The Thematic Network SAFER EURORO: An Integrated Approach to Safe European RoRo Ferry Design

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For a period of more than 10 years, a safety culture approach has been promoted through the theme "Design for Safety," which aims at integrating safety cost effectively in the ship design process. There is a considerable wealth of information amassed over these years of research and development on safety-critical areas. One of the main elements of the research and development (R&D) work is the assurance of safety within the ship design process, in the continuous search for improving the current state of affairs. Through bold steps in the direction advocated by "Design for Safety," it is slowly but steadily being recognized that this approach can greatly contribute to the overall cost-effective improvement of safety in shipping while nurturing the evolution of proper practice in the field.

On this background, the paper attempts a thorough overview of related R&D developments over the last decade. Particular emphasis is placed on the developments that have taken place as part of the activities of the Thematic Network SAFER EURORO and associated research projects, which have led to the development of a recent major research initiative, the Integrated Project SAFEDOR, which is expected to lead research development in the area for the years to come.

1. Introduction

Recent well-publicized marine disasters triggered a chain of events that raised safety awareness among researchers and the wider public alike. 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 first-principles and performance-based approaches to safety is emerging, and this is paving the way to evolutionary changes in design, where safety is dealt with as a central issue with serious economic implications rather than a simplistic compliance. Concerted efforts to respond to these developments in the marine industry led to the establishment of the first significant EU Thematic Network (TN) on *Design for Safety* (SAFER EURORO—ERB BRRT-CT97 to 5015) on October 1, 1997 for a period of 4 years, initially as a Type 1 TN with 33 contracted participants. This figure has grown to 122 organizations through the activities of the research and development projects associated with the TN, covering the whole spectrum of the maritime industry. SAFER EURORO operated from 2001 onward until November 2005 as a Type 2 TN (SAFER EURORO II—G3RT-CT-2001 to 05050).

In simple terms, the strategic aim of SAFER EURORO was *to integrate safety cost effectively within the design process in a way that safety "drives" ship design.* The scope of the TN was to provide the necessary motivation and stimulation toward 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. In view of the varying nature of the technical information necessary in the attempt to formalize the safety assessment and design processes, the overall program was structured as a cluster of individual thematic areas, each addressing a specialist field in ship design. In this respect, five areas have been considered, namely: Design for Structural Safety, Design for Ship and Cargo Survival, Design for Passenger Survival, Design for Seaworthiness, and Design for Fire Safety. The structure of the Thematic Network also includes two horizontal functions, namely Safety Assessment and Safe Ferry Design, each addressing common and integrative issues aiming at the development of the Design for Safety methodology.*

2. Motivation for design for safety

The first principle in "Design for Production" as recommended by (Storch et al. 1995) is to "use common sense," and by analogy nothing stirringly new is advocated in suggesting "Design for Safety" as the way forward to improving ship safety. However, even though good designs should always take into account safety matters, this has invariably been governed by minimum compliance with the rules and hence not addressed optimally. Many may argue that competent

* The overall technical coordinator of the SAFER EURORO Thematic Network was The Ship Stability Research Centre of the Universities of Glasgow and Strathclyde. Coordinators of the Thematic Areas and Horizontal Functions were the following: Thematic Area 1 (Design for Structural Safety): Germanischer Lloyd; Thematic Area 2 (Design for Ship and Cargo Survival): WS Atkins; Thematic Area 3 (Design for Passenger Survival): TNO; Thematic Area 4 (Design for Seaworthiness): SIREHNA; Thematic Area 5 (Design for Fire Safety): RINA and Fincantieri; Horizontal Function 1 (Safety Assessment): Det Norske Veritas; and Horizontal Function 2 (Safe Ferry Design): Ship Design Laboratory, National Technical University of Athens.

designers have always strived to produce safe designs, but history demonstrably shows that intention is not a substitute for methodological treatment when it concerns a complex and multidisciplinary subject such as ship safety. To this end, a formalized methodology for designing safe ships must be adopted aiming to promote safety to the heart of the design process rather than being seen to be in conflict with ship production and operation and be treated in isolation from other ship design factors.

A historical exploration into the development of safety of life at sea (SOLAS) and an examination of the safety-related drivers reveals trends that ought to be considered with care in facing a future full of new challenges. These include:

- Enhancement of safety is sought through legislation.
- Regulations address mainly the ship itself, more specifically areas perceived to be safety critical (e.g., subdivision).
- Clear goals and objectives are missing (prescriptive regulations).
- Safety rules and regulations have been driven by disaster and public outrage (reactive approach). Raising safety standards has always been preceded by casualties including considerable loss of life or property or environmental damage.
- The pace of rule development until recently has been slow.
- Safety has been treated as a separate, conflicting engineering discipline without any consideration of cost-effectiveness analyses or attempt in understanding how it interacts with other design factors.
- Vested interests always delayed and often defeated the imposition of new regulations or forced a compromise that was unwise or unworkable. As a result, maritime law has constantly shown a large time interval between accidents and prevention of their repetition.
- There are underlying trends of decreasing loss in ships and fatalities, but those have to be considered in conjunction with the decreasing human tolerance to risk that becomes unacceptable, however remote the possibility of a tragedy involving large loss of life. Today, human life is much more precious than ever before. An emerging trend concerns also the importance attached by humans to the protection of the marine environment, which must not be taken lightly.
- Developments in shipping happen faster than experience is gained, thus the traditional reliance on experience and codes of best practice is "running thin."
- Overcapacity of transportation, oversupply of services, and painfully low margins drive some of the best companies and the core of the seagoing skill-base out of shipping. The resulting combination of an aging fleet, substandard ships, and multinational crews presents safety problems.
- Global media coverage brings the accident at the door of the public and is capable of stirring strong emotions.
- Shift of safety focus from hardware to software follows wide awareness and growing appreciation of the role of human factors on safety matters.
- Phenomenal progress in science and technology over the recent past presents the shipping industry with opportunities to meet emerging challenges cost effectively and safely.

Considering the above, adopting a risk-based design methodology that embraces innovation and promotes routine uti-

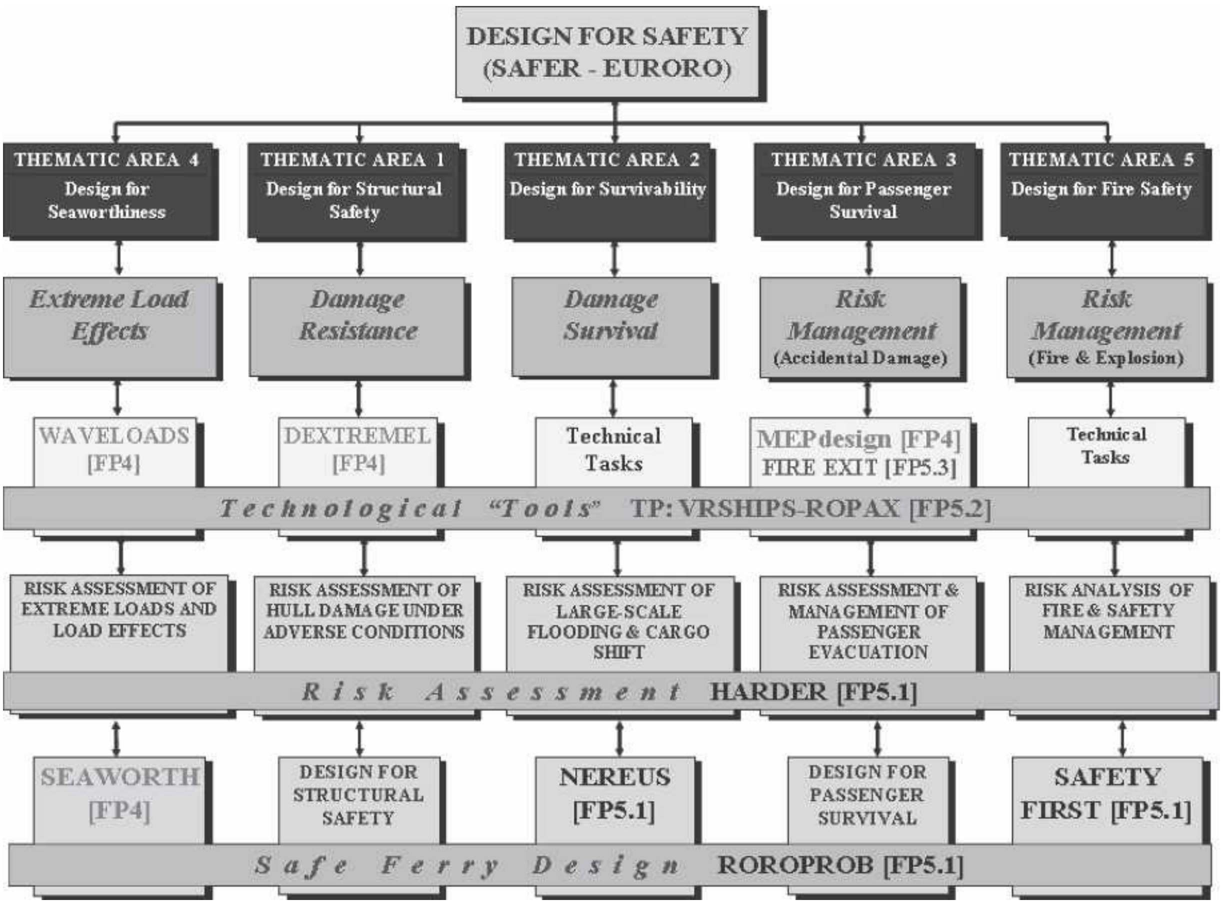

Fig. 1 SAFER EURORO Cluster

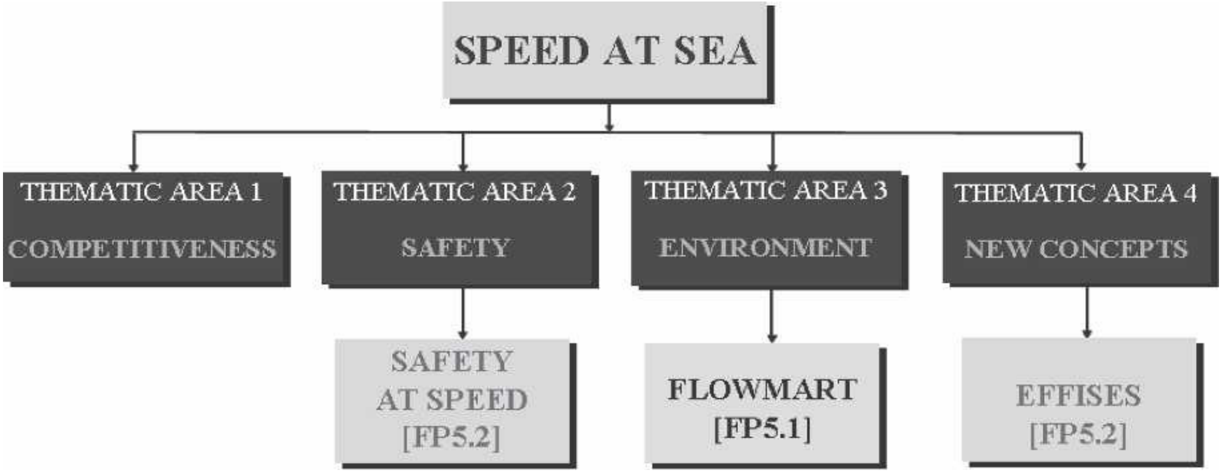

Fig. 2 SAFETY AT SPEED Cluster

lization of first-principles tools will lead to cost-effective ways of dealing with safety. It will further lead to building and sustaining competitive advantage, particularly so for knowledge-intensive and safety-critical ships; knowledge-intensive as such ship concepts are fuelled by innovation and safety-critical as such ship design safety is indeed a design "driver."

3. SAFER EURORO aim and objectives

The principal aim of the SAFER EURORO Thematic Network was (SAFER EURORO 1997 2001):

> To effectively co-ordinate RTD activity aiming to ensure the realisation of a formalised "Design for Safety" methodology for routine application in the shipyards, by utilising advanced design techniques to integrate and exploit the development of relevant critical technologies and risk-based frameworks, and to demonstrate the practical applicability and potential of the proposed methodology in the design and operation of RoRo ships.

Specific technical objectives include:

- To continue developing and strengthening links and synergy within each thematic area and to ensure effective integration among the areas, facilitating concurrent engineering practices while accounting for the requirements dictated by the evolution of ship design and operation.
- To pursue systematic monitoring, review, analysis, and transfer of technological developments within each thematic area in support of risk-based methodologies and design integrative processes.
- To synchronize research effort through scheduling of the pertinent but diverse research activities involved in the associated RTD projects, through purposely organized meetings and workshops, and through appropriate dissemination and knowledge transfer, to take full advantage of the overlaps and synergies among projects to target and exploit deliverables maximally.
- To identify and integrate relevant transnetwork research activities, particularly in the TN CEPS where design is at the core (one CEPS project, namely CRASH COASTER is important in the pursuit of SAFER EURORO targets and one Technology Platform, namely VRSHIPS-ROPAX 2000, represents a joint effort between SAFER EURORO and CEPS).
- In this respect, to maintain and support a research direction that is clear enough and well suited to the targeted objectives of the industry and the priorities and contents of Maritime Industry RDCG Master Plan and

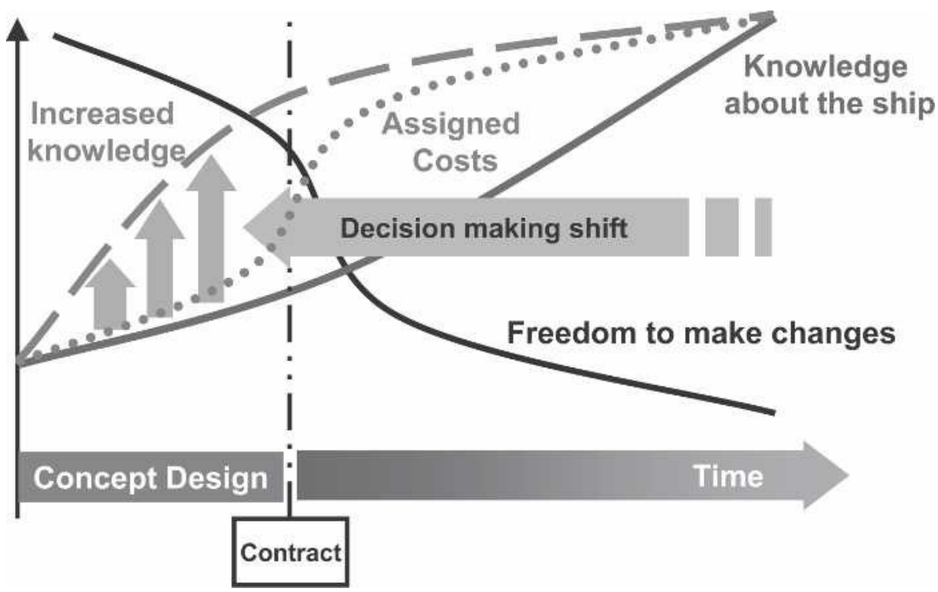

Fig. 3 Elements of the design process

to offer recommendations for updating the latter, as required.

- To retain emphasis on the generic nature of the formalism to ascertain capability of application to all safety-critical vessels while accounting for wider aspects of ship safety (e.g., life-cycle issues, environment, operation, management, production, human factors engineering, legislation) and to facilitate the formation of a European Research Area on the basic underlying philosophy of "Design for Safety."

4. Achievements and structure

The impact of SAFER EURORO on the maritime industry over the past 10 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 safety through the activities of SAFER EURORO include:

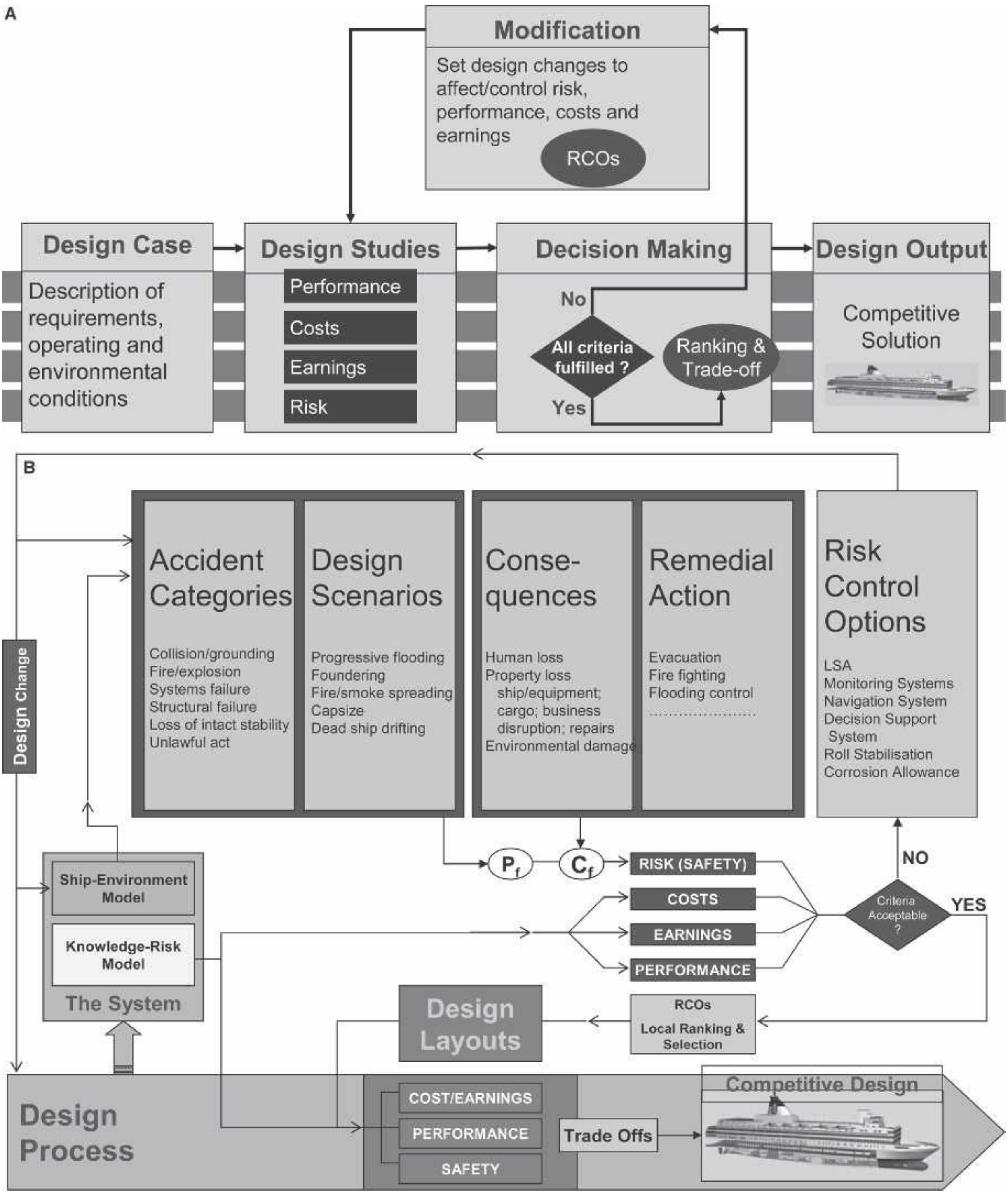

Fig. 4 Framework for risk-based ship design

- 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 addons, bringing home the long overdue realization that lack of safety or ineffective approaches to safety can drive shippers out of business.
- The internationalization of the TN output, the significant contribution to the regulatory process, and the increasing realization by industry that scientific approaches to dealing with ship safety offer unique opportunities to build and sustain competitive advantage have helped create a momentum that is now proving to provide the "fuel" and the inspiration toward achieving the goals of the TN.
- More importantly, effective cooperation between all 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.

The European Commission has actively responded to these challenges by retaining 12 FP4 and FP5 proposals on "Design for Safety" prepared through SAFER EURORO (nine concerning safer RoRo/passenger ships and three addressing the safety of high-speed craft). Also, there are four further retained projects running under the SAFER EURORO umbrella (FIRE EXIT, COMAND, COMPASS, and SAFECRAFTS). 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 SAFER EURORO cluster and the SAFETY AT SPEED cluster are illustrated in Figs. 1 and 2, respectively.

The success of SAFER EURORO depended critically on the integration of all of these developments into "design tools" that would lead to cost-effective safer ships. On a more general basis, safety at sea-related research and development (R&D) activities has contributed to the development of:

- **Critical Technologies.** This refers to the development of a series of quantifiable, readily available, and evolutionary tools and techniques enabling the analysis of all the organizational, 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.
- **Risk-Based Frameworks.** This describes the structuring of appropriate risk-management techniques and methodologies, including guidelines for the proper utilization of tools and techniques developed for behavioral 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 utilization of advanced design techniques, as developed in other industrial sectors but appropriately modified and structured, such as virtual reality and product modeling 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.

5. Risk-based ship design

Based on the understanding that risk-based design relies on systematic integration of risk analysis in the design process, it is imperative that such integration addresses all design phases, in particular the early phases of design when major decisions affect costs and performance crucially and when the freedom to make such decisions is at its maximum. To allow for early focus toward ship safety, relevant information on cost, earnings, and performance is paramount in treating safety as a design objective and in decision-making for cost effectiveness.

It is indeed the concept design stage that holds the greatest potential for introducing product and safety innovations. Ship design, in particular, is uniquely characterized by the fact that some of the most important decisions regarding the vessel are taken at the early stages of the process. This allows little possibility to positively affect cost and performance in all later design actions, which are inevitably bound within the set frame prescribed by the early decisions. Figure 3 illustrates this situation.

As the design process proceeds, the knowledge about the design increases while at the same time the freedom to make changes decreases due to the large costs associated with these changes. To become more competitive, a decision-making shift is required toward the precontract stage and hence efforts must be deployed to maximize knowledge that can be achieved only by advanced first-principles tools. The emphasis toward safety approaches based on first-principles calculations can only be linked to the need for explicit consideration of safety necessary in goal-setting and performance-based standards. In this respect, the scope for new measures designed to reduce risk must be far greater than attempting to minimize the consequences.

Traditionally, ship design practice has focused on balancing technical and economic considerations, with adherence to safety requirements being a design periphery at best, if not a design afterthought. Furthermore, within conventional ship design practice any safety-related consideration is treated through compliance with prescriptive regulations. In this manner, safety is imposed as a constraint to the design process of a ship, an undertaking that has resulted in the ill-based concept that investment in safety compromises returns. A second closely related observation is that this approach is hindering the transfer of knowledge among the design, production, and operational phases, thus not allowing the development of competitive designs to be based on a rational basis but rather on the designer's competence.

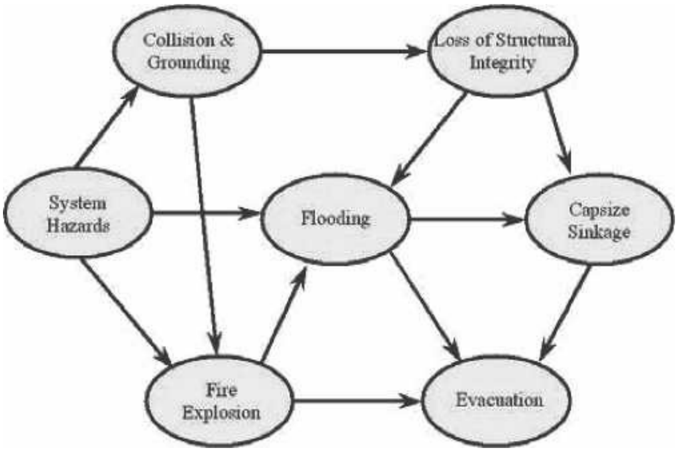

Fig. 5 Sequence of senarios

Table 1 Research activity and outcome

Activity	R&D Project	Research Outcome
Structural loads and responses	**DEXTREMEL:** Design for Structural Safety Under Extreme Loads **Duration:** Dec 1997 to Nov 2000 **Coordinator:** Germanischer Lloyd	Simulation methods to predict residual structural strength of damaged RoRo ferries, providing rapid evaluation of new concepts. Formulation of prenormative design guidelines.
	WAVELOADS: Advanced Methods to Predict Wave-Induced Loads for High Speed Craft **Duration:** Jan 1998 to June 2001 **Coordinator:** Germanischer Lloyd	Strength analyses of representative structural configurations. Development of a practical numerical technique for the prediction of wave-induced loads, validated by systematic model tests in a towing basin. Guidelines and recommendations for structural improvements and rule development.
	SEAWORTH: Improved Ship Design for Marine Safety: Extreme Load Effects and Hydroelastic Coupling **Duration:** Dec 1997 to May 2001 **Coordination:** SIREHNA	Prediction tools and methodologies for extreme accidental hydrodynamic loading and associated hydroelastic response. Database of numerical (hydrodynamics, structural analyses, and hydroelastic coupling) and experimental (seakeeping in model basin and water impact tests in bow shapes) results.
	CRASHCOASTER: Crashworthy Side Structures **Duration:** May 2000 to April 2004 **Coordinator:** TNO	Systematic investigation into the resistance of side structures against collision (crashworthiness) for improved survivability following damage for coasters and medium-sized RoRo cargo ships.
Damage stability and survivability	**NEREUS:** First Principles Design for Damage Resistance Against Capsize **Duration:** Jan 2000 to March 2003 **Coordinator:** Color Line Marine	Innovative design methodology based on a risk-assessment approach, employing first-principles models representative of the physics involved in the flooding process.
	COMAND: Decision Support for Emergency Response **Duration:** Feb 2003 to April 2005 **Coordinator:** MARTEC S.p.A.	Integrated flooding control decision support system (DSS) for use with current safety management systems (SMS) for any ship type.
Ship motions	**FLOWMART:** Efficient Low-Wash Maritime Transportation **Duration:** Feb 2000 to Jan 2003 **Coordinator:** University of Strathclyde	CFD method and software for the assessment of wave- and wash-making characteristics of high-speed craft. Validation by means of model-testing and full-scale trials. Development of demonstrator hull forms.
	COMPASS: A Rational Approach for Reduction of Motion Sickness and Improvement of Passenger Comfort **Duration:** Sept 2002 to Nov 2005 **Coordinator:** CETENA	Motion sickness prediction models and corresponding standards for passenger comfort. Mathematical modeling, full-scale trials laboratory tests.
Evacuation	**MEP Design:** Mustering and Evacuation of Passengers: Scientific Basis for Design **Duration:** Dec 1997 to May 2001 **Coordinator:** TNO	Study on the effects of design features such as "intuitive" systems for guiding passengers, corridors, and stairs that offer improved walkability in moving or a listed/heeled ship. Improved tools (computer programs) for the prediction of mastering and evacuation. Pragmatic value tested and evaluated.
	FIRE EXIT: Formulation of Immediate Response and Evacuation Strategies through Intelligent Simulation Assessment and Large-Scale Testing **Duration:** Sept 2002 to Oct 2005 **Coordinator:** British Maritime Technology	Ship evacuation simulator capable of addressing issues of mustering, ship motions, fire, and abandonment. Also development of concept design software, enabling conceptual designs to be tested at an early stage.
	SAFECRAFTS: Safe Abandoning of Ships, Improvement of Current Life Saving Appliances Systems **Duration:** Feb 2004 to Jan 2008 **Coordinator:** TNO	Conceptual improvements of evacuation systems in terms of passenger/crew survivability with reference to lifesaving appliances (LSA). Model- and full-scale tests of novel rescue system concepts under extreme weather conditions.
Fire	**SAFETY FIRST:** Design for Safety: Ship Fire Engineering Analysis Toolkit **Duration:** March 2000 to March 2003 **Coordinator:** Fincantieri	Fire safety toolkit for carrying out fire risk assessment for ships for the application of the IMO's alternative design regulations.
Integrated design environment	**VRSHIPS-ROPAX 2000:** Life-Cycle Virtual Reality Ship System(s) **Duration:** Aug 2001 to Oct 2005 **Coordinator:** University of Strathclyde	Software platform to facilitate the integration and provision of the desired functionality of a virtual ship system that could support all the life phases of a ship including design, production, and operation.
Risk assessment	**HARDER:** Harmonization of Rules and Design Rationale **Duration:** March 2000 to May 2003 **Coordinator:** Det Norske Veritas	Fully validated concept of probabilistic damage stability. Recommendations from the project have been summarized in regulatory format.
Safe design	**ROROPROB:** Probabilistic Rules-Based Optimal Design of RoRo Passenger Ships **Duration:** March 2000 to May 2003 **Coordinator:** Deltamarin	Design methodology developed and implemented on design demonstrators, using the probabilistic framework for damage stability and optimization tools and methods, for effective subdivision of passenger RoRo vessels.
	S@S: Safety at Speed **Duration:** July 2001 to June 2004 **Coordinator:** Danish Maritime Institute (FORCE Technology)	Integrated design tool, which would enable the design of advanced high-speed craft such that they meet the required safety level at the lowest possible through-life cost, and enable a rational assessment of the cost implications of the variation of safety-related parameters.
	EFFISES: Energy Efficient Safe Innovative Fast Ships and Vessels **Duration:** March 2001 to Oct 2005 **Coordinator:** SES Europe	Improved fuel and hull efficiency, performance, reduced emissions, and wash/wake by utilizing innovative unconventional air-cushion/air-lubrication techniques in combination with approved catamaran configurations.

Risk-based ship design, on the other hand, facilitates design optimization through a formalized design methodology that integrates systematically risk analysis in the design process with prevention/reduction of risk (to life, property, and the environment) embedded as a design objective, alongside standard design objectives (such as speed, cargo capacity, passenger capacity, and turnaround times)—again through routine utilization of advanced first-principles tools. In so doing, safety is becoming a central life-cycle issue, addressed critically as early as possible within design. Appropriate coupling of typical risk analysis techniques with first-principles methods and tools offers the potential for these requirements, not only to provide design input and to be implemented within the design process, but also to assist in the development and assessment of the effectiveness of rules and regulations and in the proposal of appropriate criteria. Figure 4 illustrates a framework for risk-based ship design.

What makes risk-based design feasible and manageable, hence practicable, derives from the fact that ship safety, as a top-down process, is governed only by a handful of factors which, when considered individually or in combination, define a limited set of design scenarios with calculable probabilities of occurrence and consequences that could collectively quantify the life-cycle risk of a ship at sea. Related to this, it is important to point out that even though the absolute value of a quantified risk may be questionable, the relative risk values of the considered design scenarios allow for prioritization of risk-control options/design changes to achieve design objectives optimally. Typically, the scenarios shown in Fig. 5 provide the "structural links" to be used for the development of the risk-based design methodology, comprising the following elements:

- Advanced first-principles tools for predicting frequency and consequences of key incidents; hence pertinent data (technical, cost, accident/incident statistics) is of paramount importance.
- Comprehensive and numerically efficient risk/cost models at generic level depicting knowledge of ship systems, services, functions, and attributes and their relation to principal hazards and risks.
- Development and consolidation of a risk-based design framework to facilitate systematic integration of risk analysis in the design process and a software platform that "glues" together disparate design activities and provides general support to the designer during design creation.
- An integrated design environment to accommodate the integration between traditional design tools and risk-based simulation tools and to support decision making in the search for competitive design solutions.

6. Tools developed

As part of the activities of the associated R&D projects, a number of tools, methods, and procedures pertaining to the critical technologies under consideration have been developed. Table 1 provides a brief outline of the research activities and outcome for each of these R&D projects.

7. Current research—SAFEDOR

A EC-funded four-year Integrated Project on "Design, Operation, Regulation for Safety" started its activities on February 2005, with the primary goal to enhance maritime safety through innovation (SAFEDOR 2005). It is certain that it will take some time before the impact from such a project is fully appreciated, but expectations are high, conviction is strong, and ideas well shaped and matured over many years of work within SAFER EURORO and elsewhere. Such expectations are clearly reflected in the strategic objectives of SAFEDOR as outlined below, attainment of which will see drastic changes in the whole of maritime industry, hopefully for the better:

- Develop a risk-based and internationally accepted regulatory framework to facilitate first-principles approaches to safety.
- Develop design methods and tools to assess operational, extreme, accidental, and catastrophic scenarios, accounting for the human element, and integrate these into a design environment.
- Develop innovative solutions and products for safe, secure, and economic operation of ships.
- Produce prototype designs for European safety-critical vessels to validate the proposed methodology and document its practicability.
- Transfer systematically knowledge to the wider maritime community and add a stimulus to the development of a safety culture.
- Improve training at universities and aptitudes of maritime industry staff in new technological, methodological, and regulatory developments.

8. Conclusions

Responding to well-publicized marine disasters, the marine industry strives to shape safety through concerted efforts on an international scale. The progress is slow amid burdens of inertia and tradition, but it points in the right direction. Maintaining or improving ship safety at the rightful level, however, requires more than disaster-triggered reactions. It requires the systematic use of scientific method in all its forms together with a change in people's attitude to safety as well as willingness from the establishment to sustain both. In the past, the ability and understanding to respond to these needs were lacking. Today, scientific and technological breakthroughs offer unique opportunities to make a difference in improving ship safety. One realization of these is the establishment of the Thematic Network SAFER EURORO under the theme "Design for Safety" that has recently culminated to setting up the largest ever EU-funded research project on safety, SAFEDOR—giving us all hope and scope for a step change in dealing with maritime safety.

Acknowledgments

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