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Master's Thesis

An Application of FSA Methodology to Fore-end watertight integrity of Bulk Carriers

Graduate School of Chosun University

Department of Naval Architecture and Ocean Engineering

Lee Hyun Jin

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벌크선의 선수가장자리 방수구획에 대한
공식안전평가의 적용

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Advisor : Professor Kwon, Young Sub

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<tr><th colspan="6">저작물 이용 허락서</th></tr>
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본인이 저작한 위의 저작물에 대하여 다음과 같은 조건아래 조선대학교가 저작물을 이용할 수 있도록 허락하고 동의합니다.

- 다 음 -

1. 저작물의 DB구축 및 인터넷을 포함한 정보통신망에의 공개를 위한 저작물의 복제, 기억장치에의 저장, 전송 등을 허락함
2. 위의 목적을 위하여 필요한 범위 내에서의 편집・형식상의 변경을 허락함. 다만, 저작물의 내용변경은 금지함.
3. 배포・전송된 저작물의 영리적 목적을 위한 복제, 저장, 전송 등은 금지함.
4. 저작물에 대한 이용기간은 5년으로 하고, 기간종료 3개월 이내에 별도의 의사 표시가 없을 경우에는 저작물의 이용기간을 계속 연장함.
5. 해당 저작물의 저작권을 타인에게 양도하거나 또는 출판을 허락을 하였을 경우에는 1개월 이내에 대학에 이를 통보함.
6. 조선대학교는 저작물의 이용허락 이후 해당 저작물로 인하여 발생하는 타인에 의한 권리 침해에 대하여 일체의 법적 책임을 지지 않음
7. 소속대학의 협정기관에 저작물의 제공 및 인터넷 등 정보통신망을 이용한 저작물의 전송・출력을 허락함.

동의여부 : 동의(0) 반대( )

2007년 2월 23일

저작자: 이 현 진 (서명 또는 인)

조선대학교 총장 귀하

후 기

제가 이 자리에 있게 無에서 有를 창조해주신 부모님께 깊은 감사를 드리며, 늘 감사하는 마음을 심어주신 주님께도 감사를 드립니다. 선박해양이 좋아서 입학을 했고, 학과생활을 하며 권영섭 교수님의 학자적인 분위기를 존경하며 선박안전 분야의 연구를 위해 대학원 생활을 시작하게 된 이래 유수와 같이 흘러온 시간 속에서 이렇게 결실을 맺게 되었습니다.

논문을 작성하면서 어려운 점을 느낄 때 마다, 여러 자료 수집을 위해 조언을 많이 해주시고, 참고문헌 역추적의 재미를 알려주신 지도 교수님이신 권영섭 교수님께 깊은 감사를 표합니다. 또 영국에서 박사학위를 받으시고, 귀국 하시여 제 논문에 많은 지도를 해주신 김수웅 선배님께도 감사를 드립니다. 늘 부족한 선배를 보며 묵묵히 따라와 준 후배들에게도 미안한 마음과 고마운 마음을 전해봅니다. 부족한 저에게 가르침을 주신 박제웅 교수님, 방한서 교수님, 윤덕영 교수님, 이귀주 교수님, 인생 이야기를 많이 들려주신 김도정 교수님께도 감사를 표하고 싶습니다. 또 늘 바래지 않는 인연인 NURI & BK21사업단의 식구들, 저의 대학원 생활을 잘 할 수 있도록 도와주신 모든 분들께 감사를 드립니다. 앞으로도 이 생활을 바탕으로 사회에서 다른 사람들에게 도움이 될 수 있는 제가 되고자 노력하겠습니다.

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초 록

벌크선의 선수가장자리 방수구획에 대한 공식안전평가의 적용

이 현 진

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21세기 해양산업 분야에서 안전은 '서비스'가 아닌 '부가가치'이다. 선박의 경쟁력의 핵심은 '저렴한 배'가 아닌 '안전한 배'가 되어야 하고, 수명주기 안전성 확보는 선박 및 해양구조물 관련 산업에서의 필수적인 과제로 인식되어 지고 있다. 선박은 육상이 아닌 바다에서 이동하기 때문에 사고가 일어날 경우 대형 사고로 이어지기 쉽고 구조작업이 육상에서 보다 힘들다. 그리고 선박 사고는 많은 인명 피해와 환경오염을 초래한다는 점에서 국제사회에서 심각한 문제로 대두 되어 왔다. 특히 지난 10년간 확대되고 있는 벌크선 사고와 같은 많은 선박 사고에 대처하기 위하여 최근 국제해사기구(IMO)에서는 선박의 안전성 제고를 위한 혁신적인 방법으로 기존의 안전성 확보 방법보다 적극적이고 균형적인 공식안전평가(Formal Safety Assessment)를 권장하고 있다. 이에 따라 각국의 선급은 공식안전평가의 적용방식에서부터 운영에 이르는 광범위한 내용을 검토, 연구 개발하고 있다. 본 연구는 공식안전평가의 일부로써 벌크선의 선수가장자리 방수구획에 공식

안전평가 5단계 즉 1단계 위해요소파악 , 2단계 사건수목해석 조정영향도, 3단계 위험제어수단 및 위험통제 방안, 4단계 비용 및 편익의 파악, 5단계 의사결정 에 벌크선의 선수가장자리 방수구획에 적용하여, Forecastle 의 구조를 개선하여 비용은 많이 들더라도 기존 벌크선보다 안전한 방수구획을 확보하는 방안을 제시하였다.

Chapter1. Introduction

1.1. Background of Research

Recently safety levels at sea are high, but statistics show that on average 5 ships and 20 seafarers were lost each week during the ten-year period to 1994.(Maritime Coast guard Agency, UK) On World Maritime Day that year, IMO Secretary General Bill O'Neil said " We have become so used to the risks involved in seafaring that we have come to see them as a cost that has to be paid, a price which is exacted for challenging the wrath of the oceans. But accidents are not inevitable - we can and should be prevented". Regulations play an important part in preventing accidents. Most Previous regulations have been derived in a piecemeal way, and very often in reaction to accidents. As a result, certain existing measures may be irrelevant, inconsistent or excessive. Poor regulations do not encourage compliance. On the other hand, Formal Safety Assessment(FSA) is to be balanced by owners and crew, comprehensive and appropriate, are likely to lead to improved compliance as well as intrinsically safer ships. Rationality in shipping regulation is a highly desirable goal.(Maritime Coast guard Agency, UK).

The method of FSA applied in this case is one which aims to use a risk-based approach to determine which are the most cost-effective risk reduction options for bulk carrier type, and incorporate these findings in an appropriate regulation.

The object of this study is the fore peak flooding, due to the loss of watertightness through the various access openings on deck. In theory, a bulk carrier strictly compliant with current regulations in not supposed to withstand the flooding of the fore peak and one hold. If this is the case, the bulk carrier can be rapidly lost, due to either loss of reserve of buoyancy, or capsizing for loss of stability due to free surface effects combined with wave and wind inclining moments, or hull girder collapse.

1.2. Approach

The accident scenario was assumed to take place in any of the North Atlantic, Pacific Ocean and Indian Ocean, as they are the zones where most commodities are traded(Eknes et al, 1997). and where most of the bulk carriers were lost.

Two scenarios of fore end flooding were investigated:

1. flooding starting from the fore-peak and propagating to hold No.1 (Senario A)
2. flooding starting from the hold No.1 and propagating to fore-peak (Senario B)

The water ingress, in this model, was assumed to occur exclusively through to the loss of watertightness of some fittings on the fore-peak (air pipes, companionway hatch, etc) and hatch cover No.1, caused by the loads due to the sea action.

The basic tools used in this study are:

- event tree analysis, to provide a clear picture of the most important accident sequences
- fault tree analysis, to represent the causes of the ET modes
- a simplified probabilistic methodology to model the sea induced loads. The risk model was then tuned against the available casualty statistics, which represents the reality of the accidents.

The risk model was used to assess the effectiveness of forecastle/bulwark and monitoring system; for deck fittings, no statistical data is available, furthermore the current regulations do not set any explicit scantling criteria for them. Therefore, this RCO was cursorily assessed by assuming the same effectiveness of the forecastle / bulwark.

1.3. Objectives

The main aim of this thesis is to develop an environment that adopts an integrated approach to the management and control of the Bulk Carriers safety. Formal Safety Assessment has two main reasons for this are two fold : First, these rules and regulations have evolved over a long period and in course of time very few people are able to remember or understand the original reason for a specific requirement. It is therefore very difficult for anyone to challenge it in detail.

Secondly, it is not simply a question of users interpreting how a rule or regulation is to work; they also have to satisfy the authorities' understanding of that regulation. Agreement can sometimes be difficult, depending on the practical experience of those involved.

Chapter2. Bulk Carrier Safety

2.1. History

Bulk carriers were developed in the 1950s to carry large quantities of non-packed commodities such as grains, coal and iron ore. Some 5,000 bulk carriers trade around the world, providing a crucial service to world commodities transportation. Bulk carrier operators must be aware of the specific safety concerns related to this type of ship. Loading of cargo must be done carefully, to ensure cargo cannot shift during a voyage leading to stability problems. Large hatch covers must be watertight and secure.(IMO)

Following a spate of losses of bulk carriers in the early 1990s, IMO in November 1997 adopted new regulations in SOLAS containing specific safety requirements for bulk carriers, Chapter XII-Additional Safety Measures for Bulk Carriers. In the same month, the 20th Assembly of IMO adopted the "BUL Code"- the Code of Practice for the safe unloading and loading of bulk carriers (resolution A, 862(20)).

Following the 1998 publication of the report into the sinking of the bulk carrier Derbyshire, the Maritime Safety Commitee (MSC) initiated a further review of bulk carrier safety, involving the use of Formal Safety Assessment(FSA) studies to help assess what further changes in regulations might be needed.

The DERBYSHIRE, a British oil/bulk/ore carrier, was lost without trace twenty five years ago with the loss of 44 lives. she had loaded 157,447 tones of iron ore concentrates at Sept-Iles in Canada and was within five days of the end of a two month voyage to Kawasaki in Japan when she encountered the tropical revolving storm Typhoon Orchid in the South China Sea. Her last signals indicated that she was hove to in a violent storm with a force 11 wind and 30 foot waves. It seems probable she foundered late in the evening of 9th September 1980.(MCA,1998-2004) No mayday distress signal was received, and no wreckage was found other than a small oil slick and, much later, a lifeboat. The vessel was only four years old, well maintained and operated, and manned by competent crew and master. She was then, and remains to this day, the largest Red Ensign ship ever lost. In the case of DERBYSHIRE it is most likely that had cracking taken place it is probable that it took place so rapidly and extensively that total structural failure resulted. This was followed by the capsize or the inhabited portion of the ship abaft Frame 65, this probably accounts for the complete absence of any distress message.

In the mean time, the safety of bulk shipping was also attracting international attention because of the mounting losses of ships and lives. Intercargo(http://www.intercargo.org) statistics show that between 1990 and 1990 there were over 250 lives lost in 55 sinking of bulk carriers. Six bulk carriers were lost over an 18 month period sailing from Australia alone.

Loss rates remained high throughout the 1990s, with over 750 lives and 150 vessels lost in that decade. The figures are substantially higher when adding the casualties on those ships which carry bulk cargoes but for technical reasons are not actually classed as "bulk carriers". Bulk carrier safety had the full attention of international regulators and researchers when the ITF(International Transport Workers Federation) and the DFA (Derbyshire Family Association) announced the discovery of the wreck of the DERBYSHIRE.

Also, according to European Maritime Safety Agency, 74% are general cargo and bulk carriers losses in the world. serious concerns have been expressed about the safety of bulk carriers for some time particularly following a spate of losses in the early 1990s.(MSC 74th,5) Bulk carrier safety has for long been high on the agenda at the IMO and elsewhere.

2.2. Background Information

2.2.1 Recently introduced risk control options

Over the past 10 years, several risk control options have been implemented for bulk carriers:

• the Enhanced Survey Programme (ESP) (IACS, 1999)

• IACS UR S21 (IACS, 1997)

• SOLAS chapter XII - applicable to bulk carriers over 150m (IMO,2000)

The influences of the different implemented risk control options are schematically shown in the fault and event trees below.

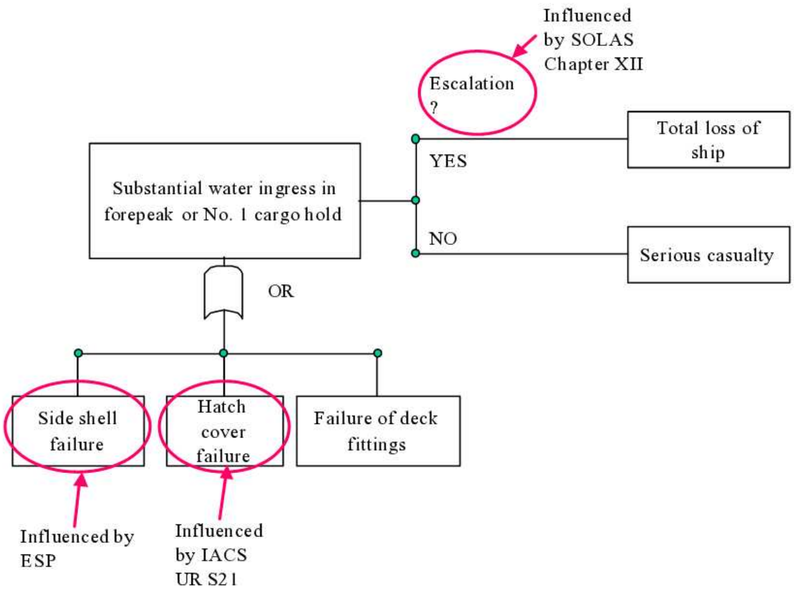

Figure 1. Simple risk model showing the influence of the ESP, IACS UR S21, and SOLAS Chapter Ⅻ

In the sections below, the effectiveness of each of these risk control options in discussed.

The estimates given refer to the terms Gross Cost of Averting a Fatality (Gross CAF) and Net Cost of Averting a Fatality (net CAF). Their definitions are:

$$\text{Gross CAF} = \frac{\triangle C}{\triangle R}$$

$$\text{Net CAF} = \frac{\triangle C - \triangle B}{\triangle R}$$

where $\triangle C$ is the cost per ship of the risk control option,

$\triangle B$ is the economic benefit per ship resulting from the implementation of the risk control option

and $\triangle R$ is the risk reduction per ship, in terms of number of fatalities averted, implied by the risk control option.

2.2.2 The Enhanced Survey Programme (ESP)

The Enhanced Survey Programme (ESP) was implemented as an IACS Unified Requirement on 1 July 1993 (IACS, 1999).

The average overall cost due to ESP was estimated to app. US$66,000 per Bulk Carrier, whereas the risk reduction due to ESP was estimated based on historical casualty data. This risk reduction may include effects from other implemented measures, like the ISM code, but due to lack of detailed information, the entire risk reduction was attributed to ESP.

ESP may prevent side shell failure and hence side shell failure casualties. The number of serious casualties due to side shell failure was found to have declined by app. 19% following the introduction of ESP, corresponding to app. 0.0022 fatalities averted per ship year, and 0.055 fatalities averted per ship lifetime of 25 years. This gave a Gross Cost of Averting a (statistical) Fatality (CAF) of US$1.2million, which is a measure of the Willingness To Pay implied by the decision to implement the ESP.

2.2.3 IACS UR S21

IACS UR S21 was implemented in July 1998 (IACS, 1997), giving stricter requirements for the design of hatch cover, compared to the International Load Line Convention of 1966 (ILLC66) Based on structural reliability analyses and estimates based on casualty statistics, IACS UR S21 was estimated to reduce the annual probability of No. 1 hatch cover collapse by between 91 and 99% compared to ILLC 66. The hatch cover collapse failure mode was estimated to account for 70% of serious casualties related to hatch covers.

The estimated probability of failure for a capesize No.1 hatch cover is presented in the table below.

Table 1. Annual probability of hatch cover failure

Case	Probability of hatch cover coollapse, estimated by structural reliability analysis	Probability of hatch cover collapse, estimated from casualty data
Initial design, ILLC66	9.35 10^{-4}	2.9 10^{-4} -1.4 10^{-3}
UR S21	1.16 10^{-5}	-

The marginal cost effectiveness of UR S21 at the time of its implementation was estimated to US$1.54 million, which is close to the recommended decision criterion of MSC 72/16.

Since the implementation of IACS UR S21, SOLAS XII has also been implemented. SOLAS XII is partly aiming at mitigating consequences given flooding of cargo holds. For the future, this will probably reduce the probability of escalation given flooding of No. 1 cargo hold. When evaluating a further increase in the design loads of IACS UR S21, this effect should be taken into account. UR S21 is presently under consideration for amendment in the light of the recommendations from the Derbyshire hearing.

2.2.4 SOLAS Chapter XII

The SOLAS Chapter XII contains several Risk Control Measures. Cost effectiveness analysis was carried out of the risk control options applying ti bulkhead capacity for new-buildings and existing bulk carriers, see Table 2. Table 2 shows the results for the two risk control options evaluated. The estimated effect of ESP was accounted for in the analysis.

Table 2. Summary of Cost Effectiveness Analyses				
RCO No.	RCO description	RCO costs, △C(US$)	Risk reduction, △R(fatalities averted)	Gross CAF(US$million per fatality averted)
RCO1	Requirements of structural strength at flooding condition and damage stability for new bulk carrier(Regulation 4and 5 in SOLAS ChapterⅫ for new bulk carrier)	77,000 -144,000	1.47E-01	0.5-.10
RCO2	Requirements of structural strength at flooding condition and damage stability for existing bulk carrier (Regulation 4 and 6 in SOLAS ChapterⅫ for existing bulk carrier)	108,000 -138,000	4.54E-02	2.4-3.0

2.2.5 Residual risk considerations

The risk model as shown in Figure 2 above was used to estimate the residual risk after the implementation of ESP, IACS UR S21 and SOLAS Chapter-XII.

For existing bulk carriers, the combined effect of ESP and SOLAS Chapter XII was estimated to reduce the number of fatalities per ship year due to structural failure by approximately 26%, compared to the casualties in the period from 1978 to 1998. This corresponds to a reduction of 20% in the total PLL(Potential Loss of Life) for bulk carriers.

For new-buildings, ESP, IACS UR S21, and SOLAS Chapter Ⅻ was estimated to reduce the expected number of fatalities ore ship year due to structural failure by approximately 67%. This corresponds to a reduction of 50% in the total Potential Loss of Life (PLL) for bulk carriers. The PLL is defined as the mean number of fatalities oer ship year. Since the major part of structural failure related casualties occurs to the older part of the bulk carrier fleet, this means that it may take some time before the new-building modifications will affect the casualty statistics significantly.

2.3. FSA study of Bulk Carrier

Bulk Carrier FSA study, parallel activities in support of the DERBYSHIRE Inquiry are being funded by the UK MSA, including model tests to assess the loads on hatch covers forward for various sizes of vessel. also Japan and Korea have been undertaking their own FSA studies into bulk carriers and Norway has undertaken a FSA study into the evacuation of bulk carriers. Taking all the various studies referred to above it estimated that a total of about €2M is current being spent on bulk carrier safety work. This is shown diagrammatically in figure 2

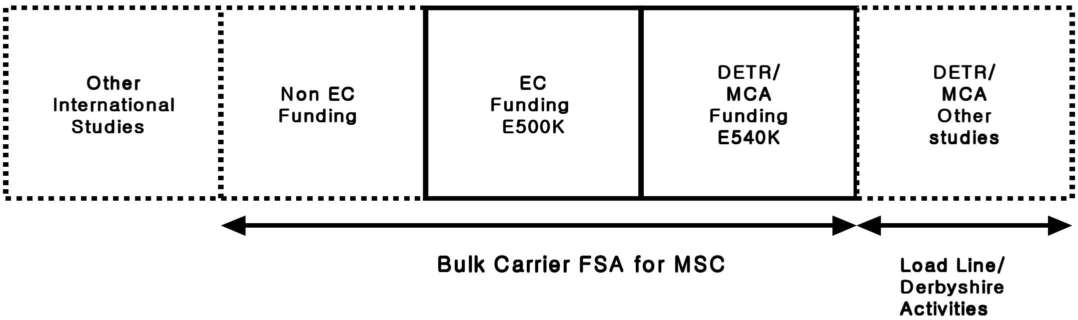

Figure 2. International funding of Bulk Carrier Research

This study is now complete and Executive Summary was reported to IMO in document reference MSC 74/5/4[2]. In this study was concerned with the fore-end watertight integrity of bulk carriers with length exceeding 150 meters and assessed 8 new risk control options plus 3 already implements risk control options. A number of recommendations are made for further consideration by IACS(International Association of Classification Societies), and significantly the report concludes that there is no evidence to suggest that bulk carriers with length less than 150 meters are at less risk than large bulk carriers. This increases the importance of work package 6a, which considers the application of SOLAS Ch XII and other risk control options to bulk carriers of length less than 150 meters.

Bulk carrier's feature is not important for Fore-end watertight integrity of Bulk Carriers but it is basic of Bulk carrier(Lee Eun Chang, 2002). so that is Bulk Carrier's feature;

- High density cargo and low freeboard of, for instance, B-60 or B-100 type ships, leading to high green water on hatch covers;
- Damp and salt-laden air, dusty and abrasive cargo, leading to protective coating damage and accelerated corrosion;
- Gas from coal, other acidic condition and sweating of inner face of hatch cover plating, leading to rapid corrosion;
- Dust of fine particles from cargo debris and detached debris of coating on top plate of hatch coaming, leading to obstruction of the hatch cover operation;
- Unbalance of hatch cover driving force due to excessive heel or trim, leading to wheel derailment of damage to wheel bearings;
- Careless cargo handling and hatch opening/closing, leading to local

structural damage;

- large opening, leading to high local stress and water leakage caused by relatively large deformation; and

- Long rolling period, leading to wave impact possibly on hatch coaming.

FSA's basic is on the all of potential situation. so we need all of problem about that, like this; (Lee Eun Chang, 2002).

- Foundering ; Foundering is defined as a vessel sinking permanently so that many fatalities and loss of the vessel are resulted in.

Foundering may be the final result from other accident categories. In many of foundering accidents of bulk carriers the initial failure events and their escalations to foundering are not very clear. Loss of hatch covers or their severe structural damage should lead to sudden ingress of seawater in rough sea and consequently results in foundering.

- Flooding ; Flooding is defined as seawater, or ballast water, entering a space from which it should which it should be excluded, in such a quantity that there is a possibility of preventing from foundering. Entire cargo in flooded space could be affected by water ingress and its quality should be seriously spoiled. Bulk carrier constructions with large hold and accordingly large hatch opening together with the low freeboard result in vulnerability to flooding of cargo hold

- Leakage ; Leakage is, an accident category less worse than flooding, defined as seawater, or ballast water, entering a space from which it should be excluded, in such a quantity that part of cargo in that space is influenced by water ingress. Damages of securing arrangements such as rubber packing, compression bar and drainage way should lead to leakage. Severity in deterioration of cargo quality depends directly on the kind of cargo. That is, it doesn't matter in case of coal and ore because they are loaded in cargo hold with enough humidity on purpose while it will be of great importance in case of humidity sensitive cargo such as grains.

- Structural Failure ; Structural Failure is defined as yielding or buckling, corrosion and crack propagation or fracture of structural components in hatchway system due to the excessive and/or repetitive loads.

Beyond the scope, Bulk carrier accident from engine, fire, explosion , collision and human error etc

Bulk carrier safety related prescription;

- International Load Line Convention (ILLC)
- International Convention for the Safety of Life at Sea (SOLAS)
- International Safety Management Code (ISM Code)
- International Association of Classification Societies (IACS) Unified Requirement S21
- International Maritime Dangerous Goods Code (IMDG Code)
- Code of Safe Practice for Solid Bulk Carriers (BC Code)
- Code of Practice for the Safe Loading and Unloading of Bulk Carriers (BLU Code)
- Code of Safe Practice for Cargo Stowage and Securing
- Classification Society Rules

Chapter3. Formal Safety Assessment

3.1. Introduction

In 1992 Lord Carver's house of Lords committee published their report on the Safety Aspects of Ship Design and Technology.(Maritime Coastguard Agency, UK) The committee concluded that modern science and technology were not being adequately applied in the many fields that affect shipping safety and that the time had come for a radical change. In respect of the regulatory regime for shipping. the Carver report envisaged the adoption of safety goals based upon a quantified assessment of risks, costs and benefits coupled with the introduction of a ship safety case regime for every commercial vessel. The safety case approach had already been developed in other industries, notably the nuclear, chemical and offshore business.

FSA is a structured and systematic five-step methodology, aimed at enhancing maritime safety, including protection of life, health, the marine environment and property, by using risk analysis and cost benefit assessment. (MSC/Circ.1023)

FSA can be used as a tool to help in the evaluation of new regulations for maritime safety and protection of the marine environment or in making a comparison between existing and possibly improved regulations, with a view to achieving a balance between the various technical and operational issues, including the human element, and between maritime safety or protection of the marine environment and costs. (MSC/Circ.1023).

3.2. Methodology

FSA is a rational and systematic process that enables the cost-effective acquisition of as much practical safety, or pollution prevention, as practicable by choosing control options that give an overall reduction of risk and good value for money to stakeholder.(Lee Eun Chang, 2000) The FSA process is illustrated at Figure 1.

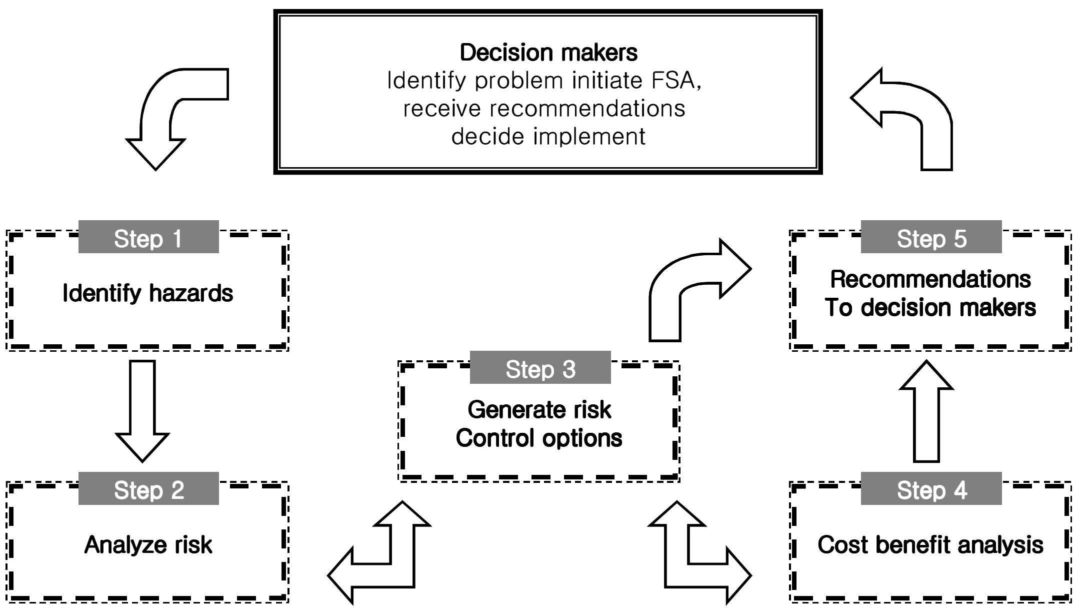

Figure 3. The FSA Process illustrated

FSA comprises of five steps, as follows:

Step 1. Identification of hazards.

The purpose of step1 is to identify a list of hazards and associated scenarios prioritized by risk level specific to the problem under review.

This purpose is achieved by the use of standard techniques to identify hazards which can contribute to accidents, and by screening these hazards using a combination of available data and judgement. The hazard identification exercise should be undertaken in the context of the functions and systems generic to the ship type or problem being considered, which were established in generic model by reviewing.

- Identifies the hazards that might cause accidents
- Takes full account of the human element
- Develops accident scenarios and outcomes arising from the identified hazards
- Ranks and screens the accident scenarios and hazards

Step 2. Assessment of the risks associated with those hazards.

The purpose of the risk analysis in step 2 is detailed investigation of the cause and consequences of the more important scenarios identified on step1. This can be achieved by the use of suitable techniques that model the risk. This allows attention to be focused upon high risk areas and to identify and evaluate the factors which influence the level of risk. different type of risk (i.e. risks to people, the environment or property) should be addressed as appropriate to the problem under consideration. Measures of risk are discussed in appendix 1.

- focuses on the important scenarios from step1
- quantifies the risk of each scenario
- analyses where these risks arise from, to focus attention on principal

underlying causes identifies the significant factors which influence the level of risk

Step 3. Consideration of alternative ways of managing those risks.

The purpose of step3 is to propose effective and practical Risk Control Options (RCOs) comprising the following four principle stages:

1. focusing on risk areas needing control;
2. identifying potential risk control measures(RCMs);
3. evaluating the effectiveness or the RCMs in reducing risk by re-evaluating step2;
4. grouping RCMs into practical regulatory options.

step 3 aims at creating risk control options that address both existing risks and risks introduced by new technology or new methods of operation and management. Both historical risks and newly identified risks(from step 1 and 2) should be considered, producing a wide range of risk control measures. Techniques designed to address both specific risks and underlying causes should be used.

• focuses attention on factors contributing to high risk
• identifies measures to control risk
• evaluates the anticipated reduction in risk by implementing these measures

Step 4. Cost benefit assessment of alternative risk management options.

The purpose of step 4 is to identify and compare benefits and costs associated with the implementation of each RCO identified and defined in step3. A cost benefit assessment may consist of the following stages:

1 consider the risk assessed in step 2, both in terms of frequency and consequence, in order to define the base case in terms of risk levels of the situation under consideration;

2 arrange the RCO(Risk Control Option)s, defined in step 3, in a way to facilitate understanding of the costs and benefits resulting from the adoption of an RCO;

3 estimate the pertinent costs and benefits for all RCO;

4 estimate and compare the cost effectiveness of each option, in terms of the cost per unit risk reduction by dividing the net cost by the risk reduction achieved as a result of implementing the option; and

5 rank the RCOs from a cost benefit perspective in order to facilitate the decision-making recommendation in step 5 (e.g. to screen those which are not cost effective or impractical)

Costs should be expressed in terms of life cycle costs and may include initial, operation, training, inspection, certification, decommission etc. Benefits may include reductions in fatalities, injuries, casualties, environmental damage and clean-up, indemnity of third party liabilities, etc. and an increase in the average life of ships.

• determine the costs and benefits for each risk control option identified in step 3 compare the cost effectiveness of these risk control options.

Step 5. Decisions on which option to select.

The purpose of step 5 is to define recommendations which should be presented to the relevant decision makers in an auditable and traceable manner. The recommendations would be based upon the comparison and ranking of all hazards and their underlying causes; the comparison and ranking of risk control options as a function of associated costs and benefits; and the identification of those risk control options which keep risks as low as reasonably practicable.

• considers the affected stakeholder and the effects of proposed options on them, based on the information about hazards, risks, options, costs and benefits
• assists in the selection of regulatory option(s)
• makes recommendations to the decision-makers

The process begins with the decision makers defining the problem to be assessed along with any relevant boundary conditions or constraints. These are presented to the group who sill carry out the FSA and provide results to the decision makers for use in their resolutions. In cases where decision makers require additional work to be conducted, they would revise the problem statement or boundary conditions or constraints, and resubmit this to the group and repeat the process as necessary. within the FSA methodology, step5 interacts with each of the there steps in arriving at decision-making recommendations. The group carrying out the FSA process should comprise suitably qualified and experienced people to reflect the range of influences and the nature of the "event" beings addressed.(MSC/Circ.1023, MEPC/Circ.392)

Chapter4. Problem Definition

4.1. Definition of the generic model

The bulk carriers considered are ships constructed with topside tanks and hopper side tanks in cargo spaces, intended primarily to carry dry cargo in bulk. This definition is in accordance with the definition as given in SOLAS Chapter IX, Regulation 1.

A bulk carrier classification, including the bulk carrier length, which is deemed to be an important parameter in a regulatory context, was adopted as shown in Table 1. In this study, the bulk carrier characterization is based on DWT.

<table>
<tr><th colspan="4">Table 3. Classification of Bulk Carrier in size
(MSC74/Inf. x submitted by Japan)</th></tr>
<tr><th>Bulk carrier</th><th>L (m)</th><th>GT</th><th>DWT (ton)</th></tr>
<tr><td>(Mini)</td><td>100-130</td><td rowspan="2">5K - 14K</td><td rowspan="2">10K-23K</td></tr>
<tr><td>Small-Handy</td><td>130-150</td></tr>
<tr><td>Handymax</td><td>150-200</td><td>14K - 30K</td><td>23K-55K</td></tr>
<tr><td>Panamax</td><td>200-230</td><td>30K - 45K</td><td>55K-80K</td></tr>
<tr><td>Capesize</td><td>230-270</td><td rowspan="2">45K+K</td><td rowspan="2">80+K</td></tr>
<tr><td>(VL)</td><td>270 +</td></tr>
</table>

Three typical bulk carrier sizes were considered. The main characteristics of the selected ships are listed in Table 4

Table 4. Bulk carriers used in the study				
Ship	**Moulded dimensions (m)**	**Deadweight (tonnes)**	**Summer freeboard (m)**	**Capacity of forepeak (m^3)**
Handymax	181*30*16.3	51,326	4.718	1,450
Panamax	217*32.25*19	83,980	5.250	1,555
Capesize	271*45*24.6	188,968	6.483	4,507

The selected ships were constructed before the entry into force of the new SOLAS Chapter XII with flush deck and B-60 freeboard.

The bulk carriers were assumed to be sailing 150 days per year in loaded condition.

4.2. Casualty statistics concerning the problem under consideration

The casualty database of Lloyd's Maritime Information Services (LMIS, 1999,2000) was used to establish a base risk level for bulk carriers. Where necessary, the information given was supplemented by Lloyd's Casualty Report (LCR). Date from 1978 to 1998 was analysed. The casualty data used contained a small number of double side skin bulk carriers.

Fleet data in the period 1979-1998 were estimated based on Lloyd's Statistical Tables (1979 to 1998). The data represents 73,600 ship years for bulk carriers larger than 20,000 DWT.

In the investigation, other data sources such as internal class survey reports and databases were referred if necessary and when available, e.g.(Japan, 1981) and (INTERCARCO, 2000)

Fleet risk results were reported in MSC 72/16. Individual risks for bulk carriers were found to be in the ALARP region, implying that cost effective risk control options should be implemented.

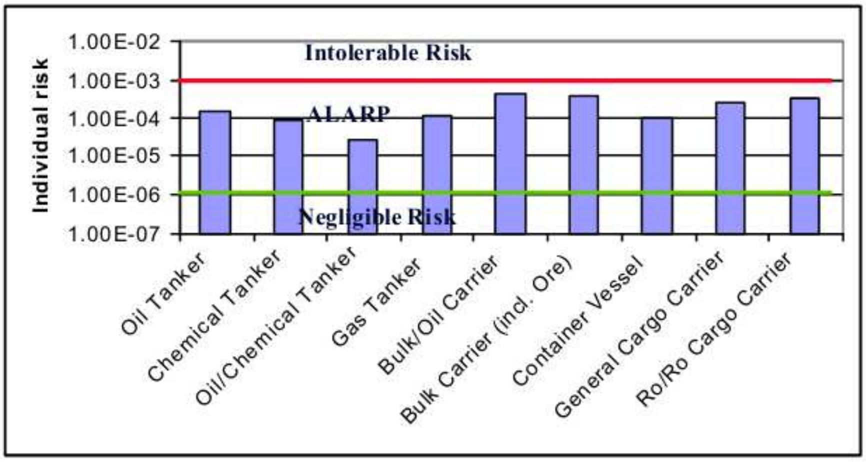

Figure 4. Individual risk of fatality to crew in different ship types(MSC 72/16)

Figure 4 gives the contribution to the average number of fatalities per ship year from different accident categories, and different failure modes for structural failure. "Structural failure" casualties are taken as casualties in the LMIS casualty database being reported as Foundered, Missing, or Hull/Machinery Damage, with sub-coding "Hull"

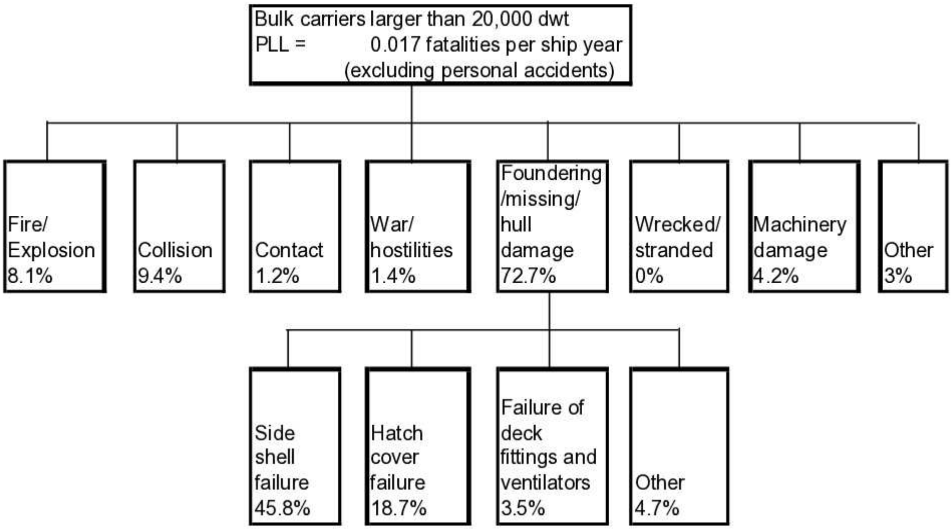

Figure 5. Risk distribution for the Potential Loss of Life (PLL), personal accidents excluded)

The analysis of historical data revealed that casualties that may be attributed to structural failure, in the period from 1978 to 1998 counted for approximately 73% of all casualty related fatalities on bulk carriers larger than 20,000 DWT.

The structural failures may be concluded to have been a major problem to bulk carrier safety, and it appears to be seasonable that this accident category was given focus in the present study.

Chapter5. Hazard Identification

5.1. Hazard List from Literature

A review of previously conducted Hazard Identifications(MSC 72/INF.4, MSC 72/INF.8, and UK MCA(2000)) was performed in order to identify relevant hazards, principal causes, and effects. The full list of hazards is given in web site (www.iacs.org.uk) The actual basic hazard analysed in this study was the "Loss of watertight integrity of the fore end including hold No.1, due to "internal' causes (i.e., excluding events such as collision, grounding etc.). Therefore, only the accident scenarios related to the 'Loss of watertight integrity of the fore-end were investigated. From the relevant historical data, the following most significant scenarios were identified:

1. side-shell failure
2. fore-peak flooding from the deck fittings
3. hatch cover failure

In this perspective, the 'hazards' as defined n the reviewed HAZARDs can be more properly viewed as possible causes and/or aggravation factors of the above scenarios.

Hazards mainly related to hatch covers and transverse bulkheads. In general, they are consistent with the ones mentioned in the above reports. A statistic of several years ago pointed out that the faults of hatch covers not directly attributable to improper use were mainly due to failures of the sealing system(50%), cover sheet plates(25%) or actuation (opening/closing) systems(25%). This is also confirmed by a recent paper (Byrne, 2000), which proposes the use of appropriate tools and checklists for the survey of hatch covers and comings.

In addition to the typical hazards (undersized seals, mishandling, corrosion and wastage of closing elements like cleats, tracks, wheels etc), in some cases the transverse and peripheral hatch cover joints are too stiff with respect to the deck, preventing them from adjusting th the hull deformations. This can be viewed as included in the design errors.

Chapter6. Risk Assessment

6.1. Probabilistic Evaluation

This section provides a general outline of the methodology followed for the risk assessment. as said earlier, the accident scenario was assumed to take place in amy of the North Atlantic, Pacific Ocean and Indian Ocean.

Two scenarios of fore-end flooding were investigated:

1. flooding starting from the fore-peak and propagating to hold No.1 (Scenario A)
2. flooding starting from the hold No.1 ad propagating to fore-peak (Scenario B)

A further possibility of escalation obviously exists, namely, flooding from hold No.1 to the adjacent holds. This scenario was investigated in Annex 4, as the RCOs dealt with in this annex would not be effective in such situations.

The two scenarios were represented by means of Event Trees(ET), that are basically the same with a different order of the nodes (Figure 6, and 7). The ET nodes represent the principal influence that affect the risk. They are described in the following; basically, the same description applies to both ETs, recalling that, for scenario B, the order is: Watertightness of hatch cover No.1 given deck wetness, detection of hold No.1 flooding, corrective action for hold No.1 flooding, watertightness of the fore-peck, detection of fore-peak flooding, corrective action for fore-peak flooding, ship survival. the frequency of each sequence was obtained by multiplying the frequency of the couple of events WH and AH by the probability of the other modes, as they are independent.

Scenario A

WF	Loss of watertightness of the fore-peak given deck wetness	**N1**	human failure
DF	Detection of fore-peak flooding	**N2**	pumping system failure
AF	Action of emptying the fore-peak	**OK**	no consequences
WH	Watertightness of the hatch No.1	**SC**	serious casualty
DH	Detection of hold No.1 flooding	**CTL**	total loss with early warming
AH	Action of emptying hold No.1	**CTLL**	total loss without early warning

Scnerio B

WH	Loss of watertightness of the fore-peak given deck wetness	**N1**	human failure
DH	Detection of hold No.1 flooding	**N2**	pumping system failure
AH	Action of emptying hold No.1	**OK**	no consequences
WF	Watertightness of the fore-peak	**SC**	serious casualty
DF	Detection of hold No.1 Flooding	**CTL**	total loss with early warming
AF	Action of emptying hold No.1	**CTLL**	total loss without early warning

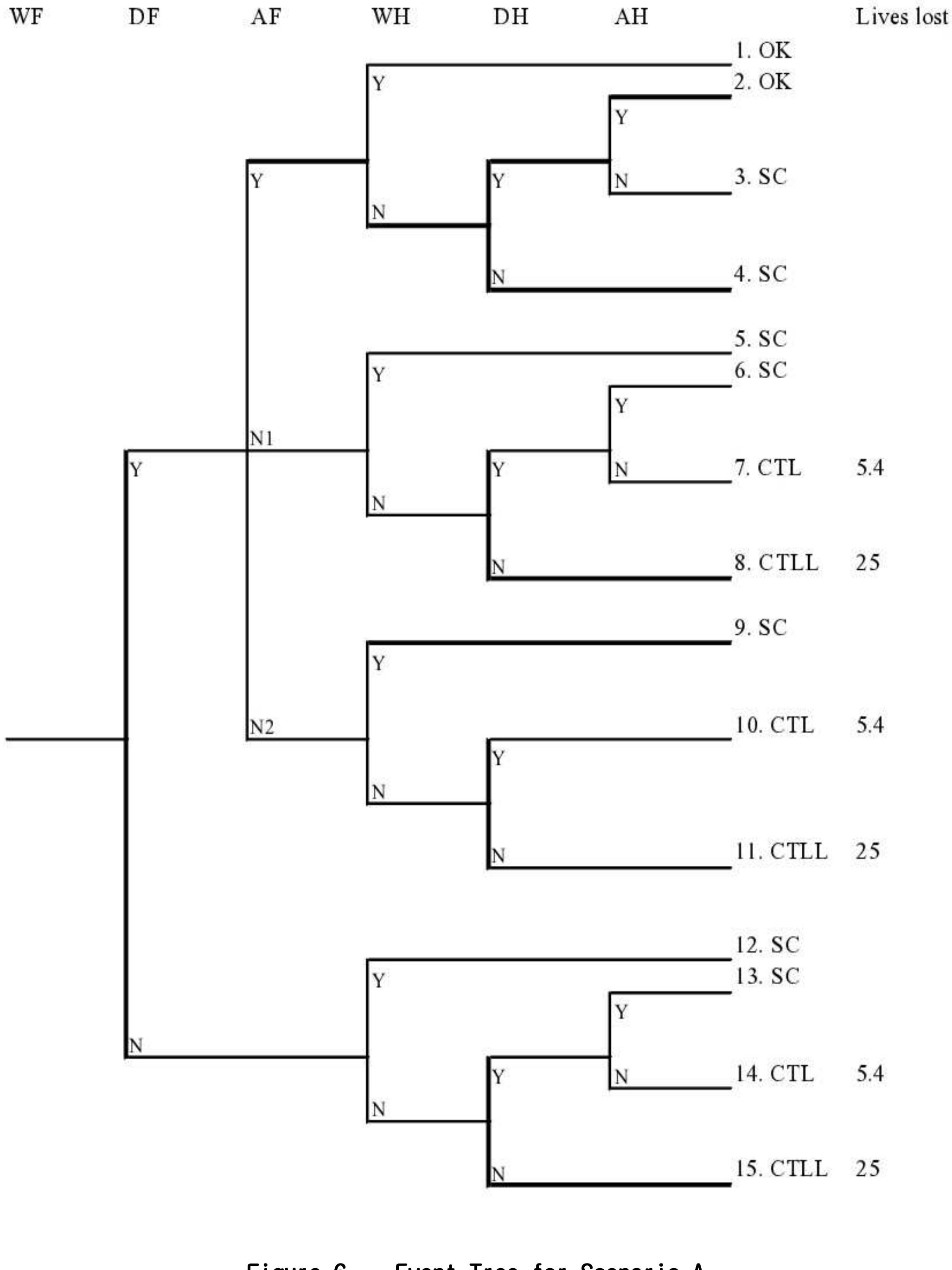

Figure 6 . Event Tree for Scenario A

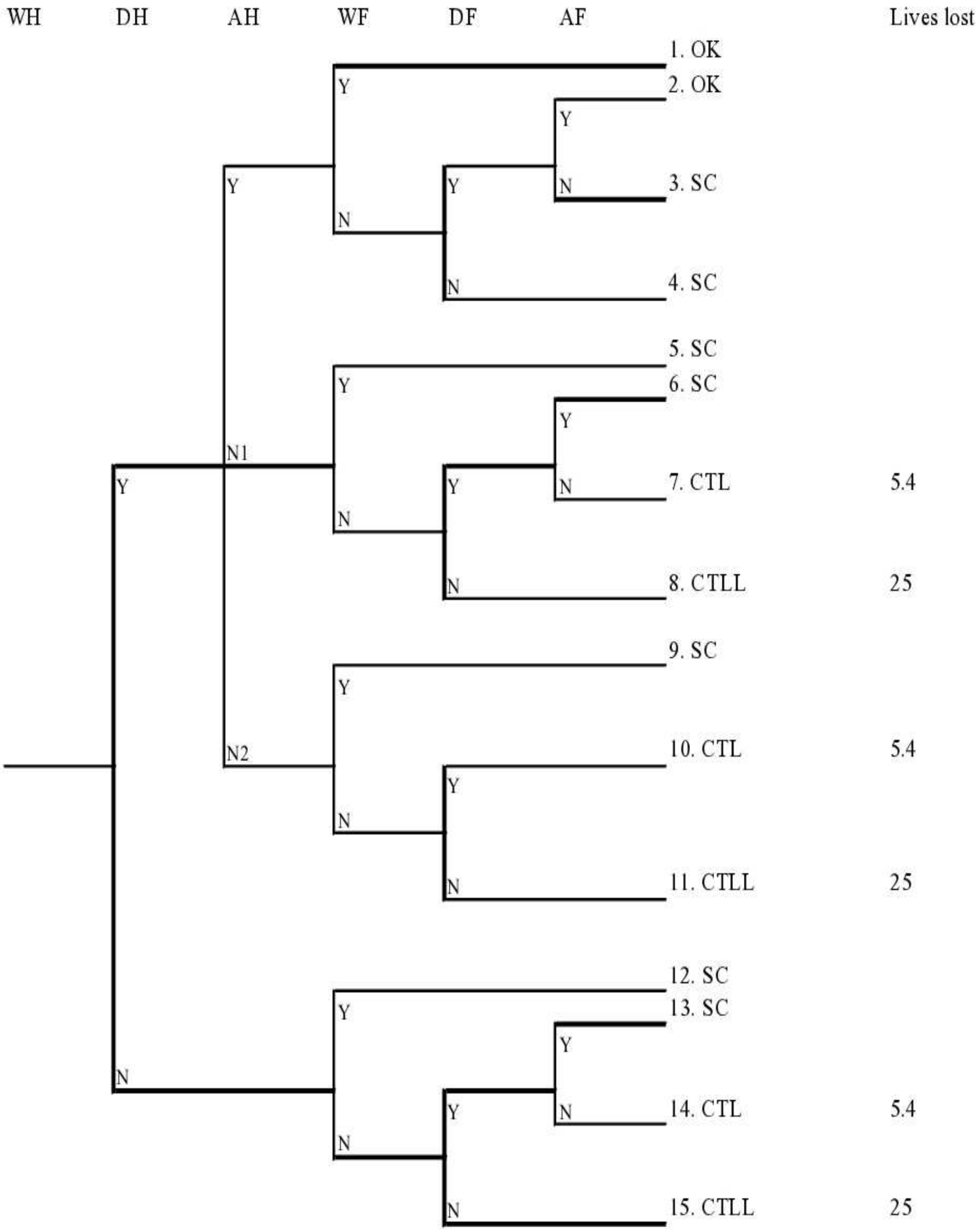

Figure 7. Event Tree for Scenario B

Scenario A	DF	AF	WH	DH	AH
1	1.000E-01	9.986E-01	8.730E-04	1.000E+00	1.000E+00
2	1.000E-01	9.986E-01	1.780E-05	1.000E-01	6.250E-02
3	1.000E-01	9.986E-01	1.780E-05	1.000E-01	9.375E-01
4	1.000E-01	9.986E-01	1.780E-05	9.000E-01	1.000E+00
5	1.000E-01	1.400E-03	8.730E-04	1.000E+00	1.000E+00
6	1.000E-01	1.400E-03	1.780E-05	1.000E-01	6.250E-02
7	1.000E-01	1.400E-03	1.780E-05	1.000E-01	9.375E-01
8	1.000E-01	1.400E-03	1.780E-05	1.000E-01	1.000E+00
9	1.000E-01	3.400E-05	8.730E-04	1.000E+00	1.000E+00
10	1.000E-01	3.400E-05	1.780E-05	1.000E-01	1.000E+00
11	1.000E-01	3.400E-05	1.780E-05	9.000E-01	1.000E+00
12	9.000E-01	1.000E+00	8.730E-04	1.000E+00	1.000E+00
13	9.000E-01	1.000E+00	1.780E-05	1.000E-01	6.250E-02
14	9.000E-01	1.000E+00	1.780E-05	1.000E-01	9.375E-01
15	9.000E-01	1.000E+00	1.780E-05	9.000E-01	1.000E+00

Scenario B	DH	AH	WF	DF	AF
1	1.000E-01	6.250E-02	8.820E-02	1.000E+00	1.000E+00
2	1.000E-01	6.250E-02	2.650E-05	1.000E-01	9.986E-01
3	1.000E-01	6.250E-02	2.650E-05	1.000E-01	1.440E-03
4	1.000E-01	6.250E-02	2.650E-05	9.000E-01	1.000E+04
5	1.000E-01	9.375E-01	8.820E-02	1.000E+00	1.000E+05
6	1.000E-01	9.375E-01	2.650E-05	1.000E-01	9.986E-01
7	1.000E-01	9.375E-01	2.650E-05	1.000E-01	1.440E-03
8	1.000E-01	9.375E-01	2.650E-04	9.000E-01	1.000E+00
9	1.000E-01	3.500E-05	8.820E-02	1.000E+00	1.000E+00
10	1.000E-01	3.500E-05	2.650E-05	1.000E-01	1.000E+00
11	1.000E-01	3.500E-05	2.650E-05	9.000E-01	1.000E+00
12	9.000E-01	1.000E+00	8.820E-05	1.000E+00	1.000E+00
13	9.000E-01	1.000E+00	2.650E-05	1.000E-01	9.986E-01
14	9.000E-01	1.000E+00	2.650E-05	1.000E-01	1.440E-03
15	9.000E-01	1.000E+00	2.650E-05	9.000E-01	1.000E+00

Risk is concerned with the frequency (probability) couple with the consequences (number of deaths, cost of damage to property or the environment) that might be caused.

Table 5. Generalised risk matrix table (IMO, 1999)

Risk Matrix		Minor	⟵	⟶	Serious
		C1	C2	C3	C4
Low	F1	1	2	3	4
	F2	2	3	4	5
	F3	3	4	5	6
	F4	4	5	6	7
	F5	5	6	7	8
	F6	6	7	8	9
High	F7	7	8	9	10

Risk judgement can be based on a Probability - Consequence Interaction Table, Which is known as risk matrix table (see table 5.) The purpose of the hazard screening is to provide a quick and simple way of ranking hazards, in terms of frequency and severity of possible outcomes with a view to setting priorities for more detailed risk evaluation. The risk matrix approach is a semi-quantitative risk ranking technique, which is used in the hazard screening process.

In the risk matrix table, the magnitude of risk (defined as product of frequency and consequence) is measured on a scale of 1 to 10 as depicted in Table 5. This is called the Risk Ranking Number (RRN) which ranges from 1(least frequent and least severe consequence) to 10 (most frequent and most severe consequence). Ranking of the various accidents determines their order in relation to one another. The RRN is indicative of the relative order of magnitude of risk. In this chapter, the approach is used with reference to either historical data or expert judgements, and indeed, the FAST results.

Frequency bands for risk table

F1	0.0000-0.0001
F2	0.0002-0.0010
F3	0.0011-0.0625
F4	0.0626-0.1000
F5	0.1001-0.9375
F6	0.9376-0.9986
F7	0.9987-1.0000

Figure 8. Frequency Bands

C1	under US$150,000 lowerest accident
C2	about US$1,500,000 accident and need a repair
C3	about US$15,000,000 with longtime reparling
C4	more than US$150,000,000 serious accident

Consequence Band

Figure 9. Consequence Bands

Scenario	DF			AF			WH			DH			AH		
1	F4	C1	4	F6	C1	6	F2	C1	2	F7	C1	7	F7	C1	7
2	F4	C1	4	F6	C1	6	F1	C1	1	F4	C1	4	F3	C1	3
3	F4	C2	5	F6	C2	7	F1	C4	4	F4	C2	5	F5	C2	6
4	F4	C2	5	F6	C2	7	F1	C4	4	F5	C2	6	F7	C1	7
5	F4	C3	6	F3	C3	5	F2	C3	4	F7	C2	8	F7	C2	8
6	F4	C3	6	F3	C1	3	F1	C4	4	F4	C2	5	F3	C2	4
7	F4	C4	7	F3	C4	3	F1	C4	4	F4	C2	5	F5	C4	8
8	F4	C3	6	F3	C2	4	F1	C3	3	F4	C2	5	F7	C4	10
9	F4	C1	4	F1	C3	3	F2	C2	3	F7	C3	9	F7	C3	9
10	F4	C1	4	F1	C2	2	F1	C3	3	F4	C2	5	F7	C3	9
11	F4	C2	5	F1	C1	1	F1	C3	3	F5	C2	6	F7	C4	10
12	F5	C1	5	F7	C2	8	F2	C2	3	F7	C2	8	F7	C2	8
13	F5	C2	6	F7	C3	9	F1	C2	2	F4	C3	6	F3	C3	5
14	F5	C3	7	F7	C3	9	F1	C2	2	F4	C3	6	F5	C4	8
15	F5	C2	6	F7	C3	9	F1	C3	3	F5	C2	6	F7	C4	10

Scenario	DH			AH			WF			DF			AF		
1	F4	C1	4	F4	C1	4	F4	C1	4	F7	C1	7	F7	C1	7
2	F4	C1	4	F4	C1	4	F1	C1	1	F7	C1	7	F5	C1	5
3	F4	C2	5	F4	C2	5	F1	C4	4	F7	C2	8	F2	C2	2
4	F4	C2	5	F4	C2	5	F1	C4	4	F6	C2	7	F7	C3	9
5	F4	C3	6	F6	C3	8	F4	C3	6	F7	C2	8	F7	C4	10
6	F4	C3	6	F6	C1	6	F1	C4	4	F4	C2	5	F6	C2	7
7	F4	C4	7	F6	C4	9	F1	C4	4	F4	C2	5	F2	C4	5
8	F4	C3	6	F6	C2	7	F1	C3	3	F5	C2	6	F7	C4	10
9	F4	C1	4	F1	C3	3	F4	C2	5	F7	C3	9	F7	C3	9
10	F4	C1	4	F1	C2	2	F1	C3	3	F4	C2	5	F7	C3	9
11	F4	C2	5	F1	C1	1	F1	C3	3	F5	C2	6	F7	C4	10
12	F5	C1	5	F7	C2	8	F1	C2	2	F7	C2	8	F7	C2	8
13	F5	C2	6	F7	C3	9	F1	C2	2	F4	C3	6	F6	C3	8
14	F5	C3	7	F7	C3	9	F1	C2	2	F4	C3	6	F3	C4	6
15	F5	C2	6	F7	C3	9	F1	C3	3	F5	C2	6	F7	C4	10

6.2. Description of ET Nodes

The nodes are below described for the ET of Scenario A, as those of Scenario B do not differ in nature, but only in the order of their position in the two ETs.

Initiating Event : Loss of Watertightness of the Fore-peak (WF)
This event is of course conditioned to the presence of deck wetness, the probability of which was inferred by combining the statistics on bulk carrier routes obtained from (Eknes et al ,1997) and the tables of sea states in the various sea areas.

This node should, in principle, have as many outcomes as the various possibilities of water ingress from the fore-peak openings.

However, the events of failure of watertightness of two or more openings are not necessarily independent. For instance, if two ventilating pipes are situated close enough to each other, they both could be carried away by the green sea; operators may commit the same lapse in securing cleats on more than one hatch, etc.

To get around all these vagaries, a fixed opening area as assumed for each reference vessel of the base case, corresponding to the cross sectional area of typical deck fittings (see Appendix 3 for details)

Detection of Fore-peak Flooding (DF)

This mode represents the possibility that the crew detects the flooding of the fore peak. As already explained, no level alarms or indicators are fitted, thus the detection relies on routine inspections.

Corrective Action of Fore-peak Flooding (AF)

The corrective action is the possibility of pumping the water out of the fore peak by using the ballast water pump as a biliging system. The failure of this mode can be due to either failure of both pumps or the isolating valve on the piping, or to human failure to perform the action. It was not deemed realistic that the failure of the hardware be restored within the timing of the accident sequence; therefore, if the pumping system fails, it will not be available for the mode AH described in corrective action of Hold No.1 Flooding, either

Watertightness of Hatch Cover No.1 (WH)

For scenario A, the loss of watertightness of hatch cover No.1 is due to the effects of the sea loads, which tend to become more severe if the preceding modes fail: the waves would impinge on the hatch cover which is caused by the wave load was assumed to be a fraction of the hatch area.

Detection of Hold No.1 Flooding (DH)

This node represents the possibility of detecting the water entering No.1 in the absence of means of detection as per IACS Unified Requirement S24.

Corrective Action of Hold No.1 Flooding (AH)

The corrective action is the possibility of removing the water from the hold by using the ballast water pump as a bilge system. This action fails if the hold is loaded, if the crew fails to take the proper actions or the isolating valve on the piping fails to open.

The following results were obtained.

Table 6. Frequency of total loss (per bulk carrier-year)					
Capesize		Panamax		Handymax	
A	B	A	B	A	B
$1.6*10^{-5}$	$2.4*10^{-5}$	$2.1*10^{-5}$	$9.3*10^{-5}$	$1.1*10^{-5}$	$9.5*10^{-5}$

Weighing the results on the percentage of the population corresponding to Capesize, Panamax and Handymax (about 18%, 36% and 46% respectively, from (www.intercargo.org) one obtains an overall frequency of total loss of about $1.3 * 10^{-4}$ / bulk carrier-year, which compares favorably with the reference point of 3.3

Chapter7. Risk Control Option

7.1. Risk model and approach

The scenarios addressed in this study are characterised by the following events, see Figure 6:

1. Water ingress due to side shell failure, hatch cover failure, or failure of deck fittings.

2. In some of the cases there are progressive flooding of cargo holds, leading to total loss of ship and also often fatalities. The progressive flooding may be due to collapse of bulkheads, hull girder collapse, cargo liquefaction, hatch cover collapse or side shell failure.

3. In the remaining cases, the flooding is limited, resulting in serious casualty and mot total loss, and few, if any, fatalities.

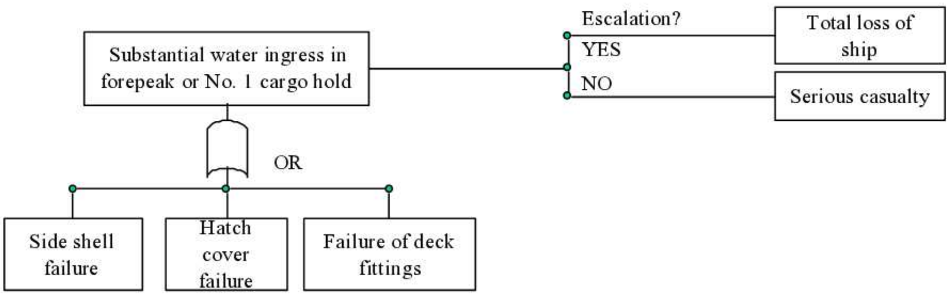

Figure 10. Scenarios under consideration

Below, flooding scenarios due to side shell failure, hatch cover failure, and failure of deck fittings are assessed, together with water ingress scenarios in general. The scenarios are assessed in terms of their contribution to the Potential Loss of life (PLL) and Economic Losses (EL), estimated from casualty data according to:

$$PLL_{scenario} = \frac{\text{Number of fatalities related to scenario}}{\text{Corresponding number of ship years}}$$

$$EL_{scenario} = \frac{\text{Number of total losses}}{\text{Corresponding number of ship years}} \quad \text{Cost of total loss}$$

$$+ \frac{\text{Number of serious casualties}}{\text{Corresponding number of ship years}} \quad \text{Cost of serious casualty}$$

7.2. Water ingress accident scenarios, 1978-1998

Reference is given to risk for bulk carriers (www.iacs.org.uk) In the LMIS casualty database, casualties involving water ingress were identified. In addition to checking by the coding of each scenario, free texts were reviewed in order to assign the casualties to the three scenarios under investigation.

The table below summarise the number of casualties identified.

Table 7. Number of serious casualties, total losses, and fatalities, 1978-1998

Scenario	Number of serious casualties, exc. total losses	Number of total losses	Number of fatalities
General water ingress scenarios	115	72	850
Flooding due to side shell failure	98	62	572
Fore peak flooding due to failure of deck fittings	7	3	44
Flooding due to hatch cover failure	11	9	246

The risk contribution from the water ingress scenarios in terms of PLL and estimated economic losses is given in the table below.

Table 8. Risk contributions from water ingress scenarios for bulk carriers 1978 to 1998

Scenario	PLL contribution (fatalities per ship)	Economic losses (US$ per ship year)
General water ingress scenarios	$1.15 * 10^{-2}$	33,000
Flooding due to side shell failure	$7.8 * 10^{-3}$	28,400
Fore peak flooding due to failure of deck fittings	$5.98 * 10^{-4}$	1,500
Flooding due to hatch cover failure	$3.34 * 10^{-3}$	3,900

The estimates given above are encumbered with statistical uncertainty. Even though the risk contribution from the water ingress scenarios in general is a significant estimate, the break down on the underlying scenarios is more uncertain, e,g. the importance of the side shell failure scenarios may be over-estimated, whereas the importance of the hatch cover failure scenarios may be underestimated. A detailed break down of the casualty data was performed, in order to assess the risks from side shell failure and hatch cover failure related to the fore end. The fore end was found to contribute with app. 50% of the fatalities due to side shell failure, whereas failure of the No. hatch cover was found to related to 244 out of the 246 hatch cover failure related fatalities.

7.3. Present risks from water ingress scenarios

In order to estimate the present risks from the water ingress scenarios considered, the effect of recently implemented risk control options were taken into account for new and existing bulk carriers. The results are given in the tables below.

Table 9. Loss matrix for bulk carrier (US$/generic accident)		
Cost item	**Serious casualties (excluding total losses)**	**Total losses**
Cost of total loss	-	16,900,000
Cost of damage repair	2,600,000	-
Cost of lost cargo	2,500,000	7,400,000
Cost of salvage	130,000	130,000
Total damage costs	5,230,000	24,430,000
Clean-up costs	378,000	378,000
Overall costs (exc. fatalities)	5,608,000	24,808,000

7.4. Fore peak flooding due to failure of deck fittings

The table below summarise the results for the risk control options related to the fore and flooding accident scenarios.

Table 10. Summary of CEA of risk control options related to fore end flooding

RCO description	$\triangle C$	$\triangle R$ **(fatalities averted per ship)**	**Gross CAF (US$ million)**	**Net CAF (US$ million)**
Forecastle, new-building				
Capsize	54,000 -102,000	2.11E-02	2.6-4.8	2.2-4.5
Panamax	29,100 -54,000	4.93E-02	0.6-1.1	0.2-0.7
Handymax	15,600 -30,000	9.33E-02	0.2-0.3	-4.9 / -2.0

7.5. Consequence Evaluation

This study is focused on the sequences of both ETs leading to loss of life. All the other sequences were not considered to bring serious consequences, and were not analyzed in detail. The consequences were distinguished into Serious Casualty (SC) if the ship survives given flooding of either fore-peak or hold No.1, Constructive Total Loss (CTL) if the ship is lost but must crew survive, Constructive Total Loss with Loss of Crew (CTLL) if the ship is lost and the crew (or most of them) do not survive.

The rationale of the separation between CTL and CTLL is that the sequences characterized by detection success and action failure bring different consequences from those characterized by detection failure and action failure, in the former case, the crew is alerted and has a higher probability of evacuation before the ship sinks. This is confirmed by the historic picture

It was decided not to include the contribution of loss of life due to SC, as the model yields a frequency of serious casualty much greater than obtained from the historical data, for various sources of conservatism ingredient in the model. however, as pointed out in 3.3 it is realistic than the SCs are much more numerous than the CTLs; the result of the model may be on the high side, but it is also very likely that the historical picture is defective.

The full details of the quantification of the two ETs is given in Appendix 2. The result are summarized in the following table.

Table 11. PLL (in fatalities/Bulk carrier-year)

Capesize		Panamax		Handymax	
A	B	A	B	A	B
$3.7*10^{-4}$	$5.9*10^{-4}$	$4.7*10^{-4}$	$2.3*10^{-4}$	$2.6*10^{-4}$	$2.4*10^{-4}$

Forecastle,15year old ship				
Capsize	180,000 -340,000	8.45E-03	21-40	20-39
Panamax	97,000 -180,000	1.97E-02	4.9-9.2	4.3-8.5
Handymax	52,000 -100,000	3.73E-02	1.4-2.7	0.8-2.1
Bulwark, new-building				
Capsize	24,000 -45,000	2.11E-02	1.1-2.1	0.8-1.8
Panamax	13,500 -25,200	4.93E-02	0.3-0.5	$-0.1^*/0.2$
Handymax	7,800 -14,100	9.33E-02	0.10-0.2	$-0.3^*/-0.2^*$
Bulwark, 15 year old ship				
Capsize	80,000 -150,000	8.45E-03	9.5-18	8.8-17
Panamax	45,000 -84,000	1.97E-02	2.3-4.2	1.7-3.7
Handymax	26,000 -47,000	3.73-02	0.7-1.3	0.1-0.6
Monitoring system for detecting water ingress in fore peak, new building				

Capsize	13,200-19,000	1.85E-02	0.7-0.9	0.2-0.4
Panamax	13,200-19,000	2.38E-02	0.5-0.7	−0.6*/−0.4*
Handymax	13,200-19,000	1.30E-01	0.1-0.13	−0.3*/−0.2*
Monitoring system for detecting water ingress in fore peak, 15 year old ships				
Capsize	40,000-57,000	7.40E-03	5.4-7.7	4.6-6.9
Panamax	40,000-57,000	9.50E-03	4.2-6.0	2.4-4.2
Handymax	40,000-57,000	5.20E-02	0.8-1.1	0.2-0.5

Chapter8. Cost Benefit Assessment

8.1. Cost Effectiveness Analysis

This section provides the Cost Effectiveness Analysis (CEA) for each of RCOs related to the watertight integrity of the fore end of bulk carriers:

RCO 1 - implementation of a forecastle

RCO 2 - implementation of a bulwark

RCO 3 - implementation of a system for monitoring the fore-peak and hold No.1

RCO 4 - implementation of a stronger design and remote closure of deck fittings. all these RCOs were evaluated on both new and existing ships.

In this study, the cost - effectiveness was expressed in terms of Gross Cost of Averting a Fatality (GCAF), defined as follows:

$$\text{GCAF} = \frac{\triangle Cost}{\triangle Risk\,Reduction}$$

$\triangle Cost$ is the marginal (additional) cost of the risk control option, whilst $\triangle Risk$ is the reduced risk in terms of fatalities averted, i.e., the expected reduction in number of fatalities. This latter should be measured in terms of Potential Loss of Life (PLL). The unit of PLL is [Expected fatalities per ship-year]. GCAF evaluates the risk control options in terms of additional safety only.

An additional cost-effectiveness measure is given by net Cost of Averting a Fatality (NCAF), where not only the increase in safety, but also the economic benefits or the investigated risk control options are accounted for. Economic benefits (or risk reduction) may also include the economic value of reduced pollution.

$$\text{NCAF}= \frac{\triangle Cost - \triangle Economic Benefits}{\triangle Riskreduction} = \text{GCAF} - \frac{\triangle Economic Benefits}{\triangle Riskriduction}$$

The study reports both measures for the risk control options.

In this study, a GCAF criterion of 3,000,000 US $ per averted fatality was adopted, consistently with doc. IMO MSC72/16 submitted by Norway (2000).

The risk variation is the difference in PLL for the two solutions, in both scenarios.

$\triangle Cost$ is the cost variation due to the implementation of the RCO (excluding the off-hire, which is very much a matter of proper planning organization)

$\triangle Risk$ is the corresponding risk decrease in terms of PLL reduction per year, multiplied by the ship's life expectancy in years.

$\triangle Economic\ benefits$, in US $ per ship lifetime, should be the sum he two of the two following terms:

- decrease in the frequency of ship loss per year multiplied by the ship's life expectancy in years, multiplied by the cost of a total loss ($24,808,000)
- decrease in the frequency of serious casualty per year multiplied by the ship's life expectancy in years, multiplied by the cost of a serious casualty ($ 5,608,000)

Future benefits due to reduced pure economic losses should be discounted at a rate defined as corporate rate of return. In this study, a corporate rate of return of 10% is used. Said $\triangle Rc$ the reduced economic losses due to the decrease of the frequency of casualty (in US $ per ship-year), r the corporate rate of return(=0.1) and n the expected ship's lifetime in years (25 or 15 for new and existing ships,) it results:

$$\triangle Economic benefits = \triangle Rc \frac{(1+r)^n - 1}{r(1+r)^n}$$

In this study, the benefits due to the reduction of Serious Casualty were not included, due to the uncertainties in this calculation. Thus, the RCOs appear less cost-effective than they really are, and the conclusions are more robust.

It is to be noted that, in principle, the NCAF thus defined may assume negative values: this implies that the economic benefits, in terms of reduced risk of losing the ship, exceed the costs of the implementation of the RCO.

8.2. Forecastle

It must be premised that this RCO, along with the Bulwark, can be proposed as a retrofit only on ships whose bridge position still allows to comply with the current regulations of navigation bridge visibility (SOLAS Chapter V, Reg. 22), otherwise other RCOs have to be adopted (modifying the bridge would raise the costs up to an unacceptable level).

The quantification or the long term probability of loss with a 2.5-m increase of the fore-end freeboard brings the following results. The overall PLL is obtained by summing up the PLL resulting from Scenario A and B, Which are treated as mutually exclusive.

Table 12. PLL (fatalities/bulk carrier-year)

	Capesize		Panamax		Hadymax	
forecastle [m]	A	B	A	B	A	B
0 (Base Case)	$3.7*10^{-4}$	$5.9*10^{-4}$	$4.7*10^{-4}$	$2.3*10^{-4}$	$2.5*10^{-4}$	$2.4*10^{-4}$
2.5	$8.0*10^{-4}$	$1.2*10^{-4}$	$5.3*10^{-4}$	$8.3*10^{-4}$	$1.0*10^{-4}$	$1.2*10^{-4}$
$\triangle PLL$	**8.45E-04**		**1.97E-03**		**3.73E-03**	

To evaluate the robustness the CFA, lower and upper cost bounds for the RCO were examined, associated to a life expectancy of 10 years for existing ships and 25 years for new buildings. It is to be recalled that the RCO cost was estimated to be 70% lower if implemented on new buildings.

This quantification does not take into account the costs of insoections, but on the other hand the benefits which may accrue from the reduction of sea damages due to the RCO implementation were not considered.

Table 13. Existing Ships of Forecastle

Ship type	GCAF (Lower bound) US$,millions per averted fatality	GCAF (Upper bound) US$,millions per averted fatality	NCAF (Lower bound) US$,millions per averted fatality	NCAF (Upper bound) US$,millions per averted fatality
Capesize	21	40	20	39
Panamax	4.9	9.2	4.3	8.5
Handymax	1.4	2.7	0.77	2.1

Table 14. New Ships of Forecastle

Ship type	GCAF (Lower bound) US$,millions per averted fatality	GCAF (Upper bound) US$,millions per averted fatality	NCAF (Lower bound) US$,millions per averted fatality	NCAF (Upper bound) US$,millions per averted fatality
Capesize	2.6	4.8	2.2	4.5
Panamax	0.6	1.1	0.24	0.74
Handymax	0.17	0.32	-4.9	-2.0

8.3. Bulwark

The same probabilities of ship loss and PLL apply as shown in the previous paragraph.

To evaluate the robustness of the CEA, lower and upper cost bounds for the RCO were examined, associated to a life expectancy of 10 years for existing ships and 25 years for new buildings. It is to be recalled that the RCO cost was estimated to be 70% lower if implemented on new buildings.

This quantification does not take into account the costs of inspections, but on the other hand the benefit which may accrue from the reduction of sea damages due to the RCO implementation were not considered.

Table 16. Existing Ships of Bulwark

Ship type	GCAF (Lower bound) US$,millions per averted fatality	GCAF (Upper bound) US$,millions per averted fatality	NCAF (Lower bound) US$,millions per averted fatality	NCAF (Upper bound) US$,millions per averted fatality
Capesize	9.5	18	8.8	17
Panamax	2.3	4.2	1.7	3.7
Handymax	0.7	1.3	0.07	0.63

Table 17. New building Ships of Bulwark

Ship type	GCAF (Lower bound) US$,millions per averted fatality	GCAF (Upper bound) US$,millions per averted fatality	NCAF (Lower bound) US$,millions per averted fatality	NCAF (Upper bound) US$,millions per averted fatality
Capesize	1.1	2.1	0.8	1.8
Panamax	0.27	0.52	-0.08	0.16
Handymax	0.1	0.15	-0.28	-0.22

8.4. Monitoring system

The inclusion of a monitoring system conceived as described in the previous section is expected to virtually eliminate the contribution of the human failure for Scenario A, where a prompt detection of the fore peak filling and operation of the pumping system can be really effective to prevent the escalation sequence. This is true, however, if the layout is such as to prevent the pumps from being flooded or disabled.

a continuous monitoring is preferable to an alarm, as it is much more user-friendly and allows for a prompter intervention. As to the requirement of ship fore and aft inclination(5° static and 7.5° dynamic, see e.g. RINA Rules 2000), it corresponds to a trim of the analyzed ship which would mot be reached even with the fore peak flooded. In any case, a timely alert of the crew is a matter of proper set point of the instrument, is only an alarm is fitted.

On the other hand, it would be less effective to prevent Scenario B, as it has been shown that the probability of operating successfully the ballast pump to empty hold No.1 is quite low; consequently, this RCO would only be useful to avoid the filling of the fore peak after hold No.1. The trim by bow would mot be fully eliminated, but only reduced. According to the initial assumptions of this study, however, the ship would mot be lost with only one hold flooded.

It can be concluded that, speaking strictly in terms of potential loss of life, the effectiveness is comparable in both scenarios. In any case, it is indisputable that the presence of a reliable and efficient means of detection contributes at least to alert the crew by giving an early warning, and, definitely, to increase the probability of a successful evacuation if noting else.

The following PLL results, in both scenarios:

Table 18. PLL (fatalities / bulk carrier-year)

	Capesize		Panamax		Handymax	
	A	B	A	B	A	B
Base case	$3.7*10^{-4}$	$5.9*10^{-4}$	$4.7*10^{-3}$	$2.3*10^{-3}$	$2.6*10^{-3}$	$2.4*10^{-3}$
with automation	$1.8*10^{-7}$	$2.0*10^{-7}$	$2.7*10^{-7}$	$7.8*10^{-7}$	$1.3*10^{-6}$	$8.0*10^{-7}$
$\triangle PLL$	7.4E-04		9.5E-04		5.2E-03	

The solution appears very effective's the PLL is reduced almost completely, This is due to the elimination of the most significant ET sequences, due to the increased reliability of the detection of water in the fore peak.

It is to be underlined that the cost estimates refer to a particularly complete monitoring system, including redundant means of detection and remote controls, and thus they are on the high side. This explains its great effectiveness, as the crew can always have the situation under control in the fore peak and boss store spaces, thus promptly detecting any anomaly. If other solutions are envisaged, it is necessary to re-analyze their cost-effectiveness by the same methodology.

Another point is that, unlike the forecastle or the bulwark, the effectiveness of the Monitoring System relies not only on design aspects (Which must achieve an intrinsically high reliability), but also on maintenance, training and spare parts: all issues that have to carried on for all the ship's lifetime.

The GCAF and NCAF for both cases was estimated as follows.

Table 19. Existing Ships

Ship type	GCAF (Lower bound) US$,millions per averted fatality	GCAF (Upper bound) US$,millions per averted fatality	NCAF (Lower bound) US$,millions per averted fatality	NCAF (Upper bound) US$,millions per averted fatality
Capesize	5.4	7.7	4.6	6.9
Panamax	4.2	6.0	2.4	4.2
Handymax	0.8	1.1	0.16	0.49

Table 20. New buildings

Ship type	GCAF (Lower bound) US$,millions per averted fatality	GCAF (Upper bound) US$,millions per averted fatality	NCAF (Lower bound) US$,millions per averted fatality	NCAF (Upper bound) US$,millions per averted fatality
Capesize	0.65	0.93	0.17	0.44
Panamax	0.51	0.72	-0.57	-0.36
Handymax	0.1	0.13	-0.27	-0.23

8.5. Upgrade of Deck Fittings

In the lack of standards to evaluate the corresponding risk decrease, the replacement of current deck fitting with sturdier ones was crudely assumed to be as effective as the implementation of a forecastle. Another important contributions of the proposed upgrade is implementation of a forecastle Another important contribution of the proposed upgrade is implementation of a forecastle. Another important contribution of the proposed upgrade is the remote closure of the fore-deck openings. This will contribute to nullify the possibility of leaving them open, at a price of additional maintenance. However, it is not possible to estimate this effect in probabilistic terms, as it would require the calculation of the contribution to the risk due to the human failures, not deducible from the casualty statistics. In any case, if the upgrade has the same effectiveness as the forecastle or bulwark, which is the most optimistic assumption, the GCAF and NCAF would be better particularly for Capesize and Panamax.

8.6. Sensitivity analysis

The analysis as affected by the following main several sources of uncertainty:

1. the approximations made in the model of compartment flooding
2. the simplifications inherent in the description of detection and corrective actions
3. the uncertainty of the input data.

The sources of type 1 uncertainties are better described in Appendix 3. They are significant, but do not play the major role one could expect, because the results (admittedly, quite conservative) of the model were tuned on the casualty statistic; thus, the conservatism was someway compensated.

The simplifications of type 2 were due to the generic nature of the bulk carrier equipment takes as reference. the actual procedure of removal of water from the flooding compartments depends very much on the reality of the specific ships, in terms of both crew's characteristics and hardware involved. However, the detailed study of the case specific tasks was out of the scope of this work.

The sensitivity analysis to type 3. The data selected for the sensitivity were: the failure of the pumping system hardware (node AF-N2 of Scenario A and AF of Scenario B) and the failure of the detection of fore peak flooding (node DF of both scenarios).

Chapter9. Discussion

As it was explained earlier, the risk picture obtained from the model is affected by various kinds of approximations. It is therefore advisable to refer to the upper bound of the CEA (worst case), to make up, at least partially, for the sources of uncertainty and not be overly optimistic in judging the RCOs.

This premised, the CEA analysis lends itself to the following considerations.

1. According to the analysis model, the risk increase as the vessel size decreases. Likewise, the CE of RCOs increases as the vessel size decreases. This is consistent with the physical model adopted, where the ship is better off the higher the freeboard and the volume of hold No.1; the reason being that, in the same spell of time, it becomes increasingly difficult to fully flood both compartments, which is actually the necessary condition to have a serious casualty of total loss, according to the escalation.

2. For new buildings, the implementation of any of the RCOs (forecastle, automation system and, especially, bulwark) is cost- effective with the exception of the forecastle in the Capesize.

3. Retrofitting existing ships brings a very different picture. No RCO appears cost-effective for Capesize and Panamax, but only for the Handymax.

4. Some sensitivity analysis carried out on some significant data used as input in the ETs did not change the CE significantly.

As for the specific RCOs, the following considerations can be made.

1. The effectiveness of the forecastle/bulwark is much more significant in preventing scenario A than B

2. The Monitoring System proposed as RCO is even more effective that the forecastle in abating the risk. The sensitivity analysis has shown that the results remain valid even with the assumption of imperfect availability of the system. The underlying reason of this behavior is that, according to the risk model and the boundary of the analysis(restricted to fore peak and hold No.1), the prompt detection of fore peak flooding enables the crew to evacuate the water from it, which, according to the basic assumptions, s sufficient to save the ship (designed to withstand hold No.1 flooding). The detection is therefore instrumental to eliminate the ause of serious casualty or even ship loss.

3. However, the following issues should be borne in mind:

- unlike the forecastle which is a preventive RCO, the effect of the system in this configuration is corrective;

- the forecastle is a passive measure totally reliable per so, whilst the monitoring system, as any active system, requires to be designed for reliability and properly managed for the whole ship's lifetime to maintain its performance;

-on the other hand, the Monitoring System may be effective for scenarios not addressed in the present study.

4. The improvement of the deck fittings appears to be the most promising RCO, once proper standards are set forth for their scantlings. In the complete version with remote actuating valves, it obtains better results than the bulwark(although of the same order of magnitude), but it becomes cost-effective for both new and existing ships for all sizes if restricted to the basic solution with replacement of the steel parts only. In this case, though, the possibility of human errors remains intact and nothing can be said about its possible impact on the results.

5. As a last consideration, the benefits due to the reduction of risk of serious casualty were not included, thus the aforesaid results are on the pessimistic side, to the advantage of their robustness.

Reference

• 이은창 "살물선의 화물창 덮개부 수밀 건전성에 공식안전평가의 적용"서울대학교 석사 학위 논문 2002

• 이은창, 이재옥, 여인철, 양영순 "살물선의 화물창 덮개부 수밀 건전성에 공식안전평가의 적용"대한조선학회지 Vol. 37, No.3, pp69-77 2002

• 허용범 "IMO 공식안전성평가에 대한 사례연구" 중앙해양안전심판원 보고서 2003

• Bas Buchner "On the Impact of Green Water Loading on Ship and Offshore Unit Design" PRADS' 95(1.430-1.443)"

• Bulk carrier safety studies 1998-2004 Maritime and Coastguard Agency MIN 228(M)

• Captain J Isbester, "ExC FNI Bulk carrier practice" The Nautical Institute, 2002 Lambeth Road, London SEI 7LQ

• D Byrne, "Hatch Covers: Maintenance and Operation with Reference to Failures in Service" ICMES/SNAME 2000 Symposium, New York

• D. Faulkner, R.A.Williams, "Design for Abnormal Ocean Waves", Trans. RINA 1996 Faltinsen O. M. "Sea Loads on Ships and Offshore Structures", Cambridge Univ.

• Guidelines for formal safety assessment for use in the IMO rule-making process MSC/Circ.1023 MEPC/Circ.392

• IACS "Evaluation of allowable hold loading for bulk carriers considering hold flooding" IACS Requirements 2000, S20, Rev. 2.

• IMO MSC 72/INF.4, "Hazard Identification of the Watertight Integrity of the Fore End of Bulk Carriers', IACS, 28 Jan 2000

• IMO MSC 73/INF.10, "An Interim Report on FSA study on Bulk Carrier Safety", submitted by Japan, 22 Sept 2000

• IMO MSC/Circ.829 & MEPC/circ.335: "Interim Guidelines for the Application of

Formal Safety Assessment to the IMO Rule-Making Process", 1998
• INTERCARGO, "Bulk Carrier Casualty Report - An analysis of vessel losses and fatalities-Statistics for 1999 and ten years of losses 1990-1999"
• Kuo, C., "Managing Ship Safety", LLP Reference Publishing, 1998
• Lloyd's List Casualty Report (1995)
• M Eknes, O C Astrup, K Ronold, S Gran, "Statistical Data for Bulk Carrier Casualties where Structural Failure May Have Been a Factor" DNV technical Report NN.96-2042, 1997
• M.K. Ochi, "Extreme Behavior of Ships in Rough Seas Slamming and Shipping of Green Water", Trans. SNAME .72, 1964
• Maritime Safety Committee 74th session Agenda Item 5
• Maritime Systems Research, 2003 (http://www.msr-consult.com)
• Masuo Kawakami, "On the Impact Strength of Ships due to Shipping Green Seas", Selected Papers from the Journal of the Society of Naval Architects of Japan, vol.8, 1971
• MCA web site (http://www.mcga.gov.uk/c4mca/mcga-safety_information.htm)
• MCA "FSA of Bulk Carriers-Hazard Identification Worksheets" 2000
• MCGA (http://www.mcga.gov.uk/c4mca/mcga safety_information.htm)
• Norway "Formal Safety Assessment, Decision Parameters Including Risk Acceptance Criteria" MSC 72/16 2000.
• RINA Rules for Classification of Ships, 2000