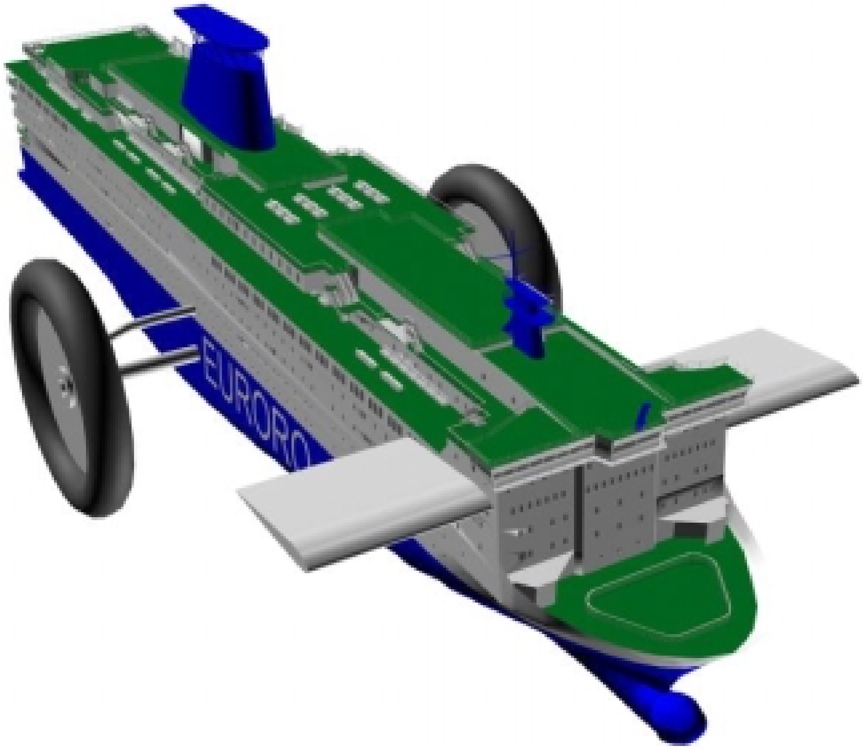
PUBLIC FINAL REPORT

# DESIGN FOR SAFETY:
# An Integrated Approach to Safe European Ro-Ro Ferry Design



# PUBLIC FINAL REPORT

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**ACRONYM: SAFER EURORO**

**TITLE:**

**DESIGN FOR SAFETY: AN INTEGRATED APPROACH TO SAFE EUROPEAN RORO FERRY DESIGN**

**THEMATIC NETWORK CO-ORDINATOR:**

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**Registro Italiano Navale (RINA)**
**Det Norske Veritas (DNV)**
**National Technical University of Athens (NTUA)**

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# TABLE OF CONTENTS

# EXECUTIVE SUMMARY

The strategic objective of SAFER EURORO TN is to facilitate the development of a formalised design methodology for safer ships by promoting an integrated approach that links ***behaviour prediction*** through the utilisation of appropriate ***technical "tools"***, ***risk assessment*** deriving from risk-based methodologies for assessing ship safety and disparate ***design activities*** and issues. Specific objectives relate to the co-ordination in the development of a series of quantifiable, readily available and evolutionary "tools", that enable the analysis, interaction and interface of all the organisational, procedural, operational, technological, environmental and human related factors concerning the occurrence of accidental or extreme events at sea. Specific objectives of the TN can be summarised as follows:

- identify, develop and strengthen links and synergies between the various key groups, currently operating in a national or bilateral fashion to enable them to function on a European level and to prepare IRP proposals for the 5th Framework Programme;
- facilitate and promote integration between the thematic areas;
- monitoring and strategic analysis of research;
- identify and facilitate technology transfer and training opportunities among the participants and in a wider context where appropriate;
- ensure adequate and effective dissemination of research results and identify opportunities and channels for exploitation of research findings;
- define the scope of targeted research in the future of "Design for Safety";
- co-ordinate CEC-funded research in this research priority area, following successful proposals in the future.

The impact of SAFER EURORO on the maritime industry of EU over the past four years has been manifold, but the most significant by far must be the instillation of a strong belief in the maritime industry that safety by design is a feasible proposition, which in turn helps to promote a safety culture that spans the whole profession. Major achievements in the strife for cost-effective safer ships through the activities of SAFER EURORO (brought to greater focus by the well publicised recent marine disasters, notably the ERIKA) include:

- The subject of safety has been forced to the forefront of developments, giving way to scientific approaches to assessing safety at the expense of the traditionally governing empiricism. As a result, a clear tendency to move from prescriptive to performance-based approaches to safety is emerging and this is paving the way to drastic evolutionary changes in design, where safety is dealt with as a central issue with serious economic implications rather than a simplistic compliance. The attention surrounding ship safety has scarcely been greater at any other time. Safety is becoming a central issue for the maritime community. The traditional inertia of the marine industry has been overcome by a new stronger resurgence of safety as a key issue that cannot be considered in isolation any longer nor fixed by add-ons, bringing home the long overdue realisation that lack of safety or ineffective approaches to safety can drive shippers out of business.
- The European Commission has actively responded to these challenges by retaining 12 proposals on "Design for Safety" prepared through SAFER EURORO (9 concerning safer Ro-Ro/passenger ships and 3 addressing the safety of high-speed craft), amounting to 45 M€ of funding. Moreover, through the adoption of an open structure partnership, enabling other areas and others partners to join the TN a true European Research Area on the

subject of Safety at Sea has thus been created and is being continuously nurtured and promoted.

- The internationalisation of the TN output, the significant contribution to the regulatory process and the increasing realisation by industry that scientific approaches to dealing with ship safety offer unique opportunities to building and sustaining competitive advantage, have helped in creating a momentum that is now proving to provide the “fuel” and the inspiration towards achieving the goals of the TN.
- More importantly, the effective co-operation between all the major players and stakeholders in the EU maritime industry led to a closer collaboration and to increased trust and respect of each of the partners potential and strengths.  EU can only be better for it.

# 1. OBJECTIVES OF THE THEMATIC NETWORK

A clear tendency of moving from prescriptive to performance-based safety standards is emerging internationally. According to this approach, compliance to safety standards will be based on a comprehensive assessment of the risks involved and risk prevention and mitigation measures accounting for information on cost and benefits. Not only is the introduction of performance standards a major development in assessing safety but it is also seen as beneficial from the industry as these readily allow consideration of alternative designs as well as a rapid implementation of technological innovation, developments and "tools". It would appear, therefore, that the approach to assessing realistically ship safety must derive from a logical framework and must, of necessity, offer the means of meaningfully taking into consideration both the operating environment and the hazards specific to the vessel in question. In addition, it is essential for a safety methodology to serve the dual purpose of enabling the identification and prioritisation of safety issues, hence safety improvements to existing ships in the short term, as well as of facilitating medium and long term development of safe innovative designs to meet the demands of emerging markets in a way that encourages the evolution of prescriptive regulations and the introduction of performance standards. In this way, it will also pave the way towards practical designs for cost-effective safety, now the focus of the whole maritime industry.

The strategic objective of the network is to facilitate the development of a formalised design methodology for safer ships by promoting an integrated approach that links ***behaviour prediction*** through the utilisation of appropriate ***technical "tools"***, ***risk assessment*** deriving from risk-based methodologies for assessing ship safety and disparate ***design activities*** and issues. Specific objectives relate to the co-ordination in the development of a series of quantifiable, readily available and evolutionary "tools", that enable the analysis, interaction and interface of all the organisational, procedural, operational, technological, environmental and human related factors concerning the occurrence of accidental or extreme events at sea.

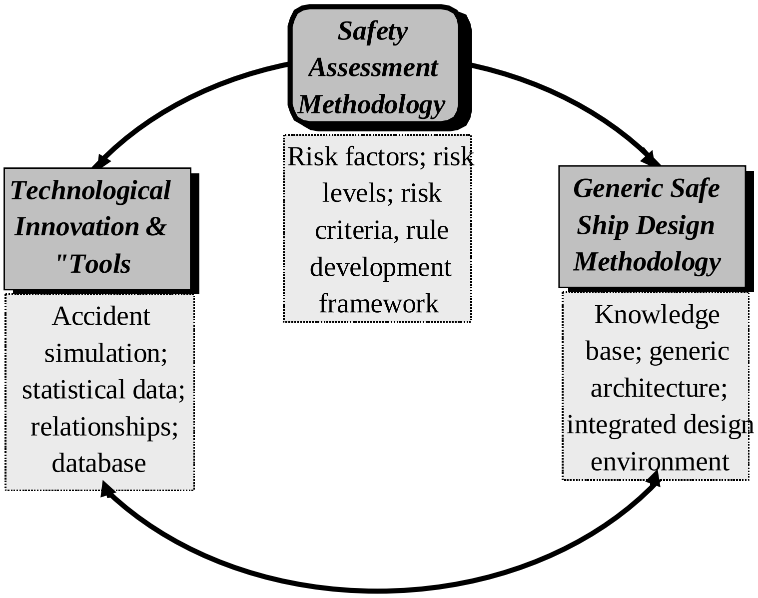

Figure 1.1: "Design for Safety" Philosophy

"Design for Safety" is, therefore, the focal area aiming at "safety improvement" and constitutes the theme on which the SAFER EURORO TN is based. The philosophy described above is demonstrated in Figure 1.1, where risk assessment and safe ship design are portrayed as integrative processes "pooling" technological developments on structural, hydrodynamic and operational aspects in a way that encourages continuous interaction and iteration.

In this respect, the Thematic Network provides the ideal environment to co-ordinate the integration of multidisciplinary technologies in this all embracing approach towards safety improvement and harmonisation of safety standards. The co-ordination of research and effective dissemination of research findings will accelerate the harmonisation of safety standards in Europe and strengthen significantly the European influence on international initiatives by the IMO and IACS.

It needs to be stressed that a methodology on safety improvement need not necessarily be particular to a specific hazard or one type of vessel. However, considering the effect recent tragic accidents had on all the areas discussed above, passenger Ro-Ro ferries are the obvious candidates for a methodological treatment. Disasters with passenger/Ro-Ro vessels involving large scale flooding of undivided deck spaces have also brought about the realisation that "*ship and cargo survival*" might have to be addressed separately from "*passenger survival*" in that the deterioration in the stability of such vessels, when damaged, could be "*catastrophic*" rather than one of graceful degradation. There has been, as a result considerable national funding in recent years aimed at specific improvements of Ro-Ro safety with projects undertaken by the majority of European Nations involving the whole spectrum of the maritime industry and academia. The need, therefore, for European-wide co-ordination and an integrated approach to tackling this subject is as obvious as it is real. There is a realisation that continuing unilateral decision-making about ferry safety will be increasingly less effective and that national Governments and institutions lack both the resources as well as the breadth and depth necessary to make a difference in the improvement of ship safety and the integration of higher safety standards in ship design, construction and operation, an achievement that would give Europe a lead in an area of paramount importance. This can be achieved only in a European context and, in this respect, specific objectives of the TN can be summarised as follows:

- identify, develop and strengthen links and synergies between the various key groups, currently operating in a national or bilateral fashion to enable them to function on a European level and to prepare IRP proposals for the 5th Framework Programme;
- facilitate and promote integration between the thematic areas;
- monitoring and strategic analysis of research;
- identify and facilitate technology transfer and training opportunities among the participants and in a wider context where appropriate;
- ensure adequate and effective dissemination of research results and identify opportunities and channels for exploitation of research findings;
- define the scope of targeted research in the future of "Design for Safety";
- co-ordinate CEC-funded research in this research priority area, following successful proposals in the future.

In accordance to this, the TN is structured into a cluster comprising five thematic areas (*Design for Structural Safety, Design for Ship and Cargo Survival, Design for Passenger Survival, Design for Seaworthiness and Design for Fire Safety*). The **purpose** of the network is to provide the necessary motivation and stimulation for technological innovation to ensure the development of a formal state-of-the-art design capability that incorporates risk management techniques for general vessel designs and conforms to enhanced safety standards, whilst accounting for other design constraints, and to ascertain that it is well defined and suited to the targeted objectives of the industry and the priorities and contents of the Maritime Industry R&D Master Plan. This represents part of the added value of the TN. The network will also ensure an effective integration among the areas, facilitating concurrent engineering practices whilst accounting for emerging needs and requirements dictated by the evolution of ship design and operation. The integration itself is the heart of the proposed methodology and, as such, it also presents a clear **way to operate** through systematic monitoring, review, analysis, and transfer of technological developments of the functions represented by each one of the five areas in support of the safety assessment and safe ship design integrative processes.

# BACKGROUND

## 2.1 Background

Recent well-published marine disasters triggered a chain of events that raised safety awareness among the whole maritime community and the wider public alike. Conventional approaches are under scrutiny and potential new approaches come under the microscope as the shipping industry is forced into responding positively. The traditional inertia has been overcome by a new stronger resurgence of safety as a key issue that cannot be considered in isolation any longer nor fixed by add-ons, bringing home the long overdue realisation that lack of safety or ineffective approaches to safety can drive shippers out of business. The attention surrounding ship safety has scarcely been greater at any other time.

In the quest for improvement of marine safety, it should be born in mind that the largest single factor contributing to the unsatisfactory state of affairs, is the compulsion to direct safety research towards rule development. The link, transfer and translation of rules-based knowledge into safe designs are subject to an undirected/haphazard process shaped by the ingenuity of designers. This problem is further compounded by the fact that the norm for rule development, i.e., codifying good practice, becomes progressively impractical as evolutionary changes happen faster than experience is gained, thus increasing the inherent potential for disaster.

Approaches to ship safety are clearly in a transitional state. Concerted efforts internationally forced the subject of safety to the forefront of developments, giving way to scientific approaches to assessing safety at the expense of the traditionally governing empiricism. As a result, a clear tendency to move from prescriptive to performance-based approaches to safety is emerging and this is paving the way to drastic evolutionary changes in design, where safety is dealt a central issue with serious economic implications rather than a simplistic compliance.

In simple terms, **the strategic objective of SAFER EURORO is to integrate safety cost-effectively within the design process in a way that safety “drives” ship design**. The scope of the TN is to provide the necessary motivation and stimulation towards the development of a formal state-of-the-art design methodology to support and nurture a safety culture paradigm in the ship design process by treating safety as a design objective rather than a constraint. Specific objectives of the on-going and planned research relate to the development of a series of quantifiable, readily available and evolutionary “tools”, that enable the analysis, interaction and interface of all the organisational, procedural, operational, technological, environmental and human related factors concerning an incident at sea. In view of the varying nature of the technical information necessary in the attempt to formalise the safety assurance and design processes, the overall programme is structured as a cluster of individual thematic areas, each addressing a specialist field in ship design and operation. In this respect, five areas have been considered throughout the duration of the TN, namely: *Design for Structural Safety, Design for Ship and Cargo Survival, Design for Passenger Survival, Design for Seaworthiness and Design for Fire Safety*. In this last report, a section on Systems Hazards has also been incorporated, to directly target developments relevant to this area.

## 2.2 Research Focus

“Design for Safety” is the focal area aiming at “safety improvement” and constitutes the theme on which the TN is based. TN-managed R&D aims to ensure an effective integration among the various design disciplines, facilitating concurrent engineering practices whilst accounting for emerging needs and requirements dictated by the evolution of ship design and operation.

The establishment of this TN is considered by the marine industry to be a significant achievement in itself, in that it "pools" together wide-ranging resources to take a pro-active role in identifying and targeting R&D areas to ensure ship safety receives long overdue consideration in the years ahead. Notably, during the past four years, SAFER EURORO was successful in attracting research funding worth over 45 million Euros and created realisable potential for integrating safety cost-effectively in the ship design process. The enhanced awareness on safety-related issues and the improved appreciation of how safety and cost interrelate and interact is slowly beginning to drive home the simple fact that scientific approaches to dealing with safety is the key to increasing competitiveness.

More specifically related R&D activities are contributing in the following:

- Development of Critical Technologies. This refers to the development of a series of quantifiable, readily available and evolutionary methodologies, tools and techniques enabling the analysis of all the organisational, procedural, operational, technological, environmental and human related factors concerning safety at sea. The broad aim is to predict the performance of a ship in limiting conditions pertaining to operational, accidental, or extreme scenarios.

- Development of Risk-Based Frameworks. This describes the structuring of appropriate safety assurance techniques and methodologies, including guidelines for the proper utilisation of tools and techniques developed for behavioural prediction and simulation of marine systems. These, in turn, provide the basis for the derivation of unified measures of safety, for design and operation, and for rule development, areas of paramount importance for the improvement of safety at sea.

- Integrated Design Environments. The utilisation of advanced design techniques, such as virtual reality and product modelling and integration, will provide the basis for exploiting the full benefit of the development of critical technologies and risk-based frameworks, in an efficient and effective manner to addressing ship safety in the broadest sense.

## 2.3 Structure of the Report

The structure adopted for the final report of SAFER EURORO TN follows the general philosophy outlined in the foregoing by describing the background to the development of a risk-based design framework on the basis of which risk/cost models can be derived, integrated and contrasted with performance indicators that allows the proposal of a risk-based design methodology and its application in design case studies. A brief description is given in the following.

### 2.3.1 Risk-Based Design Framework

The principal aim is to formulate a framework for the development of the risk-based design methodology, through the establishment of generic features that ensure safe operation of passenger Ro-Ro vessels, by utilising risk analysis methods and techniques as appropriate within a ship design environment. This involves identification of the principal hazards relating to the operation of passenger Ro-Ro vessels, the provision of a prioritised list of generic risk control options, which may include appropriate design features, measures, improved operational procedures and variations of design parameters and the establishment of appropriate trade-offs among various design and safety criteria and objectives.

### 2.3.2 Evaluation Criteria

Evaluation (acceptance) criteria on which the risk-based design methodology is to be based will be presented. The general principle is to propose a design methodology, which makes no use of the current regulatory regime. In this respect, the development of the criteria will be based on innovative methods and techniques, relevant to each criterion category. The following types of criteria and issues will be covered: socio-economic criteria; risk criteria; performance criteria; equivalence issues.

### 2.3.3 Principal Hazard Categories – Risk-Based Design Tools

Risk-based design tools, relevant to the identified hazard categories will be presented. First-principles and/or performance-based tools, already developed, should be adapted to a form appropriate for use in design application, with the view to be capable to estimate the frequency and consequences for each of the identified hazards. Relevant risk/cost models, which take into account the identified risk control options, will then be developed allowing for integration of these tools. The hazard categories to be considered follow the five Thematic Areas of SAFER EURORO TN, with the addition of the category of ship systems hazards, which form a sizeable internal accidents contributor. The interdependencies for the utilisation of the work to be developed within these work packages has been taken into account, which will help in developing and applying the risk-based design methodology. Figure 2.1 illustrates these interdependencies, together with the type of consequences (economic or loss of life) that have been considered.

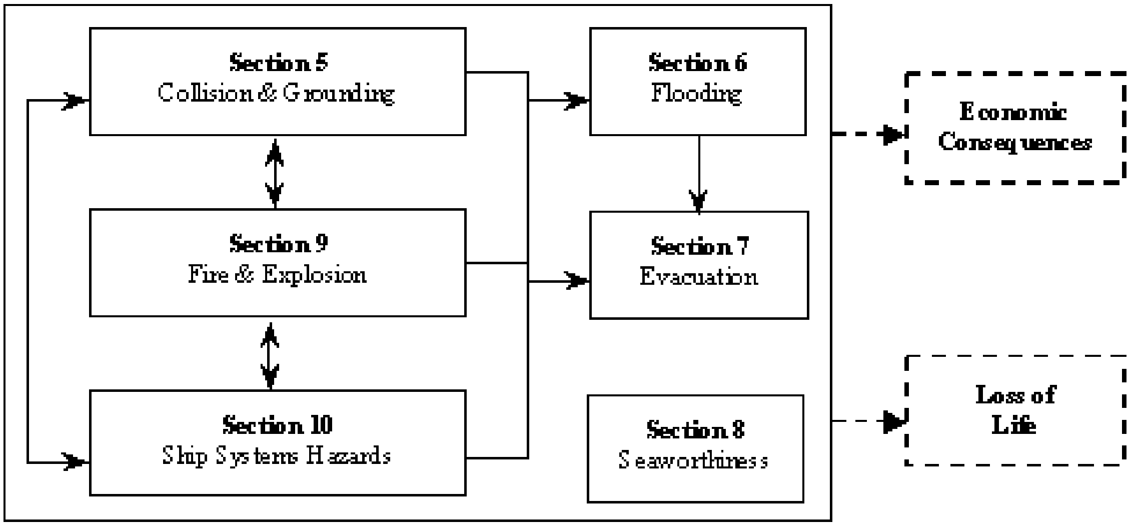

Figure 2.1: Interdependencies between Principal Hazard Categories

### 2.3.4 Risk-Based Design Methodology

The focus will be on a rational model that represents adequately the structure of the ship design process, whilst taking into account the body of first-principles methods and techniques and the generic information included in the risk-based design framework. The methodology will cover issues such as balance among the effect on safety and performance of various risk contributors or choice of appropriate risk control options and the implementation of appropriate design trade-offs within a formal optimisation procedure.

# RISK-BASED DESIGN FRAMEWORK

## 3.1 State of the Art

### 3.1.1 Background

After investing for decades in ships' hardware for the purposes of increased returns, emphasis must now be shifted towards the human element (humanware) and the organisation and management (software) before a marked improvement of safety can be achieved. With human regard for the environment at an all time high, maritime safety has to be extended to account for environmental issues, as shown in Figure 3.1 below. This broadening of safety necessitates changes in attitude and the adoption of a new approach capable of striking a balance between all the elements involved cost-effectively and throughout the life cycle of the vessel.

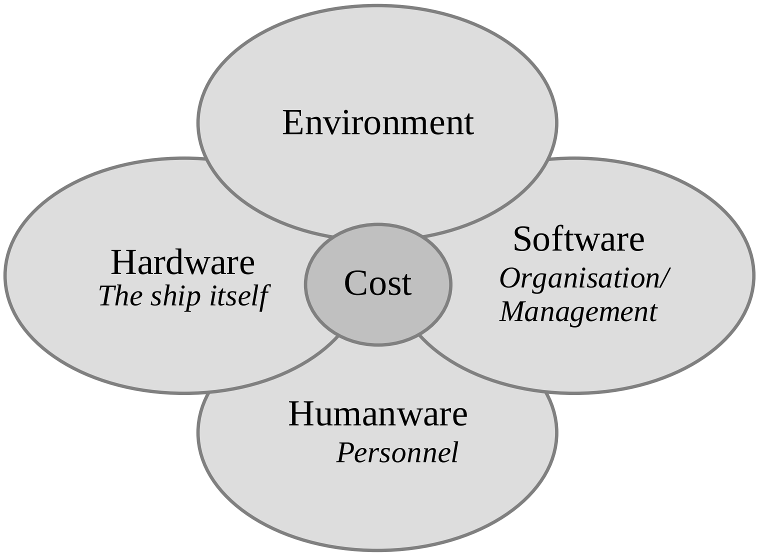

Figure 3.1: Elements of Maritime Safety

The implications deriving from this are many, bringing to surface a plethora of challenges:

- A change in attitude must come first and, hence, the role of education and training must be pivotal in this process.
- An approach to safety must be based on a comprehensive assessment of the risks involved and risk mitigation measures and must utilise routinely cost-benefit analyses to aid decision making, for safety costs money, particularly poor safety!
- Safety improvement necessitates investment in people.

### 3.1.2 Safety-Related Drivers for Change

The Shipping Industry: The shipping industry has undergone tremendous change since World War II, most significantly in the way R&D-fuelled technology has infiltrated ship design, construction, equipment, operation and management. Escalation in size, specialisation, construction material, speed, advanced satellite and terrestrial techniques for navigation, communication and vessel traffic services are typical examples. The contribution of technological developments to safety is mostly positive as the falling trends in ship losses and fatality rates will attest to that.

Societal Perception: Deficiencies in implementation, enforcement and verification of rules and regulations in terms of procedures in training, operation, management and maintenance leads to evasion, sub-standard ships and sub-standard owners and fuels a dangerous negative spiral that undermines safety at its core and affects drastically the confidence of the public at large. Furthermore, accidents have now an immediate effect and a powerful impact on the wider public with global media coverage. With even the more serious programmes appearing to be aimed more to entertain than to inform often accidents are blown out of proportion thus fuelling public outrage and strong emotions. Both give rise and support the markedly increasing influence upon democratic societies of pressure groups which trigger and influence political decisions that may be unfounded, thus undermining rather that promoting safety. Public expectation for higher safety and public regard for human life and the environment have been dramatically increased with humanity's attitude to risk becoming much less receptive to disasters, extremely so when it involves large loss of human life. In this respect, R&D activity on safety improvement is often driven by very powerful motives.

Science and Technology: Scientific progress in Marine Technology related directly to safety has been phenomenal during the recent past. Developments in mathematical modelling of non-linear systems, numerical analyses and simulation tools coupled with complex data visualisation and virtual reality technology and high performance computers can represent reality closely, particularly near the region where failures may occur. Similar developments in computational fluid dynamics, structural modelling and analyses techniques, risk assessment, concurrent engineering, artificial intelligence, knowledge-based and simulation-based design and optimisation techniques offer wide-ranging capabilities for innovative approaches to cost-effective improvement of ship safety. IMO on their part promote and support the development of probabilistic techniques to assessing safety, actively debate the adoption of a total risk-based approach (Formal Safety Assessment - FSA) and have already codified "equivalent routes" to compliance utilising performance-based approaches by means of numerical and physical model experiments. The happy co-existence of the great need for change, with regards to ship safety, and ability to respond to this need by utilising a 'total' approach to safety based on first principles that covers the whole life-cycle of the ship provides for optimism for exciting developments in the future.

### 3.1.3 Approaches to Ship Safety

Approaches to ship safety are clearly in a transitional state. Conventional approaches are under scrutiny and potential new approaches come under the microscope as the shipping industry is forced into responding positively. The lack, thus far, of a systematic and all-embracing approach to ship safety, offering a framework and a methodology that allows for a strategic overview of safety and the derivation of effective solutions, meant that the wealth of information amassed over many years of research and development on stand-alone safety-critical areas, remained under-utilised, whilst ship safety continued to being unnecessarily undermined. It also led to the discomforting lack of agreement in international terms as to what should be considered an acceptable standard of safety. Following concerted efforts on a European-wide basis to respond to the emerging needs for an integrated approach to dealing with safety as a central issue in the ship design process led to the establishment of the Thematic Network SAFER EURORO under the theme *Design for Safety*. "Design for Safety" is the focal area aiming at "safety improvement" and constitutes the theme on which the TN is based. TN-managed R&D aims to ensure an effective integration among the various design disciplines, facilitating concurrent engineering practices whilst accounting for emerging needs and requirements dictated by the evolution of ship design and operation.

### 3.1.4 On-going and Planned Research

The establishment of a significant TN on "Design for Safety" is considered by the marine industry to be a significant achievement in itself, in that it "pools" together wide-ranging resources to take a pro-active role in identifying and targeting R&D areas to ensure ship safety receives long overdue consideration in the years ahead. Notably, during the past four years, SAFER EURORO was successful in attracting research funding worth over 45 M€ and to create realisable potential for integrating safety cost-effectively in the ship design process. The enhanced awareness on safety-related issues and the improved appreciation of how safety and cost interrelate and interact is slowly beginning to drive home the simple fact that scientific approaches to dealing with safety is the key to increasing competitiveness as explained in Figure 3.2.

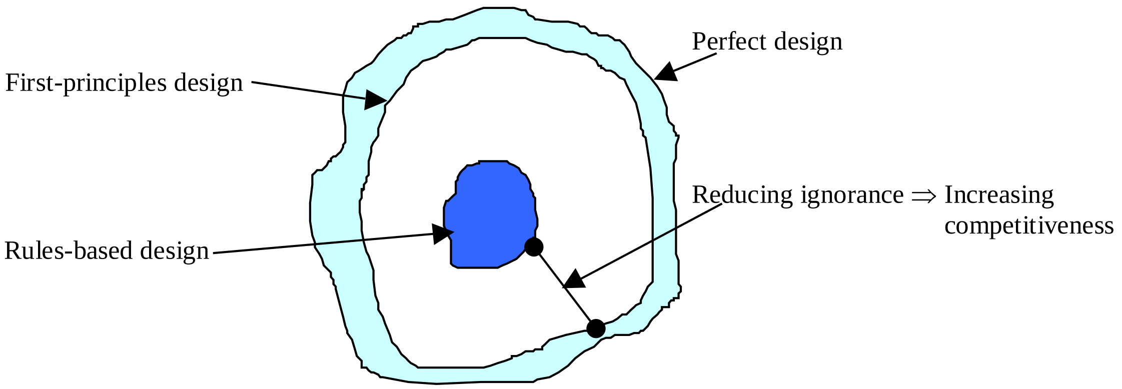

Figure 3.2: Safety and Design Competitiveness

## 3.2 Approach Adopted

The whole underlying philosophy of the SAFER EURORO TN, "Design for Safety" is innovative and consequentially, all RTD projects instigated and co-ordinated by this TN have in common a high degree of innovation, most at the for-front of international developments. The need to adopt "total" approaches to improving safety is now appreciated by all concerned. It was in fact the understanding that safety is a global concept and fragmented attempts to tackling it tend to produce biased, incomplete and ineffective solutions that led to the development of new approaches to safety as outlined above. In the quest for improvement of ship safety, the largest single factor contributing to the unsatisfactory state of affairs, as regards ship safety, is the compulsion to focus all effort towards rule development. The link, transfer and translation of rules-based knowledge into safer ship designs are subject to an undirected/haphazard process shaped by the ingenuity of ship designers. This problem is further compounded by the fact that the norm for rule development, that is codifying good practice, becomes progressively impractical as evolutionary changes now happen faster than experience is gained, thus increasing the inherent potential for disasters. To overcome the deficiencies outlined in the foregoing, the TN supports the development of a formalised "Design for Safety" methodology, by adopting an <u>integrative</u> and <u>holistic</u> approach that links safety performance prediction through the utilisation of appropriate technological “tools” and innovation, risk assessment deriving from risk-based methodologies and design as illustrated in Figure 1.1.

The underlying theme is that safety assessment will enable safe-ship-designing to be formalised as a process within an iterative procedure that allows a two-way dynamic link between tools and design, where design constraints are defined or filtered by the process of safety assessment and indeed assurance. The procedure, on the one hand, gathers and assimilates technical information, prioritises safety issues, identifies practical and cost-effective safeguards and sets requirements and constraints for the design process.

On the other hand it provides feedback from the design process to stimulate validation and refinement of the tools, in the light of the experience gained from simulation, implementation, and/or practical applications. In this process, risk assessment “pulls” together not only developments on consequence analysis tools concerning assessment of structural safety, survivability, passenger evacuation, seaworthiness and fire safety but also design measures/parameters, systems design and approaches to preventing and mitigating risks. In risk-based design methodologies cost-effectiveness of safety measures is used to achieve a balance between costs and safety optimally to render risks as low as reasonably practical, whilst accounting for other design priorities and constraints.

Approaching safety this way must derive from a logical framework and offer the means to take into consideration both the operating environment and the hazards specific to the vessel in question. With Ro-Ro vessels, for example, one of the tasks should be to quantify the probability of damage with water ingress in a given service area and, another, to quantify the consequences of damage by identifying and analysing all the important factors using probabilistic methods. In this case, however, even though it is self-evident that the risks involved can be minimised by reducing either the probability of damage or the consequences of damage, or both, there is a level beyond which consequences cannot be tolerated. Reducing the probability of damage alone will not suffice. It will be necessary, therefore, to address key questions, seeking answers concerning definition of acceptable risks, definition and management of maximum tolerable consequences and procedures for dealing with residual risks.

## 3.3 The Safety Assurance Process

An accident is the result of a chain of several undesired events, whilst the seriousness of the accident is a compound set of technical failures, operating errors, fundamental design errors, and management errors. The removal of any contributing links, or causes, may be sufficient to prevent accidents. The chain of events leading to a catastrophic accident for Ro-Ro ships is illustrated in Figure 3.3.

There are two types of technical safeguards. The one prevents accidents from happening, whilst the other mitigates the effects of accidents. They should be treated separately as their contributions to risk reduction are distinct and not comparable. The difference between these two concepts is that by preventing risks the probability, or frequency, of accident occurrence is reduced, whilst by mitigating risks the consequence of the accident is reduced.

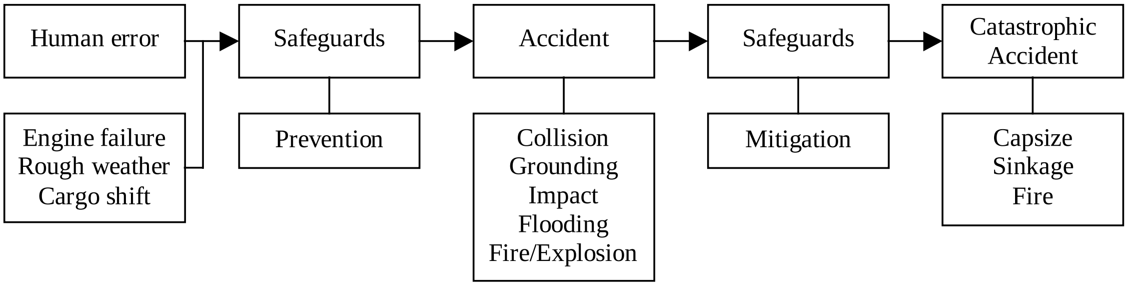

Figure 3.3: Chain of Events

On this background, a safety assurance process is established as illustrated in Figure 3.4. This process is an integral part of a larger *Design for Safety* methodology and targets optimised design of safe and cost-efficient Ro-Ro ships. The safety assurance framework accommodates the various definitions of hazard and risk assessment and their numerical approach, known as Quantitative Risk Assessment (QRA). The merit function of the framework is based on a cost-benefit analysis (CBA) comparing the costs of manufacturing and operating the proposed safety measures with the benefits of enhanced operational safety. Combined, these components comprise the safety assurance process. The main difficulty in this approach is to quantify the benefits of the safety features.

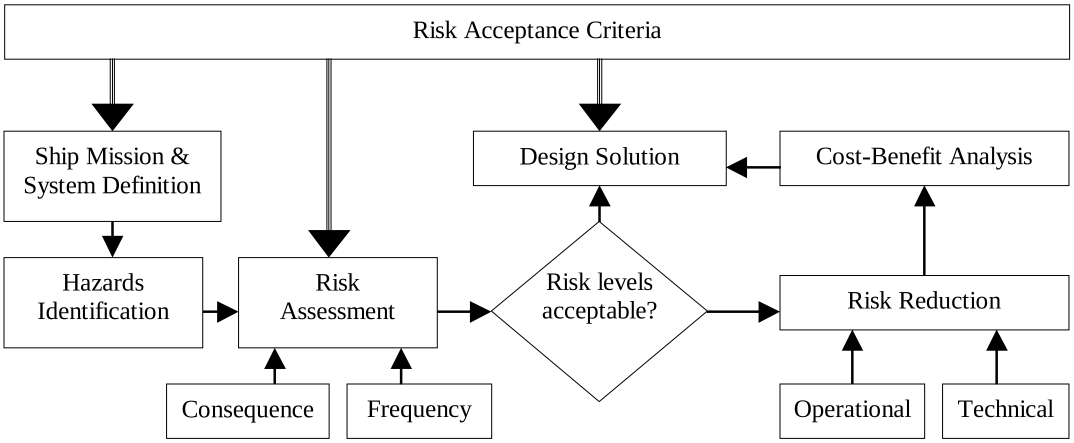

Figure 3.4: Safety Assessment Process

## 3.4 References

1. Vassalos, D.: “Shaping Ship Safety: The Face of the Future”, Marine Technology, Volume 36, Number 2, April 1999, pp. 61-74.

2. Vassalos, D., Oestvik, I. and Konovessis, D.: “Recent Developments and Application of a Formalised Design for Safety Methodology in an Integrated Environment”, Transactions of The Society of Naval Architects and Marine Engineers, Volume 108, 2000, pp. 419-445.

# EVALUATION CRITERIA

## 4.1 Background

This chapter reviews methods for deriving risk evaluation criteria and suggests criteria for various ship types. Criteria are for use in Formal Safety Assessment (FSA) or risk-based design.

FSA is a structured and systematic risk based methodology, aimed at enhancing maritime safety, including protection of life, health, the marine environment and property, by using risk and cost/benefit assessments, see IMO FSA Guidelines (IMO, 1997). FSA is consistent with the current IMO decision-making process and provides a basis for making decisions in accordance with resolutions A.500 (XII) "Objectives of the Organisation in the 1980's", and A.777 (18) "Work Methods and Organisation of Work in Committees and their Subsidiary Bodies" (IMO, 1997). FSA comprises the following steps IMO (1997):

1. identification of hazards;
2. risk assessment;
3. risk control options;
4. cost benefit assessment; and
5. recommendations for decision-making.

This represent a standard stepwise description of risk assessment techniques focussed on decision making as opposed to some technical risk analysis that are mainly used to demonstrate compliance.

Risk evaluation criteria are required in Steps 1 of FSA (when deciding not to consider unimportant hazards), in Step 4 (when evaluating the cost effectiveness of risk control options) and in Step 5 (when the FSA team present the result of cost benefit assessment and when the recommendations are formulated) see IMO (1997) paragraphs 7.3.1 and 8.2.1. In principle, different decision parameters and associated acceptance criteria may be used, and will be used unless some standardisation effort is undertaken.

Since the work with the IMO FSA Guideline was initiated in 1995, discussions have taken place at the IMO on formalising risk evaluation criteria in the organisation. However, also those Flag States and NGOs that in principle have been in favour of explicit risk evaluation criteria have felt that it would be premature to discuss this amongst an audience that has little experience with risk assessment.

On the other hand this leaves it to the FSA team to recommend or assume a risk evaluation criteria when formulating the recommendations. It therefore may seem better to formalise risk evaluation criteria to avoid receiving recommendations based one different principles. In particular when the studies are carried out as international concerted actions, the basis for risk evaluation should be agreed before the submissions from the various contributors are made. In the concerted action on FSA/BC this took place, as everyone seems to have agreed to use the MSC 72/16 document submitted by Norway (Skjong & Eknes; 2000). In the WG on Large Passenger Ships this has not taken place. This lack of standardisation seems subsequently to have resulted in large disagreements and frustration in the CG.

At MSC 71 (May 99) MSC agreed on inviting for submissions of documents on the topic. At MSC 72 (May 2000) one paper was received, MSC 72/16, which covered many of the topics and was aimed at initiating a discussion. At MSC 72 the CG was tasked with further considering this topic for inclusion in the IMO FSA Guideline. At MSC 72 it was also agreed to refer to risk evaluation criteria instead of risk acceptance criteria. This wording is expected to be easier to "sell" to decision-makers at IMO. It may be noted that one of the main purpose of regulating is to be able to decide what activities that are not acceptable, and the term "risk acceptance criteria" or just "risk criteria" is therefore the standard term in other literature. Obviously the meaning is that an activity that has been started for the benefit of someone is not acceptable for society. MSC 72/16 only relates to acceptance criteria for safety (life, injuries and ill health). A similar discussion and documentation may be necessary at IMO on environmental risk. However, it seems reasonable to believe that environmental losses will be included as economic consequences based on willingness to pay studies.

## 4.2 Application

It should be noted that the status of risk evaluation criteria is different in the different regulatory regimes that exist throughout the world. The following are some examples:

- In an industrial self-regulation regime, like the Norwegian offshore, the criteria are formulated and documented by the operator. The regulator never approves the criteria or the documentation, but have the right to review all safety-related documentation and act accordingly.
- In a safety case regime, like in many industrial sectors in the UK, the criteria are formulated by the regulator. The operator document, by the safety case, to comply with the criteria. The regulator approves the documentation, and grant permission to operate.
- At IMO the criteria are internal guidelines for the regulator to ensure internal consistence in the work. In an actual decision IMO may decide not to follow own criteria, and preferable explain why.
- In a risk-based design case the owner will present a case of safety equivalency by comparing a new design to a design case already accepted by the regulations. Alternatively safety is demonstrated in accordance with criteria given by IMO. The latter option is only possible if IMO issue own explicit criteria.

## 4.3 Methods

There are many methods to establish criteria, and this is a continuing debate in the research literature. New ways of reasoning may still appear and gain support. For example the new method described in Skjong and Ronold (1998) is regarded as a breakthrough for setting target reliabilities in structural reliability applications by Rackwitz (2001) as compared to the more classical approach used in DNV (1992), Skjong et al. (1995). Currently the main methods are:

Compare with other hazards. This implies that a comparison is made with other industries that are felt representing a reasonable target, and where the documentation is good. This approach may lead to some learning from other industries, which could add benefits. However, the method must be used competently. For example, ships may compare unfavourable on a passenger-kilometre scale and well on a ton-kilometre scale if compared to aeroplanes. And the aircraft industry never present FN diagrams. For planes the accidents are mostly all survive or are killed.

***"Shipping should be as safe as road transport"***

Comparison with natural hazards. The idea is to compare things we do to ourselves with thing done to us by Nature (God). It is generally a goal in using this approach that what we do to ourselves should be a small portion on what we can blame on Nature (God). The problem with this is that the distinction is not very clear. If a ship is designed to survive the twenty year North Atlantic extreme wave, and than meet a higher wave resulting in structural failure, that is hardly an act of God, although P&I may accept it as such.

***"Risks posed by human activity should be smaller than those posed by nature"***

Comparison with risks we normally take. We do a number of things that are hazardous, like crossing the street, driving cars, repairing the roof, and sport activities. We do not consider these activities dangerous, but in reality they are more risky than a number of individual work related risks. This is usually phrased as "The most dangerous place to be is at home". This statement is largely verified by statistics, for most white-collar workers.

***"Risk that are smaller that staying at home may be accepted"***

Comparison with previous decisions. An acceptable risk is always implicit in any building code, road standard, train safety standard etc. It is possible through analysis of data or by risk models to find the implicit risk. By comparing to standards that are accepted as "high quality", we may arrive at an evaluation criteria. As building codes are calibrated according to ISO/CEN structural reliability standards, the implicit criteria will be replaced by explicit and known criteria.

***"Risk that are smaller than in current building codes may be accepted"***

Comparisons with well informed decisions in democratic forums. From time to time risk assessment is carried out and presented to national parliaments and subject to extensive review and public debate. When a decision is finally made the value judgement on "barely acceptable" or "barely unacceptable" is disclosed in risk terms. This may be used as evaluation criteria in later risk studies.

***"Risk associated with the construction of the National Natural Gas Power Station is barely acceptable"***

### 4.4 Decision Parameters

In principle, different decision parameters may be used, and will be used unless some standardisation effort is undertaken. The advantage of standardisation is e.g. that:

- the FSA team knows what to document;
- the committee knows what to ask for;
- information are collected from many analyses in the same format;
- previous decisions may be compared to current and future decisions;
- risk based design may be based on the same criteria.

The risk evaluation criteria are normative statements or value judgments, as opposed to a statement about risk, which ideally should be objective statements of probabilities and consequences. Applications of FSA will disclose such value judgments. If evaluation criteria are not made explicit, the FSA may be used to disclose the value judgment. Risk evaluation criteria should be developed prior to extensive use of FSA to avoid that such value judgments are made on an ad hoc basis. In this chapter generic risk results for the common ship types are shown together with the evaluation criteria to indicate the effect of selecting the suggested criteria at the earliest possible stage.

To make a well-informed decision about the possible implementation of a new regulation, a new risk control option, or possible deletion of an obsolete regulation, many different decision parameters may be necessary. Reviewing the FSA Guidelines (IMO, 1997) the following decision parameters may be identified, or are suggested:

- Individual risk for a crew member (individual risk is risk of death, injury and ill health);
- Individual risk for a passenger (if relevant);
- Individual risk to third parties (as appropriate);
- Societal risk in terms of FN[1] diagrams for crew members;
- Societal risk in terms of FN diagrams for passenger (if relevant);
- Societal risk in terms of FN diagrams for third parties (as appropriate);
- Costs of each risk control options should be presented together with the effect on 1-6;
- The Gross Costs of Averting a statistical Fatality (GCAF) should be presented[2];
- The cost of reducing risk of injuries and ill health, should be presented (see discussion below);
- In cases where the risk control options can not be justified purely for safety reasons, the net economic benefit may be subtracted from the costs, and the Net Cost of Averting a Fatality [3](NCAF) should be presented.[4]

The risks and risk control options should fulfil all the criteria associated with the decision parameters above. Further criteria for environmental protection should be developed. Alternatively, all environmental consequences could be transferred to monetary units, and included in a cost benefit assessment.

For each type of the ***individual*** risks (i.e. the risk to an individual person) the risk of death, injury and ill health should be presented separately. An integrated indicator may also be presented as Equivalent Fatalities or the Disability Adjusted Life Year (DALY), see below. As different integrated indicators exist, the presentation of separate results should always be made. In case only fatality rates are presented it must be made clear if this implies that risk of injury and ill health are implicit in the numbers or explicitly excluded from the analysis. This will affect the risk evaluation criterion used, see below.

In evaluation of a specific risk control option, results before and after implementing the risk control options should be presented, IMO (1997) paragraph 6.5.1.2.

For each of the ***societal*** risk evaluation criteria, results should be presented separately and added together.

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[1] FN diagrams are plots of frequency (F) of N or more fatalities. Figures 2.2.2-2.2.4 are examples. FN diagrams are displayed in log-log scale

[2] GCAF is defined in equation 2.2.5

[3] NCAF is defined in equation 2.2.6

[4] If the net benefit is large, it may be recommended not to regulate, as the market will regulate this.

## 4.5 Risk Evaluation Criteria

The standard term used for risk evaluation criteria is “risk acceptance criteria”. The term is well established in many industries and regulations. IMO has, however, decided to use the term risk evaluation criteria to indicate that the criteria will not be used as the only decision criteria, but other considerations may be appropriate.

In general risk evaluation criteria may be implicit or explicit, and they may be high level or low level. The technical equivalency in Regulation 5 of SOLAS Chapter I is an example of a low-level implicit criterion (technical equivalency without knowing the safety). Acceptance of equivalency may also be given based on safety equivalency. This would be a high level implicit criterion. As the safety is not known in current regulations, i.e. is implicit, safety should first be established by analysis of previously accepted ships, i.e. made explicit. Thereafter safety equivalency may be demonstrated for a new solution.

It should be noted that without explicit safety objectives, it is not obvious what safety equivalency should imply. E.g. should the probability of a catastrophic accident vary with the ship size, number of passengers etc.? Does safety equivalency relate to individual risk or societal risk? In general a large number of interpretations may be possible.

Examples of high-level implicit evaluation criteria that could be formulated are:

- Ships should be as safe a workplace as land based industries, e.g. manufacturing and process industries;
- Passenger ships should be as safe transport as e.g. aeroplanes;
- Risks in shipping activities should not be disproportionate to benefits;
- Ships should not pose risks that could be reasonably avoided;
- Risks should not be unduly concentrated on particular individuals;
- Risks from catastrophic accidents should be a small portion of the total risk.

The community of risk analysts would easily interpret such high-level evaluation criteria. It is, however, unlikely that the interpretation by different analysts would be identical. FSA would hence not be consistently applied, IMO (1997) paragraph 1.2.1, and the transparency objective of FSA would not be met, IMO (1997) cover, paragraph 3. Therefore there is a need for IMO to agree on explicit risk evaluation criteria for use in future FSA.

### 4.5.1 Explicit Risk Evaluation Criteria – Individual Risk of Death, Injury and Ill Health for Passengers, Crew and Third Parties

#### *Purpose*

The purpose of *individual* risk evaluation criteria is to limit the risks to people onboard the ship or to individuals who may be affected by accidents. The criteria should define the term “intolerable and negligible level of risk” in terms of the *individual* risks of death, injury and ill health.

#### *Background*

Modern risk assessment practice is to use an *individual* risk criterion that defines the intolerable and the negligible (broadly acceptable) risk. These criteria are limits to the area where cost-effectiveness assessment may be applied, as intolerable risks must be reduced irrespectively of costs. The area where cost-effectiveness assessment may be applied are commonly referred to as the As Low As Reasonably Practicable (ALARP) area. *In this area risks should be reduced as long as the risk reduction is not disproportionate to the costs*. To reduce risks beyond where risk reduction is disproportionate to the costs is not reasonable. The cost-effectiveness criteria therefore define what is reasonable (R in ALARP, see section about Cost-Effectiveness below).

There is no single universal level of acceptable *individual* risk. People are prepared to accept a wide variety of risks depending on their own perception of the risks and benefits from the activity. In general, higher risks are accepted if the risk is voluntary, ordinary, natural, the effects are delayed and the individual consider that they have control. These factors may explain why high risks are commonly accepted in some sports, in driving cars and motorbikes, and in certain hazardous occupations where risk control depends on the individual's own skill (e.g. flying, diving).

When people are exposed to risks over which they have little or no control, they rightly expect that the appropriate authorities impose control on their behalf. It is these "involuntary" risks which risk evaluation criteria are developed to control. An appropriate level for the risk evaluation criteria would then be substantially below the total accident risks experienced in daily life, but might be similar to risks that are accepted from other involuntary sources.

*Individual* risk criteria for hazardous activities are often set using the risk levels that have been accepted from other industrial activities. This involves a judgement that the acceptability of *individual* risks is similar for all activities over whose safety the person exposed has little or no control. Thus, risk criteria for ship's crew could be similar to those for land-based industries e.g. manufacturing and offshore industries. This implies that risk criteria that have already been developed in other industries can be applied to ships.

In principle there are many different methods that may be used to set the limit of tolerable risk as mentioned previously. By comparing to other industries Tables A.1 & 2 in Appendix A is relevant. Comparing to natural hazards a risk evaluation criterion of $10^{-3}$ per ship-year for crew may be derived. The annual fatality rate for all reasons in the period of life when this is at its lowest (4-15 of age) used to be about $10^{-3}$ (in OECD member countries when this criterion was first introduced. Today this figure is down to $2 \cdot 10^{-4}$ in some countries). This was used by many regulators as an intolerable limit. For passengers it is common to use a stricter criterion, because the passengers are less informed about the risks, they are not compensated (but pay), and are less in control. A negligible or 'broadly acceptable' criterion of $10^{-6}$ should be understood as a very small number representing an insignificant risk to an individual. If exposed to only such risks an individual would live in the order of a million year.

Crewmembers on a ship should have more influence over the risks and should be better informed than passengers or members of the public near the port. It is therefore common to treat occupational risk (crew) differently than transport related risk (passengers).

### *Proposed Criteria*

*Individual* risk criteria may be proposed for ships as follows, based on those published by the UK Health & Safety Executive (HSE, 1999):

| | |
|---|---|
| Maximum tolerable risk for crew members | $10^{-3}$ annually |
| Maximum tolerable risk for passengers | $10^{-4}$ annually |
| Maximum tolerable risk for public ashore | $10^{-4}$ annually |
| Negligible risk | $10^{-6}$ annually |

Risks below the tolerable risk but above the negligible level should be made ALARP by adopting cost-effective risk reduction measures. Other regulators use similar, or slightly different criteria, see the Appendix.

The maximum tolerable criteria specified above are not particularly strict, and it may be required that all ships should meet them. When a comprehensive FSA is carried out for new ships, it may be appropriate to have a more demanding target, which should be met.

These may be indicated as follows:

| | |
|---|---|
| Target individual risk for crew members | $10^{-4}$ annually |
| Target individual risk for passengers | $10^{-5}$ annually |
| Target individual risk for public ashore | $10^{-5}$ annually |

Although it is not necessarily essential to have risks below these targets, failure to meet them would suggest that cost-effective risk control options might be available. New regulations based on an FSA should demonstrate that the new ships meet these targets, or that risks are ALARP.

Regarding the *individual* risk evaluation criteria for public ashore, indications of risk levels are given above. The responsible national authorities should decide on the *individual* risk evaluation criteria for public ashore.

### *Comparison with Historical Data*

Figure 4.1 shows the estimated average *individual* risk for crews from different ship types in the period from 1978 to 1998 (Eknes and Kvien, 1999). The data source is the LMIS casualty database, representing the ship accidents. The figures indicate that, unless personal accidents dominates, the individual fatality risk levels in the maritime industry, according to the proposed criteria, fall in the ALARP region, where risk control options should be introduced if they are cost effective. There may be exceptions among subgroups of ship types investigated or ship types that have not been investigated, like e.g. tug boats and fishing vessels.

For *individual* risks of injury and ill health similar evaluation criteria may be developed by comparing to other industries and transport. For example, if a significant proportion of the crew is injured or develops similar health problems, this should be regarded intolerable. What is significant may be judged by comparing to statistics representing larger populations.

Further, for an explicit treatment of risk of injuries and ill health more explicit criteria should be based on cost-effectiveness considerations (see the section about cost-effectiveness below). Except for such obviously intolerable cases a criterion based on cost effectiveness is suggested as more appropriate for explicit studies of risks of injuries and ill health, see below.

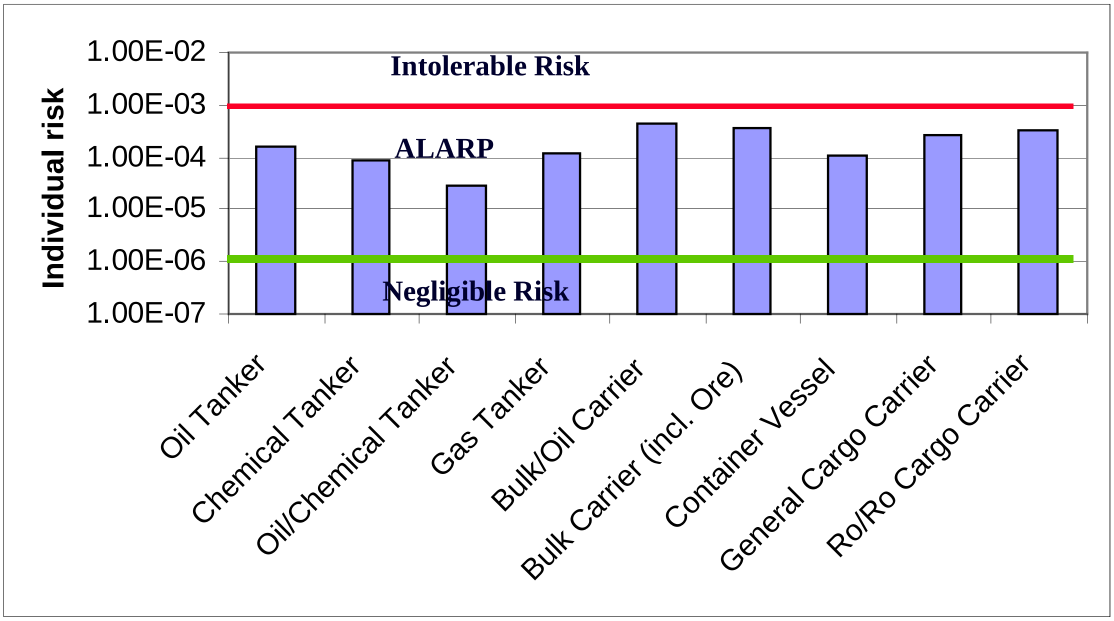

Figure 4.1: Individual fatality risk (annual) for crew of different ship types, shown together with the proposed individual risk evaluation criterion (data from 1978 to 1998, data source: LMIS/Ship accidents).

### 4.5.2 Explicit Risk Evaluation Criteria – Societal Risk to Life for Passengers, Crew and third Parties

#### *Purpose*

The purpose of *societal* risk evaluation criteria is to limit the risks from ships to whole crews, groups of passengers or the society as a whole, and to local communities (such as ports), which may be affected by ship activities. In particular, societal risk evaluation criteria are used to limit the risks of catastrophes affecting many people at the same time, since society is particularly concerned about such events. In effect the criteria define the term "acceptable level of risk" in terms of the overall *societal* risks of fatalities.

#### *Background*

In general, *societal* risk evaluation criteria, and the societies' risk aversion against large or catastrophic accidents may be considered as lacking an explicit rationale. Some risk analysts would count the risk aversion against large accidents as one of the 'risk conversion factors' representing the bias 'perceived risk' divided by 'actual risk'. E.g. Litai (1980) is listing the following factors affecting this bias: Volition, Severity, Origin, Effect Manifestation, Exposure Pattern, Controllability, Familiarity, Benefit and Necessity. The factors are found to be similar to factors addressed by Rowe (1977), Starr (1969), Kinchin (1978), Otway and Cohen (1975) and Green et al. (1998). Although the rationality may be debated, societal risk criteria are used by a large and increasing number of regulators. The problems of inconsistency are, however, often seen and debated.

FN diagrams may be established in similar ways as *individual* risk criteria. However, comparison with other industries may result in unpredictable and illogical results. The

<u>*societal*</u> risk evaluation criteria should reflect the importance of the activity to society. For example, the evaluation criteria used for a single fishing vessel should be different from the whole transport sector in a country. To formalise such observations an FN evaluation criterion may be established by considering the economic activity represented by the different ship types. This may vary by orders of magnitude. The examples given for some ship types show that when the importance to the society is accounted for, the established FN evaluation curves vary within 1- 2 orders of magnitude. The outlined method (Skjong and Eknes, 2001) may be used for any type of activity above a certain size. An obvious limitation of the principle is represented by activities of high economic value with low labour intensity in remote places, e.g. offshore oil production.

The objective of the outlined method is to establish transparent FN risk evaluation criteria with a rational foundation, which may be established from factual and available information. This way the criteria would be transparent as required in IMO (1997).

***Method***

The evaluation criteria may be associated with the economic importance of the activity in question, and calibrated against the average fatality rate per unit economic production. The importance of an activity may be measured most adequately in economic terms, assuming that what is paid in an open market represents the importance. Similarly, Gross National Product (GNP[5]) is an aggregated indicator of the economic activity. <u>*Societal*</u> risk associated with an activity may be accepted according to the importance to society of the activity.

For occupational accidents the aggregated indicator, $q$, may be defined as the average fatality rate per GNP. For transport related accidents a similar aggregated indicator, $r$, may be defined.

| | |
|---|---|
| $q = \frac{\text{Number of occupational fatalities}}{\text{GNP}}$ | to establish risk evaluation criteria for crew |
| $r = \frac{\text{Number of fatalities due to transportation}}{\text{Contribution to GNP from transportation}}$ | to establish risk evaluation criteria for passengers |

By using data from US and Norway on occupational fatalities $q$ = <u>1.5 fatalities/£ billion</u> may be estimated for the occupational fatalities and $r =$ <u>8.6 fatalities/£ billion</u> may be estimated from statistics for scheduled air traffic (ICAO, 1995; Skjong and Eknes, 2000 & 2001). Air traffic is selected for comparison because of the availability of good statistics, and the generally high safety standards.

For a specific activity (e.g. a ship), an <u>average</u> acceptable Potential Loss of Life ($PLL_A$) may be based on the Economic Value (*EV*) of the activity.

$PLL_A = q \cdot EV$ for crew/workers or $PLL_A = r \cdot EV$ for passengers. (4.1)

This states that largely the total occupational risk should be distributed between the different activities accounting for their contribution to GNP, and that large deviations from this should

---

[5] GNP = An estimate of the total money value of all the final goods and services produced in a given one-year period by the factor of production owned by a particular country's residents

be judged an indication of good reasons for scrutiny. A similar criterion should be established for a transport activity. For activities and trades, which are of less importance to the society, the society may not be willing to accept a high accidental fatality risk. For activities and trades of minor significance, and with minor contribution to the service production, only minor risks should be accepted. As the ultimate solution the fatality risk may be eliminated, by eliminating the activity itself. This way a safety budget would be established. E.g. a low economic importance corresponds to a low $PLL_A$.

FN curves are commonly regarded as useful tools. An FN curve with inclination *b on log-log scale* may be fitted to the resulting $PLL_A$ by:

$$PLL_A = \sum_{N=1}^{N_u} N f_N = F_1 \left( \frac{1}{N_u^{b-1}} + \sum_{N=1}^{N_u - 1} \frac{(N+1)^b - N^b}{N^{b-1}(N+1)^b} \right) \qquad (4.2)$$

Here $N_u$ is the upper limit of the number of fatalities that may occur in one accident; for a ship this is well defined as the maximum number of crew/passengers.

$f_N$ is the frequency of occurrence of an accident involving $N$ fatalities

and $F_1$ is the frequency of accidents involving one or more fatalities

Following the recommendation by HSC (1991), HCGPD (1983), Statoil (1995), $b$ =1 is chosen, and the above simplifies to:

$$PLL_A = F_1 \left(1 + \sum_{N=1}^{N_u - 1} \frac{1}{N+1}\right) = F_1 \sum_{N=1}^{N_u} \frac{1}{N} \qquad (4.3)$$

Some risk analysis practitioners are of the opinion that $b$ =1 is not risk averse. This is wrong, as explained in details in HSE (1991). The risk aversion may be understood by observing that small contributions to PLL comes from large N. Since this small contributions are as 'intolerable' as the comparable large contributions from small N, the b=1 is risk averse.

If solved with respect to $F_1$, Equation (4.3) gives:

$$F_1 = \frac{PLL_A}{\sum_{N=1}^{N_u} \frac{1}{N}} \qquad (4.4)$$

The ALARP region is introduced by assuming that the risk is intolerable if more than one order of magnitude above the average acceptable and negligible (broadly acceptable) if more than one order of magnitude below the average acceptable. This implies that the region where risks should be reduced to As Low As Reasonably Practicable (ALARP) ranges over two orders of magnitude, in agreement with many published FN evaluation criteria, e.g. HSE (1999). HKGPD (1993), Statoil (1995).

### *Examples of Criteria and Comparison with Data for Some Ship Types*

Figures 4.2 to 4.4 below show FN data for different tankers, bulk carriers, container vessels, and passenger Ro/Ro vessels. The FN curves are based on data from LMIS (1999). The figures also show the *societal* risk evaluation criteria established by the method outlined above. The tankers, bulk carriers and container vessels were all assumed to have an average crew size of 20. Based on data from Clarkson Research Studies (1999) the average annual turnover for the different tankers was estimated to approximately $ 5 million, while the average annual turnover for bulk carriers and container vessels was estimated to approximately $ 2.5 million. For the passenger Ro/Ro vessels, the evaluation criteria are based on data for a fleet of only 7 vessels. A passenger Ro/Ro vessel with a crew size of 140 and annual turnover of $ 50 million gives a *societal* risk evaluation criterion for crew as shown in Figure 2.2.4. A *societal* risk evaluation criterion for passengers as shown in Figure 2.2.4 results when considering a vessel carrying 1900 passengers at an annual operating revenue from tickets of $ 16 million. The evaluation criteria are based on occupational health statistics in the US and Norway, the passenger criteria are derived by comparing with air-traffic.

The historical data appears to give FN curves in the ALARP region for most of the examined ship types. The bulk carriers are different, apparently touching the borderline between the ALARP and the intolerable risk region. This may be observed to be in agreement with the concern behind the attention that has been given to bulk carriers safety in recent years, where the impression has been that the number of losses of these ships involving many fatalities has been judged as intolerable. For bulk carriers the curve is in agreement with the previous published FN curve by Mathiesen (1997) which was derived by other methods. For Passenger Ro/Ro Vessels the curve presented is in agreement with the FN diagram published by the North West European Project on Passenger Ro/Ro Vessels (DNV, 1997).

### *Third Parties*

On safety issues there will always be a conflict between the interests of third parties and industries, as the third parties will be involuntarily exposed to the risks from the industry. The shipping industry is not an exception. It should be the national authorities' responsibility to define maximum tolerable and negligible third party risk, to protect the citizens.

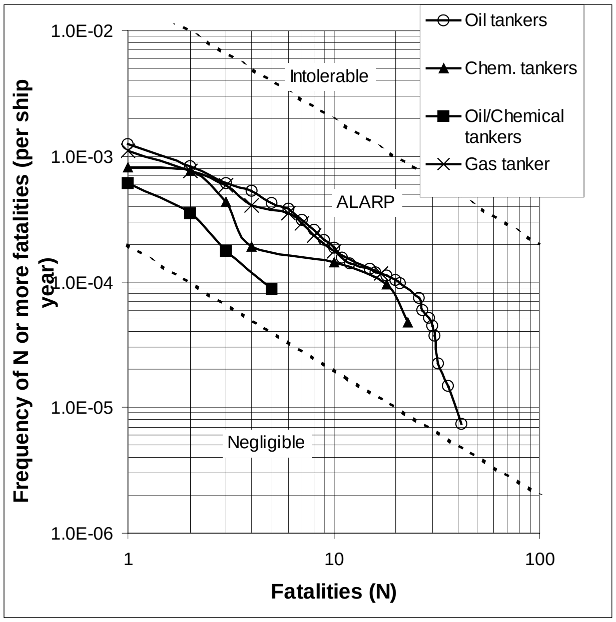

Figure 4.2: FN curves for different tankers, shown together with established risk evaluation curves. Data from 1978 to 1998. (Data source: LMIS)

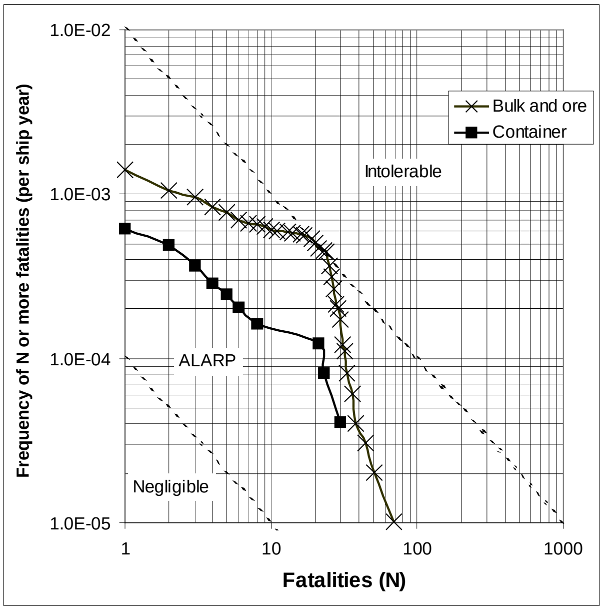

Figure 4.3: FN curves for bulk and ore carriers, and container vessels, shown together with risk evaluation criteria established by the above outlined method. Data from 1978 to 1998. (Data source: LMIS)

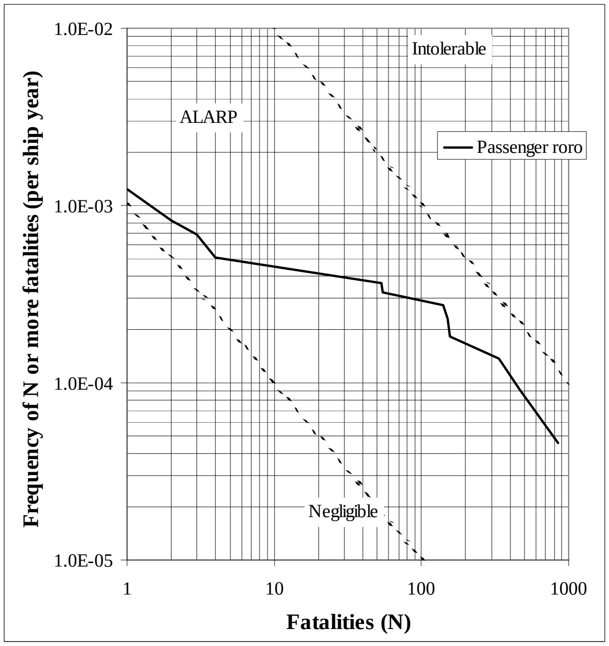

Figure 4.4: FN curve for passenger Ro/Ro ships, shown together with risk evaluation criteria established by the above outlined method. Data from 1989 to 1998. (Data source: LMIS)

## 4.6 Cost Benefit and Cost Effectiveness Assessment

### *Purpose*

The type of risk criteria proposed above may define a range within which the risks should be reduced to a level "as low as reasonably practicable" (ALARP). Within this range cost effectiveness assessment is recommended used to select reasonably practicable risk reduction measures.

The purpose of the cost effectiveness criterion will be to provide a basis for decision-making about risk control options resulting from FSA Step 3, IMO (1997) paragraph 6.5.1.

### *Background*

In a conventional cost benefit assessment the evaluation criteria is simply that the benefits outweigh the costs. In cost benefit assessment the analyst converts all risks to monetary units. The distinction between cost effectiveness assessment and cost benefit assessment is therefore quite large. Cost effectiveness assessment presents a ratio of costs to benefits, and avoids putting a value to the benefit (e.g. life saved). The value judgment is left to the decision-maker when deciding which risk control options to implement. Such a judgment is bound to be made at IMO by MSC 76 when deciding which risk control options to implement from the FSA studies carried out for bulk carriers, see MSC 74/5/3 (Japan), MSC 74/5/4 (IACS) and MSC 74/5/5 (Norway & ICFTU). These studies present results on exactly the same format, as suggested in MSC 72/16 by Norway.

Currently only a few IMO decisions and other decisions have been made within the maritime industry based on FSA. These decisions are listed in Table 2.2.1. When a decision is made to implement a risk control option the “>” is used to indicate that “a statistical fatality averted is worth more than $ x million”. It is seen that there are no inconsistencies in IMO, and based on previous well-informed decision the criterion is in the range $ 1.5 million to $ 5 million.

**Table 2.2.1: Cost of averting fatalities in actual decisions**

| Decision | Decision Maker | Value |
|---|---|---|
| Strengthening Bulkheads on Existing Bulk Carriers | IACS and IMO (1) | > $ 1.5 million |
| Helicopter Landing Area on non-Ro/Ro Passenger Ships | IMO(2) | < $ 37 million<br>($ 12 million to $ 73 billion) |
| 3 bulkheads on car deck | IMO(3) | < $ 5 million |
| 3 bulkheads on car deck | NMD(3) | > $ 5 million |
| 3 bulkheads + sponsons | IMO(3) | < 7.8 million |
| Extended sponsons only | IMO(3) | < $ 11 million |
| Collision Avoidance Training | Owner(3) | > $ 0.7 million |
| Extra Deck Officer | IMO(3) | < $ 5.5 million |

Re: (1) Mathisen et al.(1997), (2) Skjong et al.(1997), (3) DNV(1996)

Initially IMO decided to require Helicopter Landing Area (HLA) on all passenger ships. The Formal Safety Assessment that was prepared by DNV, for Norway and ICCL, showed that this requirement could not be justified as the cost were in great disproportion to the benefits for non-Ro/Ro passenger ships. The cost of averting a fatality was about $ 37 million. A decision was therefore made to repeal the requirement.

In a cost benefit assessment the analyst makes the value judgement or use prescribed criteria. All losses (life, injuries, ill health, environmental, and economic losses) are converted to monetary units. Cost benefit assessment is therefore not likely to be attractive at IMO, as the analysis may lack transparency. Cost benefit assessment is also discredited by its earlier uses by economists. Some economists found ‘value of life’ by estimating the value of man as a resource in an economic activity. The view, were pursued in e.g. Rice (1966), Lave and Seskin (1970). This approach is conflicting with ethical traditions. Most ethical systems would regard the wellbeing of man as the purpose of economic activity[6]. Early use of cost benefit assessment lead to the bizarre result that a child was worth next to nothing, because of the “low opportunity cost of replacement”.

This criticism is accounted for in cost effectiveness assessment. Society spends large sums (some 20% of Gross Domestic Product (GDP[7]) in some countries) on safety. Such use of resources cannot be justified in order to optimise economic production. However, resources are limited and society needs to put some limit to how much resources could be used for safety, and thus a cost effectiveness criterion may be proposed.

The valuation of fatality risks is a critical step in this process, and modern risk assessment practice is to highlight this issue by expressing the results in the form of a Gross Cost of

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[6] E.g. The “Homo Mensura” sentence was formulated by Protagoras (485 – 415 BC).

[7] GDP = An estimate of the total money value of all the final goods and services produced in a given one-year period using the factor of production located within a particular country's borders. (The differences between GDP and GNP arise from the facts that there may be foreign-owned companies engaged in production within the country's borders and there may be companies owned by the country's residents that are engaged in production in some other country but provide income to residents.)

Averting a Fatality (GCAF) if a risk control option were to be adopted, i.e. by cost effectiveness assessment.

$$GCAF = \frac{\Delta Cost}{\Delta Risk} \qquad (4.5)$$

$\Delta Cost$ is the marginal (additional) cost of the risk control option, whilst $\Delta Risk$ is the reduced risk in terms of fatalities averted.

This approach then requires criteria to define the GCAF values at which measures are considered just cost-effective. Again, there are many methods to identify an evaluation criterion. Alternatives are such methods as willingness to pay studies by public surveys, willingness to pay in actual decisions, studies of risk control options implemented and not implemented. If regulators could avoid implementing risk control options with high GCAFs and implement those with low GCAFs, more lives would be saved for the same budget (Condition of Pareto optimality), see e.g. Tengs et al. (1995), Ramberg and Sjøberg (1997).

An alternative cost-effectiveness measure is given by Net Cost of Averting a Fatality (NCAF), where the economic benefits of the investigated risk control options are accounted for. Economic benefits (or risk reduction) may also include the economic value of reduced pollution. The consequence of pollution may be established from clean-up costs or previous decisions. For example the OPA 90 regulations represent a cost of \$ 10.000 per barrel of oil pollution averted (see Lloyds List May 18th 2001).

$$NCAF = \frac{\Delta Cost - \Delta EconomicBenefis}{\Delta Risk} = GCAF - \frac{\Delta EconomicBenefis}{\Delta Risk} \qquad (4.6)$$

Table 4.2 gives values of GCAF used by some authorities.

**Table 4.2: Published GCAFs in use as evaluation criteria**

| ORGANISATION | SUBJECT | GCAF | SOURCE |
|---|---|---|---|
| US Federal Highway Administration | Road Transport | \$2.5m (£1.6m) | FHWA (1994) |
| UK Department of Transport | Road transport | £1.0 m (1998, up-rated with GDP per capita) | DETR (1998) |
| UK Health & Safety Executive | Industrial safety | As above or higher | HSE (1999) |
| Railtrack (UK rail infrastructure controller) | Overground railways | As above to £2.65m | Railtrack (1998) |
| London Underground Ltd | Underground railways | £2m | Rose (1994) |
| EU | Road Transport | ECU 1 million (£0.667m) | from Evans (1998) |
| Norway | All hazards | NOK 10m (£0.8m) | Norway (1996) |

Large studies in other industries have revealed large inconsistencies in safety policy. The most well known and largest study is that of Tengs et al. (1995) carried out in the US. Table 4.3 presents the average values from. These figures represent willingness to pay in actual decisions. Assuming that a fatality correspond to 35 lost life-years, the median value correspond to \$ 1.470.000 (or about £ 900 000).

| **Table 4.2: Results from Tengs et al. (1995)** | |
|---|---|
| **"Five Hundred Life-Saving Interventions and their Cost Effectiveness"** | |
| Number of measures studied | 587 |
| Range of cost effectiveness | Negative to $10 billion/life year saved |
| Median Value | $ 42.000/life year |
| Median for Medical Interventions | $ 19.000/life year |
| Median for Injury Prevention | $ 48.000/life year |
| Median for toxic control | $2.8 million/life year |

It is also possible to derive evaluation criteria expressed as GCAF from compound aggregated social indicators, see UNDP (1990) and Lind (1996). The Life Quality Index Criterion for acceptable risk implies that an option is preferred or accepted as long as the change in the Life Quality Index owing to the implementation of the option is positive. The Life Quality Index contains such indicators as GDP/capita and life expectancy at birth. As a risk control option change these two, an optimum acceptable GCAF by be derived, and as GDP and life expectancy varies between countries there are variations in the evaluation criteria. Within OECD member countries (representing some 95% of the global GDP), the variation is not very large, see Figure 4.5.

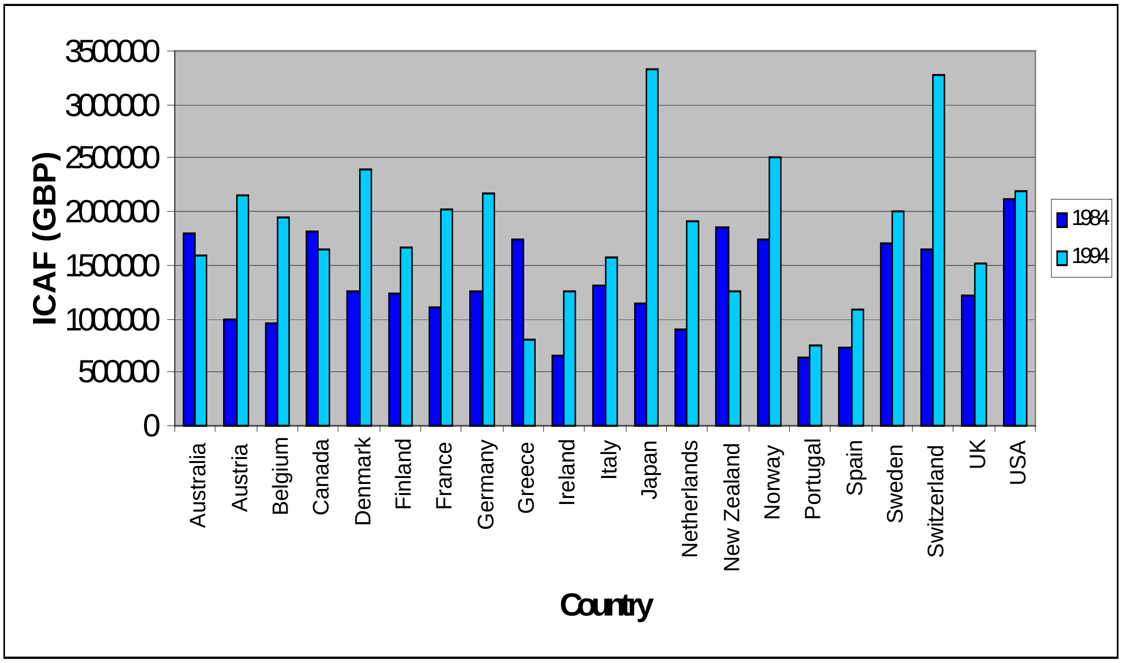

Figure 4.5: Comparison of values of implied cost of averting a fatality between the years 1984 and 1994 and between various countries (Skjong and Ronold, 1998).

Based on the above, a GCAF criterion of $ 3 million or £ 2 million may be proposed for use by IMO, in cases where fatalities in addition to representing fatality risk also represent an indicator of risk of injuries and ill health. The GCAF criterion is proposed updated every year according to the average risk free rate of return (some 5%), or if data is available by use of the formula derived by UNDP societal indicators, see Skjong and Ronold (1998). Higher values may be justified for risks that are just tolerable, and a range of £ 1 to 5 million may be indicated, see also MSC 70/WP.12, paragraph 30, referring to $ 1 to 8 million.

### *Risk of injuries and ill health*

As indicated above risk of injuries and ill health may be dealt with implicitly or explicitly. In the societal indicator approach the indicator is life-year (life expectancy at birth), and may be interpreted as an indicator of life expectancy as well as life quality. The GCAF criterion may therefore implicitly be assumed to account for risk of injuries and ill health. In separate studies of risk of injuries and ill health, the GCAF criterion is therefore initially of no use. It may therefore be suggested to use the GCAF criterion and split it into contributions covering risk of death, injuries and ill health separately.

According to the UK Department of Transport, DETR (1998), the willingness to pay for slight injuries is 0.9% of the value of prevention of a statistical fatality. The number of injuries to crew on UK registered merchant vessels during 1993-97 was 1886 compared to 15 fatalities (MAIB, 1998). The ratio of approximately 130 injuries to 1 fatality can be applied to the estimated personal accident rate above. The severity of these injuries is not defined, but they are assumed to be equivalent to lost-time injuries, as they do not necessarily involve medical evacuation. It is not clear how comprehensively they are reported. This suggests that the overall cost of injuries could be approximately equal to the loss value of fatalities (0.9% of 130 = 1.17). Similar results have previously been reported in MSC 68/INF.6. By defining serious injuries as 1/10 equivalent fatalities, and minor injuries as 1/100 equivalent fatality the data suggested a 1:1 correspondence (or actually 14:14.89). These result are highly uncertain, and for comparison, fatalities on Norwegian roads are estimated to contribute with approximately 14% of the total costs of fatalities and injuries, whereas the injuries are estimated to contribute the remaining 86% (Elvik, 1993). The relatively large difference between these estimates may be explained by minor injuries in traffic on average being more severe than minor injuries for crewmembers. It is thus initially, in the lack of better statistics, proposed to split the GCAF criterion equally between the two contributors, one applying for fatalities and one for risk of injuries and ill health. As more knowledge is gained, this should be revised.

A criterion based on the Disability Adjusted Life Years (DALYs) gained may be used for risk control options affecting injury and health. This would be similar to the equivalent fatality approach suggested in MSC68/INF.6 An evaluation criterion may be established based on the GCAF criterion, see below.

Attempts to measure and value quality of life are a more recent innovation, with a number of approaches being used. The DALY is now advocated as a measure for health effects by the World Health Organisation (WHO), see WHO Annual Report (2000). Particular efforts have been invested in researching ways in which an overall health index might be constructed to locate a specific health state on a continuum between 0 (= death) and 1 (= perfect health). Obviously the portrayal of health like this is far from ideal, since, for example, the definition of perfect health is subjective and some individuals have argued that some health states are worse than death.

The DALYs are presently crude measurements, but may be sufficient in prioritising risk control options, which is the use in a risk assessment. It is necessary to be aware of their limitations, and more research may make the process better documented, justified and useful.

The Disability Adjusted Life Year (DALY) has been created to combine the quantity and quality of life. The basic idea of a DALY is straightforward. In its simplest form it takes one year of perfect health-life expectancy to be worth 1, but regards one year of less than perfect health-life expectancy as less than 1.

DALYs may provide an indication of the benefits gained from a variety of RCOs in terms of quality of life and survival. An example is shown in Figure 4.6. The RCO could be e.g. the use of protective shoes. The benefit of the RCO is illustrated in the Figure in terms of DALYs gained by one person.

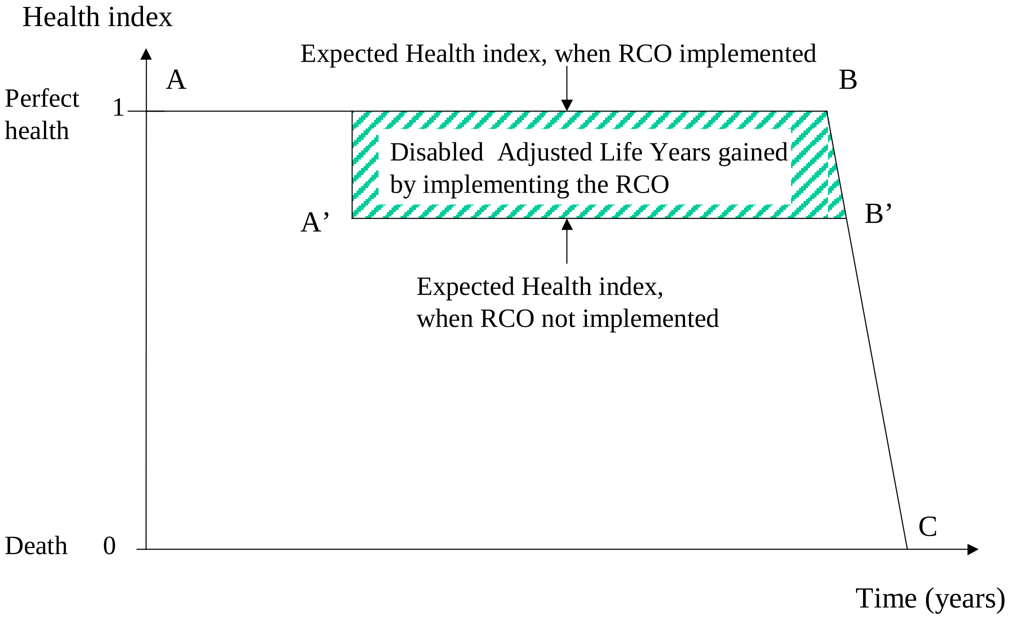

Figure 4.6: Example of Disability Adjusted Life Years gained by one person by implementing a risk control option.

Some sources of information on DALY and similar indicators may be referenced.

- The Quality of Well Being Scale (Kaplan and Anderson, 1988);
- The McMaster Health Classification System (Drummond et al., 1987);
- The Rosser and Kind Index (Kind et al., 1982);
- The EoroQol Instrument (EuroQol Group, 1990; Nord, 1991);
- The World Health Organisation.

If it is assumed that on average one prevented fatality implies 35 Disability Adjusted Life Years gained, a DALY criterion may be based on the GCAF criterion as follows:

$$DALY_{criterion} = \frac{GCAF_{criterion}\,/\,2}{\Delta e} = \frac{\$3\,\text{million}\,/2}{35} = \$42000 \text{ per Disabled Adjusted Life Year gained}$$

This figure is very close to the figure used for decisions in the health care area, where e.g. Gafni (1999) refer to a DALY of $ 35 000. The average value for life saving interventions in the US in Tengs et al. (1995) is also $ 42.000 per life-year, see Table 4.3.

### *Discount Rates in Cost Benefit and Cost Effectiveness Assessment*

Discount rates in cost benefit assessment and cost effectiveness assessment may influence results to a considerable degree. The reason is that many risk control options are technical installations and design modifications that will be part of the costs of constructing the ship, whilst the benefits may be reduced risks at the end of the design life (e.g. 20 years).

Further, it should be noted that in an economic decision the discount rate reflects the economic risk of the investment. As risks are made explicit in an FSA the discount rate should not include any element of risk premium or opportunities for alternative investments. The discount rate is not the interest rate in the corporate investment manual (the corporate rate of return).

It would also seem unethical to be able to delay an investment in safety for an economic benefit. This would be the case if the safety budget could be placed as a risk free investment, and only part of the resulting increased budget was allocated to safety. These ethical considerations are made in Skjong and Ronold (1998) to show that the GCAF criterion should increase with the risk free rate of return. A similar argument has been used by Paté-Cornell (1983).

The conclusion of the question of discount rates to be used in cost effectiveness assessment and cost benefit assessment is therefore suggested as follows:

For a decision in any given year:

- All future monetary costs should be depreciated to present value with an interest rate corresponding to a ‘risk-free’ rate of return (e.g. future maintenance, inspection, and training);
- Investment costs now is at present value and should not be depreciated;
- All monetary risks should be handled the same way as monetary costs (e.g. a NCAF criterion);
- No uncertainty or risk should be treated as a risk premium (as they are included explicitly);
- Lives saved should not be depreciated. For a decision now, all lives saved now or in the future have the same value.

For comparison with an alternative decision e.g. to delay the implementation of a risk control option:

- The evaluation criteria should be expected to increase corresponding to a ‘risk-free’ rate of return or the formula given in Skjong and Ronold (1998);
- The actual future evaluation criteria are the concern of future decision-makers.

## 4.7 Summary

The following decision parameters and evaluation criteria have been suggested:

| | **Decision Parameters** | **Evaluation Criteria** |
|---|---|---|
| 1 | Individual risk for a crew member (Individual risk is risk of death, injuries and ill health): | Figure 4.1 and preceding tables, GCAF = £ 2 million (risk of death, injuries and ill health implicit); GCAF =£ 1 million and DALY = £ 25,000 (if risk of injuries and ill health separate).[8] |
| 2 | Individual risk for a passenger (if relevant): | Same references as 1 |
| 3 | Individual risk to third parties (as appropriate): | Same as 1, Mainly National Authorities' responsibility |
| 4 | Societal risk in terms of FN diagrams for crew members | Figures 10-12 or the model used |
| 5 | Societal risk in terms of FN diagrams for passenger (if relevant): | Figures 10-12 or the model used |
| 6 | Societal risk in terms of FN diagrams for third parties (as appropriate): | Mainly National Authorities' responsibility |
| 7 | Costs of each risk control options should be presented together with the effect on 1-6 | Not Applicable |
| 8 | The Gross Cost of Averting a statistical Fatality (GCAF) should be presented: | £ 2 million, range £1-5 million. |
| 9 | The cost of reducing risk of injuries and ill health | See 1 |
| 10 | In cases where the risk control options can not be justified purely for safety reasons, the net economic benefit may be subtracted from the costs, and the Net Cost of Averting a Fatality (NCAF) should be presented. | Criteria as for GCAF |

Note that if it is accepted that the ship type analysed is already in the ALARP area, only the cost effectiveness criteria apply. This simplifies considerable and FSA reduces to a Pareto optimisation, a method that may easily be implemented as a method for risk based design that fit nicely into a concurrent engineering approach.

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[8] For discussion of uncertainty, see text

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# Appendix: Individual Risk Criteria in Use

**Table A.1: Individual Risk Criteria in Use**

| Authority | Description | Criterion (annual) |
|---|---|---|
| HSE (HSE, 1999) | Maximum tolerable risk to workers | $10^{-3}$ |
| | Maximum tolerable risk to the public | $10^{-4}$ |
| | Negligible risk | $10^{-6}$ |
| Netherlands (Bottelberghs, 1995) | Maximum tolerable for existing situations | $10^{-5}$ |
| | Maximum tolerable risk for new situations | $10^{-6}$ |
| New South Wales, Australia (DUAP, 1997) | Sensitive developments (hospitals, schools etc.) | $5 \cdot 10^{-7}$ |
| | Residential, hotels, motels, tourist resorts etc. | $1 \cdot 10^{-6}$ |
| | Commercial, retail, offices etc | $1 \cdot 10^{-5}$ |
| | Sporting complexes, active open space | $1 \cdot 10^{-5}$ |
| | Industrial | $5 \cdot 10^{-5}$ |
| Western Australia (EPA, 1998) | Sensitive developments (hospitals, schools etc.) | $5 \cdot 10^{-7}$ |
| | Residential zones | $1 \cdot 10^{-6}$ |
| | Non-industrial (commercial, sporting etc.) | $1 \cdot 10^{-5}$ |
| | Industrial | $5 \cdot 10^{-5}$ |

**Table A.2 Individual Risk in Various Industries and Activities, Mathiesen (1997)**

| Industry | Annual Individual Risk ( x$10^{-5}$) |
|---|---|
| **Oil and gas production** | 100.0 |
| **Agriculture** | 7.9 |
| **Forestry** | 15.0 |
| **Deep sea fishing** | 84.0 |
| **Energy production** | 2.5 |
| **Metal manufacturing** | 5.5 |
| **Chemical industry** | 2.1 |
| **Mechanical engineerin** | 1.9 |
| **Electrical engineering** | 0.8 |
| **Construction** | 10.0 |
| **Railways** | 9.6 |
| **All manufacturing** | 1.9 |
| **All services** | 0.7 |
| **All industries** | 1.8 |
| **Bulk carriers** | 13.0 |

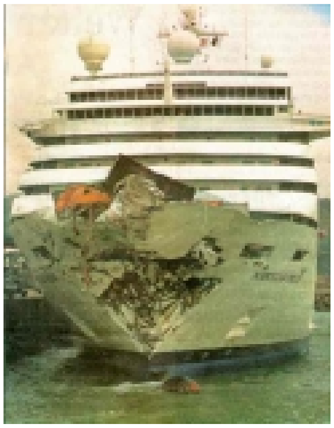
# COLLISION AND GROUNDING

Collision and grounding events are among the most common ship accidents and continuous efforts have been made to prevent these events or mitigate the associated consequences. However, collision and grounding events are likely to happen in the future and, therefore, tools for the analysis were continuously developed and / or refined. A review of procedures for the analysis of collision and grounding scenarios with emphasis on probabilistic methods is presented. First, the background and the state of the art is described with special focus on the developments that have taken place during the last four years of the thematic network's activities. Second, methods for prediction of occurrence probabilities and consequences for collision and grounding events are presented that fit into the overall theme of risk based design. Available risk control options and their associated costs are outlined in the third section. Finally, research gaps are summarized and recommendations for future research activities are given.

## 5.1 Background

Many research projects were devoted to the analysis of collision and grounding scenarios in recent years. However, research on analysis of grounding appears less prominent than collision related work. Strong European involvement in research resulted from the existing large traffic density in European waters, big construction projects, and a continuous stream of accidents. Recent events include the collision of the double-hull oil tanker "Baltic Trader" with another cargo ship north of the German Island of Rügen resulting in pollution of parts of the Danish coastline. Another accident involved the cruise ship "Norwegian Dream" that collided with a container vessel between Dover and Zeebrugge. Latest grounding events include the ferry "Express Samina" which sank off the Greek island of Paros taking 79 lives. High speed craft are particularly endangered when grounding occurs. Due to the high speed a large portion of the hull may be damaged and large flooding could lead to capsize. The high speed ferry "Sleipner" grounded in Norwegian waters and finally sank taking 19 lives. These four examples demonstrate that prevention of collision and grounding events is necessary and that a need exists for damage robust ships and tools to evaluate the effectiveness of structural improvements.

Baltic Trader



Norwegian Dream

Express Samina

Catamaran operating in Norway (giving an idea of conditions encountered by catamaran Sleipner)

Research into analysis of collision and grounding mainly addressed two topics:

- development of tools to predict the probability of occurrence on a given route / in a given area;
- establishment of a deeper knowledge of the behavior of ship structures involved in these events and derivation of new software tools to predict the consequences.

Technological advances can be reported for both topics. During the last five years, software tools were developed to predict frequency of collision on a given route (e.g., projects DEXTREMEL, ISESO). Obtaining accurate information on ship traffic in a specified sea area remains the single biggest obstacle for the standardized application of these tools. Traffic data is published only for certain areas with a high level of interest. The frequency of grounding events can in principal be predicted given detailed topological information along the route. Continuous advances in computational structure mechanics supported by even full scale experiments on ship-ship collision have lead to better understanding of the behavior of ship structures during a collision (TNO). Grounding events can now also be analyzed in full detail using advanced finite element computations. Unfortunately, practical implications for ship design are scarce and damage robust ships are still futuristic although attempts are made to quantify crashworthiness of ships (CRASHCOASTER).

The ship's ability to stay afloat after damage is the most important safety related aspect and the location of bulkheads is one of the most important design parameters. Therefore, a very strong link exists from collision to damage survivability and efforts are currently underway to model this influence (ROROPROB). Other effects with strong influence on collision that were not addressed lately like, e.g., human factors, navigation aids, maneuverability and system failures, will be partly assessed within a new project proposal (SAFERIDE). Large damages due to a collision may result in a loss of structural integrity, in particular for bulk cargo vessels. Work in this respect was also performed continuously (e.g., project DEXTREMEL).

It is necessary to underline that numerical tools for the analysis of collision events can often be readily applied to analysis of grounding events. Main difference is related to the prediction of frequency of occurrence. Damages and subsequent consequences can be assessed with the same tools. A comprehensive software package was developed in Denmark and it can be downloaded for research purposes from http://www.ish.dtu.dk/GRACAT (Friis Hansen and Simonsen 2001). The 2nd international conference on collision and grounding of ships (ICCGS) took place in July 2001 in Copenhagen, Denmark. Details can be found at the conference website: http://www.ish.dtu.dk/iccgs. A large number of citations in the next five sections refer to papers presented during this conference.

## 5.2 Risks Involved

### 5.2.1 Probability of Collision Events

The most commonly used approach to determine the probability of ship-ship collisions is based on the work of Fujii et al. (1974). This two-step procedure first requires determination of the potential number of collision candidates as if no aversive maneuvers are made. A distribution of ship traffic must be known for this part of the analysis. In the second step a so called causation factor is determined that models effect of crew and equipment related actions to avoid the collision. Note that only ship-ship collisions are dealt with here although similar tools are used to compute the probability of ship collisions with obstacles. These are described in the chapter on grounding probability.

For the computation of potential number of ship-ship collisions both the struck vessel and the striking vessel need to be described. Usually, main particulars such as length, beam, draft and speed as well as characteristics of the (bulbous) bow are required input for the analysis, see, e.g., Pedersen and Zhang (1999). Ship traffic data must be categorized into ship types and size. Ideally bow character and actual loading condition is also needed for the subsequent consequence analysis. If more than one particular route has to be investigated traffic data from different areas need to be collected. However, these data are usually not available to ship designers. Only if big construction projects are planned like, e.g., the bridge spanning the Fehmarn Belt between Germany and Denmark detailed data are collected (Gluver and Olsen 2001, Randrup-Thomsen et al. 2001). There clearly is a lack of actual ship traffic data and access to it. In addition, no generally accepted procedure exists that determines which routes one should take into account for unrestricted service condition (defines an acceptance criteria) and what the ship operator shall do in case traffic volume changes. Traffic lanes and traffic volume constitute two risk control options for this part of the analysis.

Bayesian networks can be (successfully) used for the prediction of the causation factors, see Friis Hansen and Pedersen (1998). The Bayesian network for the determination of the causation factor models effects of weather, crew actions and training, system errors, engine blackouts and maneuverability, bridge layout and navigation equipment. All these effects are risk control options that either the ship designer of the ship operator might invoke to reduce risk to ALARP. However, detailed analysis of these effects would require additional modeling of Bayesian network nodes to model the risk control options. This will be part of the proposed project SAFERIDE.

Determination of collision probability is considered advanced when compared to prediction of other hazards. Results are well suited for integration into risk assessment procedures. State-of-the-art tools exist as part of the GRACAT software package (Friis Hansen and Simonsen 2001). A sample application is presented in, e.g., Otto et al. (2001).

### 5.2.2 Consequence of Collision Events

Consequences of collisions are conveniently subdivided into two categories: i) the direct damage to the ship hull due to the collision impact, and ii) the subsequent damages like, e.g., flooding and possible capsize, fire, machinery failures, and possible loss of life. Many research projects dealt with the direct damage after a ship-ship collision and significant knowledge exists about the behavior of ship structures involved in a collision. The second category is far more difficult to model and, therefore, little work has been published yet.

Computation of hull damage for a collision event is generally a two-step procedure. First, external dynamics of the ships need to be determined. Ship motions in the horizontal plane and added mass effects must be computed. Main result of this first step is the kinetic energy available for the internal (crushing) mechanics that are evaluated in the second step. Details can be found in, e.g., Pedersen and Zhang (2000). In case of a well defined scenario ship motions need to be specified, see, for example, guidelines for the voluntary class notation COLL of Germanischer Lloyd (2001).

Structural response can be computed by a range of methods starting from empirical expressions, simplified formulas describing the structural response of larger structural elements and finally detailed finite element analyses. Only simplified formulas can be applied within the scope of a risk assessment and an example is given in Otto et al. (2001). These probabilistic methods to predict collision damage can also be used to derive *new* statistics through systematic application, for example see Tagg et al. (2001). On the other hand, complex finite element analyses and dedicated model or full scale tests are used to derive these simplified formulas and to identify optimized / crashworthy structural arrangements. Due to the uncertainty of the impact location and the variety of ship structures, many simplified formulas must be ready at hand if all possible collision damages should be assessed within a single investigation. Therefore, research work on these simplified formulas is continuously reported.

Main results from a probabilistic collision damage analysis comprise probability distributions of damage size (length, height, depth) and damage location. Main results from deterministic collision damage analysis include deformation histories of selected structural elements and the final position of the striking bow with respect to bulkheads. Only few risk control options can be invoked during the damage analysis and the most important are the selection of hull material and the arrangement of structural elements to increase the crashworthiness. A strong link to the assessment of structural integrity exists in particular for bulk cargo vessels as a large scale damage may lead to the loss of structural integrity.

However, the most important risk control option for the collision consequence analysis is the compartment layout including variable elements such as watertight doors and flooding ducts. These risk control options can only be considered in the subsequent consequence analysis (that is, after the hull damage has been occurred). The largest potential for improvements and benefits is associated with a compartment layout that is directly influenced by collision analysis. Therefore, the European research project ROROPROB (2000) was started to address this aspect. (In Germany, a nationally funded research project started recently to address the same topic.) To study effects of collision damage on bulkhead arrangement is best performed within the scope of a risk analysis.

Other consequences like fire and machinery failure are discussed and related risk control options are outlined in other chapters of this report.

### 5.2.3 Probability of Grounding Events

Grounding of ships is generally subdivided into power groundings (when the ship hits the obstacle with large velocity) and drift groundings (when the vessel hits the obstacle while drifting with small velocity). Power groundings can be considered as collisions with a fixed obstacle and the same tools as described above for ship-ship collisions can be used to determine the probability of occurrence. In addition, the same risk control options apply for probability of grounding as for collision.

To determine the probability of power grounding in a given area, obstacles such as reefs and shallow islands must be described with their respective location and properties like, e.g., distance to mean water level, size (diameter), geometric character of peak (e.g., wedge or cone). Alternatively, a two-dimensional profile of water depth along the considered route can be derived from topological data. This profile can be extended to three dimensions taking into account the width of the traffic lane. Combination of water depth and tidal information with ship's actual draft can yield the probability of power grounding. Such an approach has not been published yet although the GRACAT software package evaluates effects of fixed obstacles (Friis Hansen and Simonsen 2001).

The determination of probability for drift grounding also requires the description of obstacles as above. In addition, modeling of the drift rate is needed. The drift rate of the ship mainly depends on current, wave and wind data. If coastal waters are considered in the analysis, the possibility of tug escort and emergency anchoring must be taken into account. Both preventive actions can also be considered as risk control options. If machinery failure is the initiating cause of the drift grounding, additional risk control options like self repair can come into focus. Self repair describes the ability to restart the engine after failure. A fine analysis of drift grounding as part of a regulatory assessment is presented in Moore et al. (2001). An actual risk analysis of offshore wind energy parks also used a drift grounding model to assess the probability of collision of a ship with a wind energy tower and to give advise for the stationing of tugs (Otto 2001).

Determination of grounding probability is considered less advanced then collision probability. State-of-theart tools for prediction of power grounding probability are incorporated into the GRACAT software package (Friis Hansen and Simonsen 2001). Results of grounding probability analysis are well suited for integration into risk assessment procedures.

### 5.2.4 Consequence of Grounding Events

Consequences of groundings are conveniently subdivided into two categories (similar as for collision): i) the direct damage to the ship hull due to the grounding impact, and ii) the subsequent damages like, e.g., flooding and possible capsize, fire, machinery failures, and possible loss of life. Again, many research projects dealt with the direct damage after a grounding but only little work is known that deals with the second consequence category. In addition, consequences after the damage has occurred are likely to be similar for collision and grounding and, therefore, we restrict the following section on the first consequence category.

Two different kinds of grounding can be clearly distinguished: i) grounding on rock(s) or other well defined obstacles, and , ii) grounding on mud. If the vessel hits a rock similar structural response as in the case of collision is expected: tearing of plates and crushing of other structural members and a possibly large damage results. In addition, the vessel may slip off the rock after the damage has occurred and capsize. High speed craft are particularly endangered when grounding occurs. Due to the high speed a large portion of the hull may be damaged and rapid flooding could lead to capsize. However, if the vessel runs aground on sand or mud, overall (vertical) bending is likely to increase and the structural integrity of the vessel is endangered.

As for collision, the first step in the determination of grounding damages is the prediction of the ship motions during the grounding. Usually, roll and pitch motions are computed in addition to motions in the horizontal plane. Resulting kinetic energy estimates are then used for the computation of hull damages that in turn is performed by means of simplified formulas - derived from tests or statistics – or laborious finite element computations for well defined grounding scenarios. Today, computing power has increased to levels that investigations into optimal structural arrangements are possible, see e.g. Naar et al. 2001. As for collision, hull material and structural arrangement can be invoked as risk control options at this stage.

One noticeable difference between direct assessment of grounding and collision hull damages is the relative uncertainty of the damage location. Slight variations in trim can significantly shift the damage location. In addition, multiple rocks are the rule and, therefore, multiple damages occur. These two aspects underline the need for probabilistic approaches for grounding assessments. First, statistics based on actual groundings can be employed to derive simplified formulas, see e.g. Zhu et al. (2001). Second, numerically generated statistics can be used to derive new knowledge on, for example, effect of design modifications on oil outflow, see Tikka et al (2001). A rather elegant approach combines causes and consequences of grounding by means of simplified formulas and predicts probabilistic grounding damage distributions, see Louka and Samuelides (2001).

As for collision, the most important aspect after hull damage has occurred is damage stability of the ship. Again, the risk control option having the largest influence is compartment layout. To study effects of grounding damage on bulkhead arrangement is best performed within the scope of a risk analysis. An example is provided in Otto et al. (2001).

Other consequences like fire and machinery failure are discussed and related risk control options are outlined in other chapters of this report.

## 5.3 Costs Involved

Costs for safety measures come into play when risk control options are exercised to reduce risk levels to ALARP or lower. Collision and grounding events are similar to each other for most available risk control options and, therefore, both events (or hazard categories) are treated as one in the following. A list of applicable risk control options is given in Table 5.1. The table updates results achieved during a SAFER EURORO technical meeting of TA1 in Hamburg (see Sames et al. 2000).

Table 5.1: Risk Control Options applicable for Collision and Grounding Events

| Responsibility of / influenced by | Affects probability | Affects hull damage | Affects subsequent consequences |
|---|---|---|---|
| **Ship designer /**<br>**Ship yard** | • Bridge layout<br>• Navigation equipment<br>• Engine and steering control<br>• Maneuverability<br>• Redundant systems | • Hull material<br>• Structural arrangement | • Compartment layout<br>• Watertight doors<br>• Down / cross flooding ducts<br>• Arrangement of other critical systems |
| **Ship operator** | • Ship speed<br>• Manning levels<br>• Crew training<br>• Emergency anchoring<br>• Self repair of machinery failures (based on training)<br>• Level of maintenance | | • Level of maintenance |
| **Society** | • Vessel traffic systems<br>• Pilots<br>• Traffic lanes<br>• Traffic volume<br>• Tug escort<br>• Required inspections | | • Required inspections |
| **Nature** | • Weather conditions | | • Weather conditions |

From the overview it is seen that most risk control options affect the probability of occurrence and, in this sense, they can be called preventive risk control options. Fewer mitigating risk control options are at hand and from these, most can be invoked by the ship designer or shipyard. It will be the main challenge of future research projects (e.g., SAFERIDE) to identify the probably most effective risk control options and to set up a ranking. In addition, models for each *important* risk control option need to be developed / refined and integrated into the software environment for ship design and ship operation.

Investment in risk control options and related improvements of safety must be balanced against the potential benefits and predetermined criteria. In general, costs for implementation shall be compared to the Gross Cost of Averting a Fatality (GCAF). Individual risks shall be compared to accepted or target levels. For full details, see chapter on risk evaluation criteria.

A cost model has to be established for each risk control option to evaluate costs that results from the implementation or the omission of the considered risk control option. A sample generic cost model is presented in Table 5.2. Each risk control option can influence various modes that in turn can be related to well defined costs. For example, executing a risk control option that reduces hull damage size influences the amount of loss in revenues as well as repair costs. It is this kind of cost model that needs to be established within future research projects like, e.g., SAFERIDE.

Table 5.2: Generic Cost Model for Evaluation of Risk Control Option

| **Consequence mode** | **Cost (monetary units) without risk control option** | **Cost (monetary units) with risk control option** |
|---|---|---|
| **Total loss of the ship** | | |
| **Repair of structural damage** | | |
| **Environmental pollution** | | |
| **Loss of human life** | | |
| **Loss of reputation** | | |
| **Additional building cost** | | |
| **Loss of cargo** | | |
| **Loss of revenue** | | |
| **Total** | | |

## 5.4 Research Gaps and Future Projects

### 5.4.1 Research Gaps

Research on collision and grounding received a lot of attention (and funding) in the last decade(s). Still, some gaps remain and they are listed below with due respect of their main area of application.

Probability of Collision
Development of rational two-ship models for computation of causation factors and for analyses of related risk control options:
- For ship design
  - Effects of bridge layout and technical equipment
  - Effect of ship speed on causation factor (time to react)
  - Effect of maneuverability on causation factor (time to react)
  - Effect of engine blackout
- For ship operators (en route and human behavior)
  - Effect of vessel traffic systems (high priority)
  - Effect of pilots (even for open waters)
  - Effect of weather conditions
  - Effects of manning
  - Effect of training

Probability of Grounding
Development of models similar to collision (see above) plus:
- Include distribution of rocks, shoreline data, tides, profile data or water depth spectrum, effects of squat for restricted waters only
- Effects of emergency anchoring
- Effects of tug support

Traffic data and effects of changing traffic patterns
- Characteristics of world fleet (bows, ice class, etc.) from databases
- Data for specific routes or areas
  - Harbor reports (arriving and departing vessels), plus software for analysis
  - Satellite based observations
- Define design route
  - Weighted average of characteristic routes for unrestricted service condition
  - Single specified route for special services
  - Integration of cost/benefit into selection of design route (how bad is the route?)
  - What shall ship operators do in case traffic volume changes

Miscellaneous
- Navigation improvements
- Vessel traffic systems
- Traffic lanes and pilot systems
- Additional lighthouses, radar buoys and reflectors

Consequences of Collision and Grounding

Research gaps for both events are grouped together because differences between research needs collision and grounding are small.

Directly related to Hull Damage

- Development and / or refinement of methods to deal with conventional vessels and HSC
- Flexible input of structural arrangement
    - only midship section for collision?
    - Only double bottom for grounding?
- Flexibility of bows, ice class strengthening
- Effects of power and drift groundings

Related to Consequences after Hull Damage has occurred

- Fast and accurate method to predict damage stability as function of damage size, damage location and compartment layout. Results include
    - Heel angle, time to capsize and list of flooded escape routes as input for evacuation
    - Accelerations for HSC
    - Outflow of fluids
    - Effects related to change in weather conditions
- Other risk control options that need to be considered are
    - Effects of watertight doors
    - Effects of flooding control, pipes, air pipes, valves, cross flow
- Effects of maintenance, inspections and training should also be taken into account to assess the consequences. In addition, criteria for survivability are needed for the damage stability assessment.

### 5.4.2 Recommendations for Future Projects

Apart from already running and submitted research projects, the following recommendations for future research projects can be given (without ranking):

- Systematic collection of ship traffic data in European waters
- Update of probability predictions for collision and grounding with focus on identified risk control options
- Development of fast and accurate method for assessment of damage stability for integration into probabilistic software tool

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Related Research Projects:

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# FLOODING

Flooding represents one of the primary major hazards for ship in general and Ro-Ro passenger vessels in particular. Historically, should the escalation of an initiating event lead to the flooding of the Ro-Ro deck, catastrophic failure in the form of a capsize and sinking is frequently the final outcome. Flooding therefore represents a serious consequence, worthy of extensive efforts to mitigate, somewhat independently of the probability of typical initiating events such as collision or other forms of structural failure.

In this final report of Safer-EuRoRo, we review the background to recent research into flooding and the ship's ability to survive such events in a sea-way, examine the advances made, appraise the risks and establish the costs associated with design for survivability. Finally, we also examine the currently perceived gaps and further work needed.

## 6.1 Background

It has long been understood that the process of flooding and its interaction with ship behaviour in a seaway is complex and highly non-linear. In the past, regulatory approaches paid little attention to this however, choosing instead to rely on concepts of static stability, and the assumption that these would be appropriate to the special Ro-Ro concept. Ship losses such as the European Gateway, Herald of Free Enterprise and the Estonia in particular, accompanied by extensive loss of life in the latter cases, demonstrated however theses traditional methods were wholly inadequate for this design concept. Accordingly, a number of important developments occurred. These included:

- The Joint North West European Research Project: within which the behaviour of Ro-Ro vessels following damage in a seaway was studied mathematically and experimentally, and ideas developed for more appropriate regulatory approaches.

- The development of the Stockholm Agreement: which, as implemented within SOLAS (Resolution 14), defines the manner in which static stability calculations should be carried out for vessels with Ro-Ro decks, defining amounts of water on deck to be assumed as a function of freeboard and sea-state.

- The development of tank testing methods and moreover, protocols within SOLAS (Resolution 14, Appendix 1), that may be used to establish a basis for safety.

- The development of European research funding, in the form of the Safer-EuRoRo Thematic Network and latterly, a number of pertinent research projects, aimed specifically at the improvement of Ro-Ro passenger vessel design through better understanding of the fundamentals of ship survivability.

The current state of the art can be examined at a number of levels, and is defined here with respect to (a) design approaches, (b) the development of tools for survivability assessment and (c) research into the fundamentals. In practice, some overlap exists between these. Each of these is now reviewed in turn.

### 6.1.1 Design Approaches

As might be expected, the practice of Ro-Ro vessel design has been led by the recent additions to SOLAS with respect to taking account of water on deck. The leading issues are those relating to the requirements relating to freeboard, the use of longitudinal subdivision within B/5, and the areas and sea-states within which the vessel operate. Typically, naval architects are establishing designs that fit within Resolution 14 and, working to meet these requirements has led to certain changes in their principal particulars. Where this proves difficult to achieve within a particular owner's set constraints, alternative approaches to demonstrating compliance through tank testing have been employed. Most of the resulting changes have generally been thought to lead to increased costs. It is however difficult to see how these changes have yet led to any rational decrease in the risk to human life and hence the cost-benefit of these changes is far from proven.

A more practical outcome of these recent changes has been the implementation of tank testing to a defined protocol, ensuring that the main parameters are common wherever the test is being carried out. Thus far, the emphasis has been to demonstrate that existing vessels wishing to comply under SOLAS are able to survive in seas of Hs = 4m when damaged. The benefit of such an approach is that where vessels require modification, these can be tried out and recommendations made accordingly. Thus the basis for safety may more easily be established from the point of view of cost of modifications.

Work to establish more rational risk based design methodologies is fundamental to the Safer-EuRoRo Thematic Network. The majority of this development work is being carried out within three key projects NEREUS, ROROPROB and HARDER. An overall risk based methodology is also to be developed within the SAFERIDE project, a proposal for which has been submitted within the last call of FP5. All of these developments call for a fundamental change in the manner in which ships are designed and the adoption of risk based strategies for making key decisions. Before this approach can gain favour however, not only have naval architects to be guided in the use of these methodologies (and a knowledge-base/experience developed), but key consequence analysis tools must be validated and made reliable. The following section describes briefly the state of the art in this respect.

### 6.1.2 Development of Tools

A range of possible approaches to assessing the survivability of a Ro-Ro vessel subject to flooding exists. In the broadest sense, the tools are required to establish whether or not a particular Ro-Ro vessel, with a given arrangement of compartments, level of damage, and other intact particulars (e.g. height of centre of gravity, freeboard) is able to survive indefinitely in an assumed sea-state. There is a range of technical approaches, which vary in complexity from the purely empirical to complex numerical simulation.

The Static Equivalent Method (SEM) provides the most straightforward method by which to relate damage, flooding and survival sea-state. It relies upon two key assumptions, namely that the mode of capsize of the flooded vessel is essentially static, and that the amount of water on deck to produce this condition can be related to the significant wave height. This approach promises to provide an ideal preliminary consequence analysis tool for concept design. However further work is required to validate and gain confidence in its general applicability.

The next level of complexity in numerical modelling involves the use of simulation tools for ship dynamics, enhanced to take account of the presence of flooding and flood water. Typically, these models rely on hydraulic assumptions to predict the rate of flooding and the simple assumption that the internal water surface remains horizontal, in terms of the applied internal fluid loads. A number of examples exist (2,3), and these models have proven capable of predicting many of the features of flooded vessel motions, as well as trends in survivability as a function of key parameters such as KG, freeboard, etc. These tools are being most widely used in conjunction with tank testing to enhance the results of experimental studies and study trade-offs in design solutions.

The above approaches represent the current, practical state of the art, with respect to consequence analysis tools. However, techniques that are still under development, such as those described in the following section.

### 6.1.3 Research into Progressive and Transient Flooding Models

The main characteristic of these models is that an attempt is made to include the majority of the dynamic effects. The tools described below are all under development, but are already providing more detailed resolution of the processes involved.

PROTEUS3: one of the third generation of Strathclyde University SSRC numerical modelling tools. This model is currently being updated from using the assumption of a horizontal surface for the floodwater to a two body approach in which the floodwater motion will be calculated using an additional equation for its motion. This will improve predictions in cases where sloshing of the floodwater is important. Much development work is currently being undertaken.

WS Atkins coupled 6DOF/CFD model uses the AQWA potential flow code, a ship dynamics model based on CASSANDRA, and the AEA Technology RANS solver CFX4 to produce a realistic simulation of flooding and sloshing water within a damaged vessel at sea. The model has been tested against several different cases and has shown itself to simulate the dynamics of a damaged Ro-Ro well, without recourse to empirical data. It is computationally expensive to run, but the data generated by the model is already proving invaluable in determining the underlying physics of the problem. Results from the initial development of this system are soon to be published as RINA Transactions. The current development and validation of this modelling approach is being pursued through the NEREUS project.

FREDYN: MARIN developed this numerical tool during the last ten years in the context of the Co-operative Research Navies (CRNAV) to predict the response of a damaged ship in a variety of conditions. FREDYN has been further developed during this year, partly in preparation towards the testing which will be undertaken during the NEREUS project, though details are not available at present.

As a result to the research work funded by the Greek Secretariat General for Research and Technology, NTUA–SDL has created a simulation tool resembling those developed at SSRC. Recently an improved new type quasi-hydrostatic model has been implemented to account for sloshing effects, as described in [13].

Another model similar to those of SSRC and NTUA was developed by Chang & Blume in 1997. In this model for large depths of flooding and large angles of heel, a plane free surface is assumed and Lagrange's equations of motion used to derive a simulation of the fluid motions. For the shallow water case, for which hydraulic jumps and partially dry regions may occur, Glimm's method is used to solve the depth averaged shallow water equations. This model has undergone no change in last twelve months.

Many of the above developments have taken place within or associated with Safer-EuRoRo or related projects such as NEREUS, HARDER and ROROPROB. There is no doubt in the minds of the authors that the support of these projects by the Commission has been vital to that advances made. In the same manner, the existence of a structure such as that provided by the Thematic Network, has provided a strong and effective focal point and forum for discussion. The state of the art has been advanced significantly by these measures, and it is clear that the influence of this primarily European research on the global regulatory environment is significant.

### 6.1.4 World-wide Research

Notable pieces of research from outside the European Community include:

Bass and Cumming[4] carried out tests of a model fishing vessel containing a tank of water to assess the ability of a coupled ship dynamics code (MOTSIM) and VOF CFD code (FLOW-3D) to calculate the motions of a vessel with moving floodwater in extreme conditions. Although the volume of water in the tank remained constant ie there was no flooding or down-flooding, this work is relevant to the general area of numerical simulation of vessels with floodwater on deck. This work reflects fact that more modelling of flooding and floodwater movement using CFD will occur as the computational cost of carrying out the CFD calculation decreases over the next few years.

Mathematical modelling carried out by Hasegawa et. al.[5] has demonstrated clearly the importance of dynamic effects on the capsize of a damaged Ro-Ro. Using a 6DOF model with a hydraulic flooding model, they investigated the survivability of a Ro-Ro with damage to the car deck and compartment below it when subjected to a range of wave heights and periods, as well as changes to intact GM. The survival boundary for these numerical tests for fixed intact GM was clearly dependent on the wave period as well as the wave height, indicating that survival depends on dynamic effects. The attitude of the damaged vessel, whether heeled to or away from the damage, was also strongly dependent on the wave period.

Research efforts outside of the EU have provided significant background research material in the field of damaged ship survivability, and have been important to general developments in the field. However, the clear focus on the use of this type of research to advance the state of the art in design within Europe within a risk based framework is unique.

## 6.2 Risks Involved

The risks involved with respect to flooding are those relating to the risk of escalation of some initiating event, and the additional failure of mitigation systems (e.g. pumps) to operate effectively. They can be considered as an overall risk to the vessel, and as risk to passengers and crew during events or actions consequentially.

The primary initiating events are:

- Collision
- Grounding
- Structural failure of bow or stern doors and associated internal barriers to provide water-tightness.
- Mechanical failure of water-tight barriers.
- Operational safety management systems failure/human error.

The risks associated with these initiating events are dealt with elsewhere in this report, and hence no further discussion will be made here. Flooding is a consequence of any one of these if certain other escalating factors are accounted for, such as:

- In collision and grounding, a breach of the integrity of the hull (since neither initiating event necessarily causes sufficient damage a-priori).
- The extent of the damage must either:
    - ✓ extend either below the waterline or
    - ✓ be in a position sufficiently exposed in a seaway to ship water due to wave action.
- The failure of pumps to deal with the rate of flooding.

Data are available (e.g. from Classification Society databases) from which to establish the probabilities or joint probabilities of likely escalating events such as these, and are being used within projects such as NEREUS.

Once flooding has been established as a suitable outcome, the extent of the flooding and its consequences are functions of the location of the damage, the effect of ship motions, the effectiveness of cross-flooding systems in lower compartments etc.

The primary hazard to the vessel resulting from these sequences of events is of course its loss through capsize and sinking. However, unless the extent of the damage is so great that the ship floods and capsizes almost immediately, the main risks to passengers requires further evaluation. The former is of course a possible outcome for small (commuter) passenger ferries operating in busy shipping lanes, and should not in general be dismissed. However, in terms of risk analysis, the main forms of mitigation must lie with collision avoidance rather than measures to combat flooding in these cases.

The risks to individual passengers as the result of extensive flooding of the vessel are intimately related to the progression of the emergency and the management decisions made accordingly. The decision of prime concern is that of whether the vessel is to be evacuated. However, this decision is only likely to be made if the risk to the integrity of the ship is so high as to have outweighed the risks to passengers associated with evacuation, particularly as it relates to sea-state and other environmental conditions.

Flooding affects these risks in a number of ways, for example;

- It affects the survival time of the vessel and hence the time available for orderly and safe evacuation.
- It affects the attitude of the vessel and hence the manner in which passengers are able to muster and move around the ship.
- Similarly, the operation of lifeboat launch systems can be compromised as the vessel takes up angles of loll.

Thus the overall role of the flooding process is not one which poses the primary risk to passengers and the integrity of the vessel. Rather flooding acts the primary hazard, following some initiating event, which controls the rate of escalation of the emergency, firstly through the severity of the event itself, and secondly as the result of external, environmental, factors and internal factors (failures of flood and stability control).

The role of research into flooding and capsize is therefore to provide an accurate picture of how such hazards develop such that accurate quantitative measures of risk can be made.

## 6.3 Costs

In the light of the above, the main costs associated with safety systems to combat the risks presented by flooding are related to the following typical systems:

- Systems which protect from flooding following damage or failure of watertight integrity,
- Active systems which are designed to deal with the risks posed by floodwater (down-flooding, bilge pumps etc.),
- Passive systems designed to deal with the risks posed by floodwater (sub-division, cross-flooding arrangements, freeing ports etc.).

The total costs must be considered as those not only associated with the capital and labour spent in installing or building in these risk control options, but must also be weight against the potentially reduced cost of not installing these systems (as is discussed elsewhere in this report).

In the case of flooding, the cost of dealing with catastrophic failure, i.e. the loss of the ship and all passengers and crew, is the primary measure by which the cost-benefit of the above systems should be measured. In the case of systems which are designed to prevent the loss of the vessel, the Gross Cost of Averting a Fatality (GCAF) is likely to be the primary measure used.

For systems designed to reduce the number of fatalities, the Implied Cost to Avert a Fatality (ICAF) is often used in other areas of safety engineering. However, the state of the art in maritime transport safety is such that little data exists with respect to this latter measure. Typically, such systems might include the provision of additional or more sophisticated means of escape, and or means of isolating certain areas of the ship from the hazard in question. In the case of flooding, there is little chance that design solutions relating to the latter will be developed (The concept of a temporary refuge or TR has been discussed, but this can only relate to hazards such as fires or explosions). In the case of the former, considerably more research is required into the relationship between the number of individual fatalities resulting from flooding events, and the severity of the events themselves.

Thus for the foreseeable future, it is most likely that practical risk based design is likely to rely on gross measures of cost-benefit relating to total ship loss with respect to flooding, rather than to be able to establish more sophisticated measures.

## 6.4 Research Gaps and Future Projects

### 6.4.1 Research Gaps

The primary research gaps remain around the areas of:

1. The development of a suitable risk and consequence analysis based framework for design and design analysis, including cost-benefit data for flood and stability control systems.
2. The further development of technical tools – primarily in the area of their reliability in the prediction of ship survivability subject to flooding.
3. The gathering of experimental data of sufficient detail to validate advanced consequence models, particularly those using CFD.

In area 1, the development of generic event trees with appropriate forms of escalation is being studied in projects such as HARDER and is one of the likely areas of the proposed project SAFERIDE. Accompanying these developments, FMEA and appropriate databases on equipment or structural reliability can be expected. However, the use of consequence analysis tools is vital to the associated Quantified Risk Analysis (QRA), and there is a need to establish which of the many possible tools or approaches available in ship survivability assessment would be the most appropriate in each case.

Similarly, their means of application and form of output differ in each case. For example, the Static Equivalent Method might best be applied in those cases where the probability of the ship not surviving in a particular sea-state following damage is required (as it may be derived from metocean data for the value of significant wave height equivalent to the height of water on deck at the “point of no return”). This makes the approach well suited to providing event tree data and for use in QRA. However, should the simplifying assumptions inherent in the SEM prove inappropriate, modelling techniques that (for example) allow for capsize within a dynamic regime of behaviour would need to be considered. This then adds a requirement for a probabilistic approach, and potentially, the use of Monte-Carlo techniques within the risk analysis.

There is at present insufficient practice with the application of these established techniques from safety engineering to provide guidance within the field of passenger vessel safety. The development of workable methodologies for the future requires that such practice be developed through appropriate industrially focussed research. Such methodologies should also include data for cost-benefit analysis of flooding risk mitigation measures. At present, the only reliable cost data are those relating to the total loss of vessel, passengers and crew. Compared with, for example, fire safety engineering, such approaches are crude.

In area 2, there is as yet insufficient confidence in the ability either to predict capsize or survival times using the current range of models for flooding and survivability. Considerable progress is being made, however, in ensuring that each model or tool is able to make predictions that agree with particular sets of experimental data. There is therefore a continuing need for the benchmarking of the flooding and survivability modelling methods both against each other, and using common and consistent experimental data. Some progress is to be expected in this area from projects such as NEREUS. However, more work will be needed in the longer term, with equal emphasis placed on developing consistency between the different modelling approaches, and an understanding of the underlying physical behaviours that support such consistency.

Finally, the need for experimental data to validate the consequence analysis tools remains. Certain data are being gathered in the NEREUS project, and in other related activities, but it is unlikely to prove to be sufficient in the longer term. In particular, the work of the NEREUS project serves to demonstrate how difficult it is to gather flooding and flow data at the experimental scale using PIV or similar techniques. There is a considerable need to develop methods for measuring transient flow velocities near a free-surface which are both more reliable and accurate than those currently available.

### 6.4.2 Recommendations for Future Projects

It is recommended that future projects should fulfil some or all of the following:

Projects should be broadened out to cover the application of risk based methods to other forms of ships. This will allow the benefits of research to be more widely spread, the sources of a variety of forms of necessary data to be broadened, consequence models to find a wider applicability, and validation and benchmarking exercises to be generalised.

On a practical level, the reliability of all flooding and ship dynamics models should be improved. This could best be achieved in the short term through some rigorous benchmarking exercises that compare directly the predictions that the different approaches make. This is essential to gaining confidence in the application of such models and the elimination of errors of principle, and simple bugs.

Similarly, and as noted earlier, techniques for the experimental measurement of flooding and floodwater behaviour require greater refinement and reliability. A project aimed at developing flow measurement devices more appropriate to this task would be of considerable value.

At the fundamental level, projects relating to flooding should be better aimed at quantifying uncertainties, understanding the complex and non-linear nature of possible behaviours, and “mapping” those areas of predictable behaviour. Efforts to this end would require extensive computer power. To obtain a sufficient number of simulations of coupled non-linear ship dynamics, with the additional complexity of a valid CFD simulation of flooding and flood-water movement, for even a single wave spectrum, across a number of different starting conditions and wave realisations, would be a highly expensive exercise. This could only be achieved using the most advanced super-computing facilities available at the present time. However, such a “grand-challenge” exercise, if successful could bring a significant breakthrough in the understanding of ship survivability.

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# MUSTERING AND EVACUATION

When everything else fails a last escape is available on ships for saving lives exposed to risk caused by a calamity. This final escape consists of lifeboats and/or liferafts. The process of progressing towards these craft in case of an emergency is called mustering. Abandoning, i.e. embarking the boats or rafts and sailing/floating away from the ship, which has become unsafe, is called evacuation. Various systems exist for guiding people to the boats/rafts, embarking and launching. The maritime community, through IMO, acknowledges the unsatisfactory performance of these mustering and evacuation systems. An important issue is the lack of an adequate methodology for assessing the various systems. Moreover various systems prove to perform rather poor in non still water conditions. Several projects have been or are still being carried out under the umbrella of SAFER EURORO filling these gaps. The results of the projects strengthen the already leading position of the EU in the area of ROPAX safety and indeed passenger ship safety. Although perhaps not fully operational yet, a clear understanding now exists of the methodology to be used. Quite a few aspects, relevant for carrying out the assessment, have been identified and investigated. Supporting evidence is provided by results from various experiments.

In this respect, the development of tools in the form of state-of-the-art computer simulation models for the prediction of evacuation scenarios, evacuation time and probability of success in different conditions must be addressed as a top priority, since it would make possible to tackle the immediate need to assess the capability of the whole passenger evacuation system pertaining to mustering routes and procedures, life-saving appliances, decision support and management, thus allowing for a meaningful evolution of passenger ship designs with enhanced evacuation performance (minimum time for safe evacuation of passengers and crew).

ESCAPE encompasses a novel methodology to address design and operation for passenger survival by focusing on design for ease of evacuation and on crisis management using decision support whilst taking into consideration the findings of MEPdesign, as well as the results from a number of nationally funded projects on passenger evacuation.

Project ESCAPE consists of four interdependent scientific and technological development Work Packages: one dealing with the development of state-of-the-art simulation tools, one addressing the development and implementation onboard ships of a crisis management system, one with the development of a '*design for ease of evacuation'* methodology, and one with the verification, validation and implementation of evacuation simulation tools for legislation, design, operation and training applications. Finally, Work Package WP0 comprises the administrative and technical co-ordination effort together with issues pertaining to exploitation and dissemination of the research output. The four work packages of ESCAPE:

- <u>Consolidation and validation of state-of-the-art passenger evacuation tools</u>; further development of these and integration with recent advances in computer simulation models of fire and smoke propagation and progressive flooding for practical application to ship design for ease of evacuation on a moving platform; interface tools and optimisation routines for use of the developed tools in real-time for on-line decision support and training purposes; benchmarking tests for assessing a ship's evacuation capability; coupling of mustering and abandonment phases to produce a complete evacuation simulation capability.
- <u>Determination of frequency (probability of occurrence) of critical evacuation scenarios</u>; consequence analysis and modelling; development of risk-cost model; identification of

hazards associated with various evacuation scenarios; risk assessment and ranking; proposal of risk control options; proposal of a risk-based methodology for crisis management and on-line decision support.

- Development of a ‘Design for Ease of Evacuation’ methodology; database and knowledge base of key parameters associated with evacuation; information and guidelines to the ship designer for implanting the developed methodology; specification for a case study and parametric investigation to identify relationships between evacuation performance parameters and ship design parameters.
- Identification of the evacuation needs of ship operators; assessment regulatory implications of ESCAPE tools and effective transfer of research advances to practice; validation of computer software using a virtual reality platform and by full-scale trials to verify applicability of ESCAPE tools.

Successful solutions of evacuation problems require effective integration of human behaviour in the above described situations and the design of safety features on cruise ships and Ro-Ro ferries. This is a very challenging task when the number of people to be moved is very large and the actual task is to be done in very confined spaces. In addition it is essential to recognise that humans commit errors, particularly in emergency situations. The research approach adopted in the ESCAPE programme uses a new method of achieving these integrations and involves the following key stages:

- Using Risk Management techniques to identify the most significant obstacles on ship for moving people, e.g., stairways and critical factors associated with managing crowds.
- Devising simulation tools to provide design data for use in crew training sessions so that they acquire the desired level of expertise.
- Implementing in practice the devised tools by gaining experience on their use with the support of ship operators during their formal evacuation training
- Training ships’ crew to respond efficiently to crisis and to familiarise themselves with the evacuation process using interactive animation and virtual reality simulation platforms will go a long way to shortening evacuation times and enhancing passenger survival.

## 7.1 Background

The general approach towards the adequacy of ship abandoning systems is uses the risk R as an adequate parameter. Risk is defined as:

$$R = pE$$

where : R the risk associated with the process to be assessed
p the probability that something will go ‘wrong’
E the effect of something going wrong.

The issues relevant are:

- Hazard identification
- Risk assessment
- Risk control

Hazard identification means identifying what can go wrong. For example when people need to go to a muster station they may get lost due to poor guidance.

The risk assessment determined the probability that something can go wrong and the effects of it. Determining the probability is usually the most difficult part in case of emergency systems. But also determining the effects are often not straightforward. As an example of an effect, one can imagine that, due to not finding the right way in time, the passenger or crew member will not make it to the lifeboat/raft and will loose his/her life.

Risk control refers to the process of decreasing the probability that something will go amiss and the process of finding means or measures to limit the consequences, i.e. the effect.

Fully applying the concept of a risk based assessment in the areas of mustering and evacuation is not yet feasible. At least not in any satisfactory manner. This is mainly due to a, most fortunate, lack of statistical data. Therefore data must be obtained in an experimental fashion. The MEPdesign project has contributed substantially in this respect. Both the mustering process and the evacuation process have been addressed.

### 7.1.1 Mustering

The progress with respect to mustering relates to the details of human behavioral data related to: Walking speed in corridors, open spaces, rounding corners, climbing and descending stairs, for level ship, listed ship, pitching and rolling ship, as a function of age, in groups or individually. Data was generated by subjecting people to more or less realistic mustering scenarios, generated in mock-ups. Moreover an actual mustering test was done on a ROPAX.

The data were recorded mainly to be input to software simulations of individual behavior. This is the main reason for detailed studies. This is quite new. Data of this type has, to our knowledge not been recorded earlier. Again, in shipping, it is quite unusual to produce such data although software simulation has already been suggested in regulations, currently according to a simplified procedure described in MSC Circ. 909.

The following general remarks are relating to the conditions under which the experiments(?)have been performed.

- Ship motion profiles based on sinusoidal representations of roll and pitch at various frequencies were preferred to those provided by DMI. The latter would not have allowed covering rolling periods other than those of the experimental ship "Kronprins Frederik".
- Pitching measures with wide angle have no practical application.
- The duration of the experiments(?) in particular those adopted when using the SMS (ship motion system) had to be somewhat limited to take account of physiological constraints such as motion sickness or fatigue and also for safety reasons.
- The fact that both the mock-ups and the SMS are limited in size imposed subject constraints. On board a vessel the accommodation is generally more spacious than the ones of the experimental conditions. This might also have led to negative effects on the subject’s performances. As a consequence, it was observed that subjects had not yet reached maximum walking velocity when passing the first sensor and that they started to decelerate before passing the last sensor. Therefore the walking speeds as measured may be seen as conservative.

There are two sets of results:

- The first one concerns the ship listing study with 4 tables presenting data on the walking speed in corridors, corners, stairs and doors as a function of the following variables:
  - age of the subjects
  - list of the ship
  - and specifics factors
- The second result of the study is a set of 6 diagrams and one table representing the walking speeds as a function of the following variables:
  - age of the subjects
  - frequencies and amplitudes of pitch and roll angles

The data will be in high demand if software simulation based on individual behaviour will be the general approach. Much of the data are also directly useful to assess effects of ship movement, and if the knowledge was put into suitable formats it may be expected that the data could be used directly by designers. The usefulness of the data is therefore large, irrespectively of the actual implementation.

Another interesting human aspect is group binding.

The work carried out in this respect started with scanning through potential sources of group data such as ticket sales/group bookings. This was followed by an empirical investigation onboard ships. The method used was to question passengers during a number of actual ferry trips. It was assumed that groups would spread during some segments of the voyage; for example, during the transit and when no meals were served. In consequence, time of the day, time since departure, voyage time remaining, and month of the year (seasonal effects) were recorded along with the results of a structured interview. A list of preliminary interview questions was "do you travel alone"; if no, "where are/is the other member(s) of your group", where would you go if you now had to find them, etc. The questionnaire was to be used again in a later investigation, when the exercise was carried out. The input of this work should be implemented in the prediction tools. One risk of this work package was assumed to be unrealistic data because what people say in an interview does not necessarily agree with what they do in an actual emergency. It was assumed that the exercise offers an opportunity to validate the interview data. Interviews were therefore also carried out during that trip.

### 7.1.2 Evacuation

Data has been generated for conventional davit launched lifeboats. Interesting results have been obtained from small-scale tests. Previous research in this area has relied more on full-scale test and mathematical modelling.

However by using smaller test specimens the research costs were reduced and the number of tests (parameter variations) could be increased. The research into life saving appliances usually also relies on performance in emergencies, as may be reported in accident investigations and to some degree on results from evacuation drills. For passenger ships, drills involving passengers and lifeboats are generally considered too risky, and therefore not carried out. Also in the future the progress in this type of research is likely to rely on all four elements. Full-scale, small-scale, accident investigations and mathematical modelling. A large number of conclusions are drawn, which deserve attention of the relevant decision maker (e.g. IMO/MSC):

- The tested davit launched lifeboats are safe only in gentle weather conditions. (Note that in most emergencies the ship is damaged and/or the weather poor, except in fire scenarios when the weather tends to be normal/calm.)
- Lowering speed is critical. (This recommendation probably belongs in a training package for the persons with the duty to lower lifeboats.)
- Short release time. (May be implemented by a manufacturer by improving release mechanisms, but also relates to training.)
- Increase davit arm. (Could be a requirement in SOLAS)
- Proper seating and seat belts (Could be a requirement in SOLAS)
- Avoid obstructions (Could be a requirement in SOLAS.)

However, as compared to modern risk based approaches to safety regulations (MSC Circ. 829), none of these conclusions is properly documented. The status of the conclusions is as proposed risk control options.

Small-scale tests of slide evacuation systems (marine evacuation systems) have also been carried out. Tests on the small-scale (1:40) have not, to our knowledge, been carried out earlier. The video recordings of the tests are extremely good in illustrating the phenomenological aspects of marine evacuation systems, and the difficulties in designing an effective and safe evacuation system. The dynamic effects of the excitation forces (the waves and the rolling ship), the “mass” represented by the number of people in the raft and platform (and the water), and the “stiffness” represented by the internal pressure in the slide, is very well illustrated. In particular the recordings make it clear that a marine evacuation system that are optimised for one set of parameters may behave poorly for other set of parameters (wave height, wave period, ship response, internal pressure in slide, length of slide). Due to this observations one generic improvement in the slide system was suggested: There should be a hinge in the slide. This would improve performance and e.g. avoid that the platform is pushed under water in some condition or passenger is launched into the air. The most important conclusions:

- Marine evacuation systems are not very safe except in good weather
- Current marine evacuation systems are optimised for effectiveness and safety in one condition are unsafe an ineffective under all other conditions
- The slide should have a hinge
- Slide length is an important parameter
- The number of liferafts should be increased, with fewer people in each.

Some work has been done on an improved lifeboat design based on the observations from the test of the conventional davit launched lifeboats—partially enclosed lifeboats (PELs). By improving the shape (increasing the deadrise angle) and allowing for increased lowering speed—or even falling the last few meters—it is demonstrated that the risk in lifeboat evacuations may be reduced. It is concluded that this new concept would need further testing before final recommendations may be made.

## 7.2 Conclusions, Research Gaps and Future Projects

It has been demonstrated that systematic use of human-factors and other research can reduce evacuation time at least 20%. This is, to some degree, theory because implementation of the achievements is not immediately clear. In this sense, work done was truly basic research.

Undue optimism has been identified among the regulations concerning evacuation analyses. This agrees with a recent publication of the International Council of Cruise Liners that real emergencies require twice as much mustering time than exercises.

Other major results are:

- New guidance concepts, especially photoluminescent strips with arrowheads
- Demonstration of the risks and ineffective standards for the abandon ship phase
- Clear suggestion how to make lifeboats safer
- Much Human Factors information relating to the assembly/mustering phase. Some of this information can be applied in any type of evaluation of effectiveness in mustering. Some data can be implemented in software models of evacuation.
- A new type of assembly software model, including, among others, the effects of ships motion on the walking speed of the passengers.

Formally the successes may be summed up as:

- requirements for all tasks have been met, with only small deviations
- detailed knowledge of group-binding effects available (work of DMI)
- detailed experimental results on way-finding errors (work at TNO)
- detailed experimental results on walking speed (work of TNO)
- detailed experimental results of the risks of using lifeboats (work of KTH)
- detailed experimental results of the risks of using slides and rafts (work of KTH)
- detailed experimental results of the excellent safety of a new type of lifeboat (work of KTH)
- general demonstration that Human Factors (HF) data are important for design
- software that may be used in HF research and perhaps in future risk assessment

The basic assumption of some of the research carried out was: try to include "the whole world" in a computer model. Looking at the gap-list (the list of missing factors) and with the wisdom of hindsight, the shortcomings of the assumption are now more apparent than they were back in 1997.

One methodological/practical problem identified is that adding more and more data makes computer models more and more cumbersome. For example, run time will "explode", a whole range of outcomes becomes possible because the number of probabilistic (=unpredictable) elements becomes larger. Moreover, the computer model will, still, lack important factors because the gap-list is almost endless.

However the work done is nevertheless useful (a) by bringing this problem to light, (b) by suggesting an alternative approach, namely, to make reality less complicated. Two examples. Specific instruction to the passengers at the beginning of the voyage would prevent much (unnecessary) search behaviour for relatives and friends during emergencies. Bringing the passengers over to their assembly stations would prevent way-finding errors during emergencies.

It is identified that no vast amount of data seems to be available for establishing probabilities for unintended events during the mustering and evacuation process. Obviously performing statistics on limited data is cumbersome.

The process of evacuating seems to have gained rather little attention up to now. The reason is obvious: the hazard involved for people during evacuation tests. At least one project proposal is known to the author aiming at addressing this aspect. The proposal is called SafeCrafts, it has been submitted to the EU in the last call within the 5th framework.

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**Projects:**

MEPdesign

ESCAPE

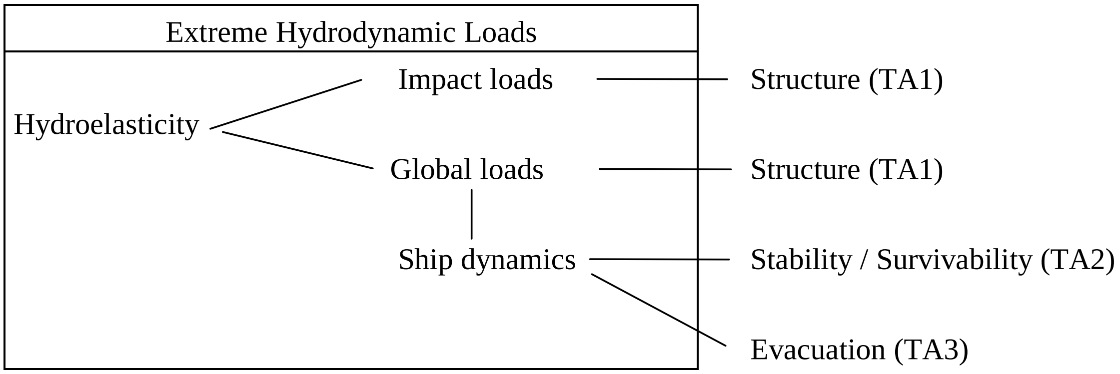
EROSII

SAFERIDE

SAFECRAFTS

# SEAWORTHINESS

Within the framework of SAFER EURORO Thematic Network, the Thematic Area 4 (TA4) "Extreme Hydrodynamic Loads" was developed. This Thematic Area is linked to other Thematic Areas in SAFER EURORO (TA 1: damage resistance, TA 2: survivability, TA 3: passenger survival).



<u>SHIP DESIGN FOR SAFETY</u>

This area of research was found to be

- a <u>critical one for Industrial Needs</u>, with concern on operational limits of ship and design limits in terms of maximum permissible levels in motions and loads, and consequences on structural response and seawothiness

- a <u>very challenging one for RTD in Maritime Industry</u>, in terms of development of numerical tools, model testing (scale effects), and full scale data/trials, to simulate hydrodynamics, hydroelasticity and ship dynamics characterised by large amplitude motions, nonlinearity and fast transient with water impacts

For Maritime Transport two technological platforms would integrate those research results, tools and methodologies: the Virtual Ship Platform, as a simulation tool (e.g. Vrships-Ropax projects), and the Intelligent Ship Platform, as an integrated control/monitoring system (e.g. Hullmon+ project, and Adismos proposal).

## 8.1 Background

Regarding the Thematic Area 4 "Extreme hydrodynamic loads" in SAFER EURORO and for practical application in ship industry two aspects have to considered: vessel construction/design (hull shape, mass distribution, structural flexibility and damping), and vessel operative conditions (vessel speeds, sea state, operative draught, ...).

Regarding integrated design safety requirements for seaworthiness several important aspects have to be considered: large ship motions, continuous waveloads associated to large ship motions, and impulsive loads associated to water impacts. And both aspects would require specific attention on hydroelastic (fluid-structure) phenomenona with concern on local and global structural strength.

In the last two decades considerable research efforts have been made particularly in the lines of new types of vessels (large catamaran, SWATH vessels, SES, ...), and also in fast monohull crafts, large bow container ship and RORO vessels. (see list of references)

To summarise, four technical areas are considered:

(1) Impacts loads

Impact loads concern impulsive (fast-transient) loads which are locally applied on the structures,

- wave induced slamming (bow slamming, bottom slamming, slamming on stern part including on propulsion systems and rudder),
- water flooding and sloshing,
- green water on the deck.

(2) Global loads

Global loads concern hull girder (low frequency) loads associated to ship sea keeping :

- wave induced bow loads,
- internal loads (shear force, vertical bending moment)

(3) Hydroelasticity

Hydroelasticity concerns both impact loads and global loads, when the structure vibrates in slamming loads or when the hull girder is sagging and hogging in large ship motions.

(4) Ship dynamics

Ship dynamics is considered in this thematic area for intact ship in sea keeping in rough seas with large ship motions and large accelerations (with necessary non linear hull girder loads and local impact loads). It also includes manoeuvring aspects (manoeuvring on waves in rough sea state, as well as manoeuvring in still water and ballast operations).

For Maritime Transport, industrial needs include design and safety requirements, as it is detailed, hereafter:

Shipbuilding and ship design

- large bow flare,
- green water on the deck,
- larger and faster ships,
- faster ships multi-hull,
- lighter material in construction,
- construction techniques,
- equipments (propellers, rudders, stabilization fins , life boats,...).

Ship owners and operators

- safe navigation (minimise damaged structure and damaged equipments, optimise passenger comfort and safety, cargo, environmental issues),
- efficient operation (minimise loss of time affecting the operational capabilities of the ship),
- integrated ship control (ship integrity).

Classification societies

- new regulations for safety,
- approach with Formal Safety Assessment,
- safety in abnormal conditions (rough sea state, extreme hydrodynamic loads).

Such a matter of interest in this technical area 'Design for Seaworthiness' is found in the COREDES clustering scheme with the technical domains: first principles design, design tools, operation (monitoring and maintenance, human environment), new concepts (ships, systems, including also on-board systems of monitoring), speed at sea, safety at sea.

This Thematic Area is linked to RTD projects such as SEAWORTH, DEXTREMEL, WAVELOADS, SHEAKS, (which are dealing with sea keeping and extreme wave loading), and Eureka project HULLMOS (which is dealing with hull monitoring systems).

The two Thematic Networks PRODIS and CEPS (with domains in hydromechanics and new concepts of ships), MARNET-CFD Thematic Network (with areas unsteady hydrodynamics and offshore engineering) and FLOATTECH Thematic Network (with areas hydrodynamic and structure analyses, have common thematic interests with technical areas of TA4 in SAFER EURORO.

In particular, in new RTD projects or proposals, the interest in developing full scale trials appears more and more important, especially for high speed craft, with measurement of loads, ship motions, vibrations, stresses, such as projects Safety at Speed, Vrships-Ropax, Hullmon+. Data from trials are considered to provide important complementary information because of scale effects, which are not well known for impact loads, hydro-elastic response, and large ship motion. Those trials are also found relevant to collect data and correlate passenger comfort and crew operability with the actual ship motion and vibration. This knowledge will be very useful to support marketing effort for passenger transport in fast ships, and to achieve optimum operation of the vessel with the crew.

The newly retained project EXPRO-CFD, more likely applied to Offshore Industry, will develop new computational fluid dynamics tools for solving nonlinear time dependent fluid loading and structure/vessel in waves and current, with concern on extreme wave loading and green water loading. The outcome of this project will be of great interest as it will produce a developed tool for prediction of hydrodynamic loads and motions of ships in the case of large ship motions.

## 8.2 Risks Involved

### 8.2.1 General

Regarding integrated design safety requirements for seaworthiness two important aspects have to be considered :

- large ship motions, with consequences on passenger comfort and sea-sickness, crew operability, cargo shift, vessel capsizing,
- continuous waveloads associated to large ship motions, with consequences on hull damages/opening and ship integrity,
- impulsive loads associated to water impacts, with consequences on hull damages/opening.

For the study of possible events of accidents, different items for their variations in design parameters/scenarios and prediction tools have been listed hereafter:

<u>Impact loads (slamming, sloshing, green water)</u>

- wall shape,
- wall structure and material,
- relative motion (ship dynamics and wave dynamics),
- momentum theory,
- potential flow theory,
- two phase flow (air cushioning),
- hydroelasticity,
- full scale measurements,
- scale effects (hydroelasticity, two phase flow),
- fatigue (vibrations, large stresses),

<u>Global loads</u>

- hull shape (e.g. large bow flare),
- hull structure (stiffness, mass, damping),
- hull girder loads (bending moment),
- hull construction and material,
- buoyancy / mass,
- forces / mass,
- relative motion / phase relation between bow motion and oncoming waves,
- full scale measurements,
- scale effects (global hydroelasticity, non linear ship motion, non linear loads),
- non linear loads (bow flare slamming),

<u>Hydroelasticity</u>

- materials and structural arrangements (stiffness, mass, damping),
- hull shape,
- hydrodynamic coefficients (added mass, damping),

- relative velocity (hull / wave) in fast transient,
- local loads,
- global loads,
- scale effects,
- full scale measurements,

Ship dynamics

- Intact ship dynamics in sea keeping,
- non linear loads,
- non linear motion,
- hydroelasticity,
- time domain simulation,
- acceleration acceptance (passengers, equipment, cargo)
- fatigue limits.

Ship dynamics in manoeuvring
- Non linear loads,
- Non linear motions,
- Loads on propulsion systems, fins, rudder,
- Time domain simulation,
- Controllability,
- Ballasting operations,
- Full scale trials and measurements (performance in manoeuvring)
- Design for manoeuvrability and controllability

### 8.2.2 Risk-Based Design Methodology

For the moment, the principal goal is to prepare a risk-cost model related to the effects on crew and passengers of large motions of a ship navigating in rough sea state that will be integrated within a risk based design methodology, in the lines of SAFERIDE proposal submitted at the 3rd Growth call. This approach is presented in the following of this report. In the preparation of the above proposal, it was agreed in the group of partners that the risk based design methodology would be focused to large ship motions and that the extreme hydrodynamic loads and related consequences would not be included. Therefore, this difficult task about risks of these extreme loads remains to be performed in other projects in 6th Framework Program.

This risk-cost model related to the effects on crew and passengers of large ship motions will be done by applying, adopting or further developing first principles tools for the estimation of frequencies and consequences. The model will allow risk balancing in a quantitative manner by taking into account the effects of available risk control options, such as options related to design (main dimensions of the ship, location of passenger spaces, weight distribution, …) and operation (loading conditions, change in the passenger areas, modification of the route, ….).

The work will focus on the effects of large motions of a ship (as a rigid body) in waves on crew and passengers (seasickness, workability to operate the ship, mobility reduction, threat to passenger safety) which can affect from a safety point of view the operation of a given ship on a given route and lead to an income decrease and possible injuries. Moreover, sea keeping performance is one of the important factors determining the success of passenger Ro-Ro vessels. Furthermore, arrangement of cabin, restaurant, etc  can be influenced by relative comfort indicators. Human comfort and operational capability are governed by the motion characteristics of a particular design, sea state, and criteria for passenger/crew tolerance.

### 8.2.3 Estimation of Frequencies of Large Ship Motions

For different passenger Ro-Ro vessels in various routes, knowing waves conditions on a given period, frequencies of being above thresholds based on existing criteria for passenger/crew comfort will be calculated through the use of frequency domain simulations followed by spectral analysis and time domain simulation. A number of comfort/operational criteria such as motion sickness incidence, subjective motion index, generalised lateral force estimator will be used. Different acceleration levels related to different activities undertaken by passengers/crew as well as exposure time will also be considered. Using these criteria and Rayleigh's probability distribution, the probability of being above a tolerance level (exceedence) can be obtained from the spectral analysis of response amplitude operators. By integration of the exceedence probability and the probabilities of different sea states and wave heading angles, a long term distribution of discomfort (seasickness) can be quantified.

### 8.2.4 Estimation of Consequences of Large Ship Motions

Consequences of large ship motions will be assessed in a quantitative manner in terms of reduction of trip numbers, possible passenger injuries, and bad impression left to passengers (comfort). This task will establish a relation between the magnitude of critical behaviour aspects and the impact on the earning capacity. The proposed method is a deterministic reproduction of the behaviour of a number of existing ships on existing routes. After evaluation of the critical behaviour aspects the results will be compared with feedback from the ship owners in the project. The result is a relation between the magnitude of calculated seasickness indicators and the impact on the earning capacity.

## 8.3 Risk Cost Model

A risk/cost model will be developed by integrating the above results. The output of such a model will be in the form of risk profiles or curves relating consequences to frequency. This will be used as an objective to achieve a balance between costs and safety in an optimum manner within the risk-based design methodology. This model will also take into account the cost related to risk control options that will be identified:options related to design (main dimensions of the ship, location of passenger spaces, weight distribution, …) and operation (loading conditions, change in the passenger areas, modification of the route, ….).

## 8.4 Research Gaps and Future Projects

### 8.4.1 Research Gaps

- Full scale measured data on ships navigating in rough sea state for long duration
- Development of risk based methodology concerning extreme hydrodynamic loads
- Scaling effects of large ship motions in waves: intercomparison between full scale measurements in sea trials, numerical predictive techniques and measurements on scaled models in hydrodynamic facilities,

- Full sea keeping simulation tools, including effects of wave loading, and slamming impacts,
- Tools / methods for determination of actual damping of ship motion under extreme hydrodynamic loads (model scale and full scale)
- For ship operation, smart systems for the detection of abnormal / dangerous ship motions
- Establish hull monitoring techniques and methodologies for ship operation and ship maintenance (integrated ship control).
- Investigate standardisation of ship hull shape, hull structure, materials with concern on extreme hydrodynamic loads and associated ship dynamics in large motions

### 8.4.2 Recommendations for Future Projects

- Long duration measurement (several years) of full scale data on several target ships to build up data base and long term prediction of extreme loads and associated consequences on ship integrity; to be combined with wave and climate measurements; the long term goal is to improve safety at sea with a better knowledge and management of critical scenarios and to develop an appropriate Intelligent Ship Platform making use of up-to-date IT-tools (data production, data communication, decision support),
- Intelligent ship monitoring applied to small ships,
- Full sea keeping simulation tools, including effects of wave loading, and slamming impacts,
- Development of risk based methodology concerning extreme hydrodynamic loads on ships.

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# FIRE AND EXPLOSION

## 9.1 Background and State of the Art

### 9.1.1 Objectives

The design of the fire protection system of ships is based on compliance with international regulations; as a consequence the application of advanced fire engineering tools during ship design is in its infancy and only few of the available examples concerns applications to merchant ships.

However, within the on-going revision of fire safety regulations, the application of advanced fire engineering methods and models are considered as a basis for the development of alternative design not complying with one or more specific fire safety requirement.

As a result, in the near future (1 July 2002) designers will be given the possibility to deviate from fire safety prescriptive requirements provided their design is checked by means of an advanced (and so far completely new) approach to fire safety.

### 9.1.2 State of the Art

The goal of TA5 was to identify the main R&D priorities and to promote the research needed for this new approach to be put into practice. Accordingly, the activities carried out within TA5 of the TN SAFER EURORO have been:

- monitoring the development of fire safety regulations at the IMO;
- assessment of the state of the art (industry wide) in fire risk analysis methodologies;
- assessment of the state of the art in existing fire and explosion consequence models and evaluation of their applicability to ships;
- development of an example of consequence modelling (design for fire safety).

The conclusions from the state of the art is provided in the following (details are given in the annual reports of TA5). It is worth mentioning that, differently from other TAs, the application of fire engineering science was a relatively new topic for the shipping industry when SAFER EURORO was initiated, taking into account this, the goals of the state of the art analysis and synthesis were:

a) assess whether application of fire risk analysis to ships is feasible using available tools from other industries, suitably customised, or if ship specific tools need to be developed from scratch;
b) collect information from other industrial fields, as those pertinent to shipping are very limited (due to the fact that the matter was completely new and innovative).

### 9.1.3 Fire Safety Regulations

The “Guidelines on Alternative Design and Arrangements for Fire Safety” was approved by IMO (FP45) (MSC/Circ.1002) in June 2001 and will enter into force on 1 July 2002.

The main points of the alternative design process are:

- a comparative analysis is to be carried out where the alternative design is assessed, in performance terms, against a “prescriptive” design;

- the assessment focuses on the deviations of the alternative design from fire safety regulations
- additional fire risk mitigation measures must be considered in order to balance these deviations
- reference is made to approaches and fire models developed for application in the civil building sector

The main steps of the assessment are as follows:

1. definition of the problem
2. identification of desired deviations from requirements
3. definition of performance parameters to be used for comparative analysis
4. definition of acceptance criteria
5. definition of the method of analysis (i.e. type and extent of the analysis)
6. definition of design fire scenarios to be analysed
7. specification of the design fires to be considered
8. execution of the comparative analysis.

The literature search on Performance Based Codes in various industrial sectors was carried in the first year and updated on a yearly basis; see T.A.5.1 report 1998,1999 and 2000 for details.

### 9.1.4 Consequence Modelling

Depending on the case under analysis the performance parameters on which the comparative assessment is to be based are related to human vulnerability (effects of heat, smoke, toxicity) or on damage to ship systems (e.g. impact of fire on the structure, the escape system, etc.).

This implies that fire consequence models are needed which are able to quantify these parameters taking into account effects such as:

- ignition sources and their characteristics
- rate of heat release of combustible material
- proximity, amount and distribution of combustible material
- ventilation characteristics
- position and characteristics of sprinklers
- fire growth rate and its modifications due to sprinkler and ventilation.

A large number of computer models and engineering correlations exist which model fires, smoke movement and explosions. However, many of them were developed for specific applications such as fires in domestic buildings or explosions in an off-shore oil and gas installation. Investigations on these existing tools were made to understand their ability to deal adequately with scenarios in a ship such as a ro-ro ferry.

Investigations have been performed to assess their ability to deal adequately with scenarios in a ship such as a ro-ro ferry. Gaps in capability and discrepancies between predictions have been highlighted. Computational Fluid Dynamics (CFD) codes are more generally applicable, and could be used to model specific situations in detail. However, the complexity of their input and their long run times makes it impractical to use CFD codes routinely at the present time.

The conclusion is that, with not dramatic customisation, most of the tools can be profitably applied to ship problems.

The literature search on fire and explosion consequence modellins was initaited in the first year and updated on a yearly basis; see T.A.5.1 report 1998,1999 and 2000 for details.

### 9.1.5 Fire Risk Analysis

The literature search on fire risk analysis methods applied in various industrial sectors, was carried out on a yearly basis; see TA5 report 1998,1999 and 2000 for details.

As a final conclusion, a typical approach for fire risk analysis applicable to passenger ships was outlined; it is noted that this approach is very similar to that used in the civil building and rail transportation sectors. The methodology is depicted in Figure 9.1, which schematically reports the fundamental steps.

When compared to the approach developed (later) by the IMO, the following emerge:

- the two methods are in agreement concerning the selection of the fire threats and the quantification of consequences and frequencies;
- however, IMO's methodology is driven by the fact that the analysis is comparative: as such, the method proposed by IMO does not seek to obtain absolute risk values, while a traditional risk analysis would try to do that.

IMO's approach is seen as a rather practical way of addressing safety and seeking acceptance by authorities.

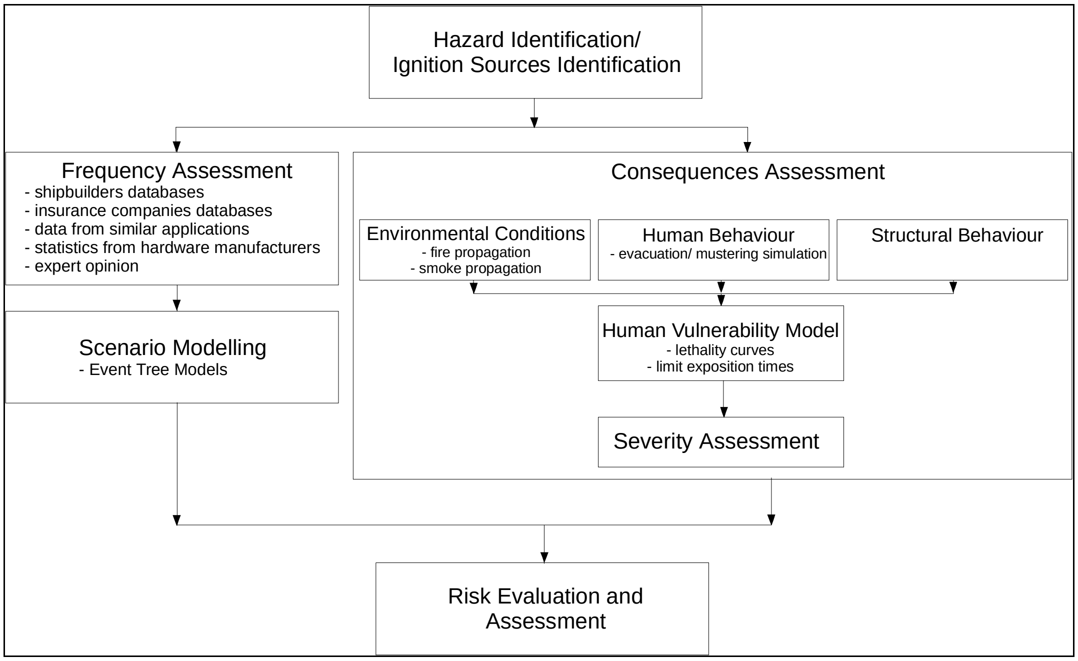


Figure 9.1: Flowchart for a Ship Fire Risk Analysis

### 9.1.6 Design for Fire Safety

This aspect was tackled in two distinct ways, as follows:

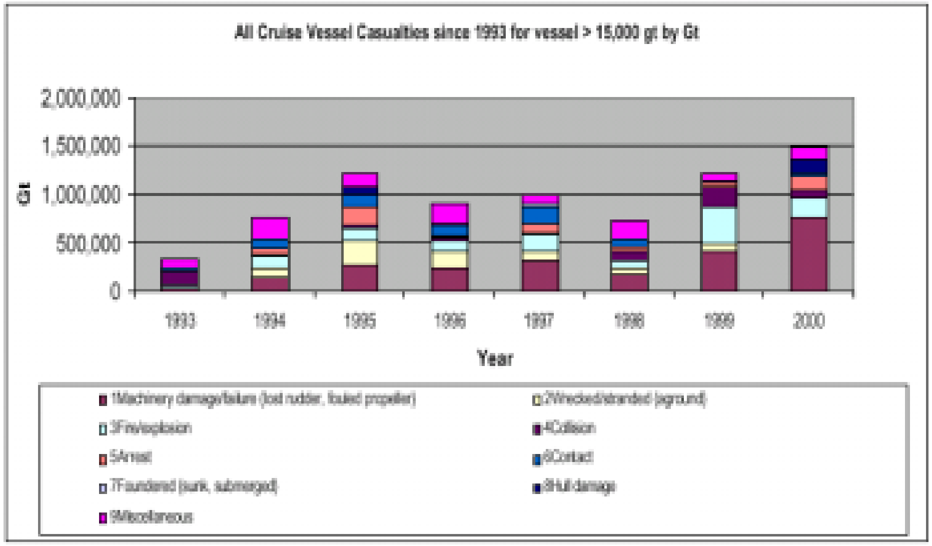
a) based on the recognised need to assign considerable and dedicated resources on the matter, an R&D project, SAFETY FIRST, was successfully submitted to the EU Commission; the project started on March 2000;
b) an example of application was developed, as outlined in the Appendix to this document.

## 9.2 Risk Involved

Fire is a major risk for passenger ships: as shown in Figure 2.7.2, provided by IUMI, fire on passenger ships has a not negligible occurrence, moreover its consequences may well be dramatic. The matter need not additional comments or data in the present report, however further details can be found in TA5 annual reports.

## 9.3 Costs

Similarly to the risk involved, the potential costs of a fire spreading outside the space of origin can be enormous. Again this statement need not data or additional proofs here.



<u>Figure 9.2</u>

## 9.4 Research Gaps and Future Projects

As already stated several times, application of fire engineering science in the shipping sector is in its infancy and, although significant steps forward have been made since 1998, in particular from a regulatory point of view and in assessing the usability of other industrial sectors' experience, much more is to be done.

More specifically, the following is recommended to be undertaken in the short/medium term, following the path pioneered by SAFER EURORO and SAFETY FIRST:

- extending the range of trial applications on realistic cases of practical engineering relevance, aiming at increasing the know how on this new approach;
- developing appropriate risk acceptance criteria;
- fine tuning fire modelling tools for use in shipping applications;
- executing a trial design of a whole ship fire safety system completely based on first principles fire engineering science.

# APPENDIX – Example of Application

## A.1 Introduction

Within SAFER EURORO TA5 – Design for Fire Safety – as a contribution to the overall SAFER EURORO demonstrator, a fire simulation was carried out considering a fire scenario in the passenger accommodation area of a hypothetical ro-pax ship. Aim of this document is to outline results as well as the main relevant information.

## A.2 Case Study Definition

### A.2.1 Geometry

The passenger cabin (compartment 1) is simply represented by a cuboid of floor area 4m x 6.08m and ceiling height 2.2m. This effectively treats the en suite shower room as an integral part of the whole cabin. The corridor adjoining the cabin (compartment 2) is 18.24 m long and 1.8 m wide with a ceiling height of 2.2m. The other corridor (compartment 3) is 36.48 m long and 1.8 m wide with a ceiling height of 2.2m. Figure A1.1 shows compartments location.

The fire is assumed to be located at the centre of the cabin floor, and the two zone model is assumed to apply in the cabin. In other words, a hot smoke layer is assumed to form at the cabin ceiling, with the remaining volume of the cabin remaining relatively cool. CFAST is then used to model the behaviour of these two layers separately. For the purpose of this illustrative example, the two corridors were also each modelled as two zones. However, it should be noted that the atmosphere may not separate into two layers in elongated geometries of this type, and a single zone approach may be more realistic for corridors in practice.

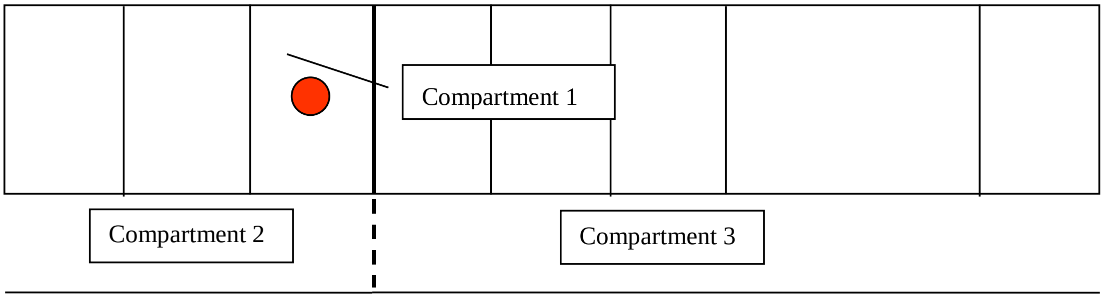


Fig. A1.1 Compartments location

### A.2.2 Fire

The assumption is made that the fire is constrained without flashover. In other words, the prescribed heat release rates are ignored if insufficient oxygen is present in the cabin to support them.

CFAST allows the user to specify the fire heat source using any two of the three parameters: heat of combustion, heat release rate, and pyrolysis[1] rate. For the purposes of this report, we

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[1] Thermal decomposition of solid fuels prior to combustion.

define the heat of combustion and heat release rate only, leaving the pyrolysis (or mass loss) rate to be calculated internally from these.

The heat release rate can be provided to CFAST as a function of time in one of four ways:

1. by selecting one of the standard $t^2$ growth curves provided within CFAST,
2. by manually specifying an alternative $t^2$ growth curve,
3. by selecting one of the predefined growth curves provided within CFAST, corresponding to a particular burning object (chair, bed etc),
4. by manually entering a particular heat release rate profile, such as a constant rate for a finite period.

In this application the standard Medium Growth Rate heat release rate was taken, whereby the heat release rate rises to 1MW in 300s, remains at this level for 600s, then decays to zero after a further 300s. This corresponds to a total heat release of 802 MJ over 1200s. The peak release rate of 1 MW is consistent with values observed in experiments involving burning furniture.

The initial fuel temperature and gaseous ignition temperature are set at the CFAST default values of 293.15 K and 493.15 K respectively. The gaseous ignition temperature determines whether unburned pyrolyzate ignites when it flows through a vent into a neighbouring compartment with higher oxygen concentration. The fraction of the released heat which goes into radiation as opposed to convection is assumed to be 0.3, which is the CFAST default value.

For constrained fires, CFAST assumes that burning will stop if the overall oxygen level falls below a critical level specified by the user. This is the “fuel rich” limit for combustion. The base case uses the default critical value of 10vol%.

### A.2.3 Chemical Species

The following ratios are assumed, based on CFAST manual recommendations:

| | |
|---|---|
| Mass ratio of hydrogen to carbon as it becomes available from the fuel | 0.1 |
| Mass ratio of oxygen to carbon as it becomes liberated from the fuel | 0 |
| Mass of hydrogen cyanide produced per unit mass of pyrolysed fuel | 0 |
| Mass of hydrogen chloride produced per unit mass of pyrolysed fuel | 0 |
| Mass of “toxic products” per unit mass of pyrolysed fuel | 0.01 |
| Mass of carbon (i.e. soot) produced per unit mass of carbon dioxide | 0.1 |
| Mass of carbon monoxide produced per unit mass of carbon dioxide | 0.1 |

### A.2.4 Ventilation

Ventilation is an important aspect since it influences the supply of oxygen to the fire and the spread of toxic gases around the system. CFAST models both natural ventilation (under doors, through vents etc) and mechanical ventilation (extractor fans, etc). Ventilation fans and dampers would normally be shut down if a fire were detected, so the base case considers natural ventilation only.

Natural ventilation between the cabin and the adjoining corridor is assumed to take place via a 1.0m x 1.9m door; natural ventilation between the two corridors is assumed to take place via the fire door. In the base case a fraction (50 %) of its full opening width is assumed.

### A.2.5 Conduction Through Surfaces

CFAST allows the user to specify heat conduction through the ceiling and/or walls and/or floor to the external environment. In addition, heat conduction may also be specified through the ceiling of one compartment and the floor of another compartment above it.

The conduction through the ceiling, walls, and floor of the cabin to the external environment were modelled. In addition, heat conduction is modelled through the ceiling of the corridor to the external environment. Materials properties are indicated in the following table:

| Material | Conductivity [W/mK] | Specific heat [J/kg/K] | Density [kg/m$^3$] | Thickness [m] |
|---|---|---|---|---|
| 1 – steel (1st layer) | 46.52 | 465 | 7800 | 0.007 |
| 2 – rockwool | 0.041 | 750 | 229 | 0.03 |
| 3 – steel (2nd layer) | 46.52 | 465 | 7800 | 0.007 |

### A.2.6 Detectors/Sprinklers

CFAST includes a facility for modelling fire detection and suppression by sprinklers. The following values have been used.

| **Compartment** | **Cabin** | **Corridor 1** | **Corridor 2** |
|---|---|---|---|
| Sprinkler | Commercial sprinkler | Commercial sprinkler | Commercial sprinkler |
| Status | On | On | On |
| RTI [[(m*s)$^{.5}$] | 278 | 278 | 278 |
| X | 2.0 | 0.9 | 0.9 |
| Y | 3.04 | 9.12 | 9.12 |
| Z | 2.199 | 2.199 | 2.199 |
| Activation temperature [k] | 330.37 | 330.37 | 330.37 |
| Spray density [m/s] | 8.3E-05 | 8.3E-05 | 8.3E-05 |
| Detector | Heat detector | - | - |
| Status | Off | - | - |
| RTI [(m*s)$^{.5}$] | 278 | - | - |
| X | 2.0 | - | - |
| Y | 3.04 | - | - |
| Z | 2.199 | - | - |
| Activation temperature [k] | 304.261 | - | - |
| Spray density [m/s] | - | - | - |

### A.2.7 Ambient Conditions

The ambient conditions assumed for the calculations are:

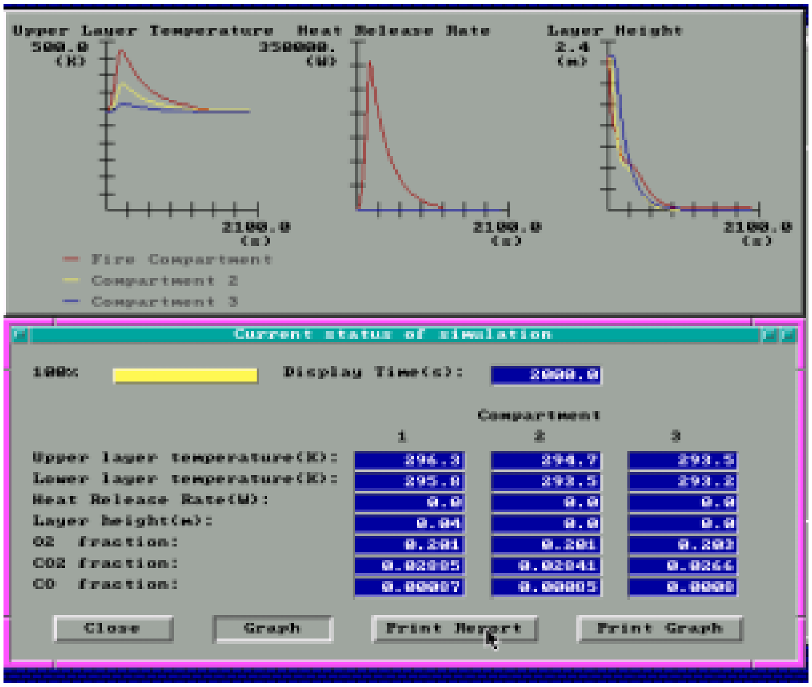
| | Cabin and Corridors | External |
|---|---|---|
| Temperature | 293.15K | 293.15K |
| Relative Humidity | 50% | 50% |
| Pressure | 1.013 bar | 1.013 bar |
| Station Elevation | 0 | 0 |

Wind effects are neglected.

## A.3 Results

Figure A1.2 shows the time history of Upper Layer Temperature, Heat Release Rate and Layer Height vs. time and the fraction of CO, $CO_2$ and $O_2$ at the end of the simulation. The same information is provided in Figures A1.3 to A1.6 respectively at 300, 600, 1000 and 1500 s after fire outbreak. Fire was suppressed by the sprinkler when the temperature of activation was reached, therefore the input heat release profile was not fully achieved (not all combustible material was burnt). This mitigates the achieved temperatures, but does not prevent the smoke layer growing to engulf the cabin, leading potentially to impaired visibility and toxic effects.

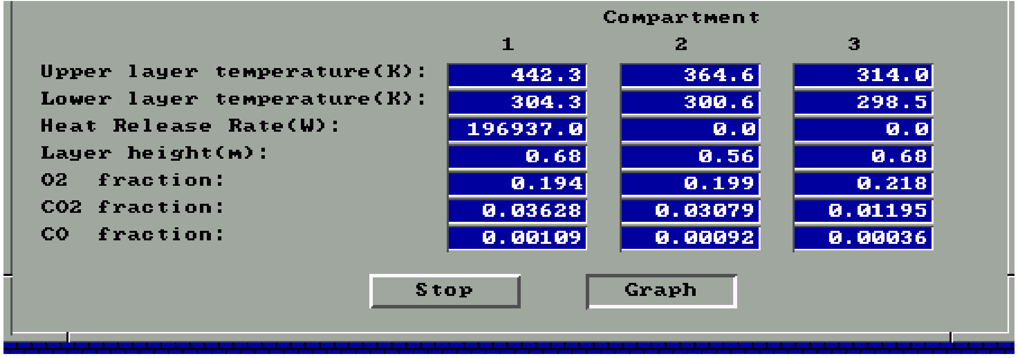
More detailed information is available in CFAST output regarding, for example, structure temperatures, chemical concentrations and optical densities, but they are not reproduced here.



Display Time(s): 2000.0

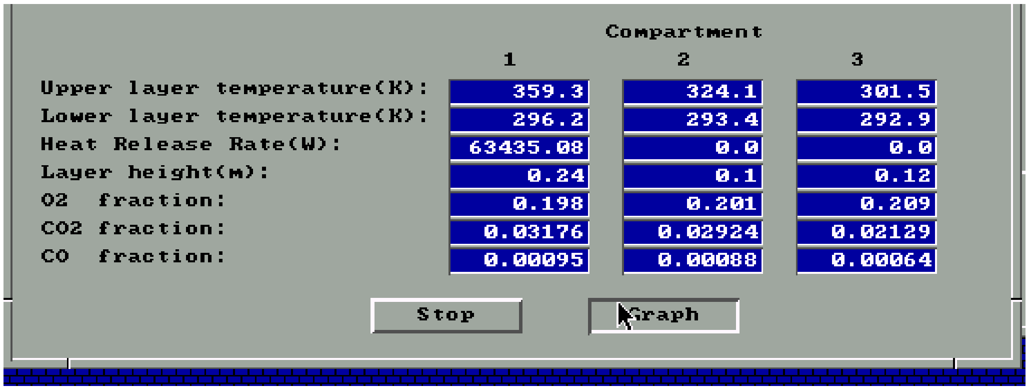
| | Compartment 1 | 2 | 3 |
|---|---|---|---|
| Upper layer temperature(K): | 296.3 | 294.7 | 293.5 |
| Lower layer temperature(K): | 295.0 | 293.5 | 293.2 |
| Heat Release Rate(W): | 0.0 | 0.0 | 0.0 |
| Layer height(m): | 0.04 | 0.0 | 0.0 |
| O2 fraction: | 0.201 | 0.201 | 0.203 |
| CO2 fraction: | 0.02005 | 0.02041 | 0.0266 |
| CO fraction: | 0.00007 | 0.00005 | 0.0000 |

Fig. A1.2



| | Compartment 1 | 2 | 3 |
|---|---|---|---|
| Upper layer temperature(K): | 442.3 | 364.6 | 314.0 |
| Lower layer temperature(K): | 304.3 | 300.6 | 298.5 |
| Heat Release Rate(W): | 196937.0 | 0.0 | 0.0 |
| Layer height(m): | 0.68 | 0.56 | 0.68 |
| O2 fraction: | 0.194 | 0.199 | 0.218 |
| CO2 fraction: | 0.03628 | 0.03079 | 0.01195 |
| CO fraction: | 0.00109 | 0.00092 | 0.00036 |

Fig. A1.3 (t = 300 s)



| | Compartment 1 | 2 | 3 |
|---|---|---|---|
| Upper layer temperature(K): | 359.3 | 324.1 | 301.5 |
| Lower layer temperature(K): | 296.2 | 293.4 | 292.9 |
| Heat Release Rate(W): | 63435.08 | 0.0 | 0.0 |
| Layer height(m): | 0.24 | 0.1 | 0.12 |
| O2 fraction: | 0.198 | 0.201 | 0.209 |
| CO2 fraction: | 0.03176 | 0.02924 | 0.02129 |
| CO fraction: | 0.00095 | 0.00088 | 0.00064 |

Fig. A1.4 (t = 600 s)

| | Compartment | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| Upper layer temperature(K): | 318.0 | 304.6 | 295.1 |
| Lower layer temperature(K): | 296.4 | 293.6 | 293.2 |
| Heat Release Rate(W): | 13998.61 | 0.0 | 0.0 |
| Layer height(m): | 0.03 | 0.01 | 0.02 |
| O2 fraction: | 0.198 | 0.2 | 0.205 |
| CO2 fraction: | 0.03153 | 0.02951 | 0.02451 |
| CO fraction: | 0.00095 | 0.00089 | 0.00074 |

Fig. A1.5 (t = 1000 s)

| | 1 | 2 | 3 |
|---|---|---|---|
| Upper layer temperature(K): | 297.5 | 295.4 | 293.5 |
| Lower layer temperature(K): | 295.9 | 293.6 | 293.2 |
| Heat Release Rate(W): | 0.0 | 0.0 | 0.0 |
| Layer height(m): | 0.03 | 0.0 | 0.0 |
| O2 fraction: | 0.2 | 0.201 | 0.204 |
| CO2 fraction: | 0.02962 | 0.02884 | 0.02611 |
| CO fraction: | 0.00089 | 0.00087 | 0.00078 |

Fig. A1.6 (t = 1500 s)

# SYSTEM HAZARDS

### 10.1 Background

In the context of ship machinery and equipment systems a *system hazard* means a potential threat to human life, health, property or the environment resulting from system failures. The system subject to analysis may either be examined by analysing hardware failures of its constituent subsystems or components, or by analysing failures of the functions the system is designed to perform. Starting point for both approaches is a system breakdown, which is *hardware oriented* or *functional* respectively.

Both approaches have their advantages and drawbacks and are accepted techniques. As an example for a generic *hardware oriented* system breakdown the following high-level decomposition may serve:

- **Propulsion System**
  - Diesel engine/ gas turbine
  - Gearbox
  - Coupling
  - Shaft
- **Electrical System**
  - Generators/ UPS
  - Ship's network
  - Switchboards, switchgear
  - Accumulators, batteries
- **Auxiliary Systems**
  - Fuel system
  - Lubrication oil system
  - Cooling water system
  - Pneumatic system
  - Hydraulic system
  - Bilge and ballast water system
  - Fire and explosion protection system
- **Exhaust gas system**

- **Automation and Control System**

- **Navigation System**

- **Communication System**

Similarly, a high-level *functional oriented* system breakdown may look as follows:

- **Propulsion**
  - Generate main propulsion power
  - Transmit torque and thrust
  - Control and monitor main engine

- **Electrical power supply and distribution**
  - Generate mechanical and electrical energy
  - Distribute electrical energy

  - Provide emergency energy generating capability
  - Monitor and control electrical energy generation and distribution

- **Auxiliary functions**
  - Supply and treat fuel oil
  - Supply and treat lubrication oil
  - Cool sea water and fresh water
  - Generate and distribute compressed air
  - Generate and distribute hydraulic power
  - Transfer and treat exhaust gas
  - Generate steam
  - Supply fresh air to engine room
- **Steering**
- **Safety functions**
- **General ship and support functions**
- **Navigation**
- **Communication**

Systems may fail in different ways. In relation to the functional decomposition shown above these failures may be addressed in generic form by considering the following failure conditions:

- Loss of function (detected/ undetected)
- Malfunction (detected/ undetected)
- Incorrect function
- Reduced performance
- Inadvertent function
- Interrupted function

## 10.2 Analysis, Assessment and Control of Risks

Different terminology is used for describing the process of establishing levels of risks associated with certain operations, evaluating the acceptability of the established risk level, identifying means of controlling the risk and deciding on which action to take, if requires. Among the more common terms found in the literature are risk analysis, risk assessment, safety assessment, and design safety case. A classic approach towards risk assessment comprises the following five steps:

1. Hazard identification
2. Risk analysis and assessment
3. Identification of risk control options
4. Cost benefit analysis
5. Recommendations for decision making

For each of these steps a number of methods are available and discussed in detail in the literature. For further information the reader is referred to these sources, however, it is worthwhile at this point to recall the main objectives of each step.

### *Hazard identification*

The purpose of the *hazard identification* process is to identify all conceivable and relevant hazards. The analysis is usually performed by a number of experts providing expertise for the topic under analysis. The hazard identification is supported by incident/ accident information from historical records, checklists, and the experience and expertise of the selected experts. Apart from identifying hazards, the analysis should also address possible effects on the system under consideration and on the vessel, possible causes for hazards, and safeguards to prevent hazards or mitigate consequences. The principle result of a hazard identification is list of hazards and prioritised scenarios.

### *Risk analysis and assessment*

*Risk analysis* comprises two main activities: (i) probability modelling and (ii) consequence modelling. Probability modelling uses standard techniques such as fault tree analysis, reliability block diagrams, etc.. Apart from establishing probabilities for top level event, fault trees identify initiating events and how these combine to contribute to the top event. Consequence analysis is concerned with a detailed analysis of the possible developments resulting from a failure or from an accident. A commonly used technique to support consequence modelling is *event tree analysis*. The risk itself can be expressed qualitatively as the combination of frequency and consequence, and quantitatively as the product of probability and consequence/ expected loss.

### *Identification of risk control options*

There are two principle ways of *controlling risk*: by

(i) *preventive measures* aimed at reducing the probability of an occurrence, and
(ii) *mitigating measures* aimed at reducing the severity of the outcome.

The types of action required to control risks may be either *technical* (by design, built in, added on) or *procedural* (implementing of defined procedures). The results of this step should list possible risk control options together with their potential to reduce risk.

Examples of application of formalised risk control preventive and/or mitigating measures are in merchant ship design and operation rare. However, typical applications may be found for navy ships and should be considered in future developments of merchant ship design and operational procedures. A typical example of risk mitigation measure in navy ships is the so-called risk *Deactivation Diagram,* described briefly below.

The *Deactivation Diagram* depicts all the required functional elements of a naval system or mission area for its safe operation. These elements are illustrated in their actual flow sequence (parallel or serial), enabling the identification of redundancies and non-redundancies of the system components. The system is considered safely *operational* if there is an unbroken path that can be traced through the diagram from the beginning to the end. The analysis of this diagram identifies the singularly vital (non-redundant) system components and describes the requirements on measures for physical protection of these components against possible threats. Additionally it helps to ensure compatible levels of redundancy throughout the deactivation diagram hierarchy. Given that the materialization of the redundancy includes the physical separation between each of the redundant components, the actual layout of the system onboard must be determined. This layout includes the shipboard locations of:

- All main system components
- All distribution elements
- All secondary support required
- Isolation and segregation features
- Connections to user equipment.

The next step is the imposition of the *Damage Modes* in order to ascertain the degree of damage tolerance of the ship. This is achieved by imposing specific damage modes, in a systematic manner, on the various systems. Thereafter the Deactivation Diagrams are modified in order to identify possible “LOST” components. Following the hierarchy, the impact of each damage mode is traced, e.g. the fraction of damage to a mission profile as result of the damage in the overall system. Finally the results are documented in the *Deactivation Diagram – Damage Tolerance Analysis Report*. The report indicates those modes that result in loss of the navy ship’s *mission area capability* or loss of *fire fighting capability*.

Based on the above, several major Navies, particularly the US Navy, have already proceeded to the development of design guidelines for ships with enhanced survivability. One such example is the Section 072 of the General Specifications for Ships of the United States Navy[i], the MIL-STD-1629[ii], the DI-R-7085 and the U.S.N. DDS 072-4[iii]. The latter reference specifies a five-step procedure for the estimation of the survivability of a system, namely:

- Development of a Deactivation Diagram
- Identification of physical location of all system components
- Imposition of damage modes upon the System layout and Identification of “Destroyed” Components.
- Modification of the Deactivation Diagrams to reflect impact of lost components on System/Mission area.
- Summary of results, identification of all damage modes resulting in a loss of mission.

### *Cost benefit analysis*

The aim of a *cost benefit assessment* is to rank the risk control options according to their cost effectiveness. Types of cost to be considered include *investment costs, costs related to operation* and *training,* and *costs related to inspection and maintenance*. *Benefits* include *reduced number of fatalities/ injuries, reduced loss of property, and reduced damage to the environment.*

### *Recommendations for decision making*

Finally, *recommendations* to decision makers are made on which risk control options are the most suitable in terms of cost effectiveness and their ability to reduce the risk to a level *As Low As Reasonably Practicable (ALARP).*

## 10.3 Shortcomings of Current Safety Assessment Application

The present application of the safety assessment process outlined above to marine systems suffers from a number of problems, most notably

(i) fragmentation,
(ii) system complexity, and
(iii) inconsistency in the application.

The first problem of fragmentation is evidenced by the current lack of a holistic and comprehensive approach. A systematic analysis, starting with an examination of functional failures and progressing to low level component failure modes, is not required and therefore not undertaken. Where safety assessment methods are being used, the focus is on selected systems (e.g. for HSC), which are identified a priori as safety relevant, or on selected areas for which design deviations from the prescriptive rules are sought.

Closely related to the fragmentation problem is the issue of system complexity. The classical approach to safety assessment comprising hazard identification, risk analysis and the identification of risk control options constitutes a very considerable effort for complex systems such as a ship propulsion plant, the electrical system, or the automation system, including computer hardware and software. The process is very labour intensive and error prone, particularly when design changes are still introduced while the analysis progresses. As ships are still very much one-off designs the effort is considered unacceptable and, moreover, shipyards often do not have the necessary skill base.

The problem of inconsistency in the application arises when different analysts conduct parts of the analysis for a complex system. The situation can arise where suppliers of subsystems perform an FMEA for their part of the system and these various FMEAs are inadequately integrated by the body with overall system responsibility, e.g. the shipyard. As a result the analysis is likely to vary in scope and detail for the different parts, and this is compounded by a lack of attention to interfaces. Moreover, common cause considerations are often not adequately addressed to substantiate redundancy claims.

## 10.4 Integration of System Hazards and Risk Control into a Risk-Based Design (RBD) Procedure

System representation in form of a block diagram where the individual blocks are linked by flow of energy, material or data can be usefully employed to examine the dynamic behaviour of the system under a variety of operating conditions. It can thus contribute to the consequence analysis by simulating malfunctions of individual functions or hardware components. Furthermore, it provides information on the system topography that can be harnessed for further system analysis, this time from a safety perspective.

Commercial simulation software packages are readily available on the market. Similarly, tools for safety analysis are available and a suitable tool for the safety analysis part with powerful fault tree analysis capabilities can be selected. What is missing and not available is a tool that provides the interface between *simulation models* on the one hand and *safety analysis tools* on the other. The relationship between simulation tool, interface module and fault tree analysis tool is illustrated in the integrated model below (Figure 10.1).

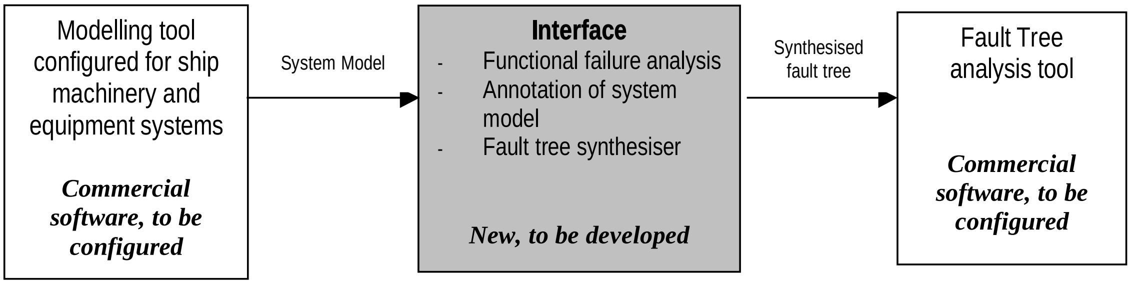


Figure 10.1: Integrated Model

The benefits of such an integrated tool for the prospective user (e.g. shipyard, system supplier) are derived from the fact that it will be possible to evaluate the safety and reliability of a new system design right from the beginning of the design process and to examine the effect of design modifications, while having access to the full range of evaluation methods of mature safety analysis software.

The approach also supports first principle analysis and the desire by end users to move away from prescriptive type regulations which are perceived as inflexible and an obstacle to innovation. Moreover, the present trend by regulators to allow designs with an equivalent level of safety to that implied by prescriptive regulations is taken into account by providing the tool for establishing the risk level of a proposed alternative design.

## 10.5 Future Research Needs

The shortcomings identified above can be addressed by integrating design tools and safety analysis tools for ship machinery and equipment systems. The process of integration should be automated as far as possible (e.g. automatic generation of *fault trees*) to reduce the effort for the analysis and thus increase the acceptability in the industry. An additional benefit that can be derived from automating the process lies in the improved robustness of the analysis which becomes less susceptible to errors. Also, the safety assessment can become an ongoing process in an evolving design and, thanks to the degree of automation, design modifications can readily be implemented in the analysis.

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[i] "Section 072 *General Specifications for ships of the United States Navy*", Department of the Navy, Naval Sea Systems Command, 1986 Edition.

[ii] MILITARY STANDARD MIL-STD-1629A, "PROCEDURES FOR PERFORMING A FAILURE MODE, EFFECTS AND CRITICALITY ANALYSIS", 24 November 1980, Department of Defense, U.S.A.

[iii] DESIGN DATA SHEET DDS-072-4, "Hull, Mechanical, and Electrical Systems Survivability", Department of the Navy, Naval Sea Systems Command, March 1986.

# RISK-BASED DESIGN METHODOLOGY

## 11.1 Background

The relationships between risk reduction measures and ship performance must be established in the early design phases, as keeping this relationship outside the design process will only result in local optimisation of safety. The effects of risk reducing design features on resistance, seakeeping, loading/unloading, stability, etc. should be determined by utilising relevant tools in the design process. This aspect is fundamental in the Design for Safety philosophy.

Risk-Based Design adopts a holistic approach that integrates risk analysis in the design process. Risk analysis pools together not only developments on consequence analysis tools concerning collision, grounding, large scale flooding, cargo shift, extreme load effects, fire and passenger evacuation but also design measures/parameters, systems design and approaches to preventing and mitigating risks. Cost-effectiveness of safety enhancing design features or measures is used as a basis to achieve balance between costs and safety optimally to render risks as low as reasonably practical whilst accounting for other design priorities and constraints.

Figure 11.1 illustrates the overall framework of the Risk-Based Design approach. Through the interfacing of top-down (consequence analysis) and bottom-up (frequency prediction) models, assisted where appropriate by comprehensive data and knowledge bases, pertaining to incident statistics and design and operational measures applicable to risk prevention and mitigation, rational decision-support, that carries out trade-offs among various design and safety indicators, is possible. The latter can therefore lead to the development of optimised design solutions. The various systems of the vessel can be analysed using classical risk analysis techniques, such as Fault Tree Analysis (FTA) and Failure Modes and Effect Analysis (FMEA).

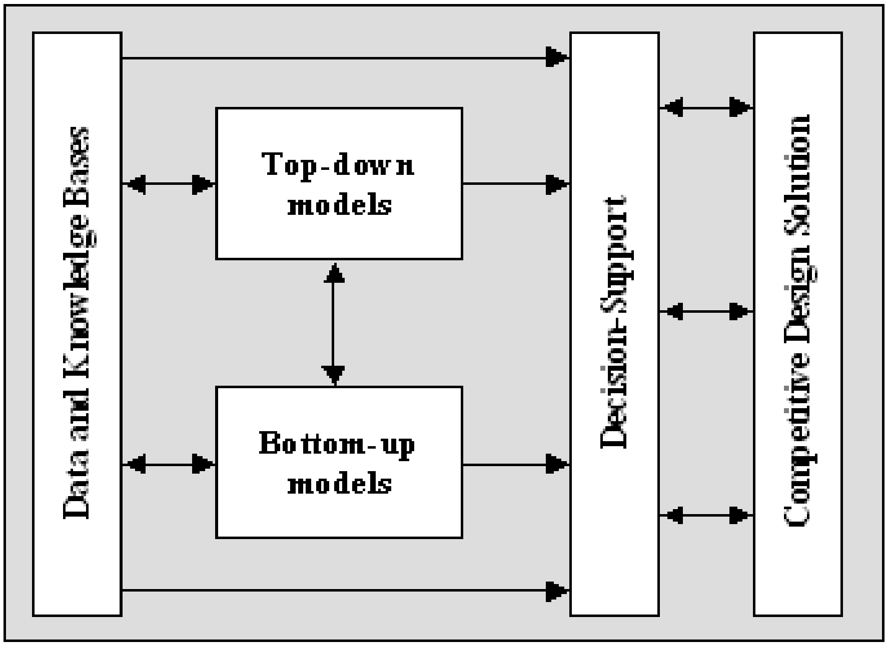


Figure 11.1: Risk-Based Design Approach

An operational procedure onboard a ship could be treated as a system and hence analysed using the same techniques. Human factors and interaction can also be modelled within this analysis. Bottom-up models are concerned with the quantification of these systems' representations. When a bottom level cause is considered as initiating, the respective representation is yielding a frequency (likelihood) of the top-level event occurring. Starting from the top event the outcomes (consequences) and their severity are established, utilising the top-down models. The analysis starts with the construction of representations of the chain of events that lead to potential outcomes following an accident. This is being performed in a generic manner, using Event Tree Analysis (ETA). Following this, the task is to establish the branch probabilities of the event trees. This can be achieved in a number of ways, using available statistical data, expert judgement or first-principles consequence analysis tools. The overall frequency of the top-level event can be broken down into expected frequencies of the final outcomes of this event happening. According to the severity of each of the individual outcomes (number of implied fatalities and/or injuries, extent of environmental pollution and implied property loss, that includes damage repair, insurance costs, business interruption, etc.), the outcomes can be classified and appropriate actions taken.

Figure 11.2 shows a breakdown of the generic categories, both technical and operational, of the measures that can be taken to either reduce the frequency of an accident occurring (prevention) or lessen its consequences (mitigation). When considering implementing various safety-enhancing measures (risk control options, RCOs), their costs and benefits can be evaluated and checked using established criteria, for example the Implied Cost to Avert a Fatality (ICAF). This idea could be extended to considering genuine design features for risk reduction or mitigation. Decision support can assist in selecting the best option available whilst taking into account interaction with other ship functions.

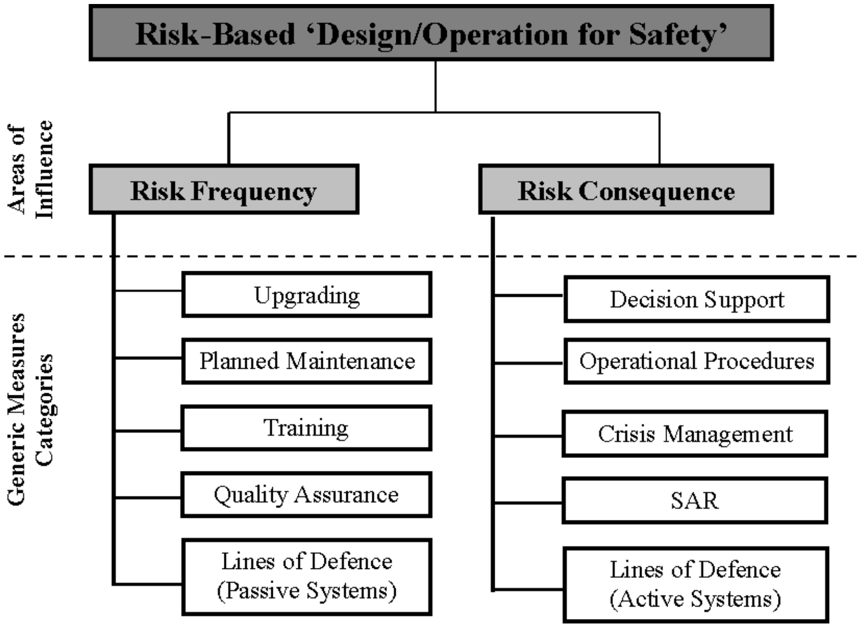
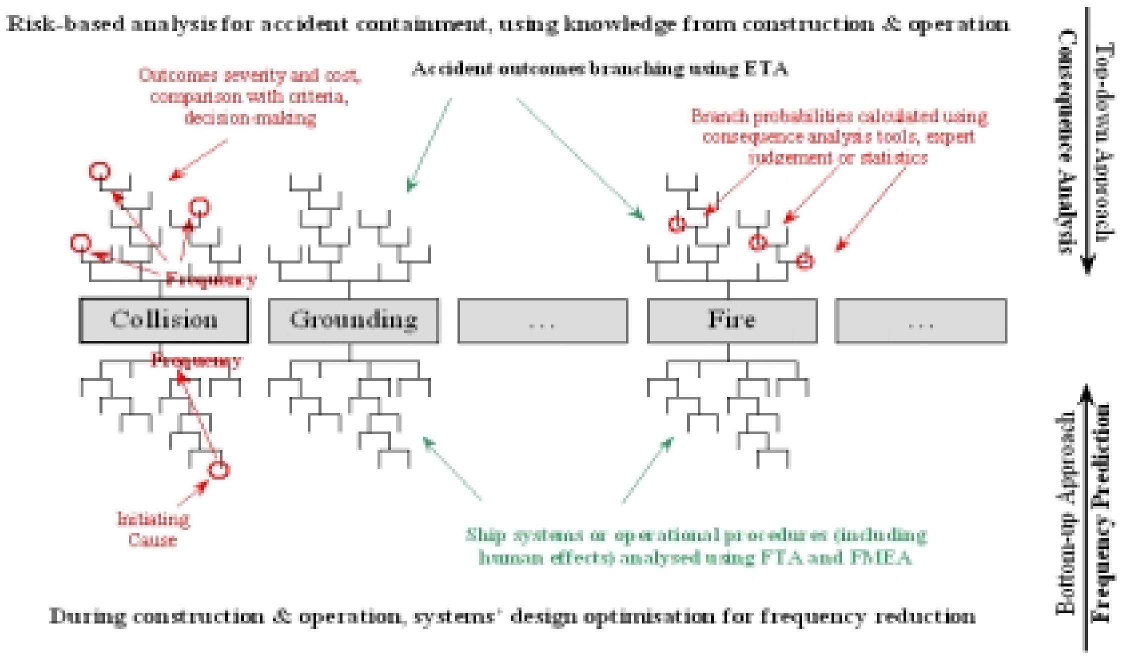


Figure 11.2: Risk Remedial Measures (RCOs)

Risk-Based Design, as a life-cycle process, should involve all the phases of a vessel, i.e. design, production and operation, as well as facilitate the transfer of knowledge among these phases. The latter is considered to be of paramount importance, since it is evidently the main cause for many deficiencies during operation and could result in significant improvements for the whole process. These interactions are illustrated in Figure 11.3.



<u>Figure 11.3</u>: Life-Cycle Risk-Based Design Process

## 11.2 Risk-Based Design for Safety Methodology

The Design for Safety methodology, illustrated in Figure 11.4, is an iterative process whereby an optimal solution for a ship design is sought that is safe-, performance- and cost-effective using a top-down approach. The input required is a ship design, which is developed using information modelling techniques. Risk analysis is performed for the design concept and the resulting quantified risk level is controlled against established risk acceptance criteria. Risk reduction measures, or design features, are considered when a ship fails to meet these criteria. There is a general distinction between risk reduction and mitigation means and both must be considered in order to develop an optimal design. On the basis of applying risk reduction measures "new ship designs" are developed and the effects of the changes are again evaluated against risk acceptance criteria.

Designs that are considered to be safe are put forward in the procedure and cost-benefit analysis of the risk reduction measures are performed. Using ICAF (Implied Cost of Averting a Fatality) criteria the new design solutions are evaluated based on their cost-benefit performance and economic viable design solutions are put forward in the process. The safe and cost-effective design solutions are thereafter assessed for their effect on other performance factors, such as seakeeping, cargo capacity, operational efficiency, turnaround time, etc. The resulting solutions of this process are weighted and the best design is put forward in the process for further development.

The methodology has potential to accommodate multiple accident events, where the effects from the various event-driven design configurations are assessed. In such a scenario, event-driven design features may be conflicting necessitating the use of decision support models in order to derive the best overall design configuration.

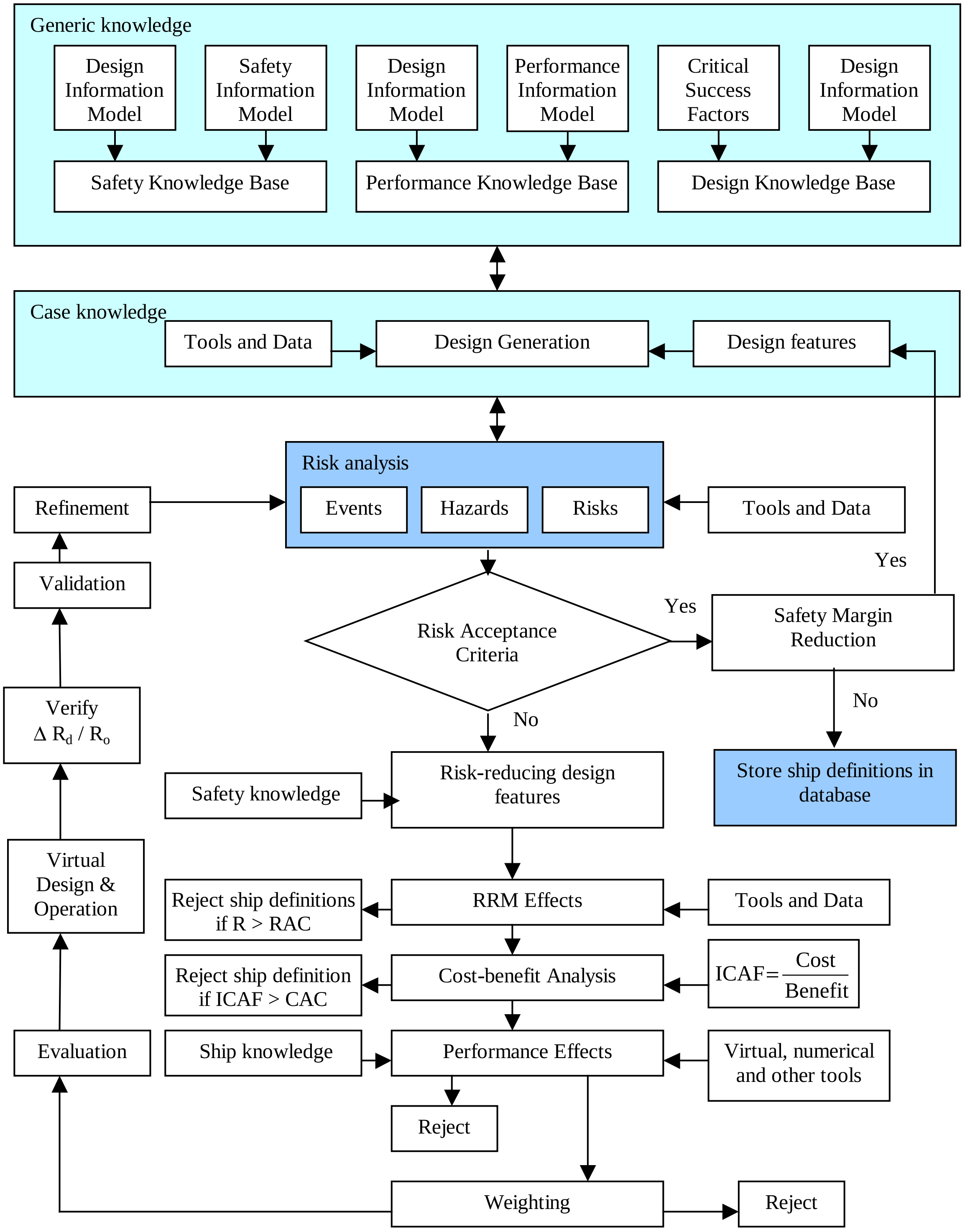


Figure 11.4: A Generic Design for Safety Methodology

## 11.3 An Integrated Design Environment Architecture (IDEA) for Safety

An Integrated Design Environment Architecture (IDEA) provides the designer with a means to assess the technical and analytical characteristics of the design using relevant tools. The IDEA must be formalised indicating that entities, attributes and relationships for the relevant issues are generic. This allows information to dynamically change, for altering design input and innovations can be readily implemented. The design information is stored in object-oriented knowledge bases, which are updated independently as required. A control and management function is needed to accommodate these issues. The Design for Safety procedure outlined in the foregoing has been accommodated in an IDEA using blackboard systems as the platform. An IDEA is illustrated in Figure 11.5, having a central blackboard to control and manage the overall ship design process applying the appropriate knowledge bases, tools and methodologies as and when required in building a design solution.

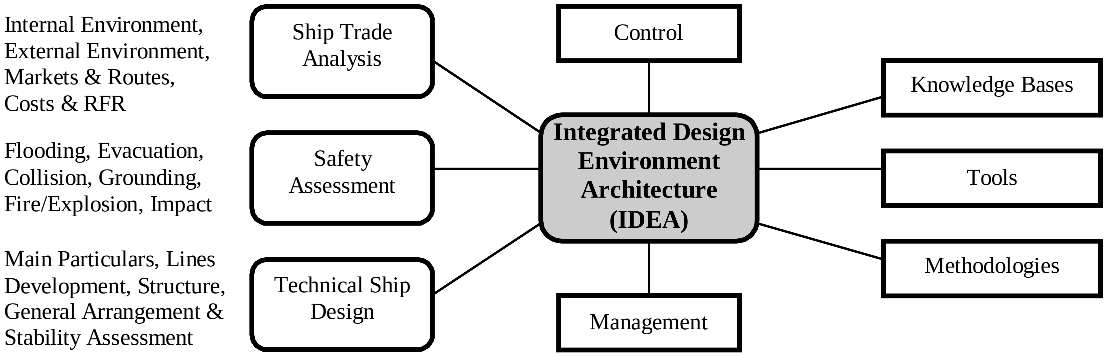


Figure 11.5: An IDEA for Safety

Blackboard Systems

Ship design is a complex engineering decision-making process involving the integration of many subsystems into a final design solution. There are many ship design methods, which have been developed based upon the ingenuity and experience of separate design capabilities and experience around the world. The basic constituent and of central importance to all methods is the ship design spiral.

This was introduced decades ago by Evans, and in more recent years attempts have been made for enhancement by applying various means of computer technology and modelling techniques. The ship design spiral advocates an iterative, step-wise solution procedure that is time-consuming and produces results, which may be acceptable but not necessarily optimal. It certainly does not take into account the whole life cycle of the ship and is not capable of accommodating effectively and efficiently contemporary and future ship design tools and concepts.

There are two major trends evident in ship design research and development today: (i) the pursuit of a definite theory of ship design, (ii) the development and application of computer-based tools in design. Regarding the latter, a great deal of work has been undertaken by industry and academia world-wide resulting in quality software packages, advances in technology and scientific understanding, which combined have shortened considerably the time required during the ship design process. Regarding the former, ship design is still in need of a formalised framework to control and manage the design process in an efficient way with the potential to take advantage of new emerging computer technologies. To this end, blackboard systems have been identified to have such a potential and are being utilised as the platform to overcome the stated deficiencies.

### *Fundamentals of Blackboard Systems*

Blackboard systems (BBS) are regarded as a part of the Artificial Intelligence family and originated with the Hearsay project in the USA twenty years ago. BBS constitute the fundamental assumption of design co-ordination, a formalisation within concurrent engineering. Design co-ordination emphasises that tasks must not necessarily be carried out concurrently, but rather in such fashion as to achieve optimum performance.

Design co-ordination is defined as a high level concept of the planning, scheduling, representation, decision-making and control of product development with respect to time, tasks, resource utilisation and design aspects.

The philosophy of blackboard systems is to opportunistically piece together a solution on the blackboard by using external knowledge sources, which are working co-operatively and are activated by a control mechanism, be it human or software programs, applying the right knowledge at the right time.

In this respect, various sources of knowledge participate in forming and modifying the emerging solution by knowledge sources contributing opportunistically when called upon. Furthermore, as steps are taken towards the solution, the processing commitments are minimised since the solution is built incrementally and steps of forward chaining can be arbitrarily interleaved with steps of backward chaining. Blackboard systems are particularly effective for incremental solution generation, which is typical for the ship design process, where the knowledge sources contribute to the solution as appropriate outperforming a problem solver that uses the traditional ship design approach to generate a solution.

### *Blackboard System Components*

Knowledge sources: Independent modules that contain the knowledge needed to solve the problem, having a formal structure to receive and send information in order to communicate with the blackboard. Knowledge sources are static repositories of knowledge activated in a predetermined way by trigger functions, or instances, which are the active functions looking for a triggering command or condition on the blackboard. Knowledge sources can be referred to as agents in engineering applications where the technology supports the integration of fully autonomous software and human expertise. Knowledge sources can be added or deleted from the blackboard system as required without influencing the overall performance of the blackboard, they can have a wide diversity in ways of representing information and problem solving techniques, but must operate based upon a common interaction language. With regard to ship design, lines development could be such a knowledge source, engine selection another, both performed in the ship design process based upon separate methods, tools, and information.

<u>The blackboard</u>: A global structure that is available to all knowledge sources and serves as a storage medium of raw input data, partial and final solutions, and control information, as a communication medium and buffer, and as a knowledge source trigger mechanism.

<u>A control component</u>: It directs the problem-solving process by allowing knowledge sources to respond opportunistically to changes on the blackboard database. The control triggers any knowledge source based upon a defined ranking, and it can change the focus of attention based on the state of the solution.

### *Control Shells*

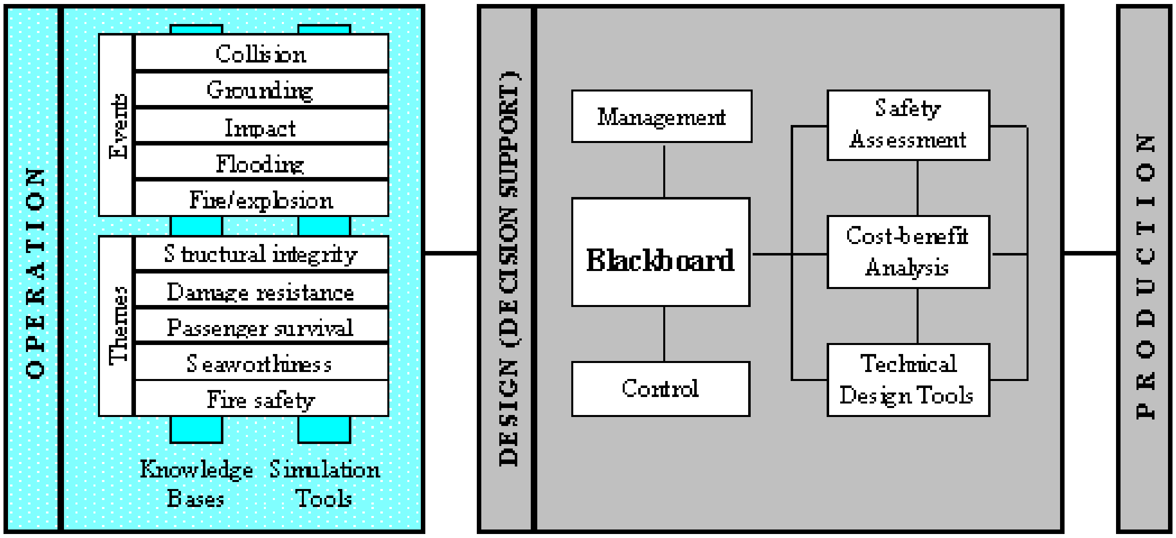
To execute the code of a Knowledge Source (KS), a control shell is required to activate it. This knowledge-source activation (KSA) represents the use of the KS in response to particular conditions in the application. A given KS can be activated as often as is appropriate in an application. Events represent the occurrence of actions within the application or external occurrences. The occurrence of an event can cause the control shell to trigger a KS or perform other activities, such as revalidating a KSA immediately before execution, obviating a KSA (removing it from the queue of KSAs waiting execution), or re-triggering a KSA. The control shell is a collection of control components that supports defining and activating KSs, and scheduling and executing KSAs. Events serve as the interface between the control shell and the blackboard.

Importantly, the control component must be able to make its selection among pending KS executions without sharing the expertise of the individual KSs. Without such a separation, the modularity and independence of KSs would be lost. Therefore, the control component must be able to ask for estimates from triggered KSs in decision-making.

## 11.4 An Integrated Design for Safety Environment

As already explained in the foregoing, current ship design practice is a design-check (trial-and-error) procedure, which is insufficient in itself as it keeps safety considerations outside the creative design process. It is here proposed that the vehicle for shifting safety from design periphery to the core of design is an integrated design environment utilising the outlined blackboard system philosophy. To this end, a prototype ship design blackboard system has already been developed, accommodating the Design for Safety procedure described in the foregoing. The Design for Safety process has been embedded in an integrated environment, using blackboard systems (BBS) as the platform in order to function as a decision support tool for the designer.

The integrated Design for Safety environment, illustrated in Figure 11.6, accommodates a methodological assessment of relationships between safety, cost, and design features adopting a top-down approach by assessing hazards and risks at the event level, i.e. for collision, grounding, impact, flooding, and fire/explosion. Furthermore, the IDEA accommodates the identification of risk prevention and mitigation measures, cost-benefit quantification of design features/safeguards, assessment of ship performance effects and provides decision support.



<u>Figure 11.6</u>: An Integrated Design for Safety Environment

## 11.5 Conclusions

The principal elements and the research undertaken to date towards the development of a formal state-of-the-art design methodology that supports and nurtures a safety culture paradigm in the ship design process by treating safety as a design objective rather than a constraint have been described. By adopting this <u>integrative</u> and <u>holistic</u> approach for safety assurance in design, the impact of the methodology will be significant and can lead to the achievement of the following:

- To design passenger Ro-Ro ships inherently achieving high levels of safety (low risk) from first principles, without reference to any rules;
- To make a direct comparison between performance-based design and a rules-based design;
- To integrate optimally safety assurance within the design process.

## 11.6 References

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4. Vassalos, D., Oestvik, I. and Konovessis, D.: “Design for Safety: Development and Application of a Formalised Methodology”, Proceedings of the Seventh International

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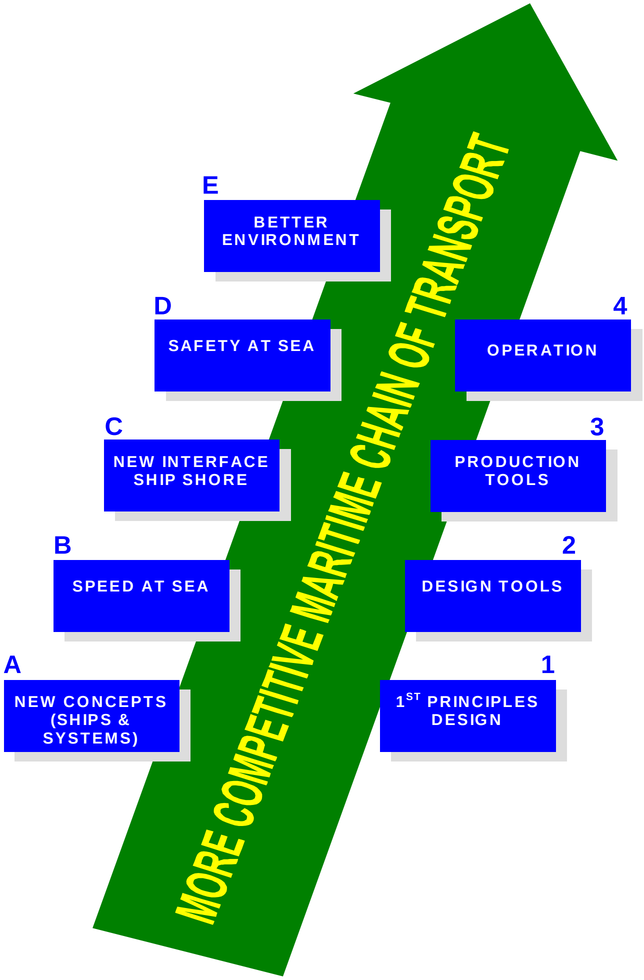
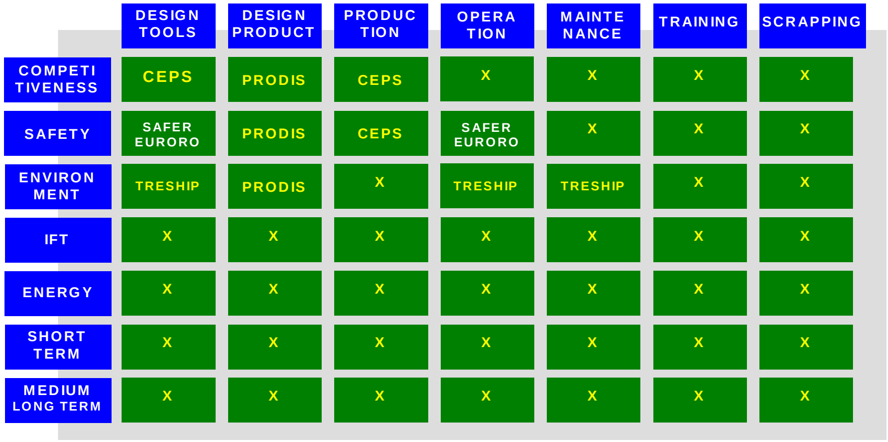
6. Oestvik, I., Konovessis, D. and Vassalos, D.: “Application of Blackboard Systems to Ship Design”, Proceedings (Part II) of the International Conference on Computers and Ships, 11-12 May 1999, London, United Kingdom, pp. 1-12.

# EUROPEAN MARITIME INDUSTRY R&D COORDINATION

In 1994 the Maritime Industries Forum (MIF) established an R&D Co-ordination Group (RDCG) consisting of representatives from the various European Associations of the maritime industries. The group acts as the formal industry interface with the European Commission on R&D related matters. In July 1996, following an organised review of the Industry's R&D needs, the RDCG developed an EU-wide Maritime Industry Masterplan. The Masterplan was subsequently successfully used across the EU R&D community during the FP4 to provide a co-ordinated and effective approach to the conversion of R&D activities into successful market solutions. One of the successful mechanisms towards facilitating appropriate clustering and promoting co-ordination was the setting up of a number of Basic and Focused Thematic Networks and the subsequent development of suitable interfaces to form a more competitive maritime chain of transport, as shown in Figure 12.1. Deriving directly from this is the SPEED AT SEA cluster, shown in Figure 12.4, coupling all the key elements represented by the four Basic Thematic Networks. The Masterplan identifies six areas of R&D activities, which are covered in two sectors, namely the Maritime Transport Chain in the 21st Century and Marine Resources. Each sector, in turn focuses on a number of Research Priority Areas (RPA), which address a number of Thematic Fields. The second area in the first sector, deals with Safe and Environmentally-friendly Maritime Transport (SEMT) as shown in Figure 12.2. The continuing importance of this area is reflected in the Key Action Land and Marine Technologies: Critical Marine Technologies - Efficient, Safe and Environmentally Friendly Ships and Vessels (3.2.1). It also formed the basis for the setting up of the largest Thematic Network under the theme "Design for Safety". This network comprises 92 participants from 13 countries and is initially targeted towards the design of safe passenger/Ro-Ro ferries (Figure 12.3).

Figure 12.1: R&D Maritime Transport Chain Clustering





| | DESIGN TOOLS | DESIGN PRODUCT | PRODUCTION | OPERATION | MAINTENANCE | TRAINING | SCRAPPING |
|---|---|---|---|---|---|---|---|
| COMPETITIVENESS | CEPS | PRODIS | CEPS | X | X | X | X |
| SAFETY | SAFER EURORO | PRODIS | CEPS | SAFER EURORO | X | X | X |
| ENVIRONMENT | TRESHIP | PRODIS | X | TRESHIP | TRESHIP | X | X |
| IFT | X | X | X | X | X | X | X |
| ENERGY | X | X | X | X | X | X | X |
| SHORT TERM | X | X | X | X | X | X | X |
| MEDIUM LONG TERM | X | X | X | X | X | X | X |

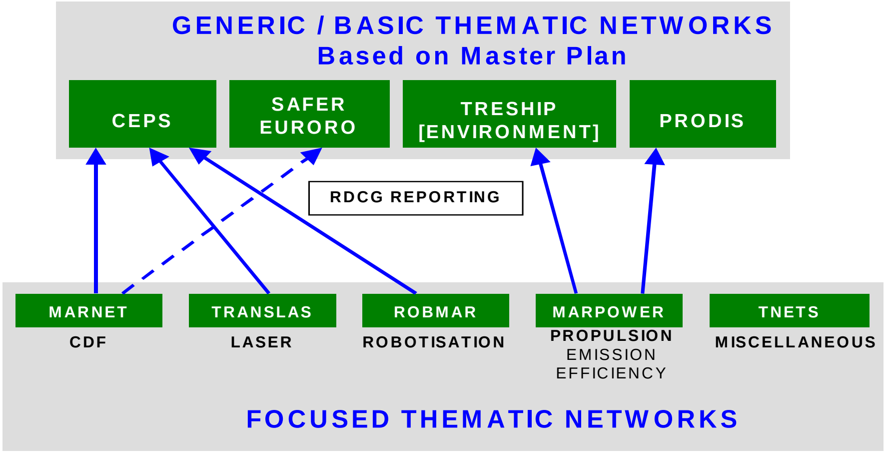


Figure 12.2: Maritime R&D Masterplan

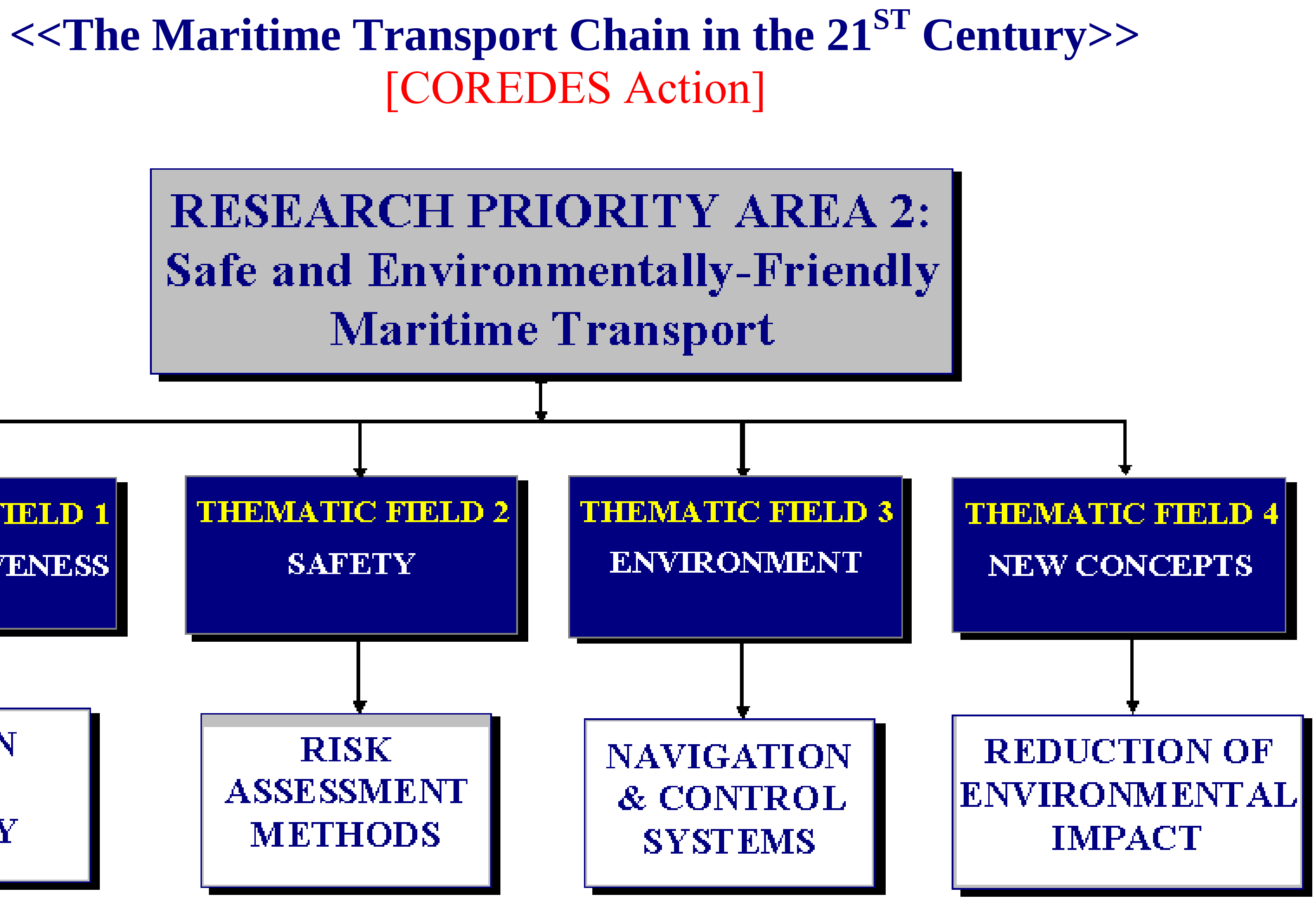


Figure 12.3: The SAFER EURORO Cluster

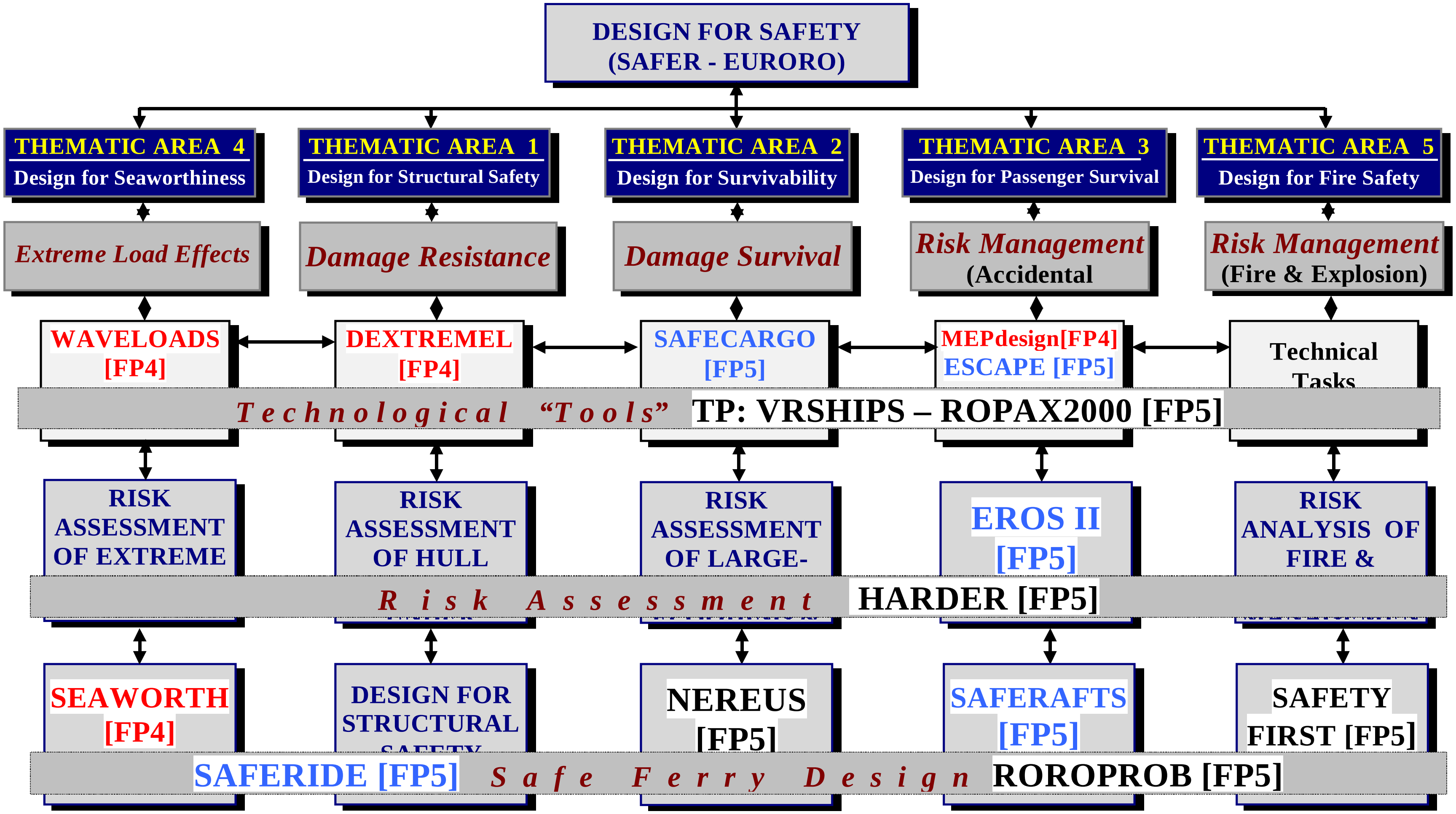
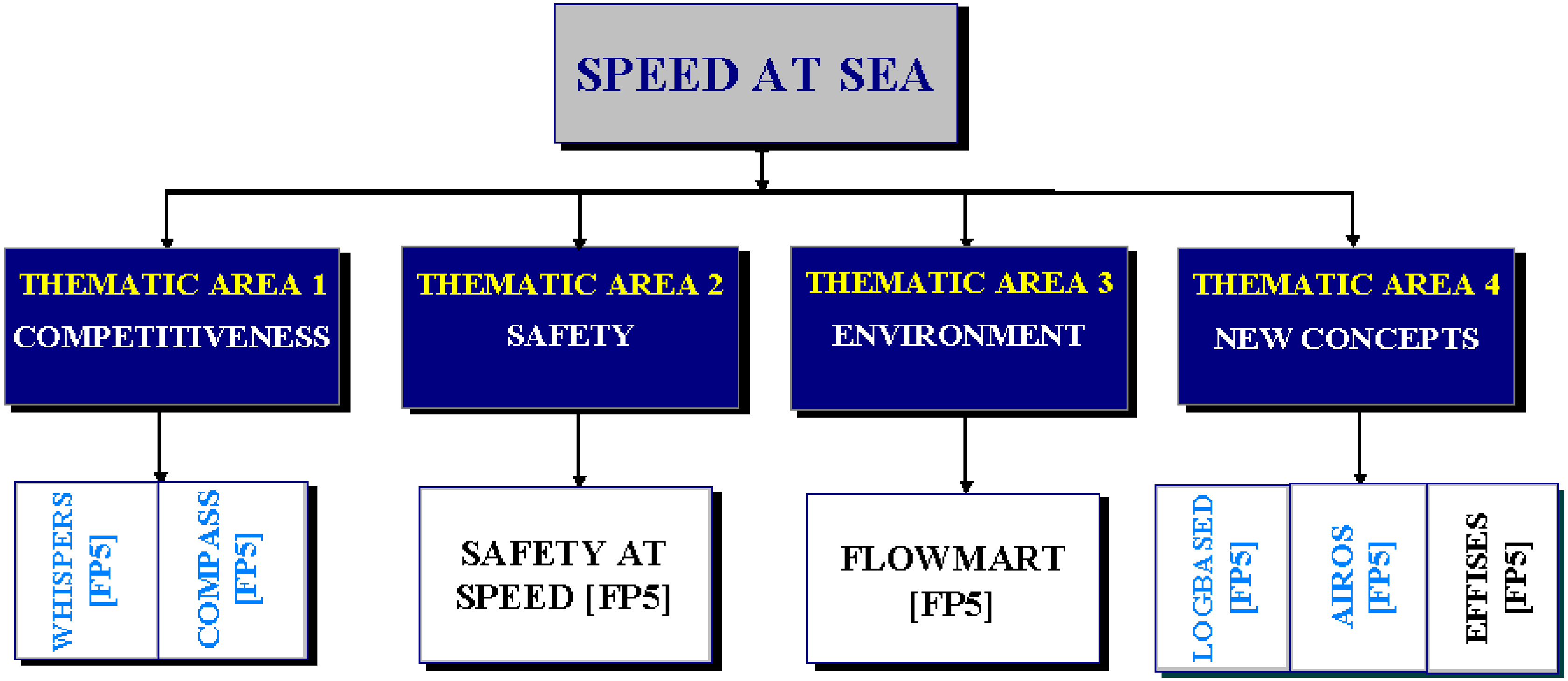


Figure 12.4: The SPEED AT SEA Cluster



# SAFER EURORO PARTICIPANTS

Contact details of the coordinators of the various activities of the Thematic Network are contained in the table that follows.

| CO-ORDINATOR | Country | ROLE | CONTACT PERSON |
|---|---|---|---|
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| GL | D | Thematic Area 1 Coordinator | Dr Pierre Sames (pcs@germanlloyd.org) |
| WSA | UK | Thematic Area 2 Coordinator | Dr Paul Gallagher (paul.gallagher@atkinsglobal.com) |
| TNO | NL | Thematic Area 3 Coordinator (Joint) | Mr Alex Vredeveldt (a.vredeveldt@bouw.tno.nl) |
| MARIN | NL | Thematic Area 3 Coordinator (Joint) | Dr Jan de Kat (j.o.dekat@marin.nl) |
| SIREHNA | F | Thematic Area 4 Coordinator | Dr Jean-Paul Borleteau (jean-paul.borleteau@sirehna.ec-nantes.fr) |
| RINA | I | Thematic Area 5 Coordinator | Dr Mario Dogliani (mario.dogliani@rina.org) |
| DNV | NO | Risk Assessment Team Coordinator | Dr Rolf Skjong (skj@dnv.com) |
| NTUA | EL | Safe Ferry Design Team Coordinator | Professor Apostolos Papanikolaou (papa@deslab.naval.ntua.gr) |

The innovative character of SAFER EURORO constitutes not only on the promotion of prototype research methods and approaches to ship design, but also to the organisation of the activities of the Network. The open structure of the TN has allowed an original compliment of 33 to grow to 92 organisations from 16 European countries participating in SAFER EURORO activities.

| | **Government Organisations** | | | **Design/ Consulting Offices** | |
|---|---|---|---|---|---|
| 1 | Maritime Coastguard Agency | UK | 47 | Alpha Marine | GR |
| 2 | APB, The Port Authority of Barcelona | E | 48 | SES Europe AS | NO |
| 3 | FIN (MCIB) | F | 49 | VTT, | FIN |
| | **Classification Societies** | | 50 | LOGIT | NO |
| 4 | Germanischer Lloyd | DE | 51 | METTLE | I |
| 5 | BV, Bureau Veritas | FR | 52 | LMG Marin | NO |
| 6 | DNV, Det Norske Veritas | NO | 53 | Carl Bro | DK |
| 7 | RINA | IT | 54 | Pelmatic-KEH | DK |
| 8 | Hellenic Register | GR | 55 | OCEA | F |
| 9 | Lloyds Register of Shipping | | | **Research / Development Organisations** | |
| 10 | ABS | UK | 56 | BMT, British Maritime Technology | UK |
| | **Shipyards & Manufacturers** | | 57 | DMI, Danish Maritime Institute | DK |
| 11 | EYD-AESA, Astilleros Espanoles | ES | 58 | SIREHNA | FR |
| 12 | Kvaerner Masa-Yards | FI | 59 | TNO | NL |
| 13 | HDW | DE | 60 | MARIN | NL |
| 14 | Empresa Natcional BAZAN | E | 61 | WS Atkins | UK |
| 15 | Chantiers De LAtlantique | F | 62 | AEA Technology | UK |
| 16 | Fincantieri | I | 63 | D' Appolonia | IT |
| 17 | AFY, Aker Finnyard | FIN | 64 | WEGEMT | UK |
| 18 | BAE SYSTEMS. | UK | 65 | ONERA | FR |
| 19 | GTI Marine & Offshore | NL | 66 | CEHIPAR | E |
| 20 | KAMEWA | S | 67 | CETENA S.p.A. | I |
| 21 | HKSE, Hamworthy KSE Group | S | 68 | HSVA | D |
| 22 | JLM, Jos L. Meyer GmbH (Meyer Werft) | D | 69 | IRCN | F |
| 23 | VAN DER GISSEN | NL | 70 | Transport Research Unit, Napier Univer. | UK |
| 24 | VDC, Vianayard | P | 71 | MARINTEK | NO |
| 25 | SZCZECIN Shipyard | PL | 72 | TMBL | S |
| 26 | FSG, Flensburger Schiffbau-Gesellschaft | D | 73 | SSPA | S |
| 27 | Mjellem & Karlsen Verft AS | NO | 74 | VBD | D |
| 28 | Katamaran Konstruktions GmbH | A | 75 | CTO, Centrum Techniki Okrętowej | PL |
| 29 | Woods Air Movement LTD | UK | | **Software Developers** | |
| 30 | LA.ME. s.r.l. | I | 76 | A/S Quasar  Consultants | NO |
| 31 | Twin Disc s.r.l. | I | 77 | MCS Internatizonal | IRL |
| 32 | WARTSILA | I | 78 | DASSAULT Systemes | F |
| 33 | FBM Marine Ltd | UK | 79 | KCS, Kockums Computer Systems AB | S |
| 34 | ALSTOM Leroux Naval | F | | **Universities** | |
| | **Ferry Operators/Owners** | | 80 | DTU | DK |
| 35 | Color Line | NO | 81 | KTH Stockholm | SE |
| 36 | Norwegian Shipowners Association | NO | 82 | NTUA | UK |
| 37 | Scandlines | DK | 83 | Newcastle University | UK |
| 38 | SEA, Sea Containers Ltd. | UK | 84 | Strathclyde University | UK |
| 39 | CONS.A.R. | I | 85 | Trieste University | IT |
| | **Design/ Consulting Offices** | | 86 | TU Delft | NL |
| 40 | Lund Mohr & G-E A | NO | 87 | IST, Instituto Superior Tecnico | P |
| 41 | Deltamarin Ltd. | FI | 88 | Lund Institute | S |
| 42 | Alpha Marine Ltd. | GR | 89 | University of Greenwich | UK |
| 43 | Three Quays Marine Services Ltd | UK | 90 | TUHH, Technical University of Hamburg | D |
| 44 | BALANCE | D | 91 | UniPATRAS, University of Patras | E |
| 45 | Engineering Solutions International LTD | IRL | 92 | University of Newcastle upon Tyne | UK |
| 46 | Competitive Concepts Europe LTD | UK | | | |

# CONCLUSIONS

The impact of SAFER EURORO on the maritime industry of EU over the past four years has been manifold, but the most significant by far must be the instillation of a strong belief in the maritime industry that safety by design is a feasible proposition, which in turn helps to promote a safety culture that spans the whole profession. Major achievements in the strife for cost-effective safer ships through the activities of SAFER EURORO (brought to greater focus by the well publicised recent marine disasters, notably the ERIKA) include:

- The subject of safety has been forced to the forefront of developments, giving way to scientific approaches to assessing safety at the expense of the traditionally governing empiricism. As a result, a clear tendency to move from prescriptive to performance-based approaches to safety is emerging and this is paving the way to drastic evolutionary changes in design, where safety is dealt with as a central issue with serious economic implications rather than a simplistic compliance. The attention surrounding ship safety has scarcely been greater at any other time. Safety is becoming a central issue for the maritime community. The traditional inertia of the marine industry has been overcome by a new stronger resurgence of safety as a key issue that cannot be considered in isolation any longer nor fixed by add-ons, bringing home the long overdue realisation that lack of safety or ineffective approaches to safety can drive shippers out of business.
- The European Commission has actively responded to these challenges by retaining 12 proposals on “Design for Safety” prepared through SAFER EURORO (9 concerning safer Ro-Ro/passenger ships and 3 addressing the safety of high-speed craft), amounting to 45 M€ of funding. Moreover, through the adoption of an open structure partnership, enabling other areas and others partners to join the TN a true European Research Area on the subject of Safety at Sea has thus been created and is being continuously nurtured and promoted.
- The internationalisation of the TN output, the significant contribution to the regulatory process and the increasing realisation by industry that scientific approaches to dealing with ship safety offer unique opportunities to building and sustaining competitive advantage, have helped in creating a momentum that is now proving to provide the “fuel” and the inspiration towards achieving the goals of the TN.
- More importantly, the effective co-operation between all the major players and stakeholders in the EU maritime industry led to a closer collaboration and to increased trust and respect of each of the partners potential and strengths. EU can only be better for it.

The added value of SAFER EURORO and its success as a TN are patently obvious but true success in this particular network could only be measured through the development implementation and integrated design for safety methodologies, providing tangible proof for the success of the “Design for Safety” philosophy. The latter has some mileage to run yet. Each principal risk associated with ferries is being currently subjected to the scientific scrutiny embedded in this philosophy through at least one RTD project retained from FP4 and FP5. A few of these projects are coming to a close, most will be half way to completion by the time SAFER EURORO comes to an end, whilst some others are due to start now and a few more yet to be submitted. Unlike other Thematic Networks, the success of SAFER EURORO depends critically on the integration of all of these into a “Design Tool” that would lead to cost-effective safer ships. This is the critical element of the whole philosophy and it could not (should not) stop with the ending of SAFER EURORO. This provides the *raison d'être* for SAFER EURORO II, a TN Type 2, aimed at co-ordination of the RTD funded projects within SAFER EURORO with the view to deliver and demonstrate a generic risk-based formalism capable of supporting practical designs for cost-effective safer ships.

# ACKNOWLEDGEMENTS

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