet.

1. Vessel's name (optional) ____________________

2. Vessel's type

☐ Bulk Carrier
☐ Coal Carrier
☐ Ore Carrier
☐ Cement Carrier
☐ Other, please specify, i.e. Caustic Soda / Bulk Carrier

☐ Self/Belt Unloader
☐ Open Hatch Carrier
☐ Semi Open Hatch Carrier
☐ Log/Lumber Carrier

☐ Woodchip Carrier
☐ Ore/Bulk/Oil
☐ Container/Bulker
☐ Laker

____

3. DWT (t) / GRT (t) / No of Holds ____________________

4. Length (OA) (m) Length (BP) (m) Breadth (m) Depth (m) Draught (Scantling) (m)

________ ________ ________ ________ ________

5. Year built / Shipyard ____________________

6. Class Notation, please specify:

____

____

____

____

7. Please photocopy and complete the next page and tick relevant boxes for <u>the vessel's voyages</u> during the <u>last year</u>.

i.e. Voyage No 23: Unloaded passage from port A / Country to port B /Country

Loaded passage from port B / Country to port C / Country

7a. Voyage No ______

7b. ***<u>Unloaded passage</u>***

- Departure Port / Country ____________________
- Destination Port / Country ____________________
- Days at sea (including anchorages, if any): ________
- Please specify if the vessel encountered adverse weather conditions, region and season month

____

____

7c. ***<u>Loaded passage</u>***

- Departure Port(s) / Country(ies)

____

____

- Destination Port(s) / Country(ies)

____

____

- Loading Condition during passage

☐ Homogenous
☐ Alternate. Holds No: ____________
☐ Block. Holds No: ____________
☐ Slack. Holds No: ____________

- Transported Cargo(es)

____

____

- Duration of passage Days at sea (including anchorages, if any): ________ Days in ports: ______
- Please specify if the vessel encountered adverse weather conditions, region and season month

____

____

Figure D.1.a. *Detailed version of the questionnaire sent to shipping companies*

Bulk Carrier movements during the last year

(All voyages for 2005, for each operated vessel)

Note: This table is for illustration only

Vessel's DWT (MT) ______________ **Year built** ______________

Voyage No	Port	Date (Arrival)	Time[*]	Date (Departure)	Time[*]	Activity (loading, unloading)	Cargo	Loading Condition during passage[*]
X,	Port A	24.12.04	17.35			Loading	Coal	
				03.01.05	09.20	Loading	Coal	Hom.
	Port B	18.01.05	12.40			Unloading	Coal	
				20.01.05	13.50	Unloading	Coal	
—	—	—	—	—	—	—	—	—
N	Port Q	27.12.05	01.40			Unloading	Grain	
				09.01.06	18.30	Unloading	Grain	

---

[*] If available

[*] If available (homogeneous, alternate or block)

Figure D.1.b. *Simplified version of the questionnaire sent to shipping companies*

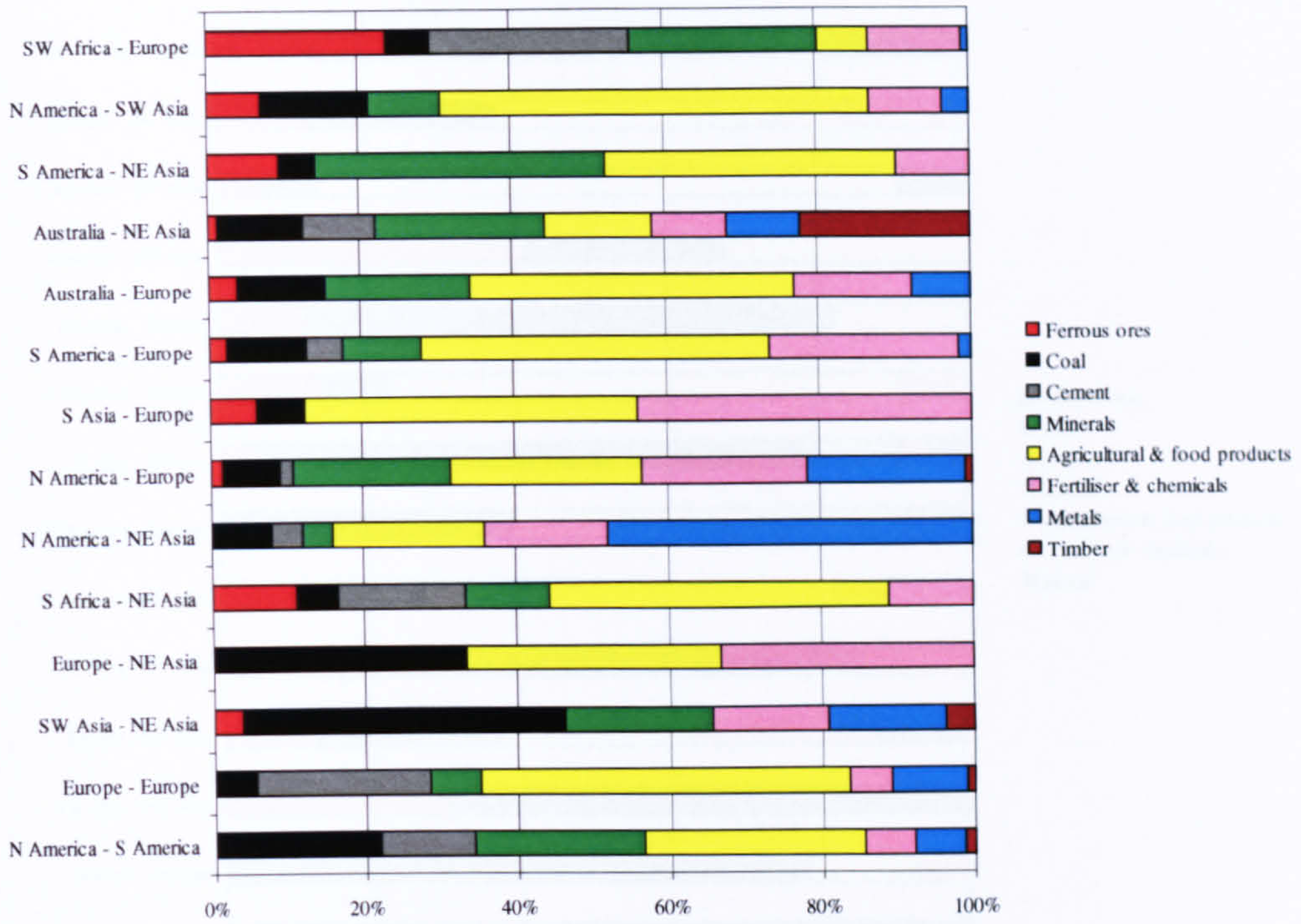


Figure D.2.a. *Annual percentage of trade routes and transported cargoes (Handysize vessels)*

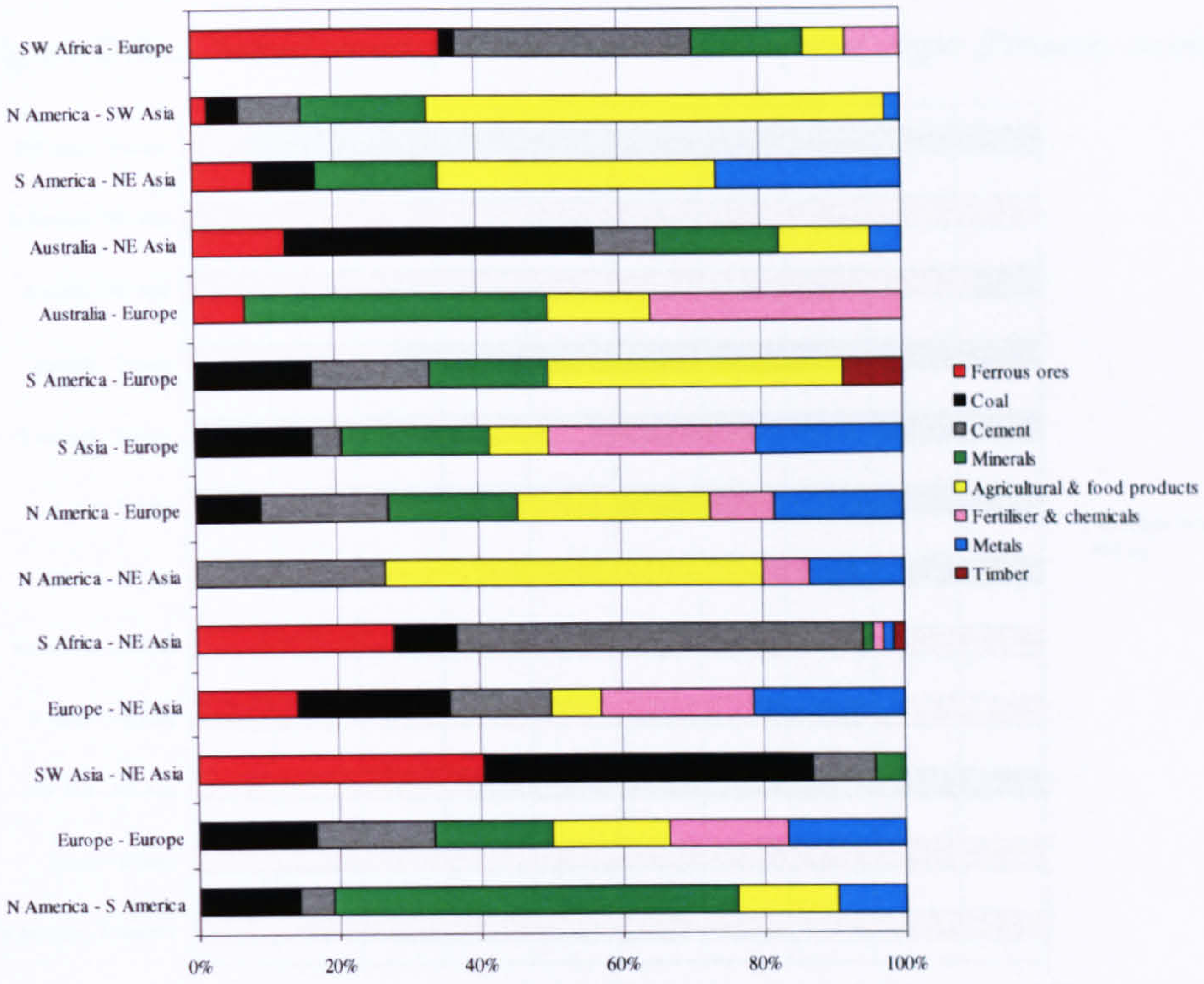


Figure D.2.b. *Annual percentage of trade routes and transported cargoes (Handymax vessels)*

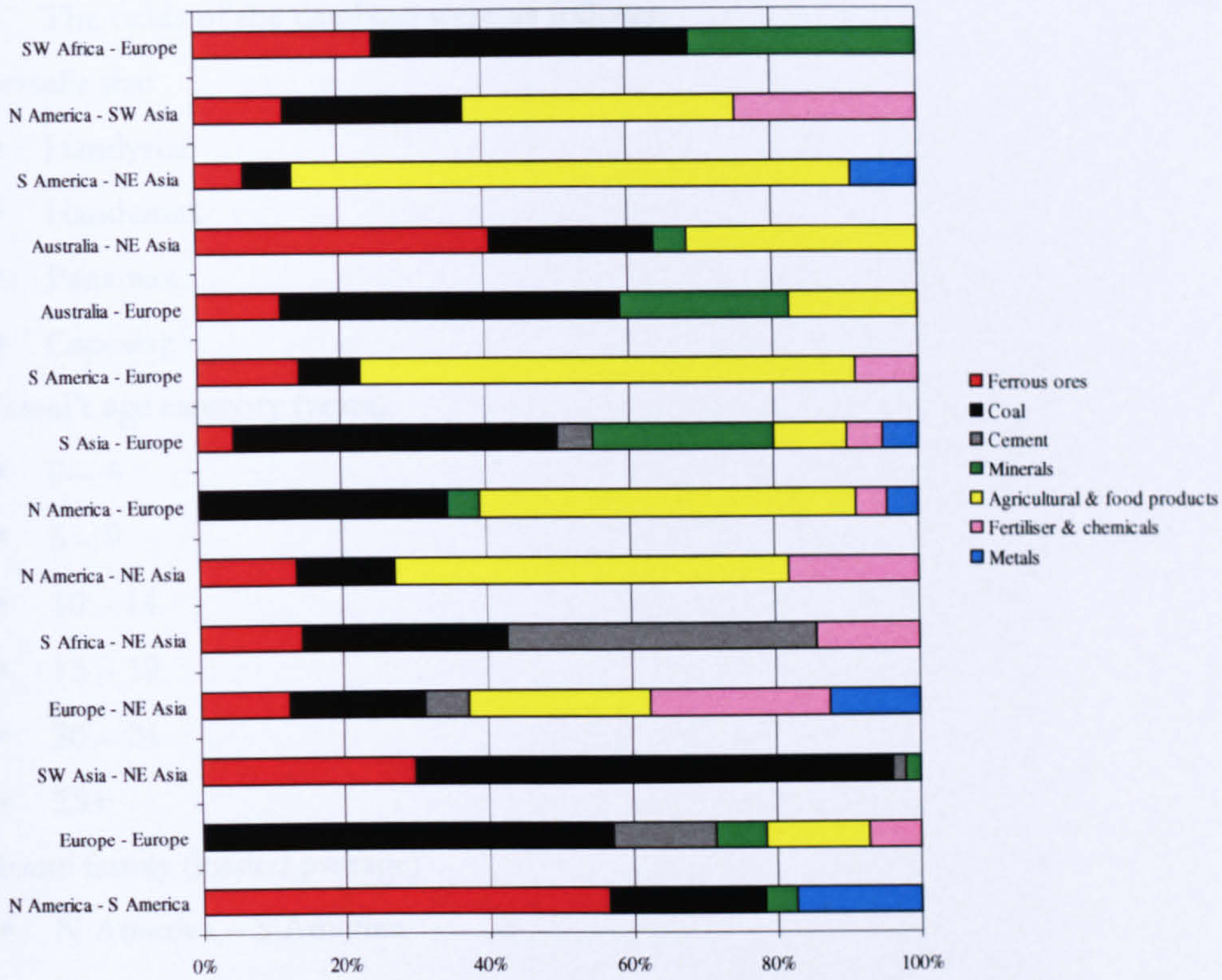


Figure D.2.c. *Annual percentage of trade routes and transported cargoes (Panamax vessels)*

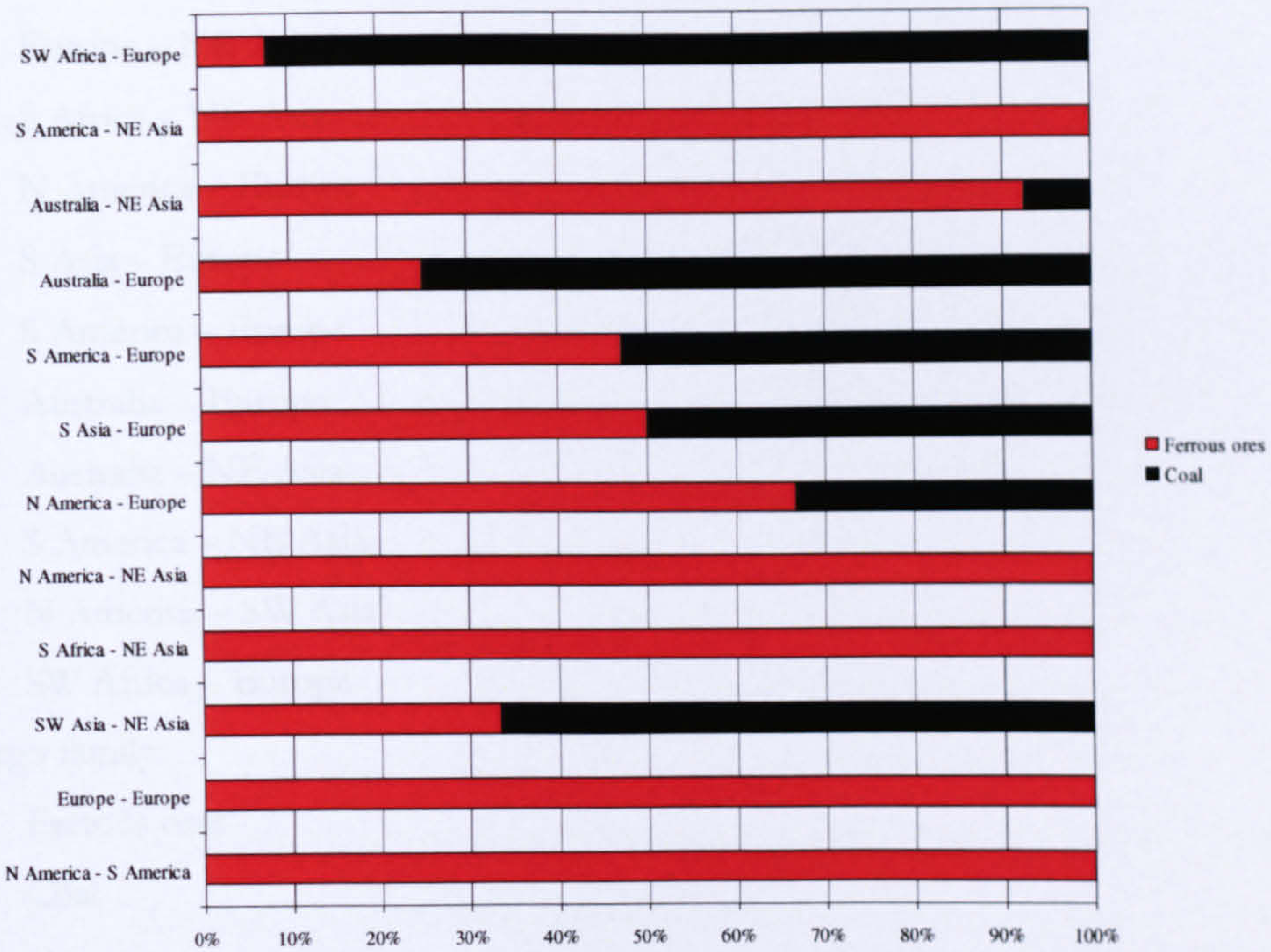


Figure D.2.d. *Annual percentage of trade routes and transported cargoes (Capesize vessels)*

The fields of the database were as follows:

1. Vessel's size
   - Handysize
   - Handymax
   - Panamax
   - Capesize
2. Vessel's age category (years)
   - 0 – 4
   - 5 – 9
   - 10 – 14
   - 15 – 19
   - 20 – 24
   - 25+
3. Route family (loaded passage)
   - N America – S America
   - Europe – Europe
   - SW Asia – NE Asia
   - Europe – NE Asia
   - S Africa – NE Asia
   - N America – Europe
   - S Asia – Europe
   - S America – Europe
   - Australia - Europe
   - Australia – NE Asia
   - S America – NE Asia
   - N America – SW Asia
   - SW Africa – Europe
4. Cargo family
   - Ferrous ores
   - Coal
   - Cement
   - Minerals

- Agricultural & food products
- Fertilizer & chemicals
- Metals
- Timber

5. Loading condition
    - Homogeneous
    - Alternate
6. Cargo characteristics (IMO 2005a, Rankin 2002)
    - Keep dry
    - Keep away from heat
    - Line container or adjacent deck
    - Possible taint problem
    - Possible fire risk
    - Possible corrosive
    - May sift or give off dust
    - May give off moisture
    - May be dangerous goods
    - May require ventilating
7. Cargo density[29] (kg/m^3) (IMO 2005a, Rankin 2002, Packard 1985)
    - Low (<1,250)
    - Medium (1,250 ~ 1,780)
    - High (>1,780)
8. Days at sea (loaded passage)
9. Days in ports (loaded passage)

D.3. Outcome

The captured knowledge was used as an input for filling the BN's Probability Tables (Conditional or Unconditional) (**Appendix E**).

---

[29] Referring to SOLAS Ch. XII Reg. 10 (IMO 2004a).

D.4. Disclaimer

Although the target was set to collect voyage information from more than 600 vessels, unfortunately this goal was not fulfilled. It needs to be stressed that the lack of information and knowledge is driven by the fact of how much resources are or might be available to the analyst to obtain it. In this sense, data is transformed into knowledge by the usage of probabilities whilst for any unknowns the estimation is based on subjective interpretations of probability (i.e. loading conditions).

This page is intentionally left blank

E BN modelling: Node description

E.1. Introduction

A BN can be presented visually as a set of nodes connected by directed links where the nodes represent the distribution of possible states of the variable and the links represent the causal relationships. The links from the causal nodes (called parent nodes) to the influenced nodes (called child nodes) are given as conditional probabilities of the states of the influenced nodes, given the states of the causal nodes (Jensen 1996, Pearl 1988). Each BN can be used as an instance ("object") for constructing a larger one. Moreover, through the object – oriented paradigm (OOBN), a modular structure is provided which allows greater flexibility and robustness since each sub – network can be viewed and edited separately even if it is different (hidden) piece of the same network (Koller and Pfeffer 1997, Merten 2004). In the following section, the nodes of each object are briefly described.

E.2. Cargo_ratio OOBN

This instance node consists of the following nodes:

E.2.1. Cargo changes

States: a) once
b) twice

c) more than three

The cargo changes are assumed to follow the Poisson process meaning that there is a random occurrence of states during an extended window of observation as a function of time which in this case is one (1) year. The reader should be referred to Evans et al. (2000), Bury (1999) and Beichelt and Fatti (2002) for an in depth analysis while in **Appendix G** a brief description and sample output of the developed program for calculating the Poisson parameter is enclosed by using the data of **Appendix D**.

E.2.2. Cargo density

States: a) low
b) medium
c) high

The probabilities are based on those calculated from the data of **Appendix D**.

E.2.3. Abrasive/corrosive cargoes

States: a) yes
b) no

The probabilities are based on those calculated from the data of **Appendix D**.

E.2.4. Cargo ratio

States: a) Ferrous ores
b) Coal
c) Cement
d) Minerals
e) Agricultural & food products
f) Fertiliser & chemicals
g) Metals

h) Timber

i) Ballast

The CPT is completed by data from **Appendix D** and its distribution is given by the formula:

$(Cargo\ Ratio)_i = \alpha \cdot \dfrac{time\ with\ (cargo\ family)_i}{age\ of\ vessel}$, described at Gardiner and Melchers (2003) and α is a coefficient added for normalization. It is assumed to follow the Poisson distribution.

E.2.5. X previous

These nodes are added just as a modelling technique for constructing the time slices and follow the uniform distribution.

E.3. Route_ratio OOBN

This instance node consists of the following nodes:

E.3.1. Cargo types

States: a) Ferrous ores
b) Coal
c) Cement
d) Minerals
e) Agricultural & food products
f) Fertiliser & chemicals
g) Metals
h) Timber
i) Ballast

The cargo types are assumed to follow the Poisson process meaning that there is a random occurrence of states during an extended window of observation as a function of time which in this case is one (1) year. In **Appendix G** a brief description and sample output of the developed program for calculating the Poisson parameter is enclosed by using the data of **Appendix D**.

E.3.2. Loading conditions

States: a) homogenous
b) alternate

The probabilities are based on those calculated from the data of **Appendix D**.

E.3.3. Route ratio

States: a) N America – S America
b) Europe – Europe
c) SW Asia – NE Asia
d) Europe – NE Asia
e) S Africa – NE Asia
f) N America – NE Asia
g) N America – Europe
h) S Asia – Europe
i) S America – Europe
j) Australia – Europe
k) Australia – NE Asia
l) S America – NE Asia
m) N America – SW Asia
n) SW Africa – Europe

The CPT is completed by data from **Appendix D** and its distribution is given by the formula:

$(\boldsymbol{Route\ Ratio})_i = \boldsymbol{\alpha} \cdot \dfrac{\boldsymbol{time\ in\ (route\ family)_i}}{\boldsymbol{age\ of\ vessel}}$, described at Gardiner and Melchers (2003) and α is a coefficient added for normalization. It is assumed to follow the Poisson distribution.

E.3.4. X previous

These nodes are added just as a modelling technique for constructing the time slices and follow the uniform distribution.

E.4. Likelihood_Index_N OOBN

This instance node consists of the following nodes (where N denotes the time slice i.e. [0 – 4], [5 – 9], [10 – 14], [15 – 19], [20 – 24], [25+]):

E.4.1. Route_Ratio_N

It is the instance node described previously.

E.4.2. Cargo_Ratio_N

It is the instance node described previously.

E.4.3. Weather_Modelling

States: a) Beaufort 1 – 3
b) Beaufort 4
c) Beaufort 5

d) Beaufort 6
e) Beaufort 7
f) Beaufort 8
g) Beaufort 9
h) Beaufort 10
i) Beaufort 11
j) Beaufort 12

The probability table is filled by transforming the significant wave height measurements (annual – all directions) (Hogben et al. 1986) into the Beaufort scale of wind (UKHO 2004) through the Rayleigh distribution (Rawson and Tupper 2001).

E.4.4. Weather_Conditions

States: a) fine/calm seas
b) storms/gales/heavy seas
c) typhoon/hurricane
d) unknown

This table is completed by the data from the **Appendix B** and represents the weather at the time of the accident.

E.4.5. Likelihood_Index

States: a) N/A
b) extremely remote
c) very remote
d) remote
e) seldom
f) reasonable probable
g) probable
h) frequent

The CPTs are filled in from **Appendix B**.

E.5. Consequence_Index OOBN

The basis for constructing this instance node is provided through the information found at Japan (2002c) and consists of the following nodes:

E.5.1. Consequence index

States: a) minor
b) significant
c) severe
d) catastrophic

The CPTs are filled in from **Appendix B**.

E.5.2. Structural failure

States: a) yes
b) no

The CPTs are filled in from **Appendix B**.

E.5.3. Multiple hold flooding

States: a) No1 No2 hold
b) No1 & other hold/compartment
c) Other hold/compartment
d) Unknown

The CPTs are filled in from **Appendix B**.

E.5.4. Suspected cause (multiple)

States: a) bulkhead failure
b) opening device failure
c) side shell failure
d) unknown

The CPTs are filled in from **Appendix B**.

E.5.5. Single hold flooding

States: a) No1 hold
b) other hold/compartment
c) unknown

The CPTs are filled in from **Appendix B**.

E.5.6. Suspected cause (single)

States: a) bulkhead failure
b) opening device failure
c) side shell failure
d) unknown

The CPTs are filled in from **Apendix B**.

E.5.7. Fatalities

States: a) yes
b) no

The CPTs are filled in from **Appendix B**.

E.5.8. Shortage of strength

States: a) yes

b) no

The CPTs are filled in from **Appendix B**.

E.5.9. Excessive load

States: a) yes

b) no

The influence of weather is represented and the CPTs are filled in from **Appendix B**.

E.5.10. Other factor (cracks, dents)

States: a) yes

b) no

The CPTs are filled in from **Appendix B**.

E.5.11. Corrosion wastage

States: a) accelerated

b) not accelerated

The CPTs are filled in from **Appendix B**.

E.5.12. Improper maintenance

States: a) yes

b) no

The CPTs are filled in either with 0 or 1.

E.5.13. Corrosive cargo

States: a) yes

b) no

The CPTs are filled in either with 0 or 1.

E.5.14. Weather routine failure

States: a) yes

b) no

The CPTs are filled in either with 0 or 1.

E.5.15. Freak wave

States: a) yes

b) no

The CPTs are filled in either with 0 or 1.

E.5.16. Typhoon escaping

States: a) deciding not to pass on information

b) failure to modify speed heading

c) N/A

The CPTs are filled in by information found at BOMEL Limited (2002) and the Hazard Register (**Appendix A**).

E.5.17. Rough weather management

States: a) error in judgement

b) inappropriate choice of route

c) N/A

The CPTs are filled in by information found at BOMEL Limited (2002) and the Hazard Register (**Appendix A**).

E.5.18. Cargo operations

States: a) excellent

b) standard

c) poor

The CPTs are filled in by information found at BOMEL Limited (2002) and the Hazard Register (**Appendix A**).

E.5.19. Commercial pressure

States: a) vessel suitability

b) cargo compatibility

c) dictation of requirements

d) N/A

The CPTs are filled in by information found at BOMEL Limited (2002) and the Hazard Register (**Appendix A**).

E.5.20. Shore management

States: a) excellent

b) standard

c) poor

The CPTs are filled in by analyzing PSC inspection data (detention lists) (Paris MOU 2005, Tokyo MOU 2005, USCG PSC 2005, Viña del Mar 2005, Indian Ocean MOU 2005, Black Sea MOU 2005). Whereas cases with only one deficiency were classified as standard and the rest poor. By way of reference, the probabilities $\left(:= \frac{\textbf{No of vessels}}{\textbf{total No of detained vessels}} \right)$ are presented at **Tables E.I.A**, **B**, **C** and **D**.

E.5.21. Operating level

States: a) ceiling
- b) good practice
- c) common practice
- d) standard practice
- e) shaded area
- f) floor

The naming of states is referred to OECD (2001). The CPTs are filled in by analyzing PSC inspection data (detention lists). Whereas for the ceiling, good practice and common practice states conditional to excellent state (shore management) and standard practice, shaded area and floor conditional to poor (shore management) the Pareto Principle[30] is used. By way of reference, the probabilities $\left(:= \frac{\textbf{No of vessels}}{\textbf{2005 fleet population}} \right)$ are presented at **Tables E.I.A**, **B**, **C** and **D**.

---

[30] The Pareto Principle also known as the 80:20 Rule was propounded by Vilfredo Pareto (1848 – 1923) when he observed that 20% of the people of Italy owned 80% of the wealth. This concept of disproportion often holds in many areas (Motil n.d.).

TABLE E.I.A. *CPT of PSC detention lists for 2005 (Handysize vessels)*

Shore management	Improper maintenance	
	Yes	No
Excellent		
Standard	0.5 (31)	0.2462 (32)
Poor	0.5 (31)	0.7538 (98)
Sum	1.0 (62)	1.0000 (130)
Grand total	**192**	

Operating level	Shore management		
	Excellent	Standard	Poor
Ceiling	0.0404 (101)		
Good practice	0.1599 (400)		
Common practice	0.7997 (2000)	1.00	
Standard practice			0.125 (24)
Shaded area			0.200 (38)
Floor			0.675 (130)
Sum	1.0000 (2501)		1.000 (192)
Grand total	**2693**		

TABLE E.I.B. *CPT of PSC detention lists for 2005 (Handymax vessels)*

Shore management	Improper maintenance	
	Yes	No
Excellent		
Standard	0.5161 (16)	0.2105 (20)
Poor	0.4839 (15)	0.7895 (75)
Sum	1.0000 (31)	1.0000 (95)
Grand total	**126**	

Operating level	Shore management		
	Excellent	Standard	Poor
Ceiling	0.0401 (44)		
Good practice	0.1604 (176)		
Common practice	0.7995 (877)	1.00	
Standard practice			0.1203 (15)
Shaded area			0.2025 (26)
Floor			0.6772 (85)
Sum	1.0000 (1097)		1.0000 (126)
Grand total	**1223**		

TABLE E.I.C. *CPT of PSC detention lists for 2005 (Panamax vessels)*

Shore management	**Improper maintenance**	
	Yes	No
Excellent		
Standard	0.28125 (9)	0.1687 (14)
Poor	0.71875 (23)	0.8313 (69)
Sum	1.00000 (32)	1.0000 (83)
Grand total	**115**	

Operating level	**Shore management**		
	Excellent	Standard	Poor
Ceiling	0.0396 (39)		
Good practice	0.1606 (158)		
Common practice	0.7998 (787)	1.00	
Standard practice			0.1042 (12)
Shaded area			0.2014 (23)
Floor			0.6944 (80)
Sum	1.0000 (984)		1.0000 (115)
Grand total	**1099**		

TABLE E.I.D. *CPT of PSC detention lists for 2005 (Capesize vessels)*

Shore management	**Improper maintenance**	
	Yes	No
Excellent		
Standard	0.25 (5)	0.1071 (6)
Poor	0.75 (15)	0.8929 (50)
Sum	1.00 (20)	1.0000 (56)
Grand total	**76**	

Operating level	**Shore management**		
	Excellent	Standard	Poor
Ceiling	0.0418 (22)		
Good practice	0.1594 (84)		
Common practice	0.7988 (421)	1.00	
Standard practice			0.0526 (4)
Shaded area			0.2000 (15)
Floor			0.7474 (57)
Sum	1.0000 (527)		1.0000 (76)
Grand total	**603**		

E.6. Risk_Index_N OOBN

This instance node consists of the following nodes (where N denotes the time slice i.e. [0 – 4], [5 – 9], [10 – 14], [15 – 19], [20 – 24], [25+]):

E.6.1. Likelihood_Index_N

It is the instance node described previously.

E.6.2. Consequence_Index

It is the instance node described previously.

E.6.3. Risk_Index

States: a) Intolerable
b) ALARP High
c) ALARP Medium
d) ALARP Low
e) Negligible

The CPTs are filled by considering the IMO Risk Matrix (IMO 2002b, IMO 2007b) in four levels i.e. low likelihood/consequence, low likelihood – high consequence, high likelihood – low consequence and high likelihood – high consequence. The essence of this index should not be interpreted as the same as the risk matrix which is only for ranking of hazards but as the potential for realization of unwanted, negative outcomes of an event (vessel en voyage) and thus uncertainty of the performance of a system (vessel) (Rowe 1988, Aven 2003). Therefore, it can be represented by the equation

$$\boldsymbol{Risk := \bigcap_{n=1}^{4} \begin{pmatrix} Low \\ High \end{pmatrix} \{Likelihood, Consequence\}}.$$

This page is intentionally left blank

F Corrosion: Background and Modelling

F.1. Introduction

Corrosion has been recognized as the most important cause of deterioration (structural damage), not only from the point of view of strength loss, but also in connection with appearance of cracks, buckling and the loss of watertight integrity. Furthermore, the surface roughness of the sell plating is increased, which thus results an increase in the frictional resistance and consequently the required power to propel the vessel, hence bigger fuel consumption. Structural members come into immediate contact with seawater, with cargoes that contain water (moisture content) and with cargoes that can induce corrosion (sulphur content). It has been observed that during the early period corrosion related damage is negligible, as the age increases; corrosion starts to appear in the 4th year of life, the majority of instances appear during the period of 8th – 10th year and an overwhelming proportion occurs after the 20th year of operating life (Caridis 2001, 2002, IMO 1999, Ferguson 1993, West P&I 1994, ABS 2002).

As a phenomenon, corrosion and its consequences have significance in relation to operability and operating life of any vessel, for instance the annual corrosion related cost to the U.S. marine shipping industry is estimated at USD ($) 2.7 billion. This cost is divided into costs associated with new construction ($1.12 billion), maintenance and repairs ($810 million), and corrosion related down time ($785 million) (Johnson 2001). Work undertaken by Kattan (2005) estimates the marine coating market at some $27 billion per year of which the overall majority (70 – 80%) is for anti – corrosive paints for the various parts of the vessel. Another typical example is a $1.6 million cargo claim and unrecovered general average[31] for the side shell failure of a bulk carrier where loss of strength resulted from accelerated corrosion of side shell frames and connecting brackets (Standard-Club 1998).

Notwithstanding the above, it can be accepted that corrosion as a process is no longer the simple inception of rust and the build – up of layers of rust on the surface of metal as a result of water vapour and salt action. Instead, it is transformed in the same way a ***virus*** works, following changes in environmental or operating conditions and thus, can be identified as the starting point (or the catalyst) for any failures or disastrous events (Zamiatina et al. 2001).

F.2. Corrosion background

F.2.1. Basics

The term *corrosion* is used to denote the physical and chemical changes to materials that result from interaction with the environment. According to ASTM Designation G 15 – 05 (ASTM 2006a), corrosion is defined as the chemical or electrochemical reaction between a material, usually a metal, and its environment that produces a deterioration of material and its properties, usually an oxide is formed (FeO, Fe_3O_4, Fe_2O_3)[32], whereas similar term has been given by ISO (Skoulikidis and Vassiliou 1994). The metal degradation denoted by chemical corrosion results from the oxidation and reduction reactions with the formatted compounds occurring at their interface, whilst in electrochemical corrosion cases of degradation due to chemical processes in the presence of an electric current are concerned, hence larger quantities of energy and extent of chemical degradation are involved. Under these circumstances, through that chemical action termed electrolysis, an electric current flow is permitted from the anode (oxidised metal – loss of electrons) to the cathode

---

[31] An ocean marine loss that occurs through the voluntary sacrifice of a part of the vessel or cargo, or expenditure, to safeguard the vessel and its remaining cargo from a common peril. If the sacrifice is successful, all interests at risk contribute to the loss borne by owner of the sacrificed property based on their respective saved values. A party can insure their portion of such a loss under the conditions imposed by Maritime Law (Lambeth 1981, Brown 1986).

[32] In the presence of moisture other formed products include $Fe(OH)_2$, or $Fe(OH)_3$, or $FeO(OH)$ (Skoulikidis and Vassiliou 1994).

(electron acceptor reduced) (Shreir 1994). Electrochemical corrosion is the most commonly encountered type of corrosion in marine structures where the electrochemical process is arisen due to the ionisation of iron that is contained within them. A means for the electrochemical reactions is provided by an electrically conductive fluid (electrolyte), for example water (Skoulikidis and Vassiliou 1994). The ionisation reaction is:

$Fe \xrightarrow{H_2O} Fe^{2+} + 2e^-$

Electrons flow within the metal towards the cathode (electrolyte) and give rise to the corrosion current. At the cathode, the corrosion current has two possible ways of acting:

$2H^+ + 2e^- \rightarrow H_2 \uparrow$ or $2H_2O + O_2 + 4e^- \rightarrow 4OH^-$

The most important result of these two cathodic reactions is the formation of hydroxyl ions (OH^-) that react with the ferrous ions resulting in iron oxides (rust) (Skoulikidis and Vassiliou 1994):

$Fe^{3+} + 3OH^- \rightarrow Fe(OH)_3$ (iron hydroxide, orange colour)

$Fe(OH)_3 \rightarrow FeO(OH) + H_2O$ (iron oxide hydroxide, red – brown colour)

$2FeO(OH) \rightarrow Fe_2O_3 + H_2O$ (ferric oxide, brown rust)

If the oxygen content of the electrolyte is substantial:

$Fe^{2+} + 2OH^- \rightarrow Fe(OH)_2$ (green coloured iron hydroxide)

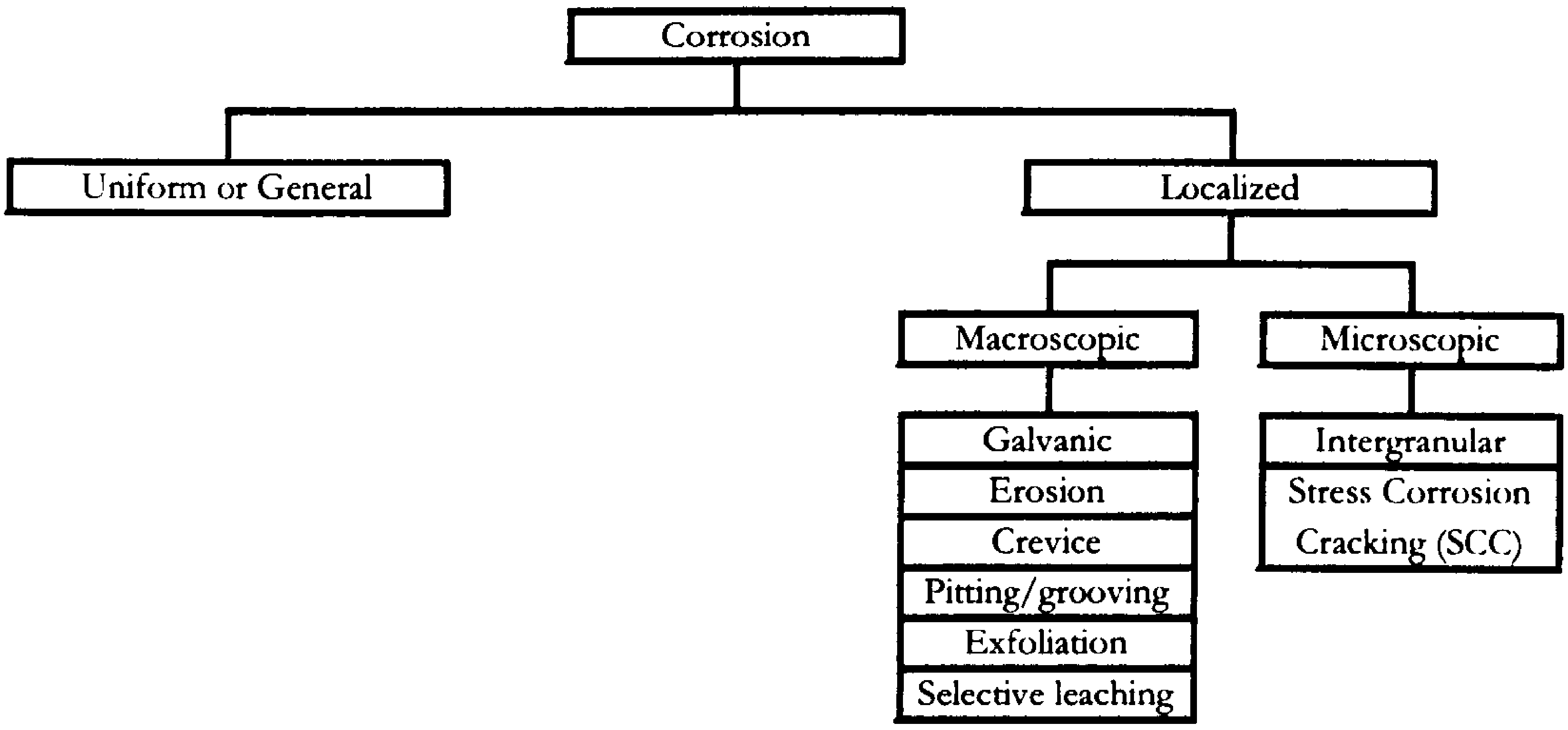
$6Fe(OH)_2 + O_2 \rightarrow 4H_2O + 2Fe_3O_4.H_2O$ (black coloured hydrated iron oxide)

$Fe_3O_4.H_2O \rightarrow H_2O + Fe_3O_4$ (ferrous ferric oxide, black rust)

F.2.2. Forms of corrosion

From the point of view of its results, corrosion can be classed as (**Table F.I**) (Skoulikidis and Vassiliou 1994):

Table F.I. *Forms of corrosion*



Generally, it can be accepted that most of the previous forms are classified under: general, pitting, stress corrosion cracking and cavitation erosion (Skoulikidis and Vassiliou 1994). From a broad view, corrosion could be separated into two categories: corrosion that is not influenced by any other process and corrosion that is influenced by another process, such as the presence of stresses or erosion. A more focused view would categorize corrosion as uniform or localized, aqueous or gaseous, wet or dry, and so forth. Other proposed classifications include (i) uniform (aqueous, gaseous, atmospheric, galvanic), (ii) localized – described as corrosion that occurs at discrete locations on a material (crevice, pitting, grooving), (iii) metallurgically influenced corrosion (welding), (iv) mechanically assisted degradation (fretting, cavitation – impingement corrosion, corrosion fatigue), (v) environmentally induced cracking (stress corrosion cracking) and (vi) microbiologically influenced corrosion (Covino and Cramer 2003).

In ship structures, the following forms of corrosion are considered (Caridis 2001, 2002):

- **Uniform or General corrosion.**

  Apparently is the most common form where the corrosion product appears as a non – protective, friable rust which can occur uniformly on uncoated, internal surfaces of the vessel. The rust scale continually breaks – off, exposing fresh metal to corrosive attack and it is appeared to have a constant depth and similar consistency over the surface.

Thickness loss cannot usually be judged visually until excessive loss has occurred. Although can be accepted as the least harmful form of corrosion since it can be easily identified, failure to remove mill scale during construction of the ship can accelerate corrosion experienced in service. Moreover, severe general corrosion, usually characterized by heavy scale accumulation, can lead to extensive steel renewals, unless faced at an earlier stage. The mechanism of general corrosion is illustrated in **Figure F.1**.

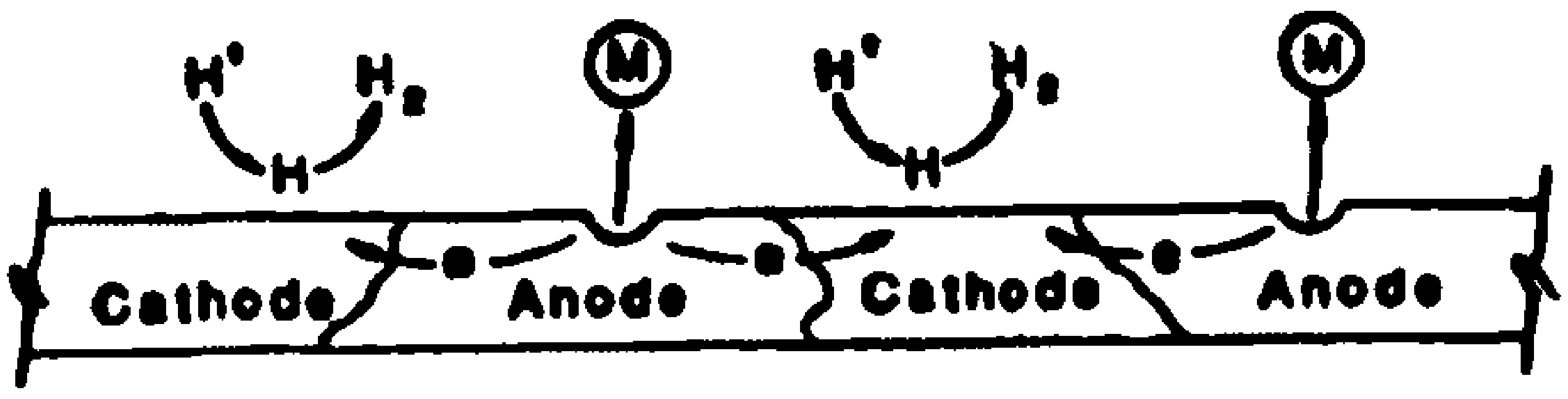


Figure F.1. *Simplified schematic of uniform corrosion*

Source: Stambaugh and Knecht (1991)

There are micro cathodic and anodic areas caused by variations in grain structure, impurities in the metal, alloying elements and other inhomogeneities. For general corrosion, the cathodic and anodic areas constantly switch back and forth due to a difference in potential or degree of polarization, thus accounting for the uniform corrosion of the surface (Stambaugh and Knecht 1991).

- **Pitting corrosion.**

  It is often described as a cavity whose diameter is the same or less than its depth, the local formation of corrosion products or the selective local solution of the surface to some depth is involved, usually grows in the direction of gravity and is normally initiated due to local breakdown of coating. It is also self – generating, i.e. autocatalytic, starting from impurities in the metal, scale or other deposits (cargo residues), or some inhomogeneity in the metal and in particular in the case of stainless steels is often accelerated in the presence of still water with low oxygen content. **Figure F.2** shows a progressive pit being formed.

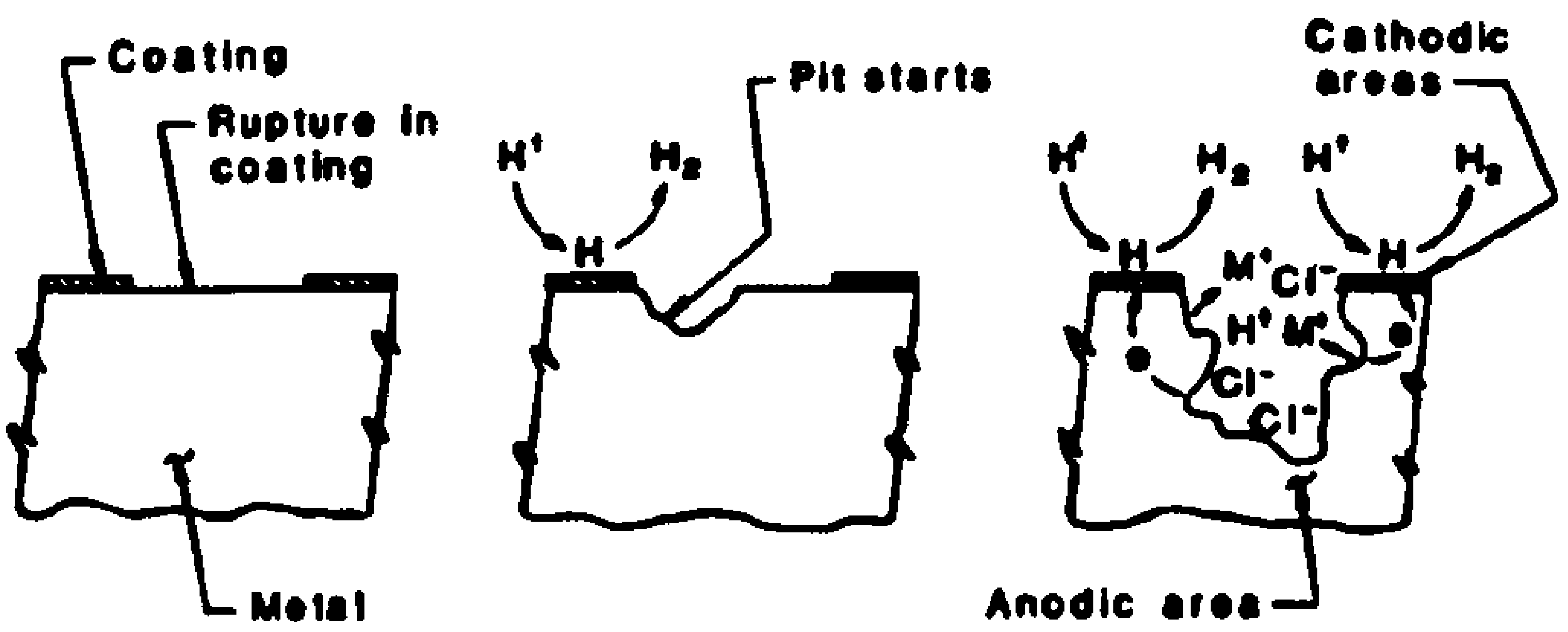


Figure F.2. *Simplified schematic of formation of a pit*

Source: Stambaugh and Knecht (1991)

If for some reason, such as the absence of oxygen, the small surfaces of the irregularity act as anodes of an electrolytic cell, the remaining part of the surface acts as a cathode. The result of the action of the electrolytic cell is accelerated galvanic corrosion. Galvanic elements can be developed to pitting corrosion by differences in oxygen concentration, temperature, flow speed and generally all forms of heterogeneity in environmental conditions. Another specialized form of pitting corrosion that arises in vessel structures is known as grooving corrosion and usually occurs in way of connections (beside welds, especially in the heat affected zone), at which flow takes place or where water may collect. The results of grooving are evident on the surface that has been attacked and have a linear form. It is arisen on vertical members (hold frames) and on horizontal bulkhead surfaces in the direction of bending (Stambaugh and Knecht 1991).

- **Stress corrosion cracking.**

  It can be considered as the most damaging of all types of corrosion from the point of view of its consequences and has serious financial repercussions for relatively small losses in material. It is observed when external loads act on surfaces with cavities that arise from pitting or impacts. These loads can cause brittle fracture of the whole cross-section, although the tensile stresses that result can be less than 10% of the rupture stress of the material.

- **Cavitation erosion – impingement attack.**

  Cavitation is the phenomenon during which in one or more parts of a wetted body, the local static pressure is smaller than the saturation pressure of the liquid at the current temperature. Consequently, the liquid evaporates and cavitation bubbles form. These bubbles, as soon as they reach a location with higher pressure, liquefy on the solid surface. As a result, when the bubbles collapse, large pressures develop which cause wear of the surface and open small craters (pittings) and cavities. Such conditions arise on rotating blades of pumps (impellers) and on ship propellers.

- **Bacterial corrosion.**

  It is also called microbiological or anaerobic corrosion and arises when environmental conditions are conducive to the growth and spreading of bacterial activity. Briefly speaking, such conditions are:

  - Stagnant waters (without oxygen).
  - Bacteria that feed on hydrocarbons such as crude oil, certain protective coatings, soft paints.
  - The presence of sulphates in seawater (the most common bacteria "breathe" using sulphate compounds instead of oxygen).
  - Optimum temperatures for the growth of bacteria (20 – 40^{0}C).

  It is often found in oil tanks, ballast tanks, the oil cargo loading and discharging piping.

F.2.3. Factors that influence corrosion

Following microscopic visual inspection of various cases of corrosion, it has been observed that corrosion is more intense (Caridis 2001, 2002, Chandler 1985, La Que 1975, Heidersbach 1987, Matsushima 2000):

- At the interface of:
  a) corroding metal or alloy/soil or water/air,
  b) corroding metal or alloy/water/river or seabed and
  c) corroding metal or alloy/water in colloid dimensions/localised bubbles of air or gas.
- With increased electrical conductivity of the corrosive environment.
- At irregular surfaces of corroding metals and alloys arising from pollution, seawater, or irregularities of the alloy crystal matrix.

- When the corrosive environment or its properties change. For example, tanks being filled with different liquids or the flow of a variety of liquids through piping. These changes accelerate the rate of corrosion when compared with steady state condition that may in fact be more intensely corrosive.
- At geometric irregularities (at a macroscopic as well as microscopic level).
- For plastic deformations and disordered crystalline structures (mechanical processing, thermal processing).
- At locations where the elastic deformation is large, there is a greater tendency and there is thus an increase in corrosion potential.
- In the presence of *eddy currents*. This phenomenon is general with regard to corrosion and appears in all cases there are large eddy currents, i.e. where no grounding is provided. For instance, the outer hull plating suffers intense corrosion during the replacement of internal tank plating and during the use of arc welding.
- In the presence of oxygen-rich seawater. The corrosion rate also increases with increased salinity and water velocity.
- At high temperatures.
- In acid solutions or in alkaline solutions without hydrolysis.
- When metals are in contact with other metals or other alloys that have large differences in the galvanic series.

In the sense of oxidation, corrosion arises in all environments, even without the direct contact of metals and alloys with oxygen or moisture. For this reason, different types of environment do not lead to any substantial differences from the point of view of the definition of corrosion. Nevertheless, because there are quantitative differences in the rates of corrosion and because on certain occasions there are differences both from the point of view of results and also the types of mechanisms that depend on the environment, the following classes are considered:

- Corrosion in air (dry, moist, clean or polluted).
- Corrosion on or within the soil (dry or liquid, clean or polluted).
- Corrosion in fresh water.
- Corrosion in seawater (within, on, in the presence of seawater, clean or polluted).
- Corrosion with exhaust gases or hot gases (dry or with moisture).
- Chemical corrosion (with chemical means).

- Nuclear corrosion (in a dry or moist environment).

Corrosion is more intensive in seawater because the contained salts increase its electrical conductivity. An additional reason is the presence of animal and plant micro-organisms, which cause pollution; this leads to inhomogeneity of the material surfaces, thus increasing the propensity to corrosion.

Furthermore, certain operating conditions and operational parameters can lead to the acceleration of corrosion. These are listed below (Caridis 2001, 2002):

- **Fatigue corrosion**

  In a corrosive environment, the fatigue strength of various metals and alloys is reduced. This reduction is due to the combined action of electrochemical factors (corrosion on the inner surfaces of the crack) and mechanical factors (fracture of the oxide layer on the crack interior).

- **Corrosion with friction**

  It is occurred on the contact surfaces of two components and over minute displacements (of the order of a micron). Because the surfaces are not completely smooth, their contact happens only at the tips of the anomalies. Hence, wear of the tips and rupture of the protective oxide coating is caused by the relative motion of the two surfaces, thus corrosion is accelerated.

- **Temperature differences**

  Within metal objects, temperature differences give rise to a potential difference between the hot and cold region. The colder region, which is more electropositive than the hotter region, corrodes more rapidly.

In connection with the above, from other studies (Paik et al. 1998, Gardiner and Melchers 1998) the operational parameters, particularly for BCs, were investigated from a broader point of view and can be summarized as:

- Moisture and sulphur content of cargo
- Trade routes
- Frequency of cargo changes
- Time with cargo and ballast
- Corrosion protection system
- Structural member location and orientation (horizontal – vertical)

Apparently, the existed corrosive environment in a cargo hold is dependent on the loading condition. An unloaded hold is corroded due to exposure to an enclosed atmosphere (atmospheric corrosion), whilst loaded is affected by the presence of a porous medium (soil). Consequently, more exposed areas are at approximately 40% of the height of the cargo hold and bulkheads (normal cargo level). The effectiveness of the protection system in the ballast tanks is affected by the ratio of time spent in ballast and the loading condition, since a sacrificial anode (in a ballast tank) is only effective when it is fully submerged. It can be accepted that the ballast tank corrosion is a function of temperature, seawater salinity and dissolved oxygen concentration which are unlikely to be constant and therefore, it is probable that corrosion rates will be varying with trade route (Gardiner and Melchers 1998, 2001, 2003).

F.3. Corrosion wastage of BC Structures

F.3.1. General

Essentially, an appreciation of the environment in which BCs operate is considered necessary for enabling a better understanding of the encountered situation. BCs (as any type of vessel) are exposed to the marine environment which is much harsher and more corrosive than to which land – based structures are subjected. Corrosion is a serious problem for anything built of metal, but for a vessel can be fatal simple because her hull is in continual contact with water, usually salt. Moreover, bearing in mind all the possible (aggressive) substances that have to be carried, the challenge for BCs is even bigger since corrosion in the cargo hold region can be accelerated by the effects of certain products including coal, phosphates, raw sulphur, salt, ores. This region can be affected by humidity resulting from the moisture contained in some cargoes, i.e. mineral and ore concentrates. Additionally, certain coal grades possess high sulphur content which when combined with water resulting from condensation or sweat, form sulphuric acid which is by virtue devastating for the structure. Furthermore, the moist saline atmosphere developed inside the wing tanks when empty can attack their internal structure and in warm temperature the corrosive effect is expedited. These occurrences may cause unseen structural degradation that is manifested increasingly over the BC's operational life and experience has shown that although the affected areas may appear to be in deceptively good condition on cursory examination, yet corrosion may in fact be well advanced (ABS 2002, GL 2004, IMO 1999).

F.3.2. Forms of corrosion in BC structures

As stated earlier, two of the most important types of corrosion are uniform and pitting corrosion. In this context it should be mentioned that their boundaries are not always clear. For instance, it has been observed that corrosion in cargo hold areas is more likely to be general corrosion when coating protection is not provided (uncoated areas of cargo hold) whereas pitting corrosion is more likely with paint coatings. It was also seen that pitting corrosion was severer at lower and middle frame parts than the upper and particularly at the webs than the faces. It was also observed that pitting corrosion was developed all over the lower part of the frame and that the shapes of pits in BC coatings differ from those found in tanker coatings. This may be due to differences in the corrosion environments around these pits (Nakai et al. 2005).

In connection with the above, it should be noted that the corrosion rate of structural members in the same part (i.e. cargo hold) may not be the same due to the different corrosive environments. As an example, let's consider the schematic corrosion progress for marine steels as a function of exposure time illustrated in **Figure F.3**. The convex curve (Type A) shows the corrosion rate decreasing as corrosion progresses. This type of behaviour is common in many environments and is brought about by the gradual build-up of protective rust layers and is observed, for example in the upper parts of cargo holds. The linear curve (Type B) is characteristic of situations where the rust layers are continually removed due to abrasion or wear or relatively minor surface strains. It is typical for the lower parts of the vessel's cargo holds used for aggressive cargoes (i.e. ores). The concave curve (Type C) is representative of corrosion accelerating with time. This is characteristic of situations where there is increasing structural surface strain from flexure of dynamically loaded structures together with excessive thinning of structural components (i.e. side shell frames). It is often seen in very advanced stages of corrosion with accelerated degradation (ISSC 2006).

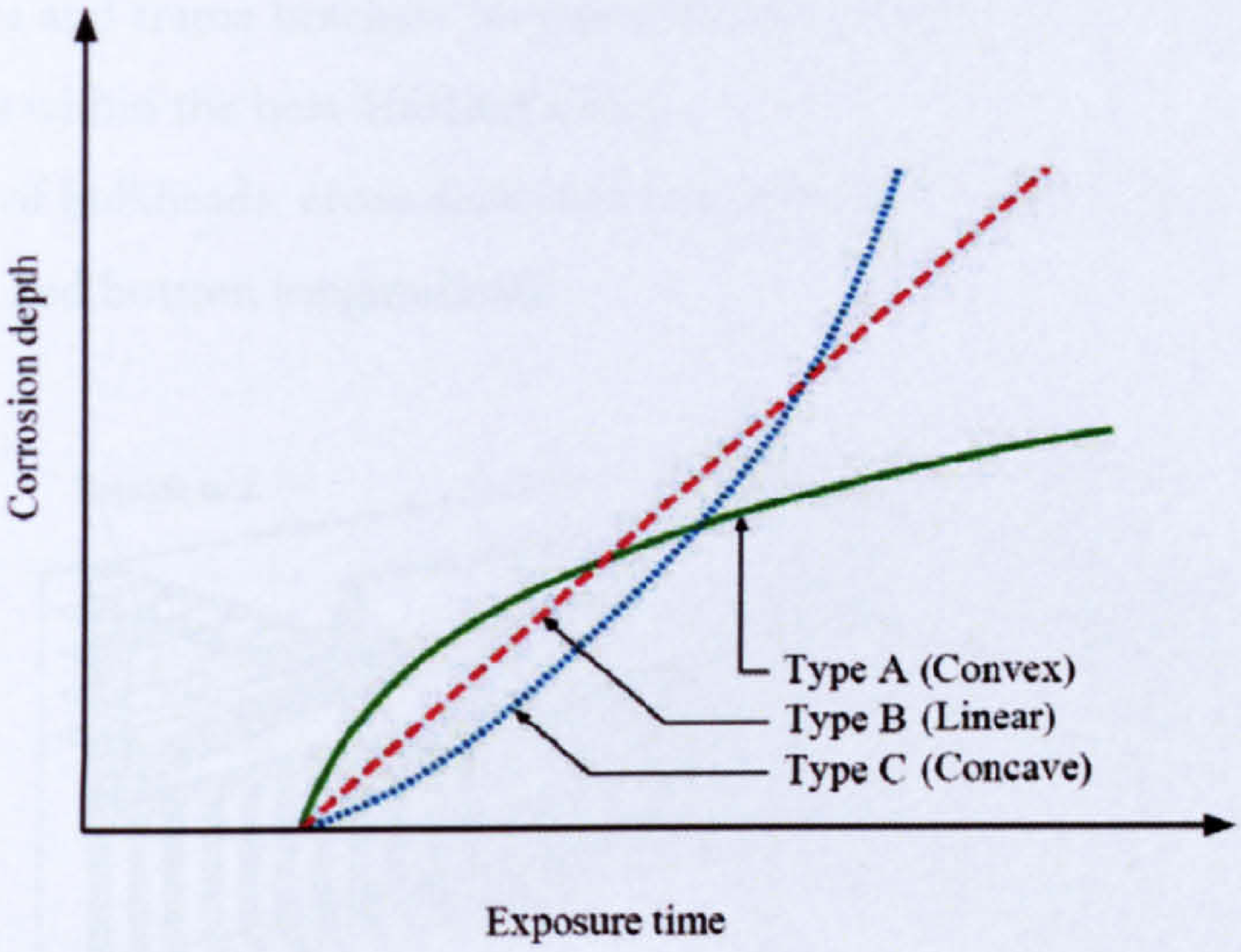


Figure F.3. *Schematic of corrosion progress for marine steels as a function of time*
Source: ISSC (2006)

Corrosion can be evaluated by visual or close – up inspections governed by skill and experience while the extent of coating breakdown is quantified and its condition is ranked according to, i.e. IACS UR Z10.2 (IACS 2007a). It should be mentioned that the extent of wastage is determined through thickness measurements taken for each structural member generally by ultrasonic sensors since the ultrasonic guided waves give high penetration power and have long propagation distance through the complicated vessel's structure (Saiarasamoot et al. 2003). Although this is considered as a tedious job due to the large number of data (about 20,000 points for a large vessel beyond the age of 15 years), with efficient computer support and standardization the examination techniques have been improved (Jaramillo et al. 2006).

Corrosion can be observed in the whole structure of a BC, but the most affected area is the cargo hold region (including outer shell). For illustrative purposes, in **Figure F.4** a typical configuration of a cargo hold of a single skin BC is shown together with problem areas where particular attention needs to be given for corrosion. Briefly, these areas can be summarized as (IACS 2004b):

A. Upper surface of tank top, hopper tank, lower stool plating and their intersections.

B. Hold frames and frame brackets (in particular the lower and upper connections and the bracket toe within the heat affected zone).

C. Upper part of bulkheads, cross deck structure and hatch corners/brackets.

D. Deck, shell and bottom longitudinals.

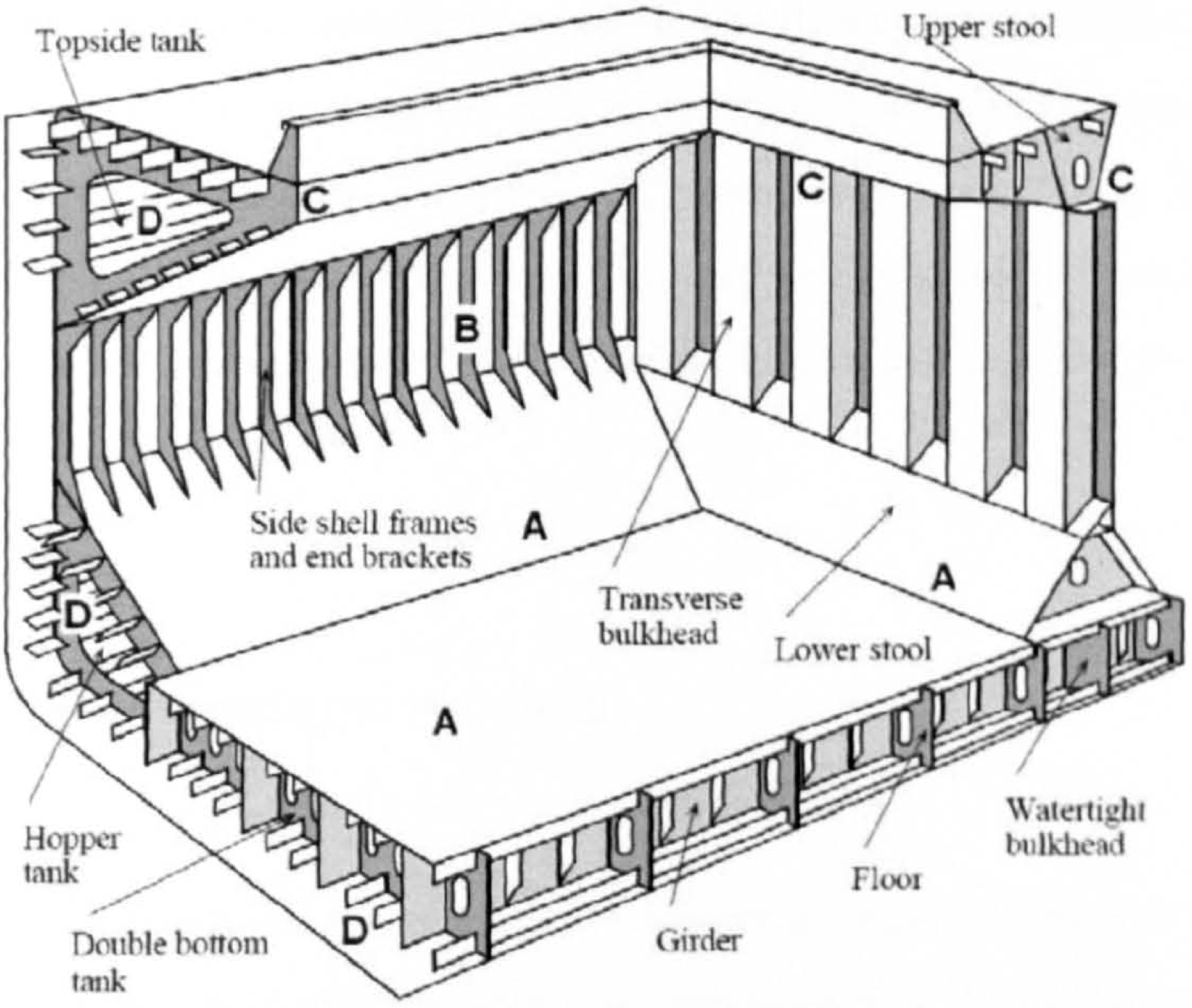


Figure F.4. *Areas liable to high corrosion in BCs*

Source: IACS (2004b)

F.4. Mathematical formulation of corrosion wastage

F.4.1. General

The realistic corrosion phenomenon cannot be identified by statistical investigations (ASTM 2006b, BSI 1996, HSE 2002b) of corroded ships alone. It is necessary to predict the corrosion rate with a reliable accuracy so that the available tolerance against corrosion can be estimated at some future point in time. The traditional means of corrosion rate prediction have been based on measurements during ship operation, case studies and sample exposure tests. The various prediction methods that have been used, whether on site or under controlled laboratory conditions, can be classed as either theoretical or empirical. In the case of the former, corrosion rates are predicted using theoretical (numerical in most cases, or polarization potential) considerations, where in the latter, measurements on real structures are used. Alternatively, corrosion rate can be predicted using real data with the concurrent application of statistical techniques. The most important difference between empirical, statistical and theoretical methods is that the statistical aim only at an estimate of the rate of corrosion without necessarily gaining an understanding of the processes involved. The statistical method is based on the development and use of a corrosion database for a particular structure that can be used to obtain the relevant corrosion rates as well as related statistical parameters (Caridis 2001, 2002, Stambaugh and Knecht 1991).

F.4.2. Corrosion wastage models

Although calculation of the amount of corrosion occurring in unit time has been used conventionally as the corrosion index in assessing the corrosion margin for the easiness of application, the evaluated annual wastage rate does not count the fact that the propagation of corrosion is proportional to time and obviously a probabilistic event (Yamamoto and Ikegami 1998, Thuanboon et al. 2006). Hence, there is a need to develop models based on corrosion mechanisms and to combine them with the corrosion wastage databases to achieve a better understanding as well as improved prediction of corrosion of ships in service. The progress of corrosion may be characterized by three phases, namely i) durability or life of the coating, ii) transition period and iii) corrosion progression. In the report of ISSC Committee V.6 (ISSC 2006) is stated that four models exist, which their development is based on the probabilistic approach and following the three phases mentioned previously. It is not the purpose of this study to state that ***x*** model is better than the others or in ***y*** model the corrosion rates are predicted with higher accuracy since it has been recognized that corrosion is a very complex phenomenon and influenced by many factors. A brief literature review of the available corrosion models is provided below.

Linear models of corrosion wastage were proposed by Southwell et al. (1979) where sort and long – term exposure results from five different ocean sites were used. By extending the previous models, steady state piece – wise linear and power models were suggested by Melchers (1994, 1998, 1999) whilst multiphase phenomenological models have been derived achieving mathematical consistency (Melchers 2003a, b, c) (**Figure F.5**). Recently, these models were reviewed incorporating highly non – linear functions $\left(a \cdot e^{bt}\right)$ (Melchers 2006). The physical – chemical approach for determining the loss of material due to corrosion was applied by Chernov and Ponomarenko (2001) and a power model was considered appropriate. A linear model with constant rate including initiation period has been preferred by Straub and Faber (2005) where the Poisson process was used for the uncertainty in the operating and environmental parameters. A three – stage time variant corrosion model has been developed by Paik et al. (1998, 2003a, b, 2004) (**Figure F.6**) with the statistical analysis of thickness measurement data. The effect of corrosion as a non – linear function of time has been formulated also by Guedes Soares and Garbatov (1999) considering three phases (**Figure F.7**) and can be expanded accounting for environmental factors (Guedes Soares et al. 2005). Moreover, this model has been validated against measured data and was considered flexible to represent the actual corrosion phenomenon (Garbatov et al. 2007). The previous model was adapted by Sun and Bai (2003) where the rate instead of the wastage was described; whilst by Ivanov et al. (2003, 2004) the transition time was substituted by a linear function. The new three – stage corrosion model formatted by Qin and Cui (2002, 2003) (**Figure F.8**) incorporates modifications of Paik's and Guedes Soares & Garbatov models which can be regarded as special cases of the recent developed model.

It needs to be stressed that these models are essentially empirical (phenomenological or mechanical representation of corrosion wastage) and have been developed for prediction of general (uniform) corrosion, but they may also be approximately applicable to pit corrosion prediction as long as the features of pits are taken into account (ISSC 2006).

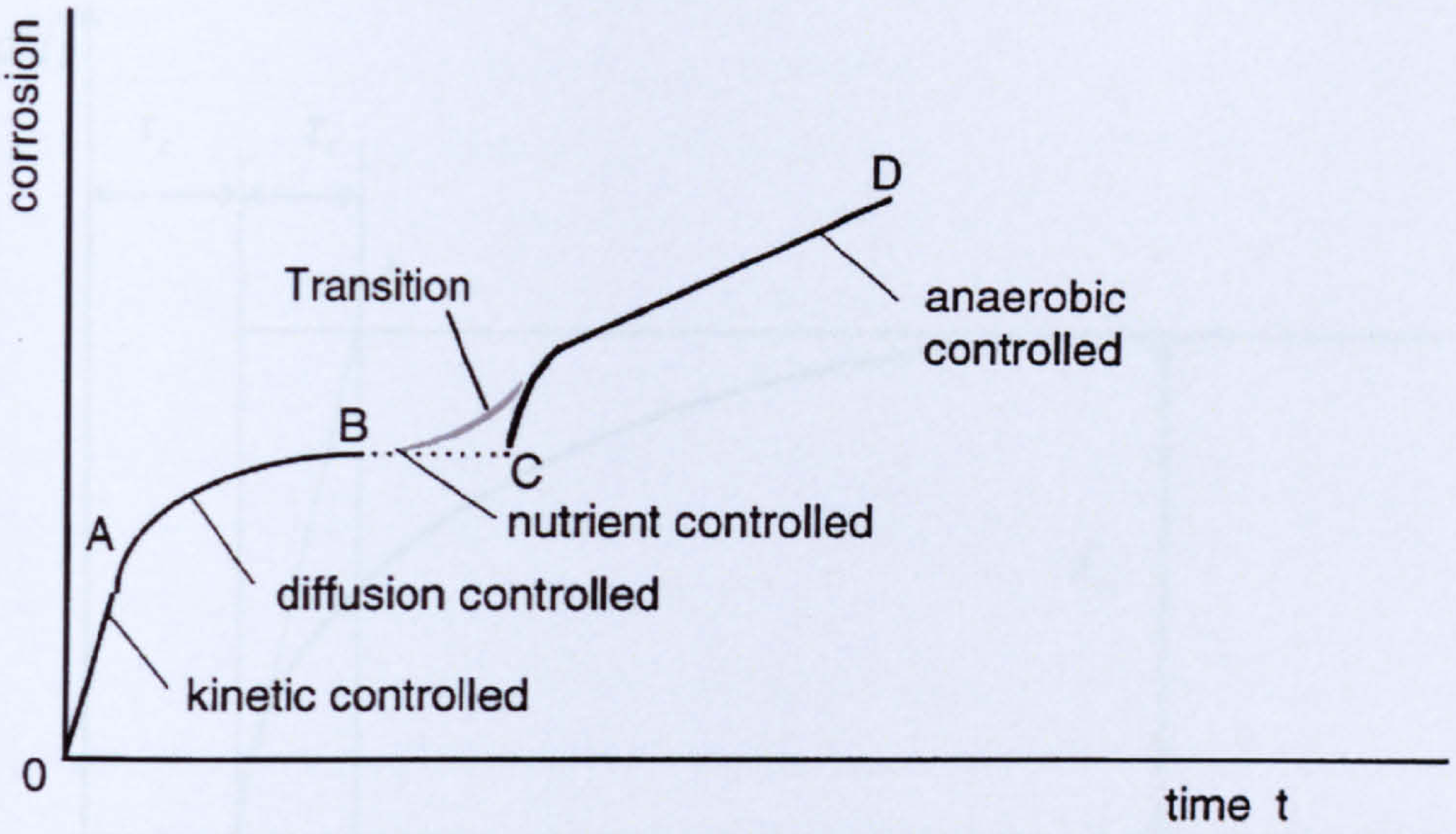


Figure F.5. *Multiphase corrosion – time model*

Source: Melchers (1994, 1998, 1999, 2003a, b, c)

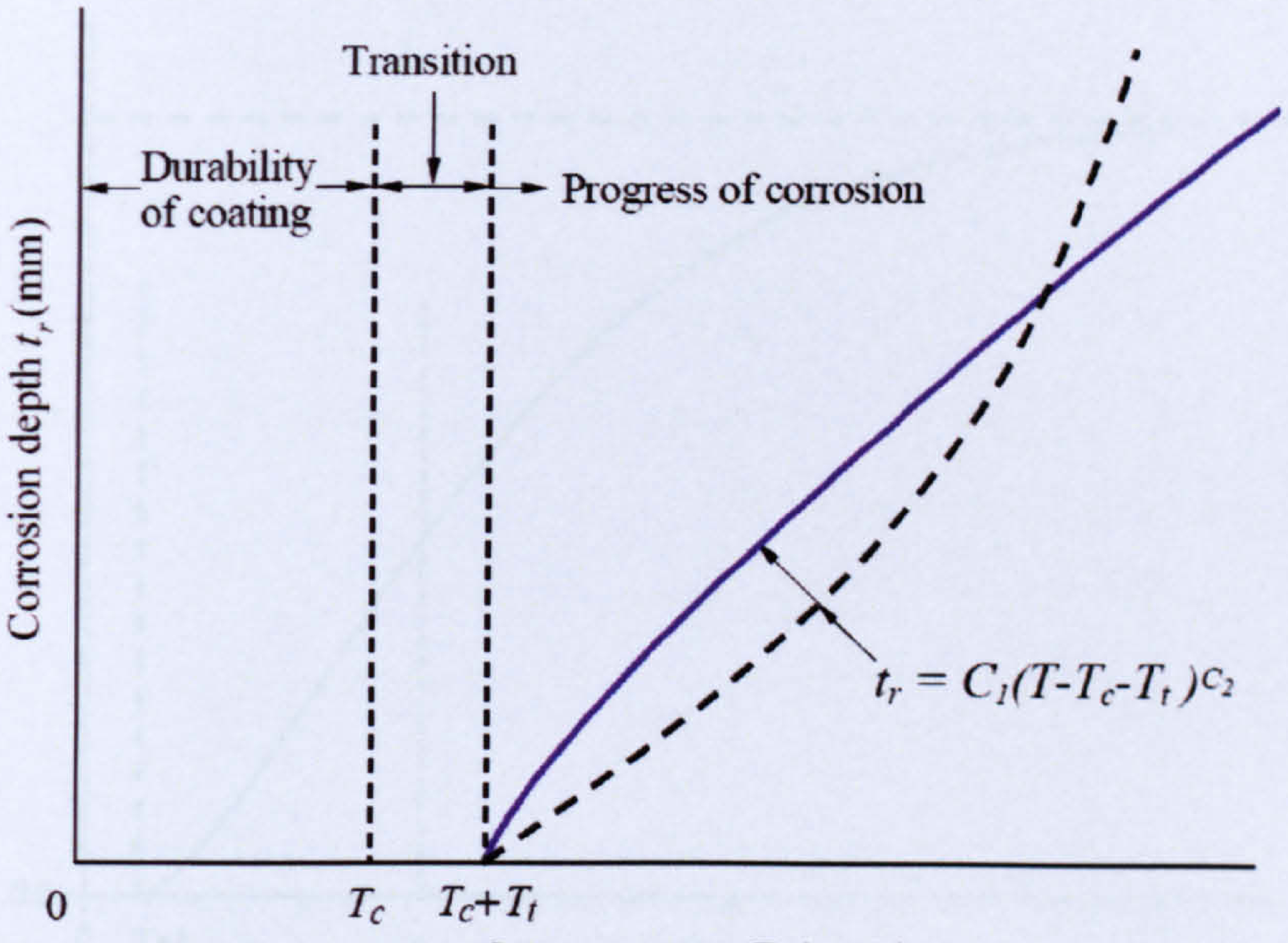


Figure F.6. *A schematic of the corrosion process for marine structures*

Source : Paik et al. (2003a, b, 2004)

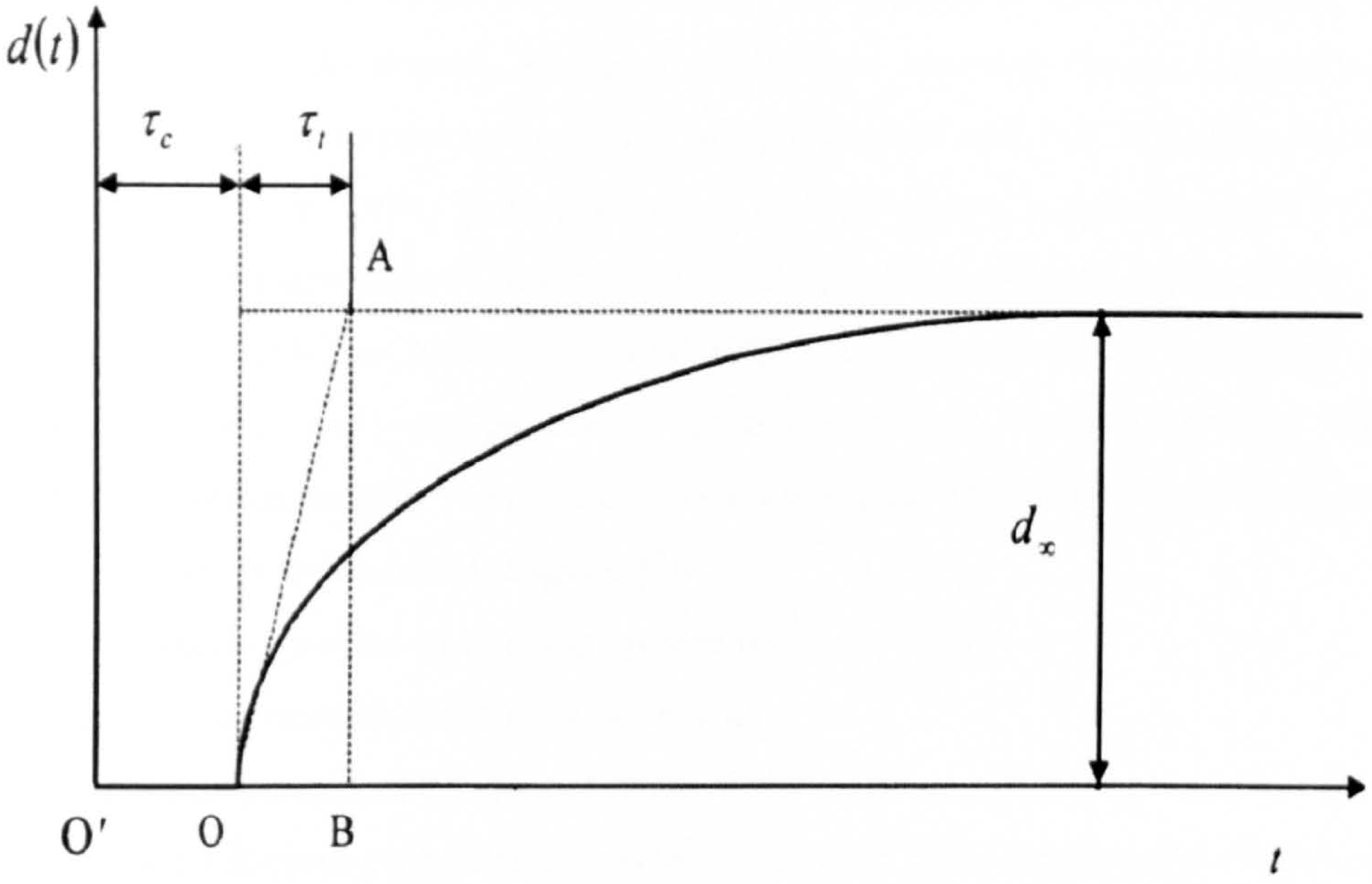


Figure F.7. *Thickness of corrosion wastage as a function of time*

Source: Guedes Soares and Garbatov (1999)

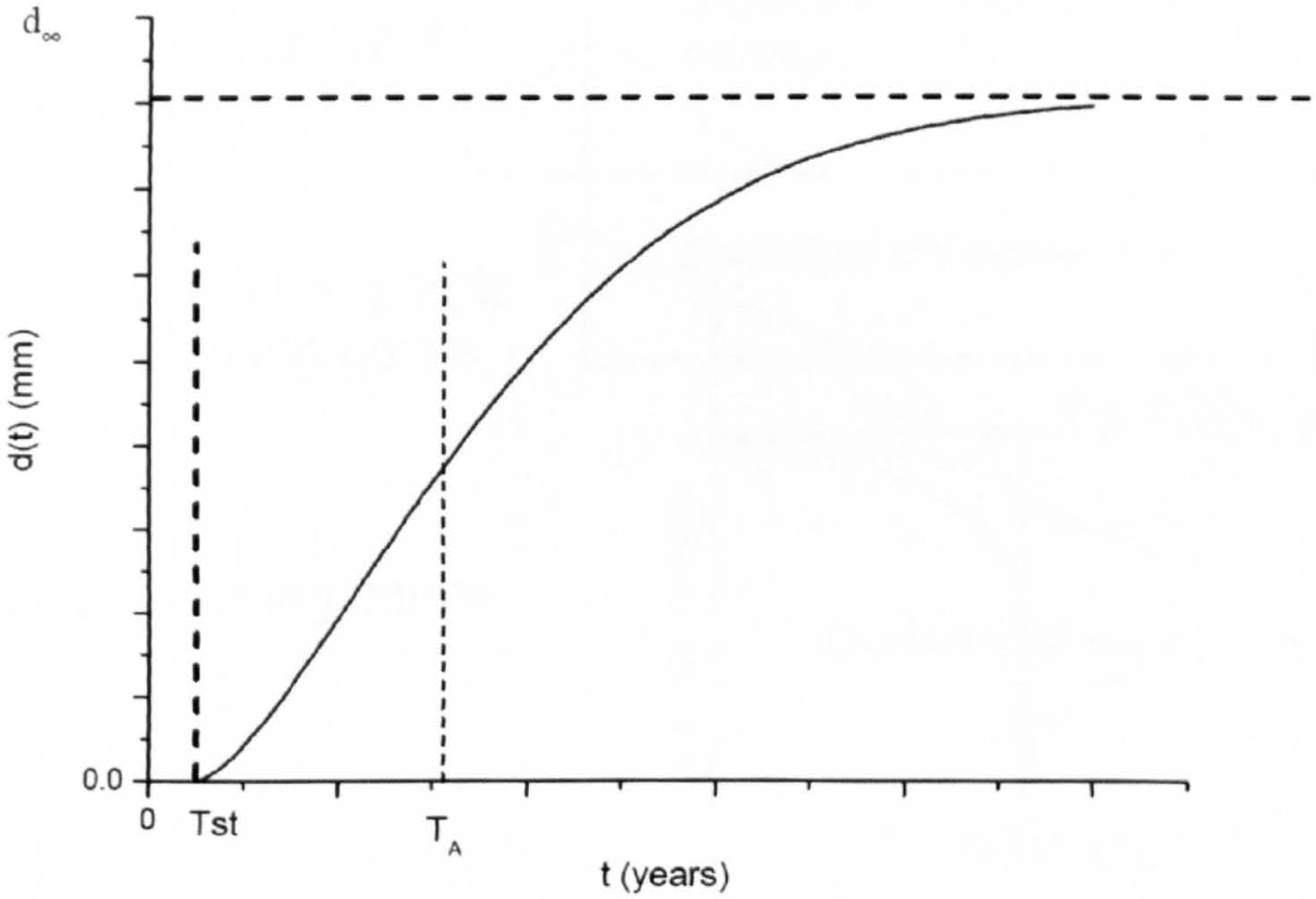


Figure F.8. *Schematic representation of corrosion wear*

Source: Qin and Cui (2003)

Another empirical model for problems of corrosion generation and progress in hull structural members developed during a multiphase research project regarding the investigation of corrosion process on ships; being started at early 90s and being finalised at mid 90s (Matoba et al. 1994, Yamamoto et al. 1994, Yamamoto and Ikegami 1996) has been proposed by Yamamoto (Yamamoto and Ikegami 1996, 1998, Yamamoto 1997, 1998, 2000, Yamamoto and Yao 2002, Sone et al. 2003, Yoneya et al. 2003). According to that approach, the wear and wastage due to pitting corrosion is considered to follow a generalized deformation after the pits have been developed all over the plate's surface. The following processes are assumed (**Figure F.9**):

(i). the deterioration process of anti – corrosive paint coatings,

(ii). The generation process of pitting points, and

(iii). The progress process of pitting points.

By introducing adequate probabilistic models in each of these processes, a model capable of integrally assessing the generation and progress events of corrosion can be constructed.

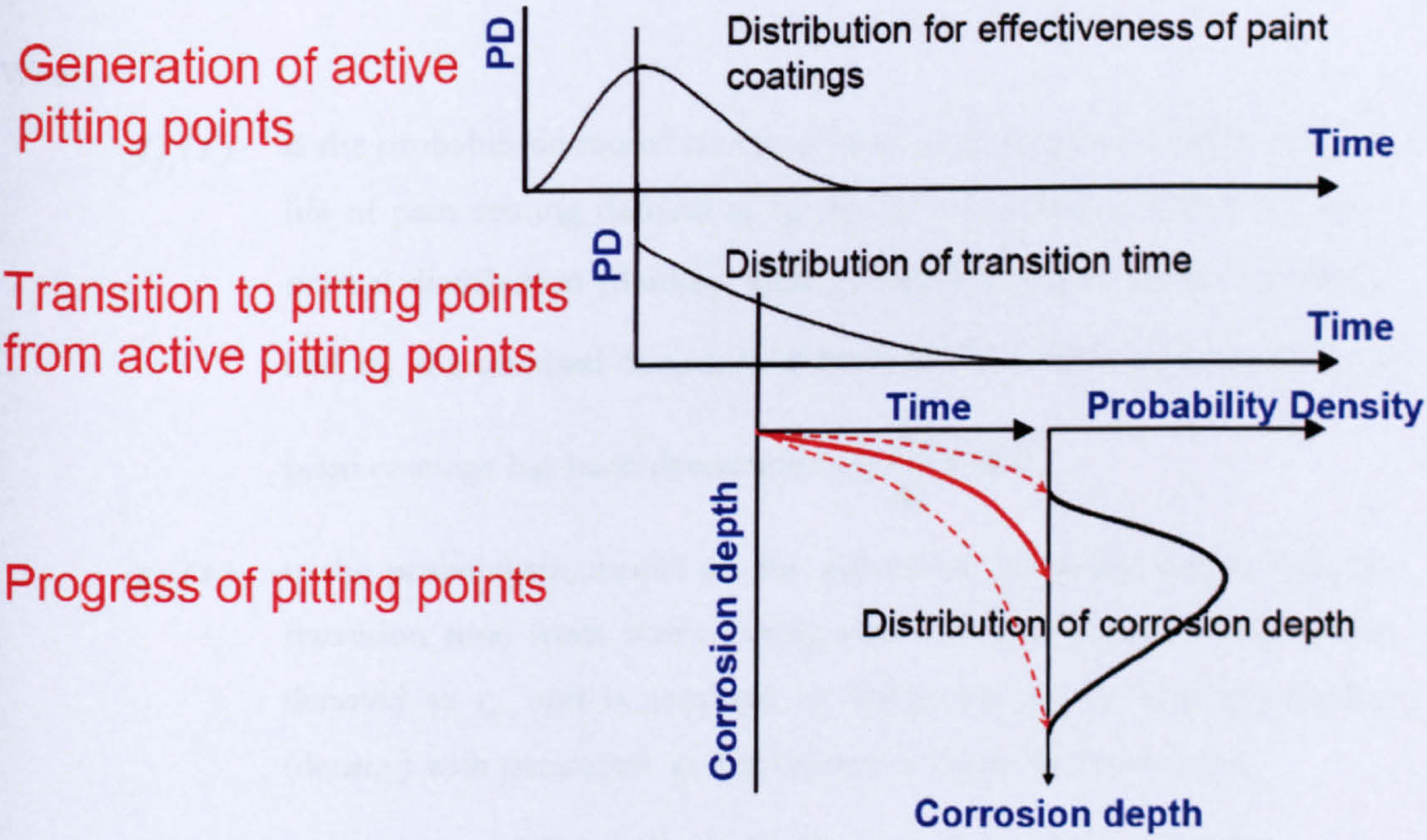


Figure F.9. *Graphical presentation of probabilistic corrosion propagation model proposed by Yamamoto*

Source: IACS (2007b)

F.4.3. Corrosion propagation model developed by Yamamoto (Yamamoto and Ikegami 1996, 1998, Yamamoto 1997)

In order to make an efficient estimation of the corrosion behaviour, it is considered that the progress of corrosion is a phenomenon governed by the conditions of deteriorating life of paint coatings and the conditions after transiting from active pitting points to pitting points, but the phenomenon of non – corrosion is independent from the behaviour of progressing corrosion. In evaluating the behaviour of the generation and progress of corrosion the events of non – corrosion and corrosion at an arbitrary time t can be expressed respectively as:

$$P[z=0/t]=1-\int_0^t f_{T_0}(t_0)\cdot G_{T_r}(t-t_0)dt_0 \qquad \text{(F.1)}$$

$$P[z=z_p/t]=\int_0^t\left\{\int_0^{t-t_0} p_z(z/t,t_0,t_r)\cdot g_{T_r}(t_r)dt_r\right\}\times f_{T_0}(t_0)dt_0 \qquad \text{(F.2)}$$

Where:

$f_{T_0}(t)$: is the probabilistic model on the effectiveness on paint coatings with the life of pain coating defined as t_0, which is assumed to follow the log – normal distribution (density) with parameters: μ_0 the mean of $ln(t_0)$ and σ_0 the standard deviation of $ln(t_0)$. The coefficient of variance of paint coatings has been determined as: $\frac{\sigma_0}{\mu_0} \approx 0.4$.

$g_{T_r}(t)$: is the probabilistic model on the generating of pitting points with the transition time from active pitting points to progressive pitting points denoted as t_r and is assumed to follow the exponential distribution (density) with parameter α the inverse of mean transition time.

$G_{T_r}(t)$: is the exponential cumulative distribution of the previous model.

$p_z(z/t,t_0,t_r)$: is the probability distribution (density) of depth of pitting corrosion z at an arbitrary time t elapsed after commissioning, provided that times t_0

and t_r are given, it can be expressed as:

$$\frac{1}{\sqrt{2\cdot\pi\cdot\sigma_a\cdot z}}\times exp\left\{-\frac{\left(ln(z)-b\cdot ln(t-t_0-t_r)-\mu_a\right)^2}{2\cdot\sigma_a^2}\right\}$$ with μ_a,σ_a the mean and standard deviation respectively of $ln(a)$. The parameters a and b are coefficients which govern the characteristics of corrosion progress of the probabilistic model on the progress of pitting points: $z(t)=a\cdot t^b$.

By way of reference, the mean and standard deviation of a can be expressed as follows:

$$\mu=E[a]=exp\left(\mu_a+\frac{\sigma_a^2}{2}\right)$$

$$\sigma=\sqrt{V[a]}=\sqrt{(E[a])^2\cdot\left\{exp\left(\sigma_a^2\right)-1\right\}}$$

In order to identify a model for corrosion behaviour of hull structural members, it is necessary to estimate the values of unknown parameters $\mu_0,\alpha,\mu_a,\sigma_a$ and b. In estimating these unknown parameters, maximum likelihood concept can be adopted by applying the data from thickness measurements which represent the generation and progress of corrosion taken at an arbitrary time t:

$Y_t=\left\{y_t^0,y_t^1,y_t^2,...y_t^M\right\}$ whereas M the final stage of corrosion (F.3)

From Eq. (F.1) and (F.2) a probability distribution (cumulative) function of the depth of pitting points at an arbitrary elapsed time could be formulated as:

$$P_{cum}=1-\left\{P[z=0/t]+P[z=z_p/t]\right\} \tag{F.4}$$

but it is very difficult to evaluate this distribution by actual calculations, so a model capable of evaluating such a distribution is constructed by treating both time and amounts of corrosion as discrete quantities.

If a unit time interval is described as Δt and the time at considering $t = K \cdot \Delta t$, the probability of generating an active pitting point within the time interval $[i \cdot \Delta t, (i+1) \cdot \Delta t]$ is given by:

$$f_i = F_{T_0}\{(i+1)\cdot \Delta t\} - F_{T_0}\{i \cdot \Delta t\}; \quad i = 0,1,\ldots K-1 \qquad \text{(F.5)}$$

The probability that the transition time is in the time interval $[j \cdot \Delta t, (j+1)\cdot \Delta t]$ is given as:

$$g_i = G_{T_r}\{(j+1)\cdot \Delta t\} - G_{T_r}\{j \cdot \Delta t\}; \quad j = 0,1,\ldots(K-1)-i \qquad \text{(F.6)}$$

If a unit depth of corrosion is described as δ, the probability that the depth of pitting corrosion is in $[m \cdot \delta, (m+1)\cdot \delta]$ with the condition that the time elapsed after the generation of progressive pitting points $t = (K-i-j)\cdot \Delta t$ is described as:

$$\xi^{(m)}_{K-i-j} = P_z\{(m+1)\cdot \delta / (K-i-j)\cdot \Delta t\} - P_z\{m \cdot \delta / (K-i-j)\cdot \Delta t\} \qquad \text{(F.7)}$$

with the capital letters denoting cumulative probabilities.

Based on these discrete quantities, the probability that the depth of corrosion is in $m^{(th)}$ state at an arbitrary time is expressed as:

$$x_k^{(m)} = \begin{cases} 1 - \sum\limits_{i=0}^{K-1}\left[f_i \cdot \left(\sum\limits_{j=0}^{(K-1)-i} g_j \right)\right] & ; \quad m = 0 \\ \sum\limits_{i=0}^{K-1}\left[f_i \cdot \left(\sum\limits_{j=0}^{(K-1)-i} \left(g_j \cdot \xi^{(m)}_{K-i-j} \right) \right)\right] & ; \quad m \geq 1 \end{cases} \qquad \text{(F.8)}$$

The log – likelihood function for estimating the unknown parameters μ_0 and α can be expressed as:

$$l(\mu_0, \alpha) = \sum_{k=1}^{K}\left[y_k^{(0)} \cdot ln\{x_k^{(0)}(\mu_0, \alpha)\} + \left(\sum_{m=1}^{M} y_k^{(m)} \right)\cdot ln\{1 - x_k^{(0)}(\mu_0, \alpha)\}\right] \qquad \text{(F.9)}$$

The log – likelihood function for estimating the unknown parameters μ_a, σ_a and b can be expressed as:

$$l\left(\mu_a,\sigma_a,b\,/\,\hat{\mu}_0,\hat{\alpha}\right)=\sum_{k=1}^{K}\left[\sum_{m=1}^{M}\left(y_k^{(m)}\cdot \ln\left\{x_k^{(m)}\left(\mu_a,\sigma_a,b\,/\,\hat{\mu}_0,\hat{\alpha}\right)\right\}\right)\right] \qquad \text{(F.10)}$$

F.4.4. Programming the probabilistic model

Initially, was attempted to develop the aforementioned probabilistic model in MathCAD (Mathsoft 2007), but it was found "weak", so programming in the environment of Visual Fortran (Compaq 2001, Visual Numerics 1997) was considered necessary. In the estimation of unknown parameters, unit time interval and unit depth are set to be 0.25 years and 0.5 mm respectively (as defined in Yamamoto and Ikegami (1996, 1998)) and the thickness measurements are represented in a two – way frequency table (histogram) as can be seen from the output file (**Annex 2**). By means of a simple change of sign, the maximum likelihood problem can be treated as locating a minimum. From Eq. (F.9) and (F.10) it is evident that the differentiation is difficult, hence the Golden Search method is applied (Bakopoulos and Chrisovergis 1994). As mentioned in Yamamoto and Ikegami (1996, 1998) and Yamamoto (1997), since parameter b is constrained between 1/3 and 1, it is estimated parametrically. In **Figure F.10** is shown a simple flow – chart (Lazos 1997) of the developed program with reference to the equations. The three probabilistic models (equations (F.5), (F.6) and (F.7)) where defined as function subprograms whilst the maximum likelihood equations (F.9) and (F.10) as subroutines.

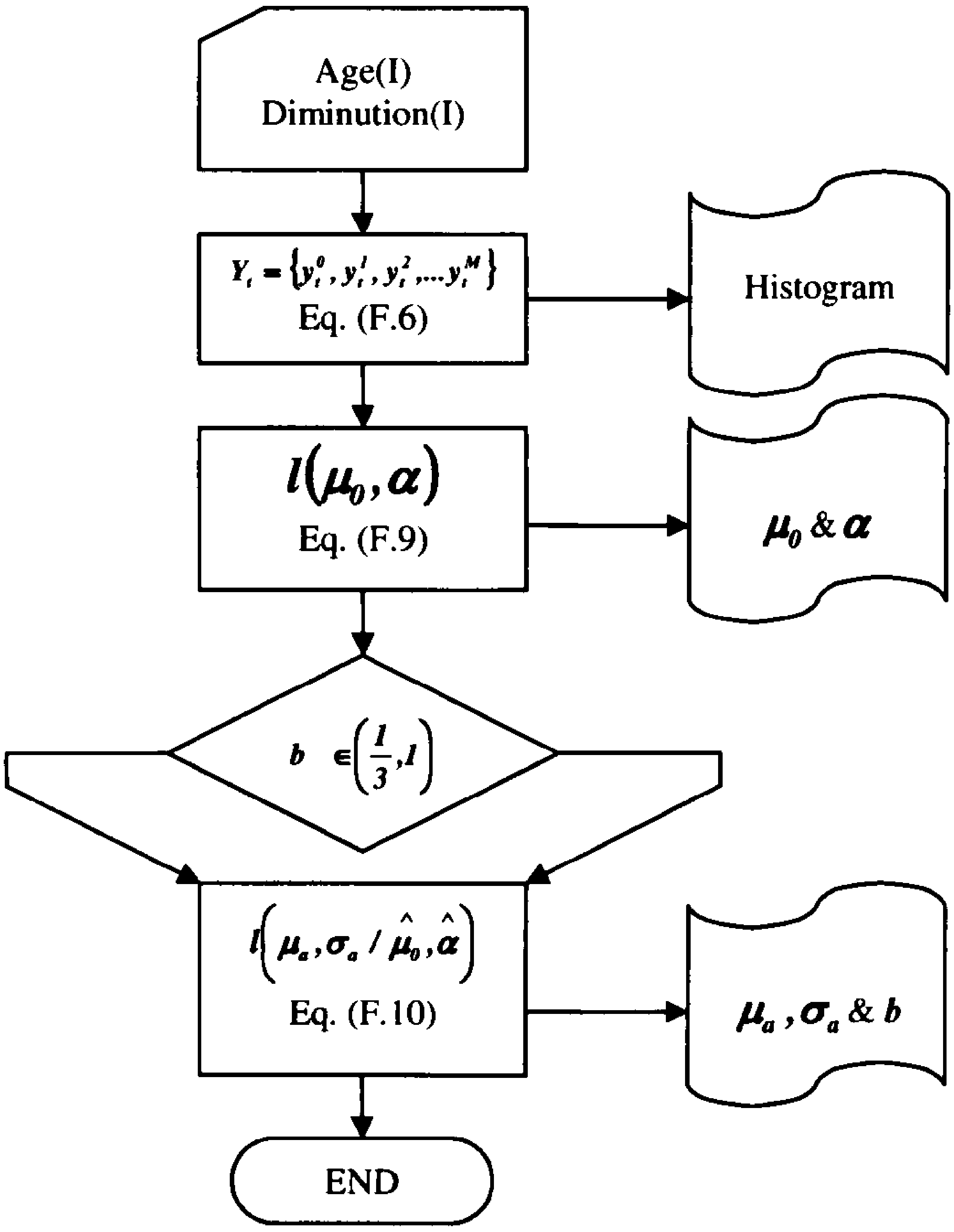


Figure F.10. *Simple flow – chart of the developed program*

F.4.5. Comparison of results

For illustrative purposes, in **Figure F.11**, the cumulative probabilities are incorporated with the thickness measurement data. It needs to be stressed that in the absence of accurate information, although the data is "guessed" the cumulative probabilities coincide well (P1(t): parameter values by Yamamoto and Ikegami (1996, 1998) and Yamamoto (1997), P2(t): parameter values by the developed program). In this figure, solid, dashed, dashed – dotted and dotted lines show the results corresponding to the 95, 85, 70 and 50 %-tile respectively. Solid circles show the actual data from plate thickness measurements.

Evidently, the assumptions of the proposed model can be explained from **Figure F.12**, where it is asserted that thickness loss is not developed exponentially, period of no corrosion exists and annual corrosion rates are not constant.

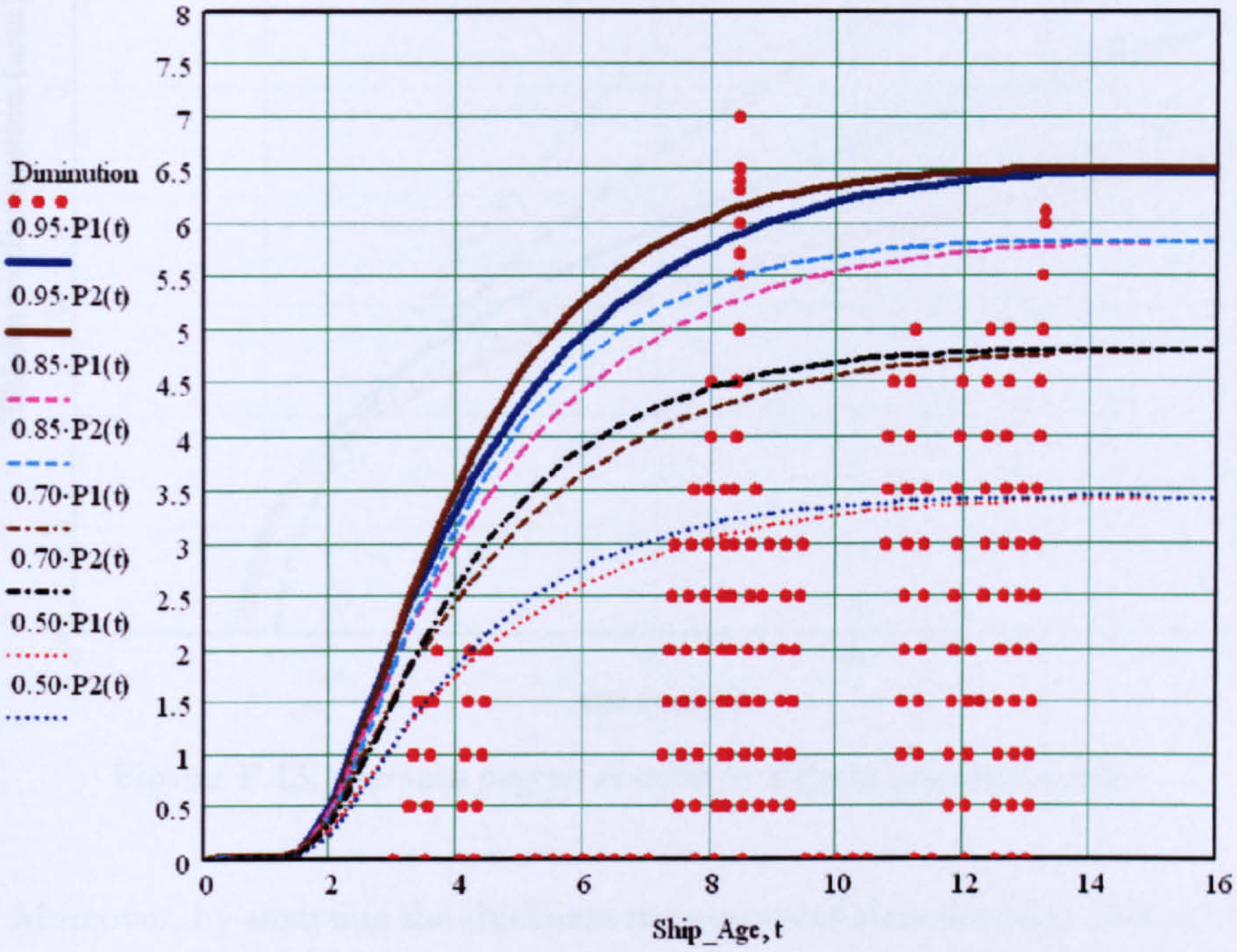


Figure F.11. *Evaluated corrosion behaviour for the lower stool (transverse bulkhead)*

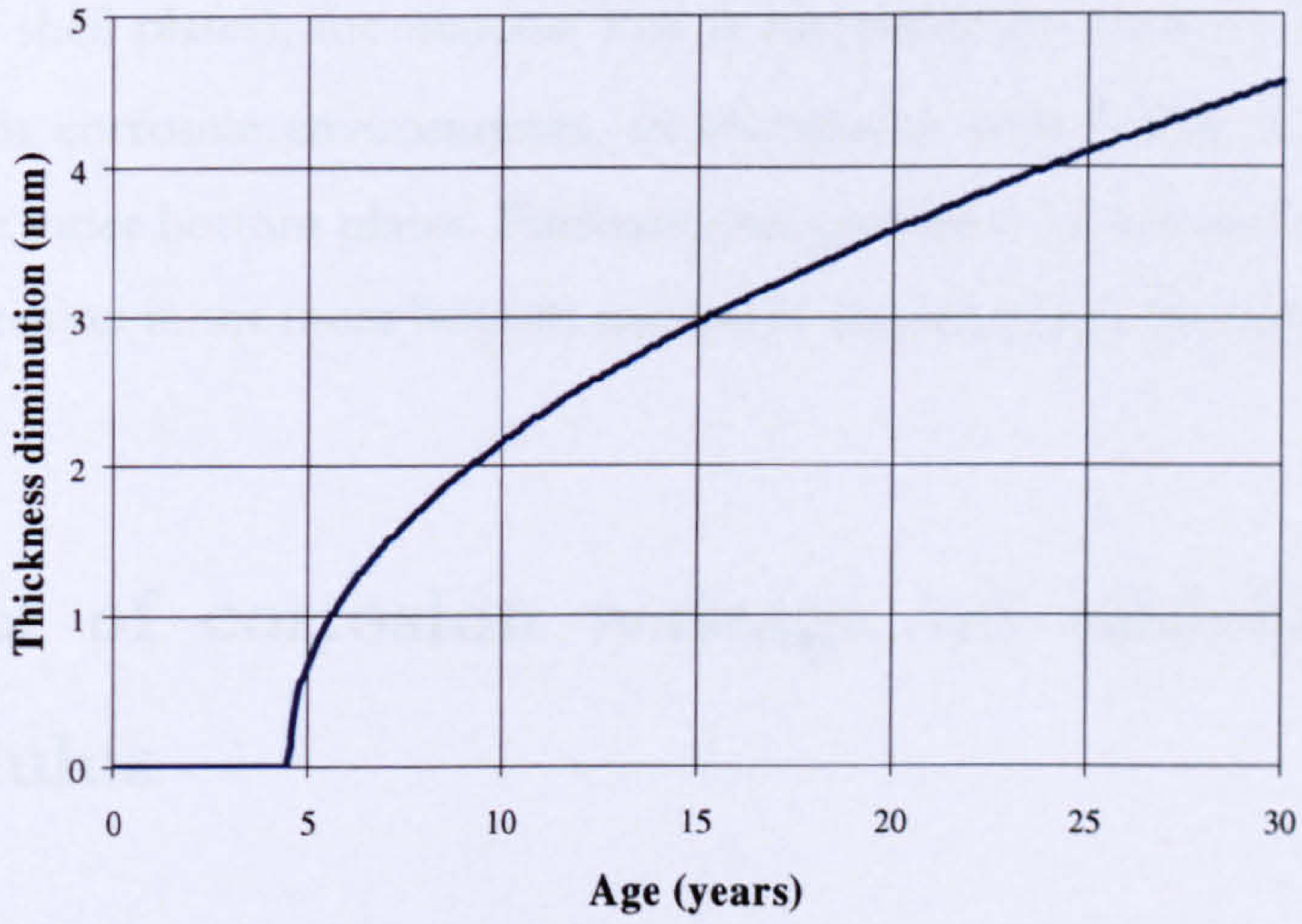


Figure F.12. *Corrosion progress in depth for the lower stool (transverse bulkhead)*

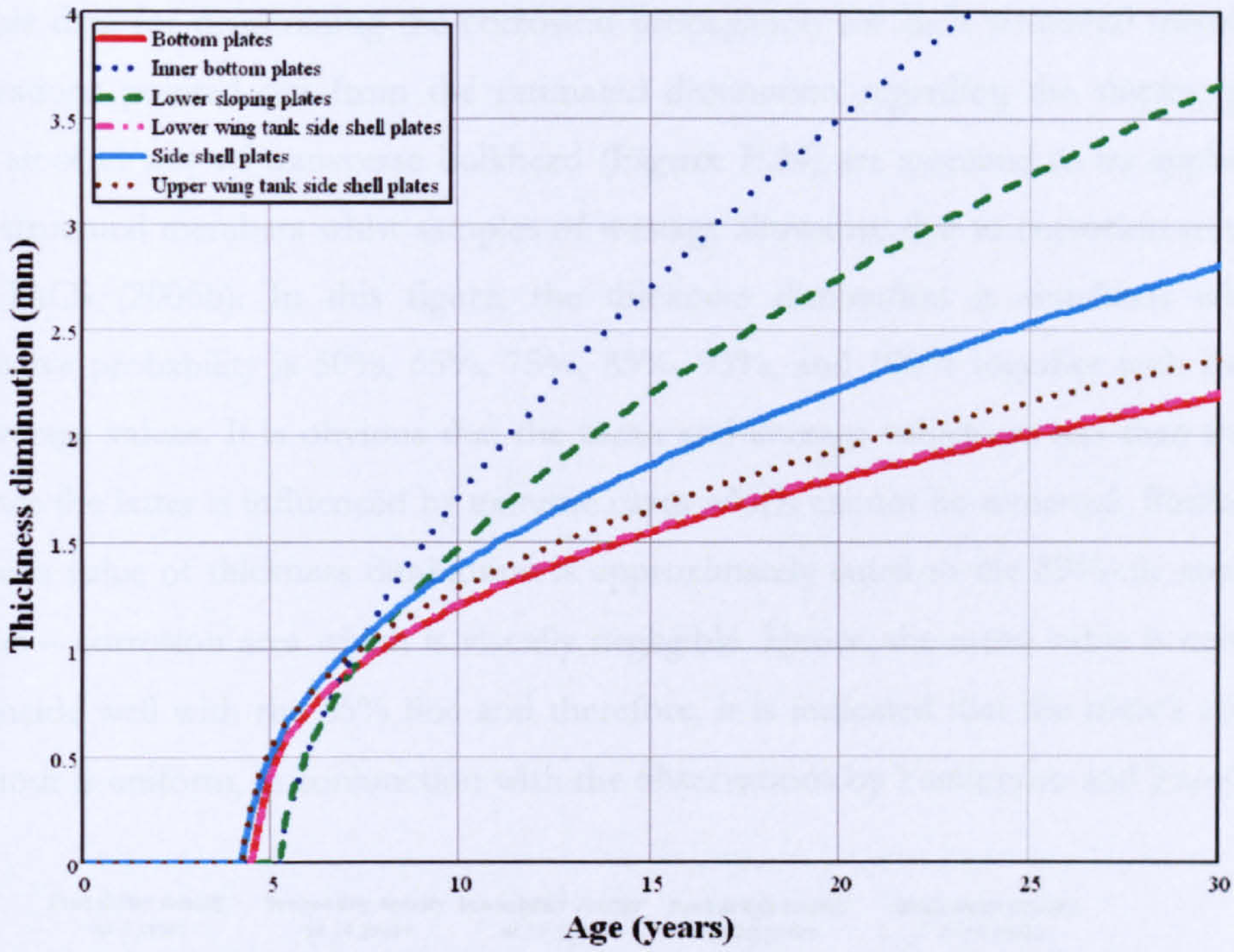


Figure F.13. *Corrosion progress in depth for different structural members*

Moreover, by analysing the thickness measurement data found at Paik et al. (1998), since there are very few databases of corrosion wastage available in the literature and have not been released to the public (Ivanov et al. 2003, Wang et al. 2005) it is seen from **Figure F.13** that although the outer shell is with continuously contact with water (bottom and lower wind shell plates), the material loss is increased for locations that are affected through different corrosive environments, in accordance with **§ F.3**. The worst case is observed for the inner bottom plates. Furthermore, corrosion of the outer shell is initiated sooner than corrosion in the inner bottom and lower sloping plates (as expected).

F.5. Effect of corrosion wastage on midship section modulus

It is generally accepted that corrosion wastage in hull structural members is scattered depending on the location and the environmental conditions. In the absence of available data for determining the corrosion propagation for each structural member, the observations pointed out from the estimated diminution regarding the sloping plate of lower stool in way of transverse bulkhead (**Figure F.14**) are assumed to be applicable to other structural members whist samples of wastage allowance due to corrosion were taken from IACS (2006b). In this figure, the thickness diminution is simulated when the cumulative probability is 50%, 65%, 75%, 85%, 95%, and 100% together with the mean and average values. It is obvious that the mean and average values are less than the 95%-tile since the latter is influenced by extreme cases which cannot be removed. Furthermore, the mean value of thickness diminution is approximately equal to the 85%-tile apart from the non – corrosion area which is visually negligible. Hence, the mean value is considered to coincide well with the 85% line and therefore, it is indicated that the plate's corrosion behaviour is uniform, in conjunction with the observations by Yamamoto and Yao (2002).

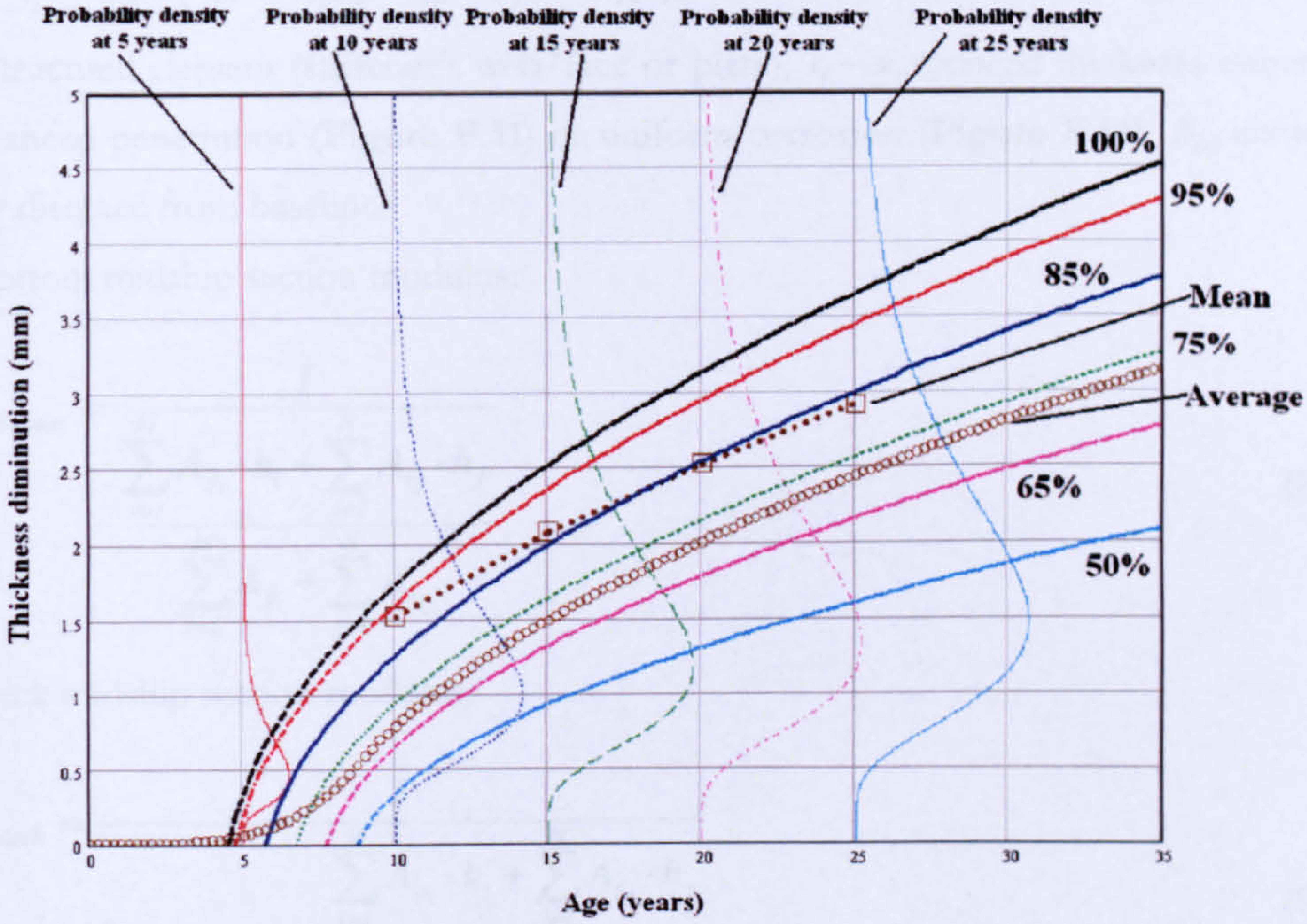


Figure F.14. *An example of the estimated diminution for the sloping plate of lower stool in way of transverse bulkhead*

A variable that is related to the resistance of the hull girder to longitudinal bending is the midship section modulus. The deck and bottom hull section modulus can be calculated by well established procedures as described at Paulling (1988), Samouelides (1999) and Rawson and Tupper (2001). Concurrently, the following equations can be applied, assuming that the dimensions of stiffeners and plates are uncorrelated; the centre of gravity coordinates and width of each structural element do not change by time and only the plates are taken into consideration for their own moment of inertia:

$$I = 2 \cdot \left[\sum_{i=1}^{M} A_{p_i} \cdot h_i^2 + \sum_{j=1}^{N} A_{s_j} \cdot h_j^2 + \sum_{i=1}^{M} \frac{l_i^3 \cdot (t_i - z_i)}{12} - \frac{\left(\sum_{i=1}^{M} A_{p_i} \cdot h_i + \sum_{j=1}^{N} A_{s_j} \cdot h_j \right)^2}{\sum_{i=1}^{M} A_{p_i} + \sum_{j=1}^{N} A_{s_j}} \right] \tag{F.11}$$

Where, I the midship section moment of inertia, $A_{p_i} = l_i \cdot (t_i - z_i)$ plate's cross sectional area, $A_{s_j} = l_{j,W} \cdot (t_{j,W} - z_{j,W}) + l_{j,F} \cdot (t_{j,F} - z_{j,F})$ stiffener's cross sectional area, l_i width of each structural element (stiffener's web/face or plate), $t_i - z_i$ reduced thickness either due to advanced penetration (**Figure F.11**) or uniform corrosion (**Figure F.14**), $h_{i/j}$ centre of gravity distance from baseline.

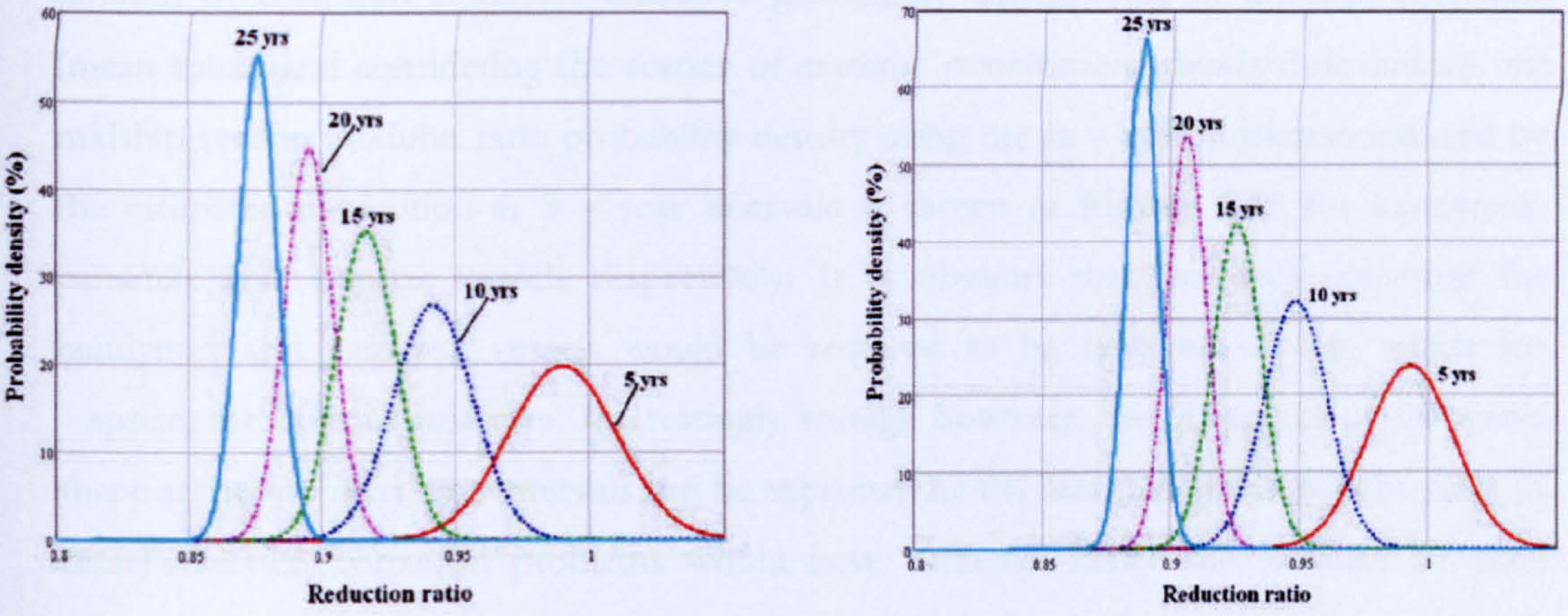
The bottom midship section modulus:

$$Z_{bottom} = \frac{I}{\dfrac{\sum_{i=1}^{M} A_{p_i} \cdot h_i + \sum_{j=1}^{N} A_{s_j} \cdot h_j}{\sum_{i=1}^{M} A_{p_i} + \sum_{j=1}^{N} A_{s_j}}} \tag{F.12}$$

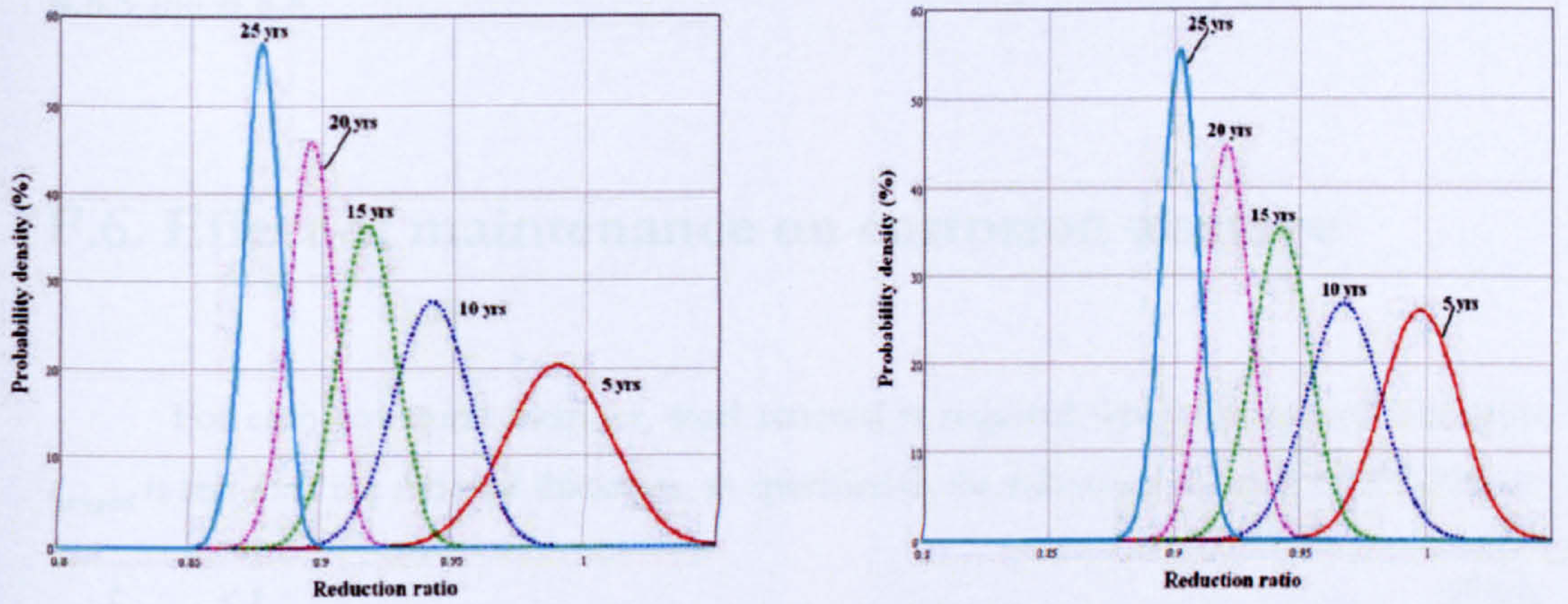
The deck midship section modulus:

$$Z_{deck} = \frac{I}{h_{hatch\ coaming} - \dfrac{\sum_{i=1}^{M} A_{p_i} \cdot h_i + \sum_{j=1}^{N} A_{s_j} \cdot h_j}{\sum_{i=1}^{M} A_{p_i} + \sum_{j=1}^{N} A_{s_j}}} \tag{F.13}$$

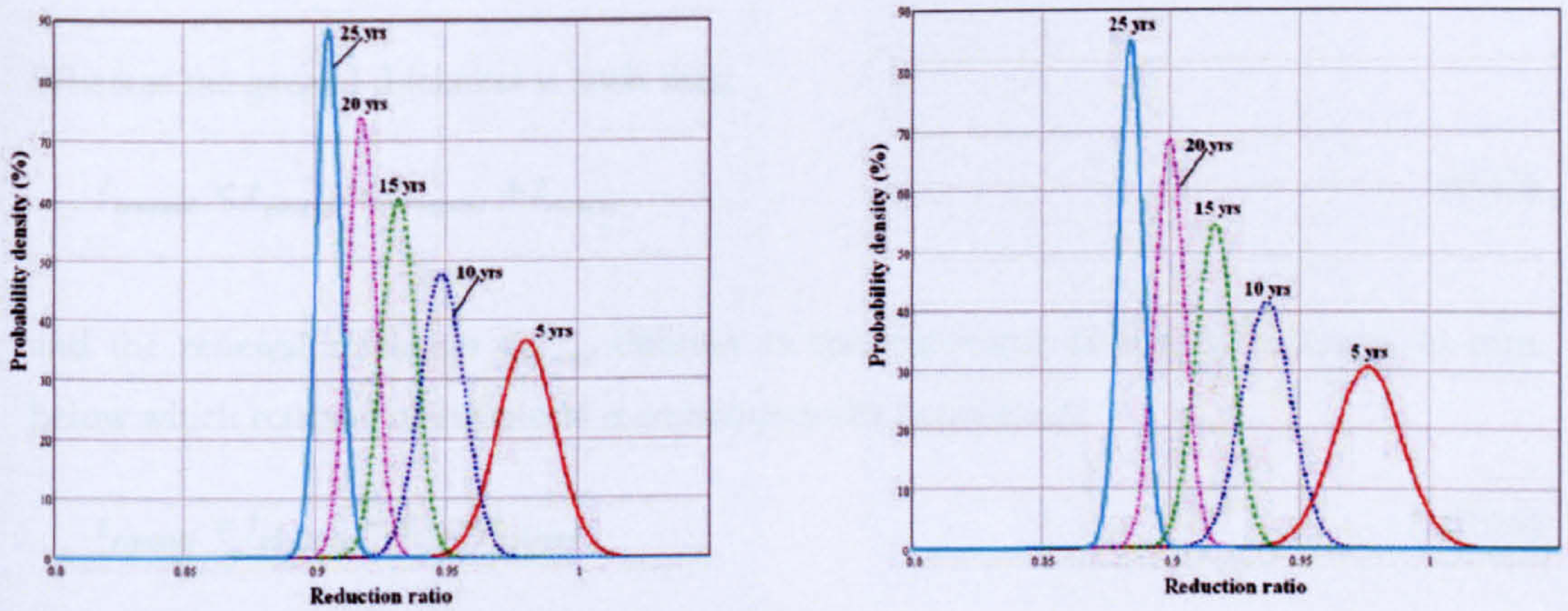
Extensive studies had been carried out (Ivanov 1986, 2002) regarding the time – variant evaluation of the cross sectional modulus in a probabilistic manner where was concluded that it follows the Normal (Gaussian) distribution. In this respect, bearing in mind that the



i. Handymax: Deck ii. Handymax: Bottom



iii. Panamax: Deck iv. Panamax: Bottom



v. Capesize: Deck vi. Capesize: Bottom

Figure F.15. *Midship section modulus reduction ratio* amount of corrosion at 85% cumulative probability corresponds to uniform corrosion (mean value) and considering the scatter of extreme penetration (standard deviation), the midship section modulus ratio probability density using the as – built thickness reduced by the estimated diminution at 5 – year intervals is shown in **Figure F.15** for handymax, panamax and apsize vessels respectively. It is obvious that the deck structure for handymax and panamax vessels would be required to be renewed sooner, whilst for apsize, the bottom structure. Interestingly enough however, the difference of the curve shape at the specified time intervals can be explained by the fact that at the twilight years of vessel's service, corrosion problems would have surfaced, hence the variance between advanced and uniform corrosion would be decreased, similar to the assumptions noted at **§ B.6.5** and **B.6.8**.

F.6. Effect of maintenance on corrosion wastage

For each structural member, steel renewal is required when the gauged thickness t_{gauged} is less than the renewal thickness, as specified in the following formula (IACS 2006a):

$$t_{gauged} < t_{renewal} \tag{F.14}$$

Whereas the gauged thickness is such that:

$$t_{renewal} < t_{gauged} < t_{renewal} + t_{reserve} \tag{F.15}$$

and the renewal thickness $t_{renewal}$ defined as the minimum allowable thickness, in mm, below which renewal of structural members is to be carried out:

$$t_{renewal} = t_{as\_built} - t_{CA} - t_{reserve} \tag{F.16}$$

Furthermore, a replacement programme at a given time interval τ_i can be estimated from the equation (Yamamoto 1997):

$$P_c[z(\tau_i) > z_{renewal}] = 1 - \int_0^{z_{renewal}} p(z/\tau_i)dz \tag{F.17}$$

with $z_{renewal}$ denoting the wastage allowance and $p(z/\tau_i)$ the density of the cumulative probability (mortality) P_{cum} specified at Eq. 4.

Additionally, the problem of severe penetration over a plate due to progress of N advancing pitting points can be evaluated by (Yamamoto 1997):

$$P_{ad}\left[max\{z(\tau_i)\} > t_{as\_built}\right] = 1 - \left[P_{cum}\right]^N \tag{F.18}$$

Moreover, a very important function for the assessment of replacement problems is the age specific failure rate or hazard function for a component (Xerokostas 1999):

$$h(\tau) = \frac{d}{d\tau}\{ln[R(\tau)]\} \tag{F.19}$$

where $R(\tau)$ is the survivor function and defined as the complement of the cumulative mortality.

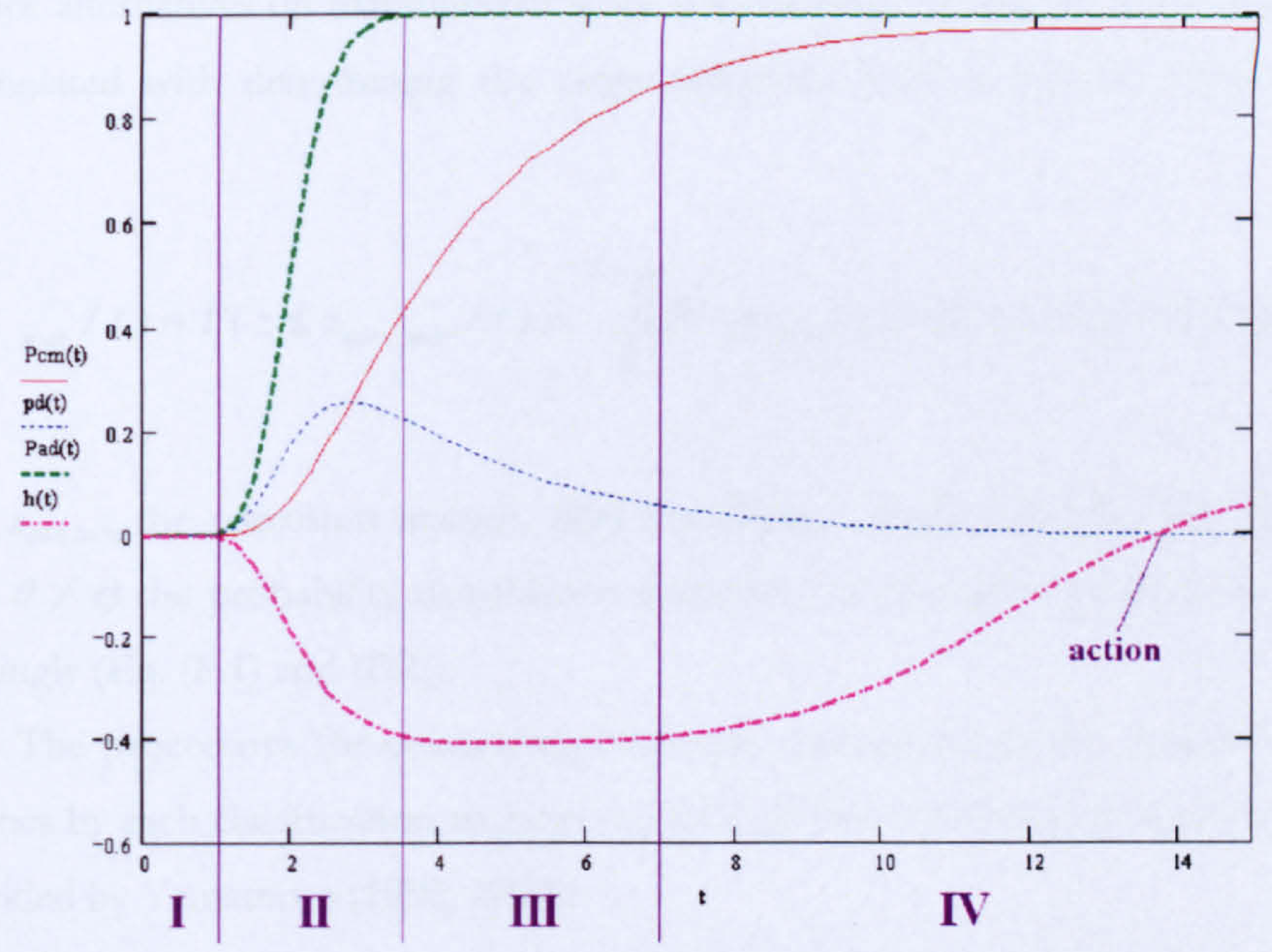


Figure F.16. *Probability functions and life periods of lower stool sloping plate (transverse bulkhead)*

In **Figure F.16**, the cumulative, density, severe penetration probability and hazard (the so – called *"bathtub curve"* (Xerokostas 1999, Dhillon 2007)) functions are illustrated for the sloping plate of lower stool in way of transverse bulkhead. As shown, the first 1.25 years (Zone I) are characterized without corrosion, whilst the next 2.50 years are considered as the component's childhood (infant mortality or wear – in, Zone II). Then the rate is constant until the 7th year (useful life, Zone III), followed by an increasing wear – out pattern (Zone VI). It should be noted that if a component's behaviour is addressed by wear – in failure, replacing it may not be advisable. However, if a wear – out mode is exhibited, replacement of that item may be an appropriate strategy. It can be observed that attention for localized corrosion should be paid from the 1st Intermediate Survey whereas for severe wastage should be given at the 2nd Special Survey. Of course, if action will be needed, that would be subject to the plate's condition either at the 2nd Special or 3rd Intermediate Survey.

Taking into account (**Figure F.16**) this outcome, it should be considered appropriate if that action could be extended at the 3rd Special Survey by increasing the corrosion allowance as illustrated in **Figure F.17**. Furthermore, the effect of different tolerance alternatives on maintenance work is considered, hence the maintenance problem is formulated with determining the target reliability level as follows (Yamamoto 1998, 2000):

$$R(z_{cor\_mar} / t) = P(z \leq z_{cor\_mar} / t) = \int_{0}^{z_{cor\_mar}} \left(P(z = z_t / t) + \delta(z) \cdot P(z = 0 / t) \right) dz \qquad \text{(F.20)}$$

where z_{cor_mar} the corrosion margin, $\delta(z)$ the Dirac – Delta function and $P(z = z_t / t)$, $P(z = 0 / t)$ the probability distribution functions of corrosion progress and generation accordingly (Eq. (F.1) and (F.2)).

The procedures for conducting thickness measurements are outlined in published guidelines by each classification society i.e. DNV (2004), LR (2005), however a brief review is provided by Yamamoto (1998, 2000):

- Depending on the vessel's age and condition, selected structural members are gauged.
- If the reference corrosion level z_g is exceeded, then additional gauging will be carried out on other members.

- If the permissible corrosion level z_r is exceeded, then the member will be renewed.

The probability of gauging a member at the I – th survey can be obtained as (Yamamoto 1998, 2000):

$$P_g(t_i) = \begin{cases} P_g(i,1) + (1 - P_g(i,1)) \cdot P_{ag}(i,1) \cdot P_g(i,2) + \\ + (1 - P_g(i,1)) \cdot P_{ag}(i,1) \cdot (1 - P_g(i,2)) \cdot P_{ag}(i,2) \cdot P_g(i,3) \end{cases} \tag{F.21}$$

Whereas:

$$P_g(i,j) = \frac{m_{i,j}}{M}, \quad \sum_j m_{i,j} = M \tag{F.22}$$

the probability of gauging a member at j – th gauging ***(j = 1, 2, 3)*** of I – th survey ***(I = 1, 2, 3, 4, 5)***, $m_{i,j}$ the number of gauged members at j – th gauging of I – th survey and M the total number of members to be gauged. By way of reference, the following relationship might be used for determining the total sample number (Caridis 2001, 2002, Stambaugh and Knecht 1991):

$$M = \frac{(Z \cdot \sigma)^2}{\Delta^2} \tag{F.23}$$

with: M = Number of samples

Z = Level of confidence statistic (= 2, for 95% of the Normal distribution)

σ = Standard deviation, which represents the error associated with individual measurements

Δ = Level of accuracy associated with the mean value of a set of N data points

$Z \cdot \sigma$ Can be considered equal to the associated instrument/operator error

Assuming σ = 0.05 mm and Δ = 0.005 mm, it follows:

$M_{95\%} = 400$

The probability of carrying out an additional gauging can be defined as (Yamamoto 1998, 2000):

$$P_{ag}(i,j)=\sum_{k=1}^{n_g}\binom{m_{i,j}\cdot n_j}{k}\cdot\left\{P(z_g/t_i)\right\}^{m_{i,j}\cdot n_j-k}\cdot\left\{1-P(z_g/t_i)\right\}^{k} \tag{F.24}$$

with n_g the reference number of points to carry out an additional gauging , n_j $(j = 1, 2, 3)$ the number of gauging points in a member at the j – th gauging, $z_g = 0.75z_r$ the reference level of additional gauging and z_r the permissible corrosion level given as:

$$z_r=\left(z_{cor\_mar}^{\frac{1}{b}}-T_I\cdot\left(E[\alpha]+\sqrt[n]{V[\alpha]}\right)^{\frac{1}{b}}\right)^{b} \tag{F.25}$$

with T_I the time interval between surveys, α, b the coefficients determining the corrosion progress (§ **F.4.3**) and n the number of time intervals.

The probability of renewal of a member at the I – th survey is obtained as (Yamamoto 1998, 2000):

$$P_r(t_i)=\begin{cases}P_g(i,1)\cdot P_{rg}(i,1)+(1-P_g(i,1))\cdot P_{ag}(i,1)\cdot P_g(i,2)\cdot P_{rg}(i,2)+\\+(1-P_g(i,1))\cdot P_{ag}(i,1)\cdot(1-P_g(i,2))\cdot P_{ag}(i,2)\cdot P_{rg}(i,3)\end{cases} \tag{F.26}$$

whereas

$$P_{rg}(i,j)=\sum_{k=1}^{n_r}\binom{n_j}{k}\cdot\left\{P(z_r/t_i)\right\}^{n_j-k}\cdot\left\{1-P(z_r/t_i)\right\}^{k} \tag{F.27}$$

the probability of renewal of a member at the j – th gauging of the I – th survey and n_r the reference number of points in a member to renew.

In connection with the above, the cumulative probability (reliability) of the depth of corrosion after thickness measurements at time t_i may be written as (Yamamoto 1998, 2000):

$$R_{tm}(z/t)=P_r(t_i)\cdot R(z/t-t_i)+(1-P_r(t_i))\cdot R(z/t) \tag{F.28}$$

In **Figure F.18** the effect on maintenance is illustrated. It is obvious that the reliability level is beyond 90% and assuming that the target level could be 98% (it is generally accepted that renewal of steel in primary members cannot always restore structural integrity to its original level), the renewal(s) can be performed at the next survey. Hence, it is envisaged that the off – hire time due to repairs can be reduced.

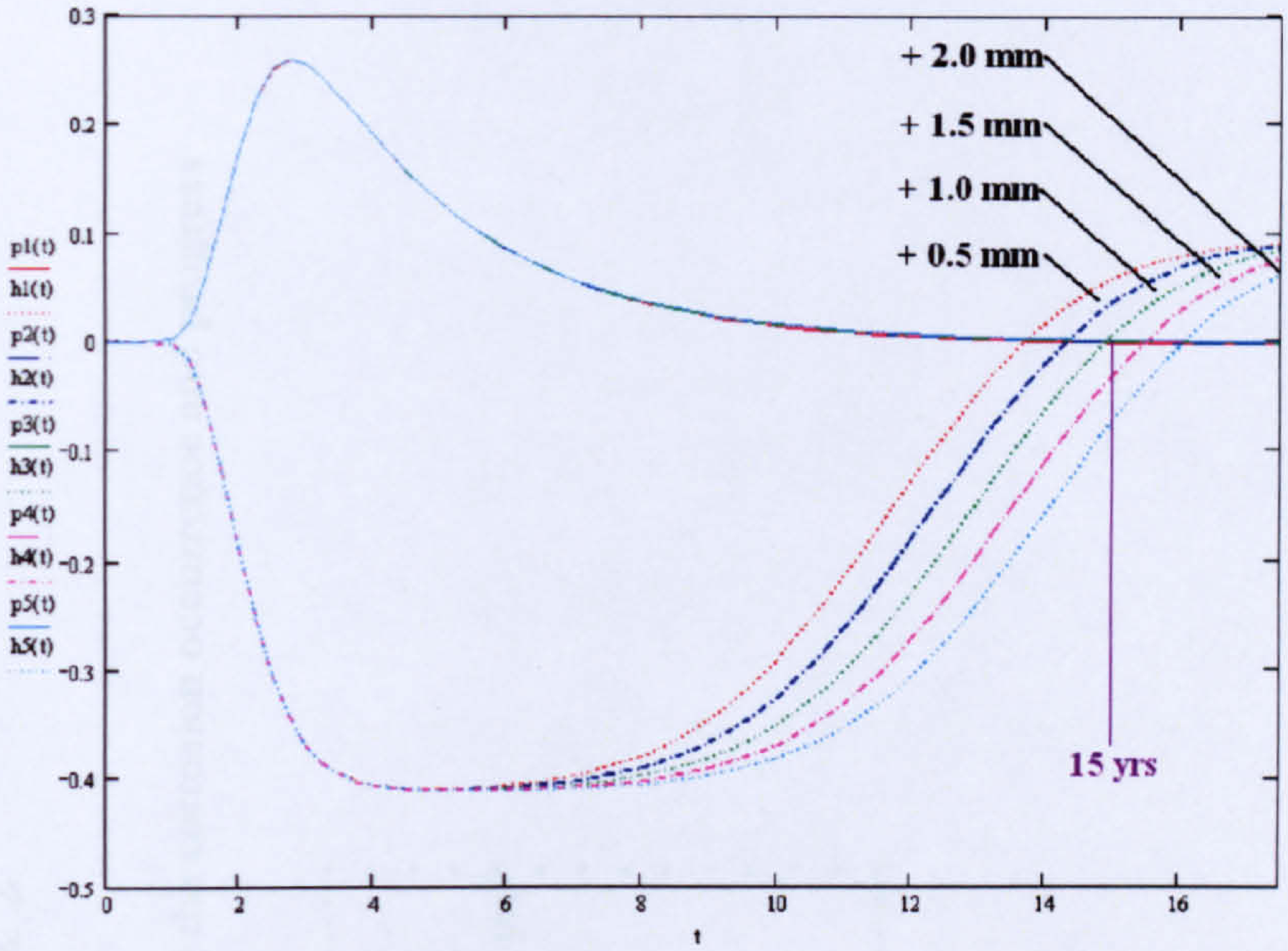


Figure F.17. *Probability density p(t) and hazard h(t) functions for the sloping plate of lower stool in way of transverse bulkhead with different alternatives*

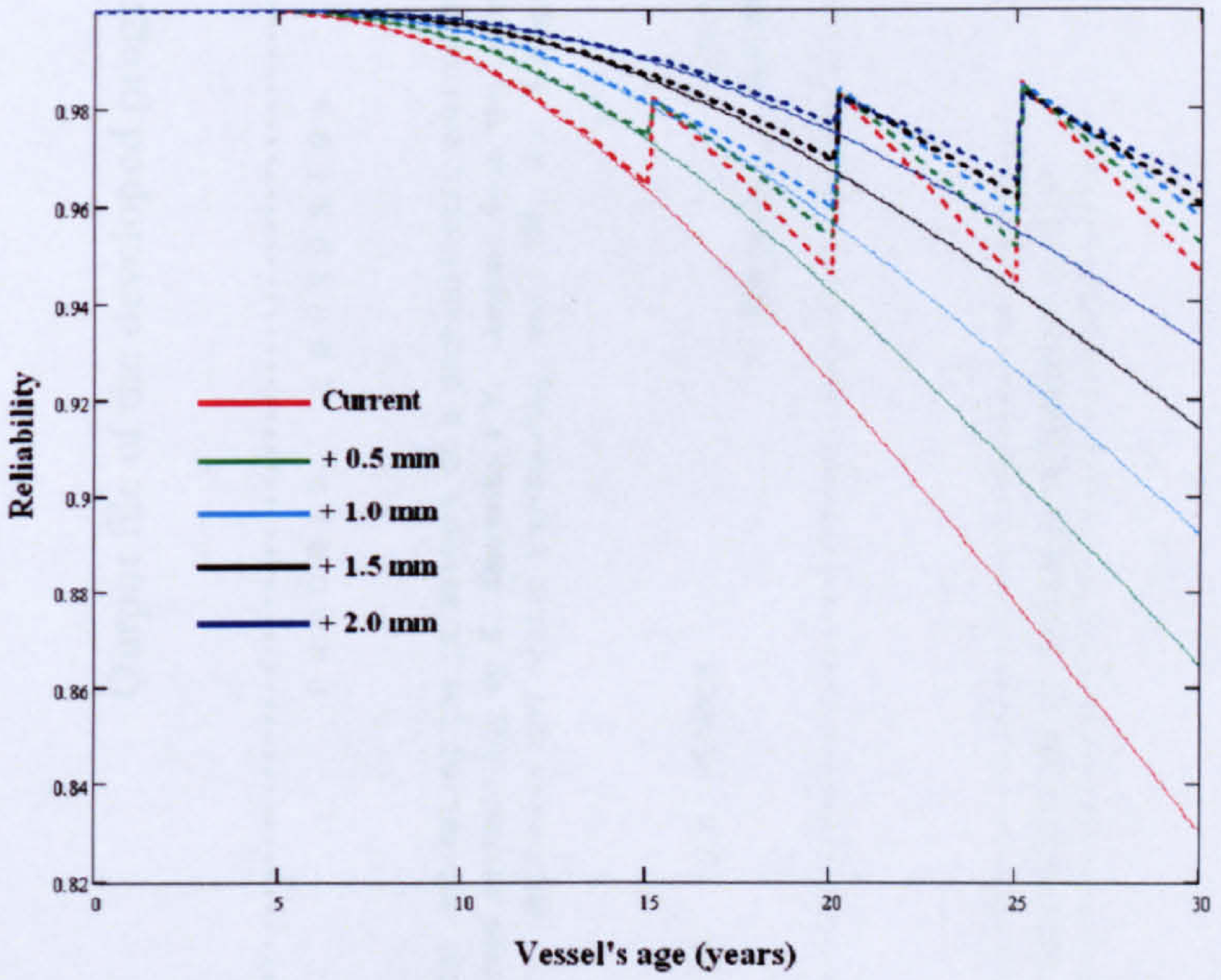


Figure F.18. *Effect of maintenance at the lower stool sloping plate in way of transverse bulkhead considering different alternatives*

ANNEX 2

Output file of the developed program regarding the corrosion occurrence and progress

```
*****************************************************************************************
*                          P R O G R A M   C O R R O S I O N                            *
*                                                                                       *
*                                                                                       *
* Program for estimating the parameters of a probabilistic corrosion model based on the *
*     proposed methodology by N. Yamamoto & K. Ikegami,from the Journal of Offshore     *
*             Mechanics and Arctic Engineering, Vol. 120, No. 3,August 1998             *
*                                                                                       *
*                                                                                       *
*                                                                                       *
*          BY    G.A. PSARROS                                  OCTOBER 2006             *
*                                              1st Revision:  NOVEMBER 2006             *
*                                                                                       *
*****************************************************************************************


**************************************************************
*HISTOGRAM REPRESENTATION OF THICKNESS MEASUREMENT I DATA*
**************************************************************
```

Cutpoints for X (yrs – Rows): 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00 2.25 2.50 2.75 3.00 3.25 3.50 3.75 4.00 4.25 4.50 4.75 5.00 5.25 5.50 5.75 6.00 6.25 6.50 6.75 7.00 7.25 7.50 7.75 8.00 8.25 8.50 8.75 9.00 9.25 9.50 9.75 10.00 10.25 10.50 10.75 11.00 11.25 11.50 11.75 12.00 12.25 12.50 12.75 13.00 13.25

Cutpoints for Y (mm - Columns): 0.00 0.50 1.00 1.50 2.00 2.50 3.00 3.50 4.00 4.50 5.00 5.50 6.00 6.50 7.50

Frequencies

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	8.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	1.0	9.0	21.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	1.0	2.0	6.0	6.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	15.0	57.0	64.0	31.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	40.0	121.0	20.0	8.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	13.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	8.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	16.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	11.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	11.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	18.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	41.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	22.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

```
29    0.0    0.0   22.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
30    0.0    3.0    0.0   28.0   36.0    7.0    2.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
31    1.0    0.0    4.0   11.0   15.0   12.0   22.0   16.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
32    0.0   10.0   12.0   30.0   20.0   52.0   18.0   14.0    2.0    5.0    0.0    0.0    0.0    0.0    0.0
33    9.0   50.0   30.0   58.0   29.0   29.0   14.0    3.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
34   30.0    0.0   60.0   82.0   90.0   65.0   28.0   24.0    8.0    2.0    5.0    1.0    3.0    3.0    1.0
35    0.0   73.0   84.0   94.0  122.0   44.0   34.0   10.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
36    0.0    1.0   21.0   21.0   12.0    1.0    1.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
37    0.0    2.0    4.0    8.0   43.0   32.0    5.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
38   40.0    0.0   27.0   32.0  137.0   39.0    1.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
39   26.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
40   27.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
41   61.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
42   19.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
43    0.0    0.0    0.0    0.0    0.0    0.0   14.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
44    0.0    0.0    1.0    0.0    0.0    0.0    0.0   23.0   39.0   22.0    0.0    0.0    0.0    0.0    0.0
45    5.0    0.0    0.0   11.0   27.0   42.0   34.0   19.0   24.0   18.0    1.0    0.0    0.0    0.0    0.0
46   78.0    0.0    3.0   18.0   33.0    3.0    7.0    1.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
47    0.0    7.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
48    1.0    0.0   36.0   37.0   33.0   61.0   39.0   43.0   39.0    6.0    0.0    0.0    0.0    0.0    0.0
49    0.0    7.0    6.0   12.0   15.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
50   21.0    0.0    0.0    0.0    0.0    2.0   20.0   42.0   37.0    4.0    1.0    0.0    0.0    0.0    0.0
51    1.0   14.0    8.0   11.0   30.0   51.0   46.0   31.0   22.0    5.0    1.0    0.0    0.0    0.0    0.0
52    2.0   14.0   21.0   22.0   44.0   48.0   32.0    9.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
53    0.0   61.0   20.0   30.0   61.0  158.0  125.0  139.0   34.0   40.0   10.0    1.0    1.0    6.0    0.0


-----------------------------------------------------------------------------


*************************************************
*ESTIMATION OF PARAMETERS Mo AND A (Non Corrosion)*
*************************************************

Mo = 0.6955
```

```
A  = 0.4114


===========================================


************************************************************
*ESTIMATION OF PARAMETERS Ma,Sa AND B (Corrosion Progress)*
************************************************************

Ma = -0.1826
Sa =  0.5050
B  =  0.4853


--------------------------------------------------------------------------------


***********************************
*EVALUATION OF CORROSION BEHAVIOUR*
***********************************

MathCAD will be used for plotting the cumulative probabilities vs TM data


--------------------------------------------------------------------------------

Time of operation was:             2788.2188 seconds

************************* END OF RESULTS *************************
```

G The developed computer program

The developed computer program was written in the environment of Visual Fortran (Compaq 2001, Visual Mumerics 1997). In the following **Figure G.1** a simple flow – chart (Lazos 1997) is illustrated with the rectangular boxes representing subroutines, where sample of the output is enclosed at the **Annex 3**.

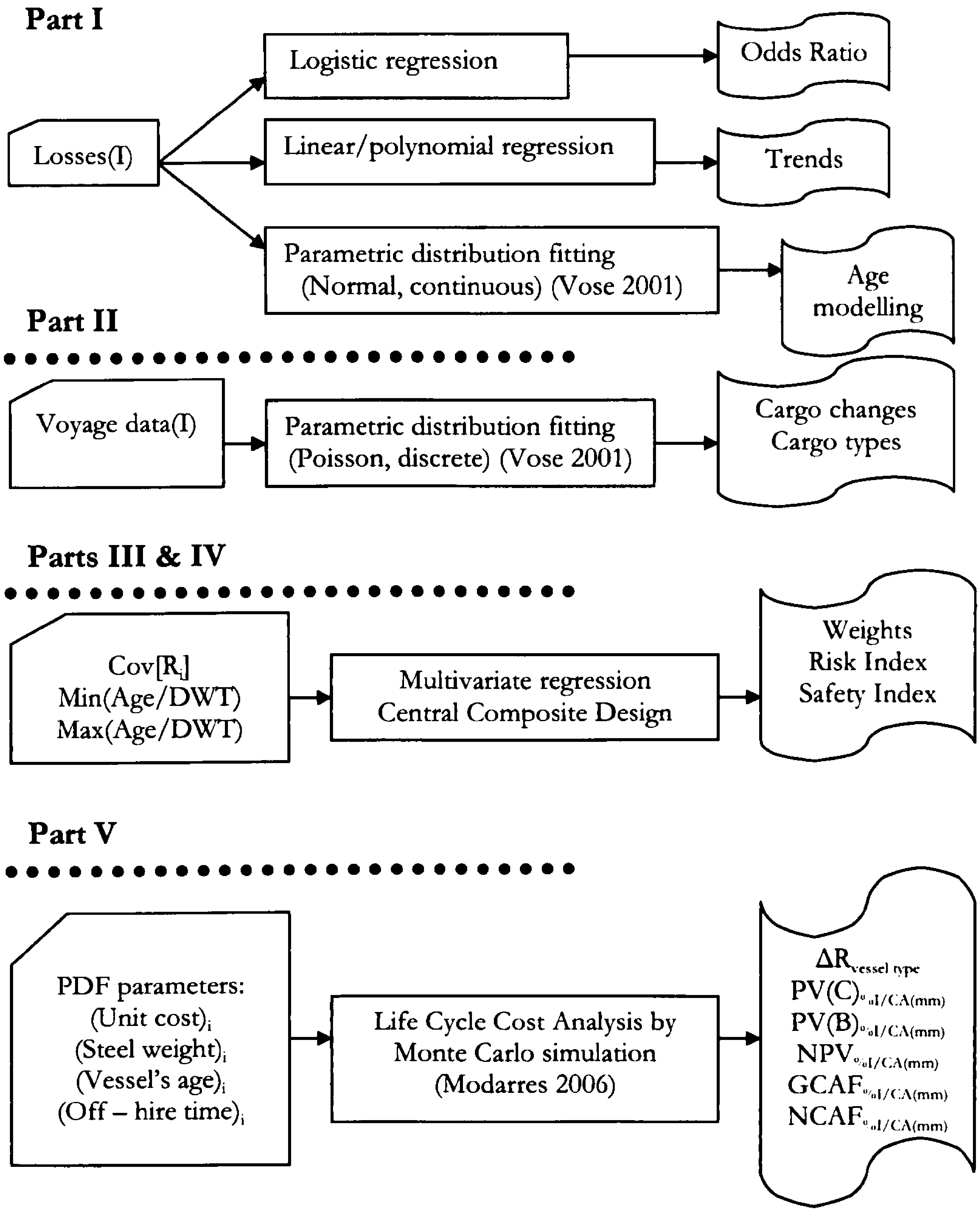


Figure G.1. *Simple flow – chart of the developed program*

ANNEX 3

Sample of the output file

```
*****************************************************************
*                                                               *
*             P R O G R A M     S A F E B U L K E R             *
*                                                               *
*  PROGRAM FOR ASSESSING THE HISTORICAL RISK PROFILE OF BULK CARRIERS  *
*    THEIR ACTUAL OPERATING PROFILE  INTERPRETING THE BN/ID RESULTS    *
*             AND PERFORM COST BENEFIT ASSESSMENT               *
*                                                               *
*        BY G.A.PSARROS                     OCTOBER 2005        *
*                            1st Revision: NOVEMBER 2005        *
*                            2nd Revision:     JUNE 2006        *
*                            3rd Revision:   AUGUST 2006        *
*                            4th Revision: NOVEMBER 2006        *
*                            5th Revision: FEBRUARY 2007        *
*                            6th Revision:    MARCH 2007        *
*                            7th Revision:     JUNE 2007        *
*                            8th Revision:     JULY 2007        *
*                                                               *
*****************************************************************

**********************************
*================================*
*PART I: HISTORICAL ACCIDENTAL RISK*
*================================*
**********************************

****************************************************
*TIME SERIES ANALYSIS FOR TOTAL LOSSES (FOUNDERINGS)*
****************************************************

SHORT-TERM FORECASTING: The linear moving average technique (Losses No.)

                                Incident       Moving             Absolute
Period    Losses    Fleet     Rate/1000      Averages         Percentage error
(Year)     No.       No.       vessels    5-Year 10-Year    5-Year (%) 10-Year (%)

 1969       1        867       1.1534     0.00    0.00        0.00       0.00
 1970       1       1169       0.8554     0.00    0.00        0.00       0.00
 1971       1       1662       0.6017     0.00    0.00        0.00       0.00
 1972       1       1887       0.5299     0.00    0.00        0.00       0.00
 1973       3       2259       1.3280     0.00    0.00        0.00       0.00
 1974       1       2656       0.3765     1.40    0.00        0.40       0.00
 1975       2       2878       0.6949     1.40    0.00        0.30       0.00
 1976       3       3141       0.9551     1.60    0.00        0.47       0.00
 1977       3       3324       0.9025     2.00    0.00        0.33       0.00
 1978       5       3664       1.3646     2.40    0.00        0.52       0.00
 1979       4       3834       1.0433     2.80    2.10        0.30       0.48
 1980      13       3902       3.3316     3.40    2.40        0.74       0.82
 1981       8       3982       2.0090     5.60    3.60        0.30       0.55
 1982       3       4195       0.7151     6.60    4.30        1.20       0.43
 1983       2       4413       0.4532     6.60    4.50        2.30       1.25
 1984       6       4549       1.3190     6.00    4.40        0.00       0.27
 1985       6       4723       1.2704     6.40    4.90        0.07       0.18
 1986       3       4750       0.6316     5.00    5.30        0.67       0.77
 1987      10       4654       2.1487     4.00    5.30        0.60       0.47
 1988       2       4594       0.4354     5.40    6.00        1.70       2.00
 1989       7       4583       1.5274     5.40    5.70        0.23       0.19
 1990      12       4651       2.5801     5.60    6.00        0.53       0.50
 1991      17       4717       3.6040     6.80    5.90        0.60       0.65
 1992       3       4736       0.6334     9.60    6.80        2.20       1.27
 1993       4       4737       0.8444     8.20    6.80        1.05       0.70
 1994       7       4754       1.4724     8.60    7.00        0.23       0.00
 1995       1       4863       0.2056     8.60    7.10        7.60       6.10
 1996       7       5084       1.3769     6.40    6.60        0.09       0.06
 1997       4       5198       0.7695     4.40    7.00        0.10       0.75
 1998       7       5318       1.3163     4.60    6.40        0.34       0.09
 1999       5       5277       0.9475     5.20    6.90        0.04       0.38
 2000       4       5278       0.7579     4.80    6.70        0.20       0.67
 2001       3       5326       0.5633     5.40    5.90        0.80       0.97
 2002       1       5435       0.1840     4.60    4.50        3.60       3.50
 2003       1       5525       0.1810     4.00    4.30        3.00       3.30
 2004       5       5591       0.8943     2.80    4.00        0.44       0.20
 2005       1       5618       0.1780     2.80    3.80        1.80       2.80

                     Mean absolute percentage error:        0.88       0.79

-------------------------------------------------------------

MEDIUM-TERM FORECASTING: The simple linear regression model (Incident rate)

R-squared  Adjusted  Est. Std. Dev.            Coefficient of
(percent) R-squared  of Model Error       Mean  Var. (percent)
   1.596     0.000           0.8009      1.085           73.79

    * * Analysis of Variance * * *
                             Sum of       Mean              Prob. Of
Source               DF     Squares      Square  Overall F  Larger F
Regression            1        0.36      0.3641      0.568    0.4562
Residual             35       22.45      0.6414
Corrected Total      36       22.81

    * * Inference on Coefficients * * *
                        Standard                  Prob. Of    Variance
Coef.     Estimate         Error  t-statistic  Larger |t|    Inflation
    1        19.55         24.50       0.7977      0.4304      34634.2
    2        -0.01          0.01      -0.7534      0.4562          1.0
```

```
MEDIUM-TERM FORECASTING: The simple polynomial regression model (Losses No.)

R-squared   Adjusted  Est. Std. Dev.              Coefficient of
(percent)  R-squared  of Model Error        Mean  Var. (percent)
   31.126     22.517           3.291       4.514           72.92

    * * Analysis of Variance * * *
                               Sum of        Mean                Prob. Of
Source                  DF    Squares      Square  Overall F  Larger F
Regression               4      156.6       39.16      3.615    0.0153
Residual                32      346.6       10.83
Corrected Total         36      503.2

    * * Inference on Coefficients * * *
                      Standard                Prob. Of
Coef.    Estimate        Error  t-statistic  Larger |t|
    1   5.749E+08    9.554E+08        0.602     0.5516
    2  -1.157E+06    1.923E+06       -0.601     0.5518
    3   8.727E+02    1.452E+03        0.601     0.5521
    4  -2.926E-01    4.872E-01       -0.601     0.5523
    5   3.680E-05    6.130E-05        0.600     0.5525
```

```
******************************
*LOGISTIC REGRESSION ANALYSIS*
******************************

LOGISTIC REGRESSION ANALYSIS OF ACCIDENT DATA RELATED TO TRANSPORTED CARGOES
MODEL: ln[p(x)/(1-p(x))]=a+bx

CARGO FAMILY                      Odds ratio     Chi-squared   D.o.f.  p-value

Ferrous ores                        12.3937          4.140         4      0.3874
Coal                                 8.6727          5.851         4      0.2106
Cement                               6.2527          8.321         4      0.0805
Minerals                             8.5221          2.846         4      0.5839
Agricultural & food products         5.7812          7.647         4      0.1054
Fertiliser & chemicals               6.7714          8.898         4      0.0637
Metals                              11.4872          2.213         4      0.6967
Timber                               6.0608          0.274         4      0.9914
Ballast                              5.7919          3.556         4      0.4693

COEFFICIENT STATISTICS (1st row: a   2nd row: b)

CARGO FAMILY                Coefficient    Standard error    Statistic       p-value

Agricultural & food products
                               -0.1447          0.0269         -5.3849         0.0000
                                0.0559          0.0433          1.2910         0.1970

-----------------------------------------------

LOGISTIC REGRESSION ANALYSIS OF ACCIDENT DATA RELATED TO TRADING ROUTES
MODEL: ln[p(x)/(1-p(x))]=a+bx

TRADING ROUTE                       Odds ratio     Chi-squared   D.o.f.  p-value

N America - S America                 8.4413          4.898         4      0.2980
Europe - Europe                       8.7913          7.579         4      0.1083
SW Asia - NE Asia                    11.3085         14.598         4      0.0056
Europe - NE Asia                      5.9598          0.573         4      0.9661
S Africa - NE Asia                    8.8724          2.773         4      0.5965
N America - NE Asia                   8.3693          1.252         4      0.8695
N America - Europe                   12.7680          7.743         4      0.1015
S Asia - Europe                       7.9219          0.035         4      0.9998
S America - Europe                    5.9924          2.066         4      0.7237
Australia - Europe                    5.5294          3.119         4      0.5382
Australia - NE Asia                   4.3099          1.524         4      0.8224
S America - NE Asia                   8.7040          5.984         4      0.2004
N America - SW Asia                   5.8925          0.468         4      0.9765
SW Africa - Europe                    5.0448          2.147         4      0.7088

COEFFICIENT STATISTICS (1st row: a   2nd row: b)

TRADING ROUTE               Coefficient    Standard error   Statistic        p-value

SW Asia - NE Asia
                               -0.0760          0.0166         -4.5757         0.0000
                                0.0434          0.0334          1.2984         0.1944

======================================================================

*******************************************************
*FITTING A PARAMETRIC DISTRIBUTION TO OBSERVED ACCIDENT DATA*
*******************************************************

FINDING THE BEST-FITTING PARAMETERS OF THE NORMAL (GAUSSIAN) DISTRIBUTION USING
 OPTIMISATION

NOTES:

Range:X : Age range (years)
X       : Midpoint value within each range (years)
Obs     : Number of observations
OPDF    : Observed probability density (PDF)
OCDF    : Observed cumulative distribution (CDF)
ECDF    : Estimated cumulative distribution (CDF)
EPDF    : Estimated probability density (PDF)
SqD PDF : Squared difference PDF
LSqDPDF : Least squares difference PDF

TRANSPORTED CARGOES
```

```
**Ferrous ores**

Range:X     X    Obs    OPDF      OCDF      ECDF      EPDF     SqD PDF   LSqDPDF

0-4        3.34   3   0.04918   0.04918   0.09884   0.09884   0.00247   0.00059
5-9        7.67   3   0.04918   0.09836   0.20715   0.10831   0.00350   0.00059
10-14     12.67   9   0.14754   0.24590   0.39300   0.18585   0.00147   0.00059
15-19     17.00  21   0.34426   0.59016   0.57938   0.18638   0.02493   0.00059
20-24     22.29  21   0.34426   0.93443   0.78135   0.20196   0.02025   0.00059
25+       28.00   3   0.04918   0.98361   0.91909   0.13774   0.00784   0.00059
                                                      Sum =   0.06045   0.00352
Mean    = 15.16 Sum   =60
St.Dev.=   9.18 Sum+1=61

Optimised Mean     = 18.46
Optimised St.Dev.  =  5.77

Perform the Chi-Square Goodness-of-fit test for the hypothesis that the observations are Normally distributed

Class intervals (ranges)    : 6
Parameters (mean & st.dev.): 2
Degrees of freedom          : 3
a                           = 0.05
The Chi-Square point is     : 7.815

  X       OCDF      ECDF

 3.34   0.04918   0.00440
 7.67   0.09836   0.03078
12.67   0.24590   0.15786
17.00   0.59016   0.40008
22.29   0.93443   0.74644
28.00   0.98361   0.95079

The test statistic is       : 0.7919

--------------------------------------------------

TRADING ROUTES

**SW Asia - NE Asia**

Range:X     X    Obs    OPDF      OCDF      ECDF      EPDF     SqD PDF   LSqDPDF

0-4        3.25   0   0.00000   0.00000   0.11382   0.11382   0.01296   0.00140
5-9        6.75   4   0.12121   0.12121   0.20300   0.08918   0.00103   0.00140
10-14     10.00   2   0.06061   0.18182   0.31481   0.11181   0.00262   0.00140
15-19     17.63   8   0.24242   0.42424   0.63169   0.31688   0.00554   0.00140
20-24     22.34  12   0.36364   0.78788   0.80001   0.16832   0.03815   0.00140
25+       27.00   6   0.18182   0.96970   0.91014   0.11013   0.00514   0.00140
                                                      Sum =   0.06544   0.00843
Mean    = 14.49 Sum   =32
St.Dev.=   9.32 Sum+1=33

Optimised Mean     = 17.49
Optimised St.Dev.  =  6.04

Perform the Chi-Square Goodness-of-fit test for the hypothesis that the observations are Normally distributed

Class intervals (ranges)    : 6
Parameters (mean & st.dev.): 2
Degrees of freedom          : 3
a                           = 0.05
The Chi-Square point is     : 7.815

  X       OCDF      ECDF

 3.25   0.00000   0.00916
 6.75   0.12121   0.03760
10.00   0.18182   0.10734
17.63   0.42424   0.50928
22.34   0.78788   0.78918
27.00   0.96970   0.94244

The test statistic is       : 0.2618

======================================================================


*********************************
*===============================*
*PART II: ACTUAL OPERATING PROFILE*
*===============================*
*********************************

*************************************************************
*INPUT FOR THE BAYESIAN NETWORK"S CONDITIONAL PROBABILITY TABLES*
*************************************************************

--------------------------------------------------------------------
FITTING A PARAMETRIC DISTRIBUTION TO OBSERVED DATA (HANDYSIZE VESSEL)
--------------------------------------------------------------------


CARGO TYPES TRANSPORTED BY THE GENERIC HANDYSIZE VESSEL


NOTES:

Obs      : Number of observations
OPDF     : Observed probability density (PDF)
EPDF     : Estimated probability density (PDF)
SqD PDF  : Squared difference PDF
LSqDPDF  : Least squares difference PDF

**(0-4) YEARS AGE RANGE**
```

```
Cargo Type                   Obs      OPDF    EPDF       SqD PDF   LSqDPDF

Ferrous_ores                  1      0.0588  0.2538     0.038014  0.007190
Coal                          3      0.1765  0.1910     0.000211  0.007190
Cement                        2      0.1176  0.2697     0.023107  0.007190
Minerals                      2      0.1176  0.2697     0.023107  0.007190
Agricultural_&_food_products  4      0.2353  0.1015     0.017908  0.007190
Fertilisers_&_chemicals       2      0.1176  0.2697     0.023107  0.007190
Metals                        2      0.1176  0.2697     0.023107  0.007190
Timber                        1      0.0588  0.2538     0.038014  0.007190
                                                Sum =   0.186576  0.057518
Voyages No =                 17

Lamda           = 2.1250

Optimised Lamda = 4.2419

Uncertainty in Lamda - N(4.24,.50)

Perform the Chi-Squared Goodness of fit test for the hypothesis that the transported cargoes follow the Poisson
Process

Class intervals (ranges) :   8
Parameters (Lamda)       :   1
Degrees of freedom       :   6
a                        : 0.05
The Chi-Squared point is :12.592

Cargo type                   Obs         OPDF      EPDF

Ferrous_ores                  1        0.05882   0.06100
Coal                          3        0.17647   0.18293
Cement                        2        0.11765   0.12937
Minerals                      2        0.11765   0.12937
Agricultural_&_food_products  4        0.23529   0.19400
Fertilisers_&_chemicals       2        0.11765   0.12937
Metals                        2        0.11765   0.12937
Timber                        1        0.05882   0.06100

The test statistic is    : 0.01343

CARGO CHANGES OF THE GENERIC HANDYSIZE VESSEL

NOTES:

X-times   : Cargo changes per year (Point for Poisson PDF)
X-value   : Observed changes per year
PPDF      : Poisson PDF
PPDFCor   : Corrected Poisson PDF
O(i)      : Observed frequency
SQDif     : Squared Difference Calculation
LSSQDif   : Least Squares Squared Difference Calculation
E(i)      : Estimated PDF

****(10-14) years age range****

X-times    X-value      PPDF

  1st        3        0.30410
  2nd        4        0.26609
  3rd        1        0.15522
  4th        0        0.00000
  5th        0        0.00000
  6th+       0        0.00000

      Sum :  8

Poisson parameter (lamda)=  1.7500

Testing of the Poisson distribution by minimizing the sum of squared deviations

X-times    PPDFCor    O(i)     SQDif     LSSQDif

  1st     0.30410    0.38     0.0165     0.0105
  2nd     0.26609    0.50     0.2056     0.0105
  3rd+    0.15522    0.12     0.0059     0.0105
                          Sum = 0.2280    0.0314

Optimised Poisson parameter (lamda)=  1.4015

Uncertainty in Lamda - N(1.40,.10)

Perform the Chi-Squared Goodness of fit test for the hypothesis that the transported cargoes follow the Poisson
Process

Class intervals (ranges) :   3
Parameters (Lamda)       :   1
Degrees of freedom       :   1
a                        : 0.05
The Chi-Squared point is : 3.841

X-times     N         O(i)       E(i)

  1st       3       0.37500    0.34509
  2nd       4       0.50000    0.30691
  3rd+      1       0.12500    0.17380

The test statistic is    : 0.13777

------------------------------------------------

----------------------------------------------------------------
FITTING A PARAMETRIC DISTRIBUTION TO OBSERVED DATA (HANDYMAX VESSEL)
----------------------------------------------------------------
```

```
CARGO TYPES TRANSPORTED BY THE GENERIC HANDYMAX VESSEL

**(5-9) YEARS AGE RANGE**

Cargo Type                    Obs     OPDF    EPDF      SqD PDF   LSqDPDF

Ferrous_ores                   3     0.1765  0.2105    0.001156  0.005308
Coal                           4     0.2353  0.1278    0.011558  0.005308
Cement                         3     0.1765  0.2105    0.001156  0.005308
Minerals                       2     0.1176  0.2600    0.020262  0.005308
Agricultural_&_food_products   2     0.1176  0.2600    0.020262  0.005308
Fertilisers_&_chemicals        1     0.0588  0.2141    0.024114  0.005308
Metals                         2     0.1176  0.2600    0.020262  0.005308
                                                Sum =  0.098768  0.037153
Voyages No =                  17

Lamda          = 2.4286

Optimised Lamda = 4.5455

Uncertainty in Lamda - N(4.55,.52)

 Perform the Chi-Squared Goodness of fit test for the hypothesis that the transported cargoes follow the Poisson
Process

Class intervals (ranges) :   8
Parameters (Lamda)       :   1
Degrees of freedom       :   6
a                        : 0.05
The Chi-Squared point is :12.592

Cargo type                    Obs       OPDF     EPDF

Ferrous_ores                   3       0.17647  0.16615
Coal                           4       0.23529  0.18881
Cement                         3       0.17647  0.16615
Minerals                       2       0.11765  0.10966
Agricultural_&_food_products   2       0.11765  0.10966
Fertilisers_&_chemicals        1       0.05882  0.04825
Metals                         2       0.11765  0.10966

The test statistic is    : 0.01679

--------------------------------------------------


CARGO CHANGES OF THE GENERIC HANDYMAX VESSEL

****(0-4) years age range****

X-times    X-value     PPDF

  1st         2       0.28993
  2nd         4       0.26922
  3rd         1       0.16666
  4th         0       0.00000
  5th         0       0.00000
  6th+        0       0.00000

     Sum :    7

Poisson parameter (lamda)=  1.8571

Testing of the Poisson distribution by minimizing the sum of squared deviations

X-times    PPDFCor   O(i)     SQDif    LSSQDif

  1st      0.28993   0.29     0.0001    0.0094
  2nd      0.26922   0.57     0.3392    0.0094
  3rd+     0.16666   0.14     0.0034    0.0094
                        Sum = 0.3427    0.0282

Optimised Poisson parameter (lamda)=  1.4404

Uncertainty in Lamda - N(1.44,.11)

 Perform the Chi-Squared Goodness of fit test for the hypothesis that the transported cargoes follow the Poisson
Process

Class intervals (ranges) :   3
Parameters (Lamda)       :   1
Degrees of freedom       :   1
a                        : 0.05
The Chi-Squared point is : 3.841

X-times     N          O(i)      E(i)

  1st       2        0.28571   0.34114
  2nd       4        0.57143   0.31182
  3rd+      1        0.14286   0.18148

The test statistic is    : 0.23336

-----------------------------------------------------------------
FITTING A PARAMETRIC DISTRIBUTION TO OBSERVED DATA (PANAMAX VESSEL)
-----------------------------------------------------------------

**(10-14) YEARS AGE RANGE**

Cargo Type                    Obs     OPDF    EPDF      SqD PDF   LSqDPDF

Ferrous_ores                   1     0.1111  0.3554    0.059696  0.016650
Coal                           2     0.2222  0.2285    0.000039  0.016650
Cement                         0     0.0000  0.2765    0.076426  0.016650
Minerals                       2     0.2222  0.2285    0.000039  0.016650
Agricultural_&_food_products   3     0.3333  0.0979    0.055416  0.016650
Fertilisers_&_chemicals        1     0.1111  0.3554    0.059696  0.016650
```

```
Metals                          0       0.0000  0.2765     0.076426  0.016650
                                                   Sum =   0.327740  0.116547
Voyages No =                    9

Lamda           = 1.2857

Optimised Lamda = 3.4022

Uncertainty in Lamda - N(3.40,.61)

Perform the Chi-Squared Goodness of fit test for the hypothesis that the transported cargoes follow the Poisson
Process

Class intervals (ranges) :   8
Parameters (Lamda)       :   1
Degrees of freedom       :   6
a                        : 0.05
The Chi-Squared point is :12.592

Cargo type                      Obs          OPDF       EPDF

Ferrous_ores                    1         0.11111    0.11329
Coal                            2         0.22222    0.19272
Cement                          0         0.00000    0.03330
Minerals                        2         0.22222    0.19272
Agricultural_&_food_products    3         0.33333    0.21856
Fertilisers_&_chemicals         1         0.11111    0.11329
Metals                          0         0.00000    0.03330

The test statistic is     : 0.13599
```

```
CARGO CHANGES OF THE GENERIC PANAMAX VESSEL

****(10-14) years age range****

X-times    X-value       PPDF

  1st         2        0.29754
  2nd         2        0.26778
  3rd         1        0.16067
  4th         0        0.00000
  5th         0        0.00000
  6th+        0        0.00000

      Sum :     5

Poisson parameter (lamda)=  1.8000

Testing of the Poisson distribution by minimizing the sum of squared deviations

X-times     PPDFCor    O(i)      SQDif    LSSQDif

  1st      0.29754   0.40     0.0353    0.0100
  2nd      0.26778   0.40     0.0653    0.0100
  3rd+     0.16067   0.20     0.0096    0.0100
                          Sum = 0.1102     0.0299

Optimised Poisson parameter (lamda)=  1.4198

Uncertainty in Lamda - N(1.42,.16)

Perform the Chi-Squared Goodness of fit test for the hypothesis that the transported cargoes follow the Poisson
Process

Class intervals (ranges) :   3
Parameters (Lamda)       :   1
Degrees of freedom       :   1
a                        : 0.05
The Chi-Squared point is : 3.841

X-times     N         O(i)       E(i)

  1st       2       0.40000    0.34326
  2nd       2       0.40000    0.30927
  3rd+      1       0.20000    0.17742

The test statistic is     : 0.03887

---------------------------------------------------------------
FITTING A PARAMETRIC DISTRIBUTION TO OBSERVED DATA (CAPESIZE VESSEL)
---------------------------------------------------------------

CARGO TYPES TRANSPORTED BY THE GENERIC CAPESIZE VESSEL


**(20-24) YEARS AGE RANGE**

Cargo Type                      Obs       OPDF     EPDF        SqD PDF    LSqDPDF

Ferrous_ores                    7       0.7778   0.0824     0.483602   0.001238
Coal                            2       0.2222   0.1125     0.012044   0.001238
                                                   Sum =    0.495645   0.002475
Voyages No =                    9

Lamda          = 4.5000

Optimised Lamda = 6.0015

Uncertainty in Lamda - N(6.00,.82)

Perform the Chi-Squared Goodness of fit test for the hypothesis that the transported cargoes follow the Poisson
Process

Class intervals (ranges) :   8
Parameters (Lamda)       :   1
Degrees of freedom       :   6
a                        : 0.05
The Chi-Squared point is :12.592
```

```
Cargo type                    Obs          OPDF       EPDF

Ferrous_ores                   7         0.77778    0.13771
Coal                           2         0.22222    0.04457

The test statistic is     : 3.68299


CARGO CHANGES OF THE GENERIC CAPESIZE VESSEL

****(10-14) years age range****

X-times    X-value      PPDF

  1st         1       0.18529
  2nd         1       0.24705
  3rd         0       0.00000
  4th         0       0.00000
  5th         1       0.07808
  6th+        0       0.00000

    Sum :     3

Poisson parameter (lamda)=  2.6667

Testing of the Poisson distribution by minimizing the sum of squared deviations

X-times     PPDFCor    O(i)      SQDif    LSSQDif

  1st     0.18529   0.33     0.1183    0.0042
  2nd     0.24705   0.33     0.0301    0.0042
  3rd+    0.07808   0.33     0.8344    0.0042
                         Sum = 0.9829    0.0125

Optimised Poisson parameter (lamda)=  1.7339

Uncertainty in Lamda - N(1.73,.22)

Perform the Chi-Squared Goodness of fit test for the hypothesis that the transported cargoes follow the Poisson
Process

Class intervals (ranges) :   3
Parameters (Lamda)       :   1
Degrees of freedom       :   1
a                        : 0.05
The Chi-Squared point is : 3.841

X-times      N          O(i)       E(i)

  1st        1        0.33333    0.30619
  2nd        1        0.33333    0.33692
  3rd+       1        0.33333    0.23605

The test statistic is     : 0.04253
```

```
************************************
*==================================*
*PART III: BN RESULTS INTERPRETATION*
*==================================*
************************************
```

```
------------------------------------------------------------
ESTIMATION OF WEIGHTING FACTORS BY MULTIPLE LINEAR REGRESSION
------------------------------------------------------------


Model: R = b1X1+b2X2+b3X4+b4X4


      B
1   0.0008
2   0.7525
3   0.1853
4   0.0614

                 Total Sum of Squares =    6929.84
             Sum of Squares for error =     688.06


ANALYSIS OF VARIANCE (ANOVA)


R-squared   Adjusted  Est. Std. Dev.
(percent)  R-squared  of Model Error
   91.718     89.352             7.01

    * * Analysis of Variance * * *
                                Sum of          Mean                  Prob. Of
Source                   DF     Squares        Square   Overall F   Larger F
Regression                4      7620.1        1905.0      38.762     0.0000
Residual                 14       688.1          49.1
Uncorrected Total        18      8308.2

    * * Sequential Statistics * * *
Indep.    Degrees of      Sum of                    Prob. Of
Variable     Freedom      Squares   F-statistic     Larger F
      1            1       6961.1       141.639       0.0000
      2            1        625.4        12.725       0.0031
      3            1         31.8         0.646       0.4350
      4            1          1.9         0.039       0.8466
```

```
----------------------------------------
APPLICATION OF RESPONSE SURFACE METHODOLOGY
----------------------------------------
```

```
Generation of an orthogonal Central Composite Design (CCD)
Notes:
Factorial points: First four
Center points   : Next four
Axial points    : Last four

NPTS =           12

        X
        1       2
1    27.25   23.62
2    27.25   22.18
3    24.36   23.62
4    24.36   22.18
5    25.81   22.90
6    25.81   22.90
7    25.81   22.90
8    25.81   22.90
9    24.06   22.90
10   27.55   22.90
11   25.81   22.03
12   25.81   23.77


The design matrix Mat:

 1.   1.44  0.72  2.0798  0.5170  1.0369
 1.   1.44 -0.72  2.0798  0.5170 -1.0369
 1.  -1.44  0.72  2.0798  0.5170 -1.0369
 1.  -1.44 -0.72  2.0798  0.5170  1.0369
 1.   0.00  0.00  0.0000  0.0000  0.0000
 1.   0.00  0.00  0.0000  0.0000  0.0000
 1.   0.00  0.00  0.0000  0.0000  0.0000
 1.   0.00  0.00  0.0000  0.0000  0.0000
 1.  -1.75  0.00  3.0450  0.0000  0.0000
 1.   1.74  0.00  3.0450  0.0000  0.0000
 1.   0.00 -0.87  0.0000  0.7569  0.0000
 1.   0.00  0.87  0.0000  0.7569  0.0000


The vector Y:

 21.69
 21.41
 21.69
 20.56
 21.07
 21.76
 21.41
 21.76
 20.84
 20.71
 20.53
 21.49


The least squares estimation of b=Inv(Tran(Mat)*Mat)*Tran(Mat)*Y:

   21.530
   -0.062
   -0.516
   -0.136
   -0.272
   -0.205


ANALYSIS OF VARIANCE (ANOVA)


R-squared   Adjusted  Est. Std. Dev.               Coefficient of
(percent)  R-squared  of Model Error         Mean  Var. (percent)
   96.718     94.092         0.01446        23.96         0.06035

    * * Analysis of Variance * * *
                                  Sum of          Mean                Prob. Of
Source                    DF     Squares        Square   Overall F   Larger F
Regression                 5     0.03080      0.007699      36.833     0.0007
Residual                   6     0.00105      0.000209
Reduced Model Total       11     0.03184

    * * Sequential Statistics * * *
Indep.    Degrees of      Sum of                     Prob. Of
Variable     Freedom     Squares   F-statistic       Larger F
      1            1     0.00009         0.419         0.5461
      2            1     0.00008         0.321         0.4356
      3            1     0.01640        78.475         0.0003
      4            1     0.00866        41.406         0.0013
      5            1     0.00565        27.033         0.0035
```

```
The complement of vector Y (Y"):

 78.31
 78.59
 78.31
 79.44
 78.93
 78.24
 78.59
 78.24
 79.16
 79.29
 79.47
 78.51


The least squares estimation of b"=Inv(Tran(Mat)*Mat)*Tran(Mat)*Y":
```

```
   78.470
    0.062
    0.516
    0.136
    0.272
    0.205


ANALYSIS OF VARIANCE (ANOVA)


R-squared   Adjusted  Est. Std. Dev.                Coefficient of
(percent)  R-squared  of Model Error          Mean  Var. (percent)
   96.718     94.092         0.01446         76.04         0.01901

    * * Analysis of Variance * * *
                                Sum of        Mean               Prob. Of
Source                    DF    Squares       Square  Overall F  Larger F
Regression                 5    0.03080     0.007699     36.833    0.0007
Residual                   6    0.00105     0.000209
Reduced Model Total       11    0.03184

    * * Sequential Statistics * * *
Indep.    Degrees of     Sum of                 Prob. Of
Variable     Freedom     Squares  F-statistic    Larger F
       1           1     0.00009        0.419      0.5461
       2           1     0.00008        0.321      0.4356
       3           1     0.01640       78.475      0.0003
       4           1     0.00866       41.405      0.0013
       5           1     0.00565       27.033      0.0035


=========================================================================

***********************************************************************
*=====================================================================*
*PART IV: ID RESULTS INTERPRETATION - PREDICTION OF FUTURE RISK LEVEL*
*=====================================================================*
***********************************************************************

--------------------------------------------------------------
ESTIMATION OF WEIGHTING FACTORS BY MULTIPLE LINEAR REGRESSION
--------------------------------------------------------------

Model: R = b1X1+b2X2+b3X4+b4X4


     B
1   0.0159
2   0.0631
3   0.4632
4   0.4578

                Total Sum of Squares =    2039.88
            Sum of Squares for error =     642.86


ANALYSIS OF VARIANCE (ANOVA)


R-squared   Adjusted  Est. Std. Dev.
(percent)  R-squared  of Model Error
   91.964     89.668           6.776

    * * Analysis of Variance * * *
                                Sum of        Mean               Prob. Of
Source                   DF     Squares       Square  Overall F  Larger F
Regression                4     7356.9        1839.2     40.054    0.0000
Residual                 14      642.9          45.9
Uncorrected Total        18     7999.8

    * * Sequential Statistics * * *
Indep.    Degrees of     Sum of                 Prob. Of
Variable     Freedom     Squares  F-statistic    Larger F
       1           1      7029.3      153.083      0.0000
       2           1       126.9        2.764      0.1186
       3           1       159.5        3.474      0.0834
       4           1        41.1        0.896      0.3600

--------------------------------------------------


-------------------------------------------
APPLICATION OF RESPONSE SURFACE METHODOLOGY
-------------------------------------------

Notes:
Factorial points: First four
Center points   : Next four
Axial points    : Last four

NPTS =          12

         X
         1       2
 1   24.45   22.23
 2   24.45   21.51
 3   23.03   22.23
 4   23.03   21.51
 5   23.74   21.87
 6   23.74   21.87
 7   23.74   21.87
 8   23.74   21.87
 9   22.88   21.87
10   24.60   21.87
11   23.74   21.44
12   23.74   22.30
```

```
The design matrix Mat:

 1.   0.71  0.36  0.5052  0.1263  0.2526
 1.   0.71 -0.36  0.5052  0.1263 -0.2526
 1.  -0.71  0.36  0.5052  0.1263 -0.2526
 1.  -0.71 -0.36  0.5052  0.1263  0.2526
 1.   0.00  0.00  0.0000  0.0000  0.0000
 1.   0.00  0.00  0.0000  0.0000  0.0000
 1.   0.00  0.00  0.0000  0.0000  0.0000
 1.   0.00  0.00  0.0000  0.0000  0.0000
 1.  -0.86  0.00  0.7396  0.0000  0.0000
 1.   0.86  0.00  0.7396  0.0000  0.0000
 1.   0.00 -0.43  0.0000  0.1849  0.0000
 1.   0.00  0.43  0.0000  0.1849  0.0000


The vector Y:

 18.19
 17.44
 18.01
 16.92
 17.15
 18.57
 17.27
 18.22
 17.11
 17.05
 16.88
 17.74

The least squares estimation of b=Inv(Tran(Mat)*Mat)*Tran(Mat)*Y:

   17.716
   -0.127
   -1.170
   -0.457
   -0.569
   -0.338


ANALYSIS OF VARIANCE (ANOVA)

R-squared   Adjusted  Est. Std. Dev.
(percent)  R-squared  of Model Error
   96.652     94.643         0.02075

    * * Analysis of Variance * * *
                                  Sum of         Mean               Prob. Of
Source                      DF    Squares        Square  Overall F  Larger F
Regression                   5    0.06212      0.02071      48.108    0.0004
Residual                     6    0.00215      0.00043
Reduced Model Total         11    0.06427

    * * Sequential Statistics * * *
Indep.    Degrees of     Sum of                   Prob. Of
Variable     Freedom     Squares   F-statistic    Larger F
       1           1     0.03286        76.352      0.0003
       2           1     0.00374         0.278      0.0001
       3           1     0.01128        26.203      0.0037
       4           1     0.00309         0.214      0.0001
       5           1     0.01798        41.770      0.0013
```

```
The complement of vector Y (Y"):

 81.81
 82.56
 81.99
 83.08
 82.85
 81.43
 82.73
 81.78
 82.89
 82.95
 83.12
 82.26

The least squares estimation of b"=Inv(Tran(Mat)*Mat)*Tran(Mat)*Y":

   82.284
    0.127
    1.170
    0.457
    0.569
    0.338


ANALYSIS OF VARIANCE (ANOVA)


R-squared   Adjusted  Est. Std. Dev.
(percent)  R-squared  of Model Error
   96.652     94.643         0.02075

    * * Analysis of Variance * * *
                                  Sum of         Mean               Prob. Of
Source                      DF    Squares        Square  Overall F  Larger F
Regression                   5    0.06212      0.02071      48.110    0.0004
Residual                     6    0.00215      0.00043
Reduced Model Total         11    0.06427

    * * Sequential Statistics * * *
Indep.    Degrees of     Sum of                   Prob. Of
Variable     Freedom     Squares   F-statistic    Larger F
       1           1     0.03286        76.356      0.0003
```

```
        2           1     0.00374       0.278      0.0001
        3           1     0.01128      26.204      0.0037
        4           1     0.00309       0.214      0.0001
        5           1     0.01798      41.770      0.0013

=====================================================================

*************************************************************
*===========================================================*
*PART V: PERFORM COST BENEFIT ASSESSMENT (CBA) OF THE PROPOSED RCO*
*===========================================================*
*************************************************************

LIFE CYCLE COST ANALYSIS (LCCA) OF CORROSION MARGINS & ALTERNATIVES

SIMULATED RESULTS (MONTE CARLO)

-------------------------------------
CBA CALACULATIONS FOR HANDYSIZE VESSEL
-------------------------------------

Histogram of risk reduction

Midpoints:  0.01455293  0.01720014  0.01984734  0.02249455  0.02514176  0.02778896  0.03043617  0.03308337
0.03573058  0.03837778  0.04102499  0.04367220  0.04631940  0.04896661  0.05161382  0.05426102  0.05690823
0.05955543  0.06220264  0.06484985
Counts:             14.         82.        385.       1627.       6120.       6665.      27043.      52874.      81976.
98056.      47925.      81845.      53180.      26833.      10983.       2269.       1697.        360.         59.
7.

                        Univariate Statistics from UVSTA

Variable          Mean      Variance     Std. Dev.     Skewness       Kurtosis
    1          0.03971    0.00003462    0.005884     0.0004142      0.01560

Variable       Minimum       Maximum        Range     Coef. Var.        Count
    1          0.01323       0.06617      0.05294       0.1482    500000.0000

Variable     Lower CLM     Upper CLM     Lower CLV     Upper CLV
    1          0.03969       0.03973    0.00003444    0.00003480

** (+0.5) mm - 5% Inflation **

Histogram of Present Value Benefits (USD)

Midpoints:     69968.89     82567.15     95165.41    107763.67    120361.94    132960.20    145558.45    158156.72
170754.98    183353.25    195951.50    208549.77    221148.03    233746.30    246344.55    258942.81    271541.06    284139.34
296737.59    309335.88
Counts:             8.          41.         315.        2305.        8992.       16740.       24503.       32261.       39301.
47038.       53413.       57222.       53695.       46023.       38421.       30322.       23073.       15524.        8393.
2410.

                        Univariate Statistics from UVSTA

Variable          Mean      Variance     Std. Dev.     Skewness       Kurtosis
    1      207705.3906    0.1800E+10   42425.2461     0.006043       -0.5724

Variable       Minimum       Maximum        Range     Coef. Var.        Count
    1       63669.7578   315635.0000  251965.2500       0.2043    500000.0000

Variable     Lower CLM     Upper CLM     Lower CLV     Upper CLV
    1      207550.8438   207859.9375    0.1791E+10    0.1809E+10

Histogram of Present Value Costs (USD)

Midpoints:     65892.27     73885.27     81878.28     89871.28     97864.28    105857.28    113850.29    121843.29
129836.29    137829.30    145822.30    153815.30    161808.30    169801.30    177794.30    185787.30    193780.31    201773.31
209766.31    217759.31
Counts:            24.         277.        1870.        7758.       20341.       36951.       53054.       66089.       73440.
72610.       61363.       45767.       31091.       17916.        7949.        2685.         669.         125.          20.
1.

                        Univariate Statistics from UVSTA

Variable          Mean      Variance     Std. Dev.     Skewness       Kurtosis
    1      133081.6094    0.4135E+09   20334.0820      0.09969       -0.3542

Variable       Minimum       Maximum        Range     Coef. Var.        Count
    1       61895.7734   221755.8125  159860.0312       0.1528    500000.0000

Variable     Lower CLM     Upper CLM     Lower CLV     Upper CLV
    1      133007.5312   133155.6875    0.4114E+09    0.4156E+09

Histogram of Net Present Value (USD)

Midpoints:      3278.84     10125.90     16972.95     23820.01     30667.06     37514.12     44361.18     51208.23
58055.29     64902.35     71749.40     78596.46     85443.52     92290.57     99137.62    105984.68    112831.74    119678.80
126525.85    133372.91
Counts:            27.         277.        2047.        7923.       14701.       21452.       28494.       35120.       41814.
48392.       53824.       53815.       47615.       40797.       33965.       27104.       20323.       13528.        7163.
1619.

                        Univariate Statistics from UVSTA

Variable          Mean      Variance     Std. Dev.     Skewness       Kurtosis
    1       74626.1094    0.5892E+09   24273.1680    -0.002074       -0.5758

Variable       Minimum       Maximum        Range     Coef. Var.        Count
    1        -144.6875   136796.4375  136941.1250       0.3253    500000.0000

Variable     Lower CLM     Upper CLM     Lower CLV     Upper CLV
    1       74537.6875    74714.5312    0.5862E+09    0.5922E+09

Histogram of Gross CAF (USD)
```

```
 Midpoints:     2070666.75     2325054.50     2579442.00     2833829.75     3088217.25     3342605.00     3596992.50
3851380.25     4105767.75     4360155.50     4614543.00     4868930.50     5123318.50     5377706.00     5632093.50
5886481.00     6140869.00     6395256.50     6649644.00     6904031.50
 Counts:            874.         10578.         32998.         60309.         85130.         96492.         86880.
63881.         37609.         17410.         5738.          1598.          356.            95.            30.
12.             7.             2.            0.              1.

                         Univariate Statistics from UVSTA

 Variable          Mean      Variance     Std. Dev.       Skewness      Kurtosis
     1        3387235.5    0.2517E+12   501659.2500        0.1867       -0.2055

 Variable       Minimum       Maximum         Range     Coef. Var.         Count
     1        1943473.0     7031225.5     5087752.5        0.1481   500000.0000

 Variable     Lower CLM     Upper CLM     Lower CLV     Upper CLV
     1        3385408.0     3389063.0    0.2504E+12    0.2530E+12


 Histogram of Net CAF (USD)

 Midpoints:    -4148922.75    -3936031.25    -3723140.00    -3510248.50    -3297357.00    -3084465.75    -2871574.25
-2658682.75    -2445791.50    -2232900.00    -2020008.62    -1807117.12    -1594225.75    -1381334.25    -1168442.88
-955551.44     -742660.06     -529768.62     -316877.19     -103985.77
 Counts:            144.          1134.          3013.          5982.         10507.         16676.         24250.
33341.         42946.         51001.         56749.         58147.         54692.         47571.         38369.
28337.         17644.          7652.          1716.           129.

                         Univariate Statistics from UVSTA

 Variable          Mean      Variance     Std. Dev.       Skewness      Kurtosis
     1       -1925622.2    0.4817E+12   694036.3125       -0.2168       -0.3731

 Variable       Minimum       Maximum         Range     Coef. Var.         Count
     1       -4255368.5     2459.9385     4257828.5       -0.3604   500000.0000

 Variable     Lower CLM     Upper CLM     Lower CLV     Upper CLV
     1       -1928150.5    -1923094.0    0.4792E+12    0.4842E+12

><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><<

 -------------------------------------
 CBA CALACULATIONS FOR HANDYMAX VESSEL
 -------------------------------------

 Histogram of risk reduction

 Midpoints:  0.00946599  0.01118743  0.01290888  0.01463032  0.01635177  0.01807321  0.01979466  0.02151611
0.02323755  0.02495900  0.02668044  0.02840189  0.03012333  0.03184478  0.03356622  0.03528767  0.03700911
0.03873056  0.04045200  0.04217345
 Counts:          14.          82.         385.        1627.        6120.        6665.       27043.       52874.       81976.
98056.       47925.       81845.       53180.       26833.       10983.        2269.        1697.         360.         59.
7.

                         Univariate Statistics from UVSTA

 Variable          Mean      Variance     Std. Dev.       Skewness      Kurtosis
     1          0.02583    0.00001469      0.003833     0.0002688     -0.006407

 Variable       Minimum       Maximum         Range     Coef. Var.         Count
     1         0.008605       0.04303       0.03443        0.1484   500000.0000

 Variable     Lower CLM     Upper CLM     Lower CLV     Upper CLV
     1          0.02581       0.02584    0.00001461    0.00001476


 ** (+1.0) mm - 15% Inflation **


 Histogram of Present Value Benefits (USD)

 Midpoints:    261417.56    288449.25    315480.91    342512.59    369544.28    396575.97    423607.62    450639.31
477671.00    504702.69    531734.38    558766.06    585797.69    612829.38    639861.06    666892.75    693924.44    720956.12
747987.81    775019.50
 Counts:            5.          27.        1784.        7447.       13236.       19095.       25240.       30834.       36599.
43105.       48866.       53436.       48407.       43114.       37010.       30970.       24659.       18786.       12336.
5044.

                         Univariate Statistics from UVSTA

 Variable          Mean      Variance     Std. Dev.       Skewness      Kurtosis
     1      556324.8125    0.1002E+11   100078.5156      -0.04405       -0.6207

 Variable       Minimum       Maximum         Range     Coef. Var.         Count
     1      247901.7188   788535.3125   540633.6250        0.1799   500000.0000

 Variable     Lower CLM     Upper CLM     Lower CLV     Upper CLV
     1      555960.2500   556689.3750    0.9964E+10    0.1007E+11


 Histogram of Present Value Costs (USD)

 Midpoints:    265821.59    305193.78    344565.94    383938.09    423310.28    462682.44    502054.59    541426.75
580798.94    620171.12    659543.25    698915.44    738287.62    777659.81    817031.94    856404.12    895776.31    935148 44
974520.62   1013892.81
 Counts:           36.         795.        6615.       24029.       49051.       73468.       88173.       87350.       70939.
48941.       28347.       13661.        5672.        2033.         638.         190.          49.           9.           3.
1.

                         Univariate Statistics from UVSTA

 Variable          Mean      Variance     Std. Dev.       Skewness      Kurtosis
     1      528738.0625    0.7173E+10    84695.0703        0.2728      -0.07131

 Variable       Minimum       Maximum         Range     Coef. Var.         Count
     1      246135.5156     1033578.9   787443.3750        0.1602   500000.0000

 Variable     Lower CLM     Upper CLM     Lower CLV     Upper CLV
```

```
    1       528429.5625   529046.5625    0.7136E+10    0.7210E+10


 Histogram of Net Present Value (USD)

 Midpoints:  -243722.33  -220675.98  -197629.66  -174583.31  -151536.97  -128490.63  -105444.29   -82397.95    -
59351.61   -36305.27   -13258.93      9787.41     32833.75     55880.09     78926.43   101972.77   125019.11   148065.45
171111.78   194158.12
 Counts:             5.           7.          54.         196.         662.        2121.        5901.       13478.       26453.
43916.      62193.        73699.       76614.       68382.       54241.       37089.       20820.       10047.       3616.
506.

                            Univariate Statistics from UVSTA

 Variable          Mean       Variance      Std. Dev.        Skewness       Kurtosis
     1       27588.5586    0.3349E+10    57867.4492        -0.05671        -0.1899

 Variable       Minimum       Maximum          Range      Coef. Var.          Count
     1     -255245.5000   205681.3125   460926.8125         2.0975     500000.0000

 Variable      Lower CLM     Upper CLM      Lower CLV      Upper CLV
     1       27377.7598    27799.3574    0.3331E+10     0.3366E+10


 Histogram of Gross CAF (USD)

 Midpoints:      13699772.00     15160632.00     16621492.00     18082352.00     19543212.00     21004072.00     22464932.00
23925792.00     25386654.00     26847514.00     28308374.00     29769234.00     31230094.00     32690954.00     34151812.00
35612672.00     37073536.00     38534396.00     39995256.00     41456116.00
 Counts:            3374.          20475.          44315.          69595.          92516.          94049.          77459.
54052.            27986.          10829.           3727.           1114.            346.            100.             36.
15.                  8.              3.              0.              1.

                            Univariate Statistics from UVSTA

 Variable          Mean       Variance      Std. Dev.        Skewness       Kurtosis
     1      20648982.00    0.8500E+13    2915483.0          0.2022        -0.1296

 Variable       Minimum       Maximum          Range      Coef. Var.          Count
     1      12969342.00   42186544.00   29217202.00         0.1412     500000.0000

 Variable      Lower CLM     Upper CLM      Lower CLV      Upper CLV
     1      20638362.00   20659602.00    0.8456E+13     0.8544E+13


 Histogram of Net CAF (USD)

 Midpoints:     -12749236.00    -11791263.00    -10833291.00     -9875318.00     -8917346.00     -7959373.00     -7001401.00
-6043428.00      -5085456.00     -4127483.25     -3169510.75     -2211538.25     -1253565.75      -295593.25       662379.25
1620351.75       2578324.25      3536296.75      4494269.00      5452242.00
 Counts:              35.            148.            442.           1065.           2353.           4526.           8029.
14089.            22546.          34583.          48113.          63349.          76165.          79380.          70384.
47432.            21507.           5289.            544.             21.

                            Univariate Statistics from UVSTA

 Variable          Mean       Variance      Std. Dev.        Skewness       Kurtosis
     1       -1369461.4    0.6115E+13    2472762.2         -0.6103         0.3158

 Variable       Minimum       Maximum          Range      Coef. Var.          Count
     1     -13228222.00     5931228.5   19159450.00        -1.8056     500000.0000

 Variable      Lower CLM     Upper CLM      Lower CLV      Upper CLV
     1       -1378469.1    -1360453.6    0.6083E+13     0.6146E+13


 ------------------------------------------------------------------

><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><

 -----------------------------------
 CBA CALACULATIONS FOR PANAMAX VESSEL
 -----------------------------------

 Histogram of risk reduction

 Midpoints:  0.00987711  0.01167318  0.01346925  0.01526532  0.01706139  0.01885746  0.02065353  0.02244960
0.02424567  0.02604174  0.02783781  0.02963388  0.03142995  0.03322602  0.03502208  0.03681815  0.03861422
0.04041030  0.04220636  0.04400243
 Counts:           14.          82.         385.        1627.        6120.        6665.       27043.       52874.       81976.
98056.      47925.       81845.       53180.       26833.       10983.        2269.        1697.         360.          59.
7.

                            Univariate Statistics from UVSTA

 Variable          Mean       Variance      Std. Dev.        Skewness       Kurtosis
     1          0.02695    0.00001595     0.003993       0.0002177        0.01752

 Variable       Minimum       Maximum          Range      Coef. Var.          Count
     1         0.008979       0.04490        0.03592         0.1482     500000.0000

 Variable      Lower CLM     Upper CLM      Lower CLV      Upper CLV
     1          0.02693       0.02696     0.00001587     0.00001603
```

```
 ** (+1.5) mm - 5% Inflation **

 Histogram of Present Value Benefits (USD)

 Midpoints:    899327.06  1125392.12  1351457.12  1577522.25  1803587.25  2029652.38  2255717.25  2481782.50
2707847.50  2933912.50  3159977.50  3386042.50  3612107.75  3838172.75  4064237.75  4290303.00  4516368.00
4742433.00  4968498.00  5194563.00
 Counts:           14.          63.         520.        2403.        8401.       20179.       34013.       47052.       57854.
65476.      67033.       61048.       49059.       36796.       25002.       14791.        7143.        2530.         555.
68.
```

```
                          Univariate Statistics from UVSTA

 Variable          Mean       Variance     Std. Dev.      Skewness      Kurtosis
     1        3104747.5    0.4026E+12   634470.5625        0.1008       -0.3963

 Variable       Minimum       Maximum         Range    Coef. Var.         Count
     1      786294.5625     5307595.5     4521301.0        0.2044   500000.0000

 Variable     Lower CLM     Upper CLM     Lower CLV     Upper CLV
     1        3102436.2     3107058.8    0.4005E+12    0.4046E+12


 Histogram of Present Value Costs (USD)

 Midpoints:    690767.06    840867.88    990968.62  1141069.38  1291170.25  1441271.00  1591371.75  1741472.50
1891573.38  2041674.12  2191775.00  2341875.75  2491976.50  2642077.25  2792178.00  2942278.75  3092379.50
3242480.25  3392581.25  3542682.00
 Counts:           34.          429.          3119.         13381.         34873.         61773.         82579.         89631.         80393.
60202.        38499.        20471.         9404.          3616.          1165.          327.           86.            12.            5.
1.

                          Univariate Statistics from UVSTA

 Variable          Mean       Variance     Std. Dev.      Skewness      Kurtosis
     1        1770355.0    0.1055E+12   324761.5312        0.2517      -0.06629

 Variable       Minimum       Maximum         Range    Coef. Var.         Count
     1      615716.6875     3617732.2     3002015.5        0.1834   500000.0000

 Variable     Lower CLM     Upper CLM     Lower CLV     Upper CLV
     1        1769172.0     1771538.0    0.1049E+12    0.1060E+12


 Histogram of Net Present Value (USD)

 Midpoints:    222046.25    324983.00    427919.72    530856.50    633793.19    736729.94    839666.69    942603.44
1045540.19  1148476.88  1251413.62  1354350.38  1457287.12  1560223.88  1663160.62  1766097.38  1869034.12
1971970.88  2074907.62  2177844.25
 Counts:           11.           33.           235.          1313.          7392.          16236.         25342.         33962.         41982.
50223.        56181.        59228.        54561.        45884.        37306.        28412.        20797.        12998.        6379.
1525.

                          Univariate Statistics from UVSTA

 Variable          Mean       Variance     Std. Dev.      Skewness      Kurtosis
     1        1334458.9    0.1109E+12   333020.4375       0.04732       -0.5457

 Variable       Minimum       Maximum         Range    Coef. Var.         Count
     1      170577.8750     2229312.8     2058734.9        0.2496   500000.0000

 Variable     Lower CLM     Upper CLM     Lower CLV     Upper CLV
     1        1333245.8     1335672.0    0.1103E+12    0.1115E+12


 Histogram of Gross CAF (USD)

 Midpoints:       44418712.00      47295764.00      50172816.00      53049868.00      55926916.00      58803968.00      61681020.00
64558072.00      67435120.00      70312176.00      73189224.00      76066272.00      78943328.00      81820376.00      84697424.00
87574480.00      90451528.00      93328584.00      96205632.00      99082680.00
 Counts:              1452.            8665.           17694.           26694.           35685.           44928.           54309.
62375.           61581.           53921.           44805.           35681.           26120.           16743.           7462.
1683.            171.             28.              2.               1.

                          Univariate Statistics from UVSTA

 Variable          Mean       Variance     Std. Dev.      Skewness      Kurtosis
     1      65918776.00    0.7697E+14     8773160.0      0.004522       -0.5643

 Variable       Minimum       Maximum         Range    Coef. Var.         Count
     1      42980188.00    0.1005E+09   57541020.00        0.1331   500000.0000

 Variable     Lower CLM     Upper CLM     Lower CLV     Upper CLV
     1      65886816.00   65950736.00    0.7657E+14    0.7737E+14


 Histogram of Net CAF (USD)

 Midpoints:      -83562816.00     -79911024.00     -76259240.00     -72607448.00     -68955656.00     -65303864.00     -61652076.00
-58000284.00     -54348496.00     -50696704.00     -47044916.00     -43393124.00     -39741332.00     -36089544.00     -32437754.00
-28785964.00     -25134172.00     -21482382.00     -17830592.00     -14178802.00
 Counts:               981.            3877.            8566.           14474.           21317.           29224.           36683.
44828.           51895.           55021.           53180.           48221.           41250.           33536.           25717.
17543.           9789.            3244.            599.             55.

                          Univariate Statistics from UVSTA

 Variable          Mean       Variance     Std. Dev.      Skewness      Kurtosis
     1     -50111756.00    0.1586E+15   12593574.00      -0.06700       -0.5105

 Variable       Minimum       Maximum         Range    Coef. Var.         Count
     1     -85388712.00  -12352907.00   73035808.00       -0.2513   500000.0000

 Variable     Lower CLM     Upper CLM     Lower CLV     Upper CLV
     1     -50157632.00  -50065880.00    0.1578E+15    0.1594E+15

><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><

 -------------------------------------
 CBA CALACULATIONS FOR CAPESIZE VESSEL
 -------------------------------------

 Histogram of risk reduction

 Midpoints:  0.01128933  0.01334201  0.01539469  0.01744737  0.01950005  0.02155273  0.02360541  0.02565809
0.02771077  0.02976345  0.03181613  0.03386881  0.03592149  0.03797417  0.04002685  0.04207953  0.04413221
0.04618489  0.04823757  0.05029025
```

```
 Counts:          14.         82.        385.       1627.       6120.       6665.      27043.      52874.      81976.
98056.      47925.      81845.      53180.      26833.      10983.       2269.       1697.        360.         59.
7.

                       Univariate Statistics from UVSTA

 Variable          Mean      Variance     Std. Dev.      Skewness      Kurtosis
     1          0.03080    0.00002083      0.004564     0.0001673      0.007527

 Variable       Minimum       Maximum         Range    Coef. Var.         Count
     1          0.01026       0.05132       0.04105        0.1482   500000.0000

 Variable     Lower CLM     Upper CLM     Lower CLV     Upper CLV
     1          0.03078       0.03081    0.00002072    0.00002094


 ** (+2.0) mm - 10% Inflation **


 Histogram of Present Value Benefits (USD)

 Midpoints:  1414321.62  1715752.25  2017182.88  2318613.50  2620044.00  2921474.75  3222905.25  3524335.75
3825766.50  4127197.00  4428627.50  4730058.00  5031489.00  5332919.50  5634350.00  5935780.50  6237211.00
6538642.00  6840072.50  7141503.00
 Counts:          11.         71.        715.       4401.      15068.      29069.      42480.      55393.      65855.
71027.      66002.      54146.      40766.      28247.      16387.       7476.       2366.        455.         60.
5.

                       Univariate Statistics from UVSTA

 Variable          Mean      Variance     Std. Dev.      Skewness      Kurtosis
     1        4145226.8   0.6537E+12   808505.2500       0.09168       -0.4353

 Variable       Minimum       Maximum         Range    Coef. Var.         Count
     1        1263606.4     7292218.5     6028612.0        0.1950   500000.0000

 Variable     Lower CLM     Upper CLM     Lower CLV     Upper CLV
     1        4142281.5     4148172.0    0.6503E+12    0.6571E+12


 Histogram of Present Value Costs (USD)

 Midpoints:  1243394.88  1546640.00  1849885.25  2153130.50  2456375.50  2759620.75  3062866.00  3366111.25
3669356.25  3972601.50  4275846.50  4579092.00  4882337.00  5185582.50  5488827.50  5792072.50  6095318.00
6398563.00  6701808.00  7005053.50
 Counts:          62.       1391.      10115.      33147.      63819.      87540.      94652.      82513.      59221.
36153.      18381.       8233.       3187.       1097.        354.        101.         24.          6.          3.
1.

                       Univariate Statistics from UVSTA

 Variable          Mean      Variance     Std. Dev.      Skewness      Kurtosis
     1        3119104.0   0.3915E+12   625730.3125        0.3537       0.06240

 Variable       Minimum       Maximum         Range    Coef. Var.         Count
     1        1091772.2     7156676.0     6064904.0        0.2006   500000.0000

 Variable     Lower CLM     Upper CLM     Lower CLV     Upper CLV
     1        3116824.5     3121383.5    0.3895E+12    0.3936E+12


 Histogram of Net Present Value (USD)

 Midpoints:  -225642.92  -120728.28   -15813.63    89101.02   194015.67   298930.31   403844.97   508759.62
613674.25   718588.94   823503.56   928418.19  1033332.88  1138247.50  1243162.12  1348076.75  1452991.50  1557906.12
1662820.75  1767735.38
 Counts:           6.         20.        110.        371.       1188.       3317.       8604.      18913.      30720.
42379.      52395.      61105.      66518.      63325.      51929.      40572.      29218.      18409.       8991.
1910.

                       Univariate Statistics from UVSTA

 Variable          Mean      Variance     Std. Dev.      Skewness      Kurtosis
     1        1026102.4   0.9123E+11   302046.0938      -0.06533       -0.4103

 Variable       Minimum       Maximum         Range    Coef. Var.         Count
     1     -278100.2500     1820192.8     2098293.0        0.2944   500000.0000

 Variable     Lower CLM     Upper CLM     Lower CLV     Upper CLV
     1        1025002.1     1027202.7    0.9076E+11    0.9170E+11


 Histogram of Gross CAF (USD)

 Midpoints:     65499068.00    70598704.00    75698336.00    80797968.00    85897600.00    90997232.00    96096864.00
101196496.00   106296128.00   111395760.00   116495392.00   121595024.00   126694656.00   131794288.00   136893920.00
141993552.00   147093184.00   152192816.00   157292448.00   162392080.00
 Counts:            2499.          11287.         20767.         30475.         39542.         49637.         58931.
65428.         60236.         50745.         41328.         31433.         21732.         11930.          3399.
529.             76.            22.             2.             2.
                       Univariate Statistics from UVSTA

 Variable          Mean      Variance     Std. Dev.      Skewness      Kurtosis
     1       0.1015E+09   0.2301E+15   15167761.00       0.01202       -0.5620

 Variable       Minimum       Maximum         Range    Coef. Var.         Count
     1      62949252.00   0.1649E+09    0.1020E+09        0.1494   500000.0000

 Variable     Lower CLM     Upper CLM     Lower CLV     Upper CLV
     1       0.1015E+09   0.1016E+09    0.2289E+15    0.2313E+15


 Histogram of Net CAF (USD)

 Midpoints:    -75680072.00   -71508208.00   -67336336.00   -63164464.00   -58992596.00   -54820728.00   -50648856.00
-46476988.00   -42305120.00   -38133252.00   -33961380.00   -29789512.00   -25617642.00   -21445774.00   -17273904.00
-13102035.00    -8930165.00    -4758296.00     -586426.88     3585442.50
```

```
 Counts:          146.          972.         2818.         6067.        11010.        18405.        28153.
39862.          50864.        59285.        64515.        62952.        56326.        44294.        29680.
15922.           6468.         1902.          333.           26.

                      Univariate Statistics from UVSTA

 Variable          Mean      Variance     Std. Dev.      Skewness      Kurtosis
     1     -34502932.00    0.1517E+15   12316339.00       -0.2216       -0.2774

 Variable       Minimum       Maximum         Range    Coef. Var.         Count
     1     -77766008.00     5671376.0   83437384.00       -0.3570   500000.0000

 Variable     Lower CLM     Upper CLM     Lower CLV     Upper CLV
     1     -34547796.00  -34458068.00    0.1509E+15    0.1525E+15

===========================END OF RESULTS===========================
```

H Milestones of the proposed research

Table H.I. *Workplan*

Event	*Keydate*
Choosing subject – Proposal	May – July 2005
Problem Def. – Acc. Analysis (Acc. Rev.)	August – Oct. 2005 (May – June 2006)
Information capture for model	Nov. – Dec. 2005 ~ Jan. – April 2006
Start model development	May 2006
Model development (Hazard Rev.)	June – Dec. 2006 (Feb. – June 2006)
Model refinement	January 2007
Results from model	February 2007
Corrosion: Models/Evaluation (App.)	Aug. – Dec. 2006 (May – July 2007)
RCO – CBA (LCCA)	March – Aug. 2007
Writing up – Review – Feedback	September 2007 – April 2008
PhD Viva	February 2009

*****