DEVELOPMENT OF A METHODOLOGY FOR ASSESSMENT OF SHIP SAFETY – MOTIVATION, BACKGROUND AND WORKED EXAMPLE

Jan Tellkamp
Flensburger Schiffbau–Gesellschaft
(Germany)

Dr. Ivan Oestvik
LMG Marin AS
(Norway)

Abstract

The paper describes the motivation for the development of a risk based design methodology, the developed methodology itself and the application of the methodology on the example of a damage stability evaluation of a RoRo passenger ship design. Part of the work described in this paper derives from the Nereus project, which is an EU FP5 RTD project.

1 INTRODUCTION

The philosophy of Design for Safety is that safer, and more cost–beneficial, ships will result provided safety issues are integrated as a performance parameter in the design proces at the early design stages. The principal question is how to integrate safety in the design process and with which means. An example on such integration is illustrated in Section 6 utilising damage stability of Ro–Ro passenger ships as an example. The philosophy advocates that the pertinent elements of safety and technical issues from the operational phase are modelled prior to having these issues synthesised into an integrated whole utilising e.g. fault/event trees. The DFS philosophy aims to facilitate the development of the DFS methodology by linking:

- Utilisation of technical tools.
- Safety assessment deriving from risk–based methodologies/theories.
- Design activities and issues.

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 technological developments and design, where design constraints are defined by the process of safety assessment. 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 refinement of tools, in the light of experience gained from implementation and/or practical applications. The approach adopted reflects the ever–greater societal demand for safe and environmental friendly transport, which may lead to future requirements for safety assessments to be performed in the ship design process. Safety assessment, or the equivalent risk analysis, is standard within the offshore industry. The philosophy expresses the view that safety assessment currently is not a part of the design process and no tools exist, thus safety assessment has been emphasised. The PhD theses by Oestvik [13] and Konovessis [11] and the work within the Nereus project [21] are among the first contributions towards developing a design tool that integrates safety in the design process in line with other design criteria, such as resistance, stability, etc. In the following sub–sections a number of issues pertaining to the DFS philosophy are discussed.

1.1 Top–Down vs. Bottom–Up Approach

A top–down approach is advocated, governed by high–level events, e.g. environmental impacts or collision and fire, and their likelihood and consequences in order to design for safety. There is literature on the theme design for safety describing it as a bottom–up approach focusing on component failure and system reliability. However, the latter approach cannot address safety in the early design phases as an integral part of the design process in line with traditional naval architect disciplines, such as resistance and general arrangement, and it rather targets the detail design phase. The bottom–up approach should be termed design for reliability and not be confused with the design for safety approach addressed in this paper. The reason the bottom–up approach cannot be utilised in the early design phases is that it requires a fully defined ship design where (near) all systems, equipment and components have been quantified for their performance, i.e. a given ship design is assessed. The top–down approach, as advocated in this paper, provides input in the earliest design phase where the criteria and boundaries for the design are being determined and safety can therefore be integrated, in line with resistance, stability, etc., in the establishment of main dimensions, hull form, internal arrangements, etc.

1.2 Risk–Reduction Measures vs. Ship Performance

The relationship between risk reduction measures (risk control options/safety enhancing 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 and design for safety will not be effective. Risk reduction measures can be technical or operational whichever is the more cost–effective. The effects of risk–reducing measures on resistance, seakeeping, loading/unloading, stability, etc. should be determined by utilising relevant tools in the design process. This aspect is fundamental in the DFS philosophy. A ship is a compromise between many conflicting requirements and past research has managed to integrate most naval architectural issues very well, e.g. stability and hydrodynamics. It is argued that this is not the case for safety and research is needed to both identify relationships with other naval architectural issues and implement this knowledge in the design process. Safety may then develop from being an afterthought to becoming an integral part of the design process allowing for (safer) better compromises than the current state–ofpractice allows.

1.3 Rules–Based vs. Risk–Based

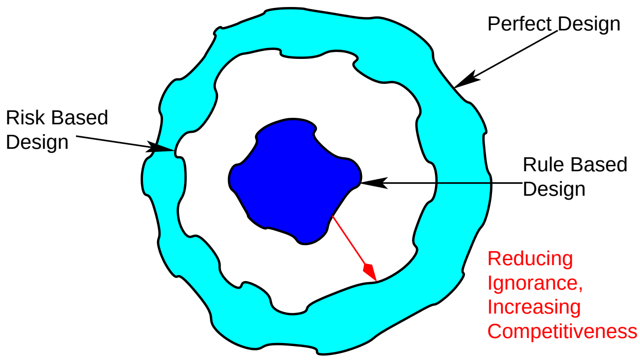


Figure 1: Relationship between ignorance and risk–based design

A chief concern in integrating safety in the design process, particularly when claiming that this must be done in a way that safety drives design, relates to the presumption that any investment in safety, expanding on class/authority requirements, does not compromise returns. This concept is ill founded. Figure 1 illustrates the relationship between economic and technical issues in a safe ship design process. The outer boundary corresponds to a design solution that achieves a perfect balance among all safety and cost criteria and constraints, which is presently unattainable. Today's practice is represented by the inner boundary, whilst it is argued that a safety–effective and cost–effective solution could be achieved by adopting risk–based design. 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 one of the keys to increase competitiveness. The shipping industry is experiencing a change from traditional prescriptive thinking, i.e. rules and regulations, to a more proactive pursuance of optimal and cost–effective solutions based upon a risk–based approach acknowledging that all designs are compromises. This change is caused by the development of technology and societal values resulting in out–dating current prescriptive rules and regulations, which will affect regulators as well as operators. A step towards a risk–based approach is the application of the DFS methodology, as described in Section 5. In such a scenario, the role of regulators will change from controller to auditor and for the operators from compliance to assessment, i.e. safety must be documented prior to operation.

2 SAFETY CONCEPTS

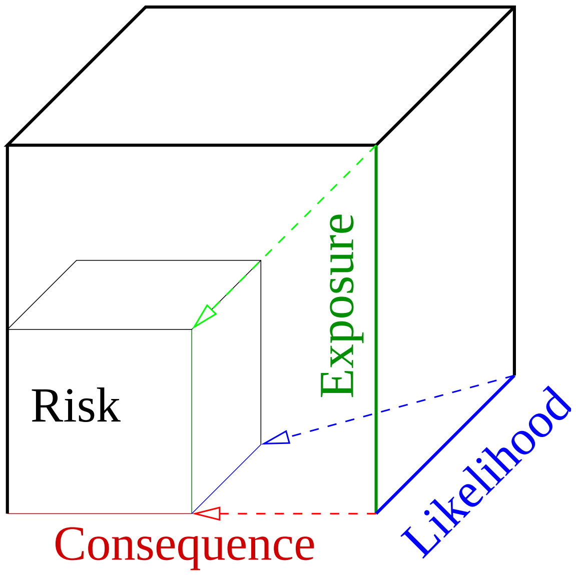


Figure 2: Elements of Risk

Today in the shipbuilding industry, we have a mixture of systems to determine safety. Their purpose is, finally, to keep risks within acceptable limits. They rely on

- prescribing design specificae,
- prescribing methodologies,
- prescribing physical properties,

or

- prescribing risk levels.

These approaches represent different stages of knowledge, available methodologies, and different levels of risk perception in the society. Most rules and regulations are based on the first three concepts given in the list above. One major drawback of some of these rules, e.g. stability rules, is, that they reflect knowledge, ship types, and calculation methods from the last millenium. This is, for example, calculation of leverarmcurves are performed for calm water and with fixed trim only. Furthermore, they focues on *what to do*, but not on *what to achieve*.

2.1 Prescriptive Design

The most simple safety concept is following prescriptive rules. A well known example is given in the bible, Noah's Ark. This first reported ocean going vessel was designed and built following clear instructions with respect to dimensions, material, and construction. It's success is obvious.

This concept was used until the 19th century in a slightly modified manner. New ships have been designed keeping the proportions of previous ones, which were accepted to be safe by the society. In some details it is still in use today.

The disadvantage is obvious: the concept prescribes a specific hardware solution and a development of alternatives and better solutions is possible in small steps only.

2.2 Prescribed Design Methodology

This methodology prescribes a procedure to follow, e.g.

1. Calculate the GZ–curve.
2. Determine $\varphi(\text{GZ}=0)$.
3. Determine GZ_{max}.
4. Determine the range of positive GZ.

5. Determine the area under the positive GZ–curve.

Then for the steps performed some properties as described in section 2.3 have to be met. An example for this are the deterministic damage stability regulations. In this framework, a vessel is just *legal* or *illegal*, but vessels can not be compared with or ranked against each other.

2.3 Prescribed Physical Properties

A more advanced safety concept is using prescribed physical properties of technical systems. One example are intact stability requirements. These requirements are based on the shape of the intact leverarmcurve in calm water:

- A certain righting lever (or range of positive righting lever or heel at equilibrium floating) has to be achieved.
- A certain area under the righting lever curve, depending on specific limiting angles, has to be met.
- A certain derivative $dh/d\varphi$, usually at the angle of equilibrium floating, has to be maintained.

Another example are rules requiring a specific section modulus for the main section of ships or for single profiles.

2.4 Prescribed risk levels

The most advanced concept is using prescribed risk levels. These levels might be expressed using

1. probabilities or frequencies, e.g. the frequency of loss of live per year for an individual passenger on a RoPAX–ferry.
2. $F-N$–Diagrams, e.g. the frequency F of having N people killed or injured onboard a ferry.
3. terms using expected values, e.g. the expected value of the cubic metres of spilled oil within the lifetime of a vessel.
4. Combinations of the above.

With this approach it is possible for the designer to balance the three elements shown in figure 2, consequence, likelihood, exposure, against each other to reach an accepted risk level. Consequently this allows to decide in the design procdess wether safety is guaranteed by risk prevention (frequency reduction) or risk mitigation measures (consequence reduction), and accounting for the respective impacts on costs and overall performance.

3 CONCEPTS FOR RISK QUANTIFICATION

In order to perform a risk based evaluation of a ship's performance, three things are necessary:

1. A methodology (or framework) which is capable of assigning numbers to risks.
2. Tools (e.g. numerical tools) which can be used within the methodology to calculate the ship's performance with respect to the problem/focus of interest.
3. The (by the society) acceptable level of safety must be known.

When developing such a methodology and those tools the following characteristics should be accounted for in order to allow for reliable evaluations of a ship's safety and an increased optimization potential in ship design:

- All available scientific knowledge should be considered.
- The methodology should be generic and thus transferable integrative to other risks.
- Both the methodology and the tools should be modular, thus modules can be exchanged if necessary. This reflects the increase in scientific knowledge over the years on one hand and the increase of knowledge of a vessel during its design.

- The results need to be transparent with respect to the basic physical phenomena/characteristics influencing the safety of a vessel. A sound understanding of physics is essential in order to improve a technical system.
- It should allow for a comparison and risk balancing between different areas of interest (e.g. damage stability and fire safety).
- It should be applicable in the early design stages where the optimization potential is largest.
- It is very important that the quality of the results can be quantified.

Quantification of aspects of technical systems like ships is basically nothing but determining a system's response to an input signal:

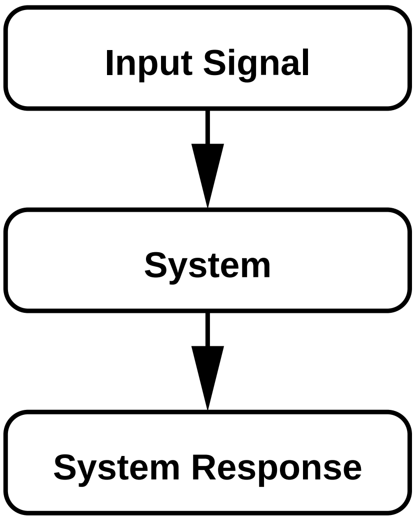


Figure 3: System Thinking

It is obvious, that the input signal depends strongly on the parameter space under consideration and the system response of interest. For example if the system's response is ship's motions, the input signal can be generated from the parameters significant waveheight, period, encounter angle, wind velocity and angle of attack. The same parameters will of course affect maximum bending moments, accelerations and load collectives.

Therfore some thoughts on how to account for the parameter space are given in the next sub–sections.

3.1 Calculation Domains in a Parameter Space

When talking about risk, the identification of the core elements of risk is necessary. In figure 2, the elements *exposure*, *frequency*, and *consequence* are identified. The elements *exposure* and *frequency* are sometimes already combined into *probability*.

It is obvious that these core elements of risk should be dealt with seperately, as this allows to distinguish between risk prevention and risk mitigation (reduction of frequency or exposure, and consequence reduction, respectively).

When estimating the risk based performance of a vessel usually a vast parameter space needs to be considered. In principle, as illustrated in figure 4, four major approaches exist to assess risks. One is to use "brute (computing) force", as illustrate on the upper left. Here the entire parameter space is covered. Further deterministic approaches, as illustrated on the right hand side, try to cut down the computational effort by either omitting regions of the parameter space which are assumed to be safe or by restricting the parameter space to known unsafe regions only. The simulation of random samples, e.g. following the Monte–Carlo Simulation approach, allows to reduce the calculation effort while covering the entire parameter space. This approach is illustrated in the lower left of figure 4.

It has to be noted that the location of safe and dangerous regions inside a parameter space depends on the attribute of system response under consideration: if the parameter space defines the environment in which a ship sails in, different attributes might be motions, load collectives, maximum bending moments and others.

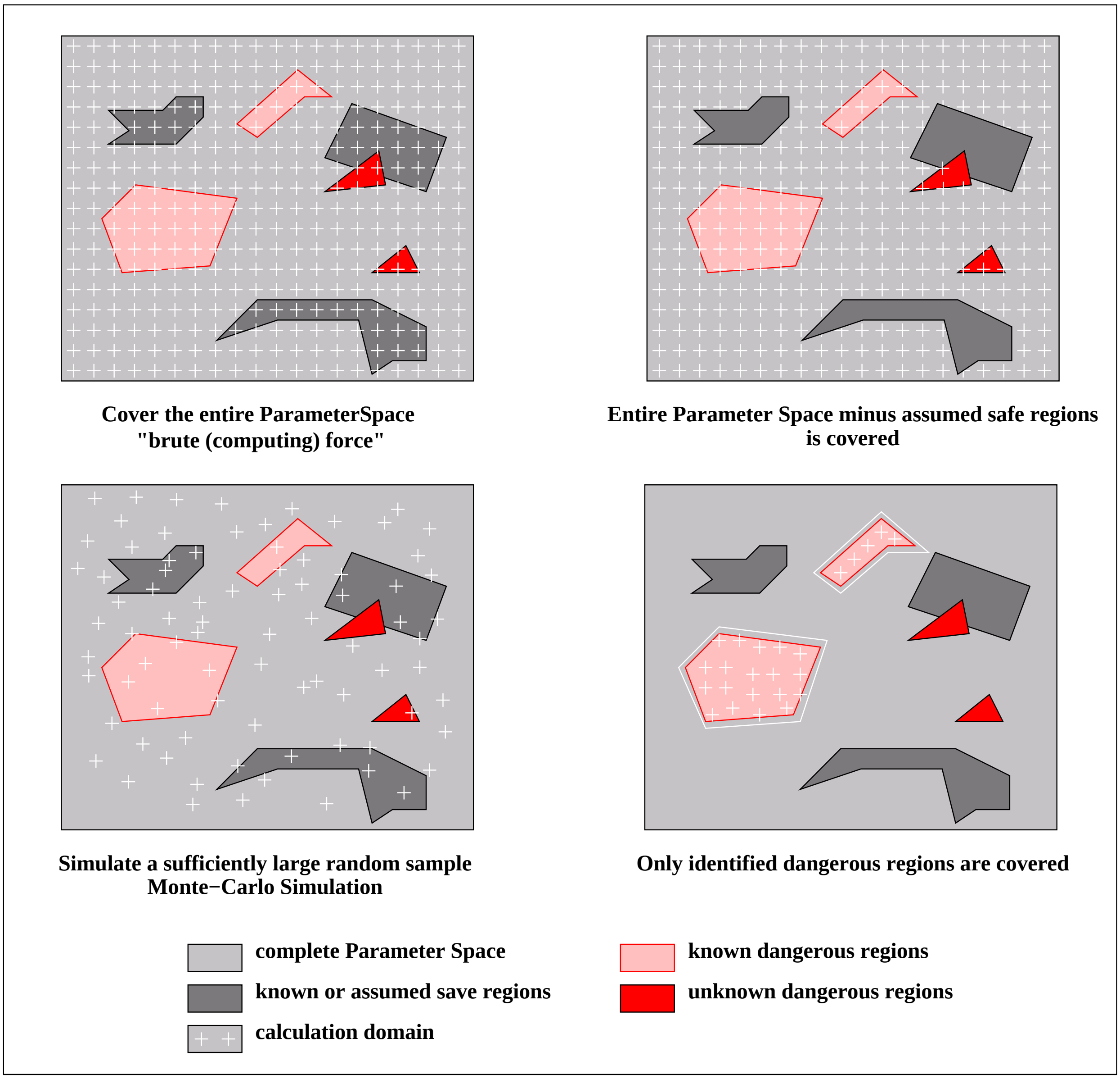


Figure 4: Different approaches towards risk quantification

Brute Force Attack

The main particularity of this approach is the discretization of the parameter space in room (and time). Therefore the calculation effort depends on the discretization chosen, the number and nature of the parameters, and of course the numerical tools applied. The advantage of this concept is that for innovative designs, where no experience is available, dangerous regions are identified. The major drawback is the computational effort.

Everything but regions assumed to be safe

If some experience with a certain attribute of a ship's behaviour in a parameter space is available, regions which are assumed to be safe might be omitted. Depending on the knowledge, this reduction might be just marginal. And still the danger of unknown dangerous regions inside in or overlapping with regions assumed to be safe exist.

Only regions assumed to be unsafe

If a noteworthy knowledge on the system response in a parameter space is available, the calculation domain might be reduced to the known unsafe regions. This is of course a vast reduction in computational effort. But still the jeopardy of unknown dangerous domains exist. This was (and partly still is) the case with parametric excitation in headseas. Furthermore, this approach is only applicable to vessels where experience is available. An example for this approach is the current Code on Intact Stability, which is based on the experience of vessels from the 1950'es, but shows deficencies for modern developments.

Probabilistic concept – Monte–Carlo Simulation

These concepts account for the probabilistic nature of parameter spaces ships typically operate in. Parameter combinations to be calculated are selected according to their respective probabilities of occurence, the results are collected in a random sample and this sample is assessed using statistical techniques.

For this approach the quality of the results can be stipulated *a priori*. Typically a level of significance and a confidence interval are demanded, and from this together with a carefully formulated null hypothesis the size of the random sample can be determined. Thus the computational effort is mainly influenced by the demands on the quality of the results. This approach has the major benefit, that it is applicable to any new ship type, and it is in line with the modern trend towards probabilistic assessment of a vessels risk performance.

Finally, this approach can account for the fact that in a given parameter space the dangerous regions for different system responses can be located in different regions.

4 METRICS

Metrics, scales and measurement are terms for assigning numbers to certain things. In principle, four different metric systems exist. For a detailed discussion see [12]. The reason for discussing the different types of metrics is the fact, that numbers must be assigned to ships or aspects of ships in order to allow decision making. Before assigning numbers, it must be clear what the purpose of using numbers is:

- Identification or grouping,
- ordering or ranking,
- giving differences,

or

- giving proportions.

When it is accepted that safety should be expressed in probabilistic terms, these thoughts become even more important, as for the different metrics not all statistical measures can be given, see the discussion below.

4.1 Nominal System

Assigning numbers to things with the aim to distinguish between individuals or groups of individuals is the most simple system. An example are call signs of vessel. Another example is assigning an attribute, e.g. *true* or *false*. This metric is useful for identification or grouping of things only.

$$\begin{array}{rl} \textit{This is element} & 3 \\ \textit{The weather criterion is met:} & \textit{true} \end{array}$$

In this system no statistical measure can be given.

4.2 Ordinal System

An ordinal metric assigns numbers to things with the aim to order them. A typical example are hull numbers given to a yards newbuildings, or frame numbers. Ordinal numbers are useful for identification and alignment of things only: *Hull no. 716 was contracted earlier than hull no. 717*

$$\begin{aligned} 716 &< 717 \\ \mathrm{GZ}_{max} &\geq 5cm \end{aligned}$$

Using this system, frequency, mode, median, and quantiles can be given.

4.3 Cardinal System

These numbers are assigned to things taking into account the proportion of differences. An example are temperatures measured in either Centigrade or Fahrenheit. Cardinal numbers order things and give the correct differences and proportions of differences between them. Consequently expressions like 'half of' or 'twice as' are ambiguous, as shown in the following example.

$$\frac{20°C - 10°C}{30°C - 15°C} = \frac{50°C - 40°C}{45°C - 30°C}$$
$$\textit{Positive Range of GZ–curve} \geq 7°$$

In addition to the ordinal system, in the cardinal system mean and variance can be given.

4.4 Absolute System

Numbers in the absolute system order things while keeping both ratios of differences and proportions of the numbers themself. This metric is well suited for performance criteria, as it allows the comparison of numbers and a rebalancing of performance criteria is possible.

$$\frac{5kg}{1kg} = \frac{10lb}{2lb}$$
$$\sum_i A_i = c \cdot R$$

In this system, additionally the variation coefficient can be given.

5 METHODOLOGY

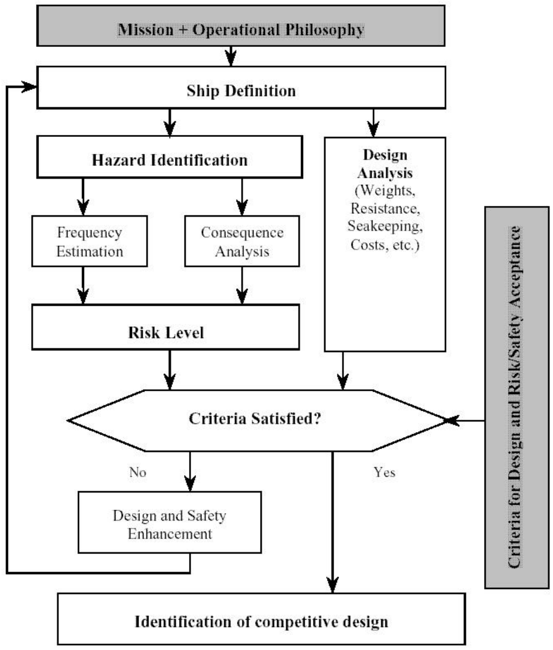


Figure 5: Design for Safety Methodology

The DFS methodology 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 e.g. 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 prevention 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 analyses of the risk reduction measures are performed. The safe and cost–effective design solutions are simultaneously 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. It is referred to Oestvik et al. [13], [23], and [22] for further details of the DFS methodology. Section 6 applies the DFS methodology to the design of a Ro–Ro passenger ship within an integrated design environment, the E4–system at Flensburg Shipyard (FSG). The methodology developed has been presented in more detail by Oestvik and Tellkamp in [14].

6 APPLICATION ON DAMAGE STABILITY

Within the FP5 research project Nereus a rational methodology was developed to evaluate the risk of capsizing of damaged vessels, [14], [20] and [21]. This methodology incorporates the thoughts given in [11] and [13]and uses the background on metrics, safety concepts, and concepts for risk quantification presented in this paper.

The task was to calculate the overall risk level of the consequence *capsize* following the hazard *collision*. Figure 6 shows the eventree for this hazard.

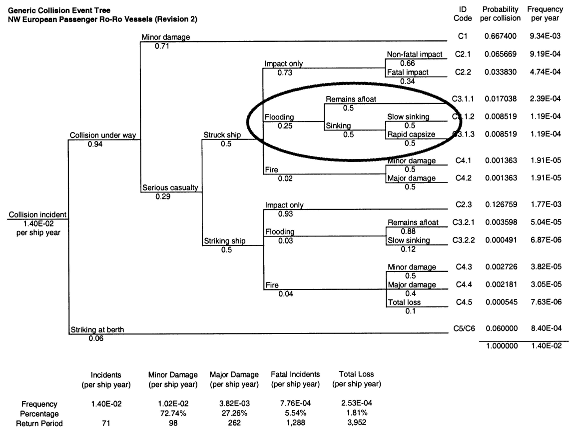


Figure 6: Probability of capsize after a collision

Following the characteristics as outlined in section 3, a set of generic tools was defined in a first step, splitting the task into frequency analysis, consequence analysis and risk quantification:

Element	Tool
Frequency analysis	F1
Damage estimation	C1
Ships response	C2
Risk quantification	R1

The elements of risk illustrated in figure 2 can be clearly identified:

- The frequency and exposure are estimated via the F1–tool,
- Consequences are dealt with by the C1– and C2–tools,
- The resulting risk level is calculated by the R1–tool.

The F1–tool actually consists of two tools: One tool to generate the environmental conditions which in this context are defined by the significant wave height and a second tool which generates the damage cases in terms of length, width and height of the damage extend. The C1–tool gererates the belonging set of damaged compartments for each damage case. While the C2–tool delivers the ship's response, i.e. an answer to the question whether the ship survives a specific combination of significant wave height and damaged compartments. With statistics being used within the F1–tool, this set of generic tools can be embedded within the framework of a Monte–Carlo–Simulation. The results of the Monte–Carlo–Simulation are then evaluated by the R1–tool – the risk quantifier.

In the NEREUS–project an existing specific tool was selected for each of the mentioned generic tools:

generic Tool	specific Tool
F1	Wave Statistics, [19]
	HARDER Damage Statistics,[9]
C1	Ship design and simulation system E4
C2	SEM, [10]
R1	the fraction of number of survived scenarios divided by the number of all generated scenarios

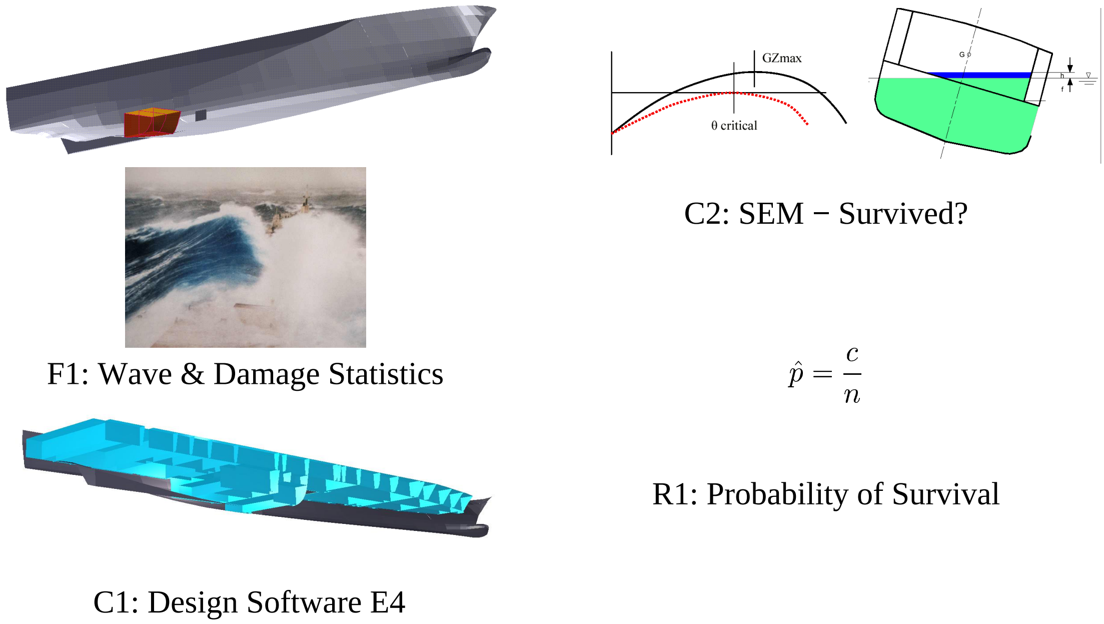


Figure 7: Identified Toolset

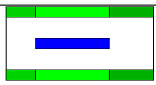
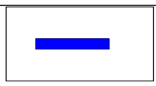
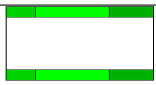
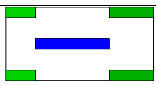
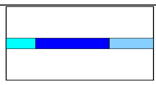
6.1 Design Excercise

Within the NEREUS–project, this methodology was applied to a Ro–Pax design. In total 15 major design variations plus a couple of minor modifications were elaborated and assessed using the developed methodology. Some results are given in table 1 below. The configurations labelled "A" to "E" show different concepts of side– and center–casings on the cardeck.

To get a reference value for the risk level, the methodology was applied on the initial design, which is the A–configuration with a height of the cardeck of 9.4m. This design is completely compliant with SOLAS and the Stockholm–Agreement for a waveheight of 4m and therefore safe by definition. The risk levels of the modifications had to be within an interval of ± 2% around this reference level, or even higher to be acceptable on a level of significance of 95%.

This implementation of the DFS methodology gives numbers in the absolute system, meaning that two different designs assessed in this methodology using the same implementation are completely comparable. As the design task was given by a functional requirement (*determine the risk level*), and not by prescribed hardware solutions, physical properties or a methodology to apply, the developed methodology is generic enough to be transfered to other safety related issues. And important as well, gain in knowledge can be reflected by exchanging one of its implemented tools, e.g. statistics to vessel specific frequency tools or the SEM to a time domain calculation.

Table 1: Comparison of Results of calculated survivabilities

Configuration		**Survivability**		
		initial Design	**modified hull**	**deck at 10m**
A		0.918	0.931	0.953
B		0.890	0.889	0.931
C		0.922	0.937	0.963
D		0.904	0.912	0.945
E		0.861	0.856	0.900

7 CONCLUSIONS

It has been shown, that by careful considerations on metrics, calculation strategies, and elements of risk, with todays knowledge and available tools it is possible to quantify a ship's performance with respect to safety issues as an integrated element of the design process in a holistic manner. Furthermore, direct calculations have been used for investigations *a posteriori* after an accident has occured since the 1980'es, see [6], [17], and [18]. For Naval Vessels only, direct assessment is applicable today *a priori*, [5].

Of importance is not that a direct calculation tool can cover all aspects of a ship's behaviour, but those of interest. For example, if in damage stability the question is how long it takes until a vessel capsizes, this aspect should be reliable calculated by the respective tool whilst the prediction of its natural frequency in this condition might be of minor interest.

As direct calculations are accepted after a hazard has occured, it is somewhat ridiculous that they are not acceptable in ship design in order to avoid dangerous situations or to mitigate their consequences *a priori*. It is anticipated that the term "Design for Safety" should be integrated in the design process. Hormann [8] calls designer to use their genius – and of course this has to be supported by direct calculations. Blome and Krüger have shown in [2] that the current Code on Intact Stability is not sufficient, as the characteristics of modern ship forms are not reflected.

Therefore a modern, integrative, and consistency ensuring approach to all safety related aspects of modern ships should incorporate all available information and knowledge at hand (scientific and vessel specific), careful decision on the metrics and selection of the calculation domain in a parameter space. In doing so it has been shown in the literature, [3], and is shown in this conference, [4], that the safety level of vessels can be increased significantly without decreasing their functionality or increasing their price. This is illustrated in figure 8 as the "Long Term Target" (green path). Even if today this might not be possible for all aspects of ship safety, at least the "Equivalent Safety Approach" (yellow graph) has proven to be suitable and applicable and should be used.

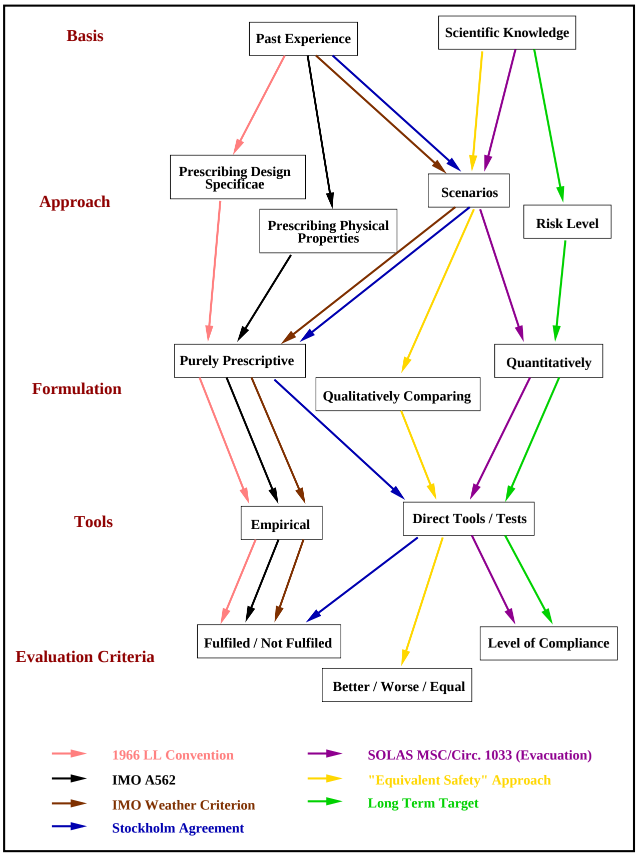


Figure 8: Different ways towards the assessment of a ships safety

8 ACKNOWLEDGEMENTS

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References

[1] V. Bertram, editor. *HIPER–Conference*, Bergen, 2002.

[2] Tobias Blome and Stefan Krüger. Stability in quartering Waves – a critical Review of today's Stability Code. In Papanikolaou [15].

[3] H. Cramer and J. Tellkamp. Towards the direct assessment of a ship's intact stability. In Grochowalski [7].

[4] Heike Cramer, Stefan Krüger, and Jürgen Sanselzon. Working towards the design of safer ships and pragmatic support for safe operation. In Rojas [16].

[5] Jan Otto de Kat and Kevin McTaggart. Capsize risk of intact frigates in irregular seas. *SNAME transactions*, 108:147–177, 2000.

[6] W. N. France, M. Levadou, T. W. Treakle, J. R. Paulling, K. Michel, and C. Moore. An investigation of head-sea parametric rolling and its influence on container lashing systems. *Marine Technology, Vol. 40*, (1):1–19, 2003.

[7] S. Grochowalski, editor. *6th International Ship Stability Workshop*, New York, 2002.

[8] Hartmut Hormann. Design for Safety. In Papanikolaou [15].

[9] IMO. DEVELOPMENT OF REVISED SOLAS CHAPTER II–1 PARTS A, B AND B–1, Investigations and proposed formulations for the factor 'p', 'r', and 'v': the probability of damage to a particular compartment or compartments. SLF 45/3/5, HARDER–Project, London, 2002. 45th Session, Agenda Item 3.

[10] IMO. DEVELOPMENT OF REVISED SOLAS CHAPTER II–1 PARTS A, B AND B–1, Investigations and proposed formulations for the factor "s", the probability of survival after flooding. SLF 45/3/3, HARDER–Project, London, 2002. 45th Session, Agenda Item 3.

[11] Dimitris Konovessis. *A risk–based design framework for damage survivability of passenger Ro–Ro vessels.* PhD thesis, University of Strathclyde, Department of Ship

and Marine Technology, The Ship Stability Research Center, Glasgow, June 2001.

[12] Odo Krappinger. Grundlagen für die Aufstellung von rationalen Entscheidungskriterien. 1968.

[13] Ivan Oestvik. *A Design for Safety Methodology*. PhD thesis, University of Strathclyde, Department of Ship and Marine Technology, The Ship Stability Research Center, Glasgow, May 2001.

[14] Ivan Oestvik and Jan Tellkamp. Design for Safety: The Philosophy and Methodology integrated in the Design of Ro–Ro Passenger Ships. In Papanikolaou [15].

[15] A. Papanikolaou, editor. *IMDC 2003 – Eigth International Marine Design Conference*, Athens, May 2003.

[16] L.P. Rojas, editor. *STAB 2003 – Eigth Internation Conference on Stability of Ships and Marine Vehicles*, Madrid, September 2003.

[17] H. Söding. Gutachten über die Belastung des Schiffes E.L.M.A. Tres durch Seegang am Vormittag des 26.11.1981. IFS Schrift 2327, Institut für Schiffbau der Universität Hamburg, 1982.

[18] H. Söding. Ermittlung der Kentergefahr aus Bewegungssimulationen. *Schiffstechnik Bd. 34*, pages 28–39, 1987.

[19] Heinrich Söding. Global Seaway Statistics. *Schiffstechnik*, 48:147–153, 2001.

[20] J. Tellkamp and H. Cramer. A methodology for design evaluation of damage stability. In Grochowalski [7].

[21] Jan Tellkamp. Application Of A Monte–Carlo–Simulation For Damage Stability Calculations. In Bertram [1].

[22] D. Vassalos, I Oestvik, and D. Konovessis. Design for safety: Development and application ofa formalised methodology. *IMDC*, May 2000.

[23] D. Vassalos, I Oestvik, and D. Konovessis. Recent developments and application of a formalised design for safety methodology in an integrated environment. *SNAME Annual Meeting*, October 2000.