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COMMITTEE IV.1

DESIGN PRINCIPLES AND CRITERIA

MANDATE

Concern for the quantification of general economic, environmental, safety and sustainability criteria for marine structures and for the development of appropriate principles for rational life-cycle design using these criteria. Special attention shall be given to the issue of Goal-Based Standards as presently proposed by IMO in respect of their objectives and requirements and plans for implementation, and to their potential for success in achieving their aims. Possible differences with the safety requirements in ISO and similar standards developed for the offshore and other maritime industries and of the current regulatory framework for ship structures shall be considered.

MEMBERS

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P. Kujala
J. McGregor
E. Rizzuto
A. Teixeira
V. Zanic
K. Yoshida

KEYWORDS

Corporate Social Responsibility, Goal-Based Standards, Goal Trees, Success Trees, Human Element, Human Factors, Life-Cycle Design, Risk Assessment, Risk-Based Design, and Sustainability.

CONTENTS

1. INTRODUCTION

The maritime industry has seen two key developments that will, in this Committee's viewpoint, have a significant influence the design and construction of marine structures for decades to come. The first is the introduction of goal-based standards (GBS) resulting from the ongoing concerns about regulatory agencies setting acceptable safety and environmental protection standards for the industry and society. The second is based upon the ever growing concern regarding climate change, although the recent economic difficulties are testing societies' commitment to this cause. Designing, building and operating ships and marine structures that are 'sustainable' will leave its footprint on the industry for years to come.

A significant part of this report is a departure from the traditional literature review of design principles and criteria for ship and offshore structures. Goal-based standards and ship sustainability are fledging areas of research and application for the maritime industry that will require a forward looking vision on setting design principles and their associated criteria. It was felt that this Committee should apply its efforts in focusing on providing insights and commentary into these developing areas. The first comments by the Committee regarding GBS were provided by Moore *et al*. (2007).

In 2002, IMO proposed a goal-based regime to motivate more innovations. Under this regime the regulators do not prescribe technical solutions but formulates goals and functional requirements in a risk-based top down approach. The advantage of such a regime is that innovative designers will have a transparent framework for regulatory compliance of the design, whereas classification societies will have more freedom for developing optimal standard design rules for which innovative design initiatives are slower (tanker, bulk carriers, general cargo ships). This chapter describes the background and the general philosophy behind the goal based standards.

The maritime industry has begun to apply risk management to the entire lifecycle, from compliance, to legislation, to managing integrity of assets. Their focus is on operating profitably while complying with legislations and regulatory requirements to ensure the best possible safety performance and the lowest possible risk (i.e. expected loss).

In the loss mitigation, owners also face the need to go beyond legislative compliance in addressing the societal concerns and substantiate that they are corporate social responsible. Societal concerns include environmental pollution and climate change through greater corporate social responsibility. When facing the future challenges of maritime operators it is paramount that any new regulatory framework is transparent and meets the needs of future societal preferences. The philosophy behind goal-based standards may very well prove to be right move in the right direction.

Furthermore, climate change initiatives related to stabilizing greenhouse gas (GHG) emissions through the development of an Energy Efficiency Design Index (EEDI) for ships is further addressed in this report. Finally, the report also focuses on traditional areas of design principles and criteria addressing matters such as ice class design and the impacts that design principles and criteria have on marine insurance.

The Committee was very active in its deliberations and formally met four times in Lyngby (October, 2006), New York City (August, 2007), Newcastle (January, 2008) and Beijing (July, 2008). Smaller, less formal groups of the Committee also met in Lyngby (September, 2008) and Høvik (December, 2008).

2. FORMULATING THE CONCEPT OF DESIGN PRINCIPLES AND CRITERIA

The design process of an engineering product can be described as the selection of a point that identifies the product in the space of the design variables (ISSC 2006, Report of Committee IV.1). The dimensions of the space depend very much on the complexity of the product and on the detail of the design (conceptual, preliminary, detailed design).

The space of the product performances, on the other hand, represents the way the product behaves throughout a given period (lifetime). Here the term ‘performance’ is given a wide meaning, embracing any kind of interaction between the product and its surroundings. Also in this case the dimensions of the space depend very much on specific case and type of analysis.

The space of the (feasible) designs can be seen as the domain of a 'performance function' which has its own range in the performance space. If we examine the process from a normative viewpoint, we may restrict the analysis to those variables that describe societal risk (and benefits) in the performance space and those variables that are to be controlled in the design space in order to affect the above mentioned performances.

The normative process is represented by the need that the performance variables lay within a certain range (typically this applies to the societal risk associated to the product operation, which should not overcome certain limits). Any design point which is mapped to a point belonging to the ‘allowed portion’ of the performances space is acceptable to the norm. There are different strategies for implementing a normative framework.

2.1 Performance-Based Design vs. Prescriptive Design

A first strategy is to set explicitly constraints in the design space thus obtaining as a consequence a limitation of the obtained range in the performance space. It is very easy to formulate this type of prescriptive requirements (a typical example in structural design is: '*scantling not less than…*'). They are easy to use for the designer and for who is requested to check the design. Another advantage is that a requirement of this kind can be set on an empirical basis: 'if too many structures break down, the minimum scantling should be increased'. This trial-and-error principle overcomes the need for a model able to predict on a theoretical basis the performances at a design stage. The normative rule validates it self through successful operation.

A drawback of the strategy is represented by the fact that design constraints set on the basis of past experience may result to be less conservative than needed (if accidents in a specific field have not yet happened, thus not prompting the necessary upgrading of rules) or, more often, more conservative (e.g. if the decision makers excessively modifies the norm as a result of a specific accident that has obtained political attention). Another important drawback of the strategy is that these prescriptive requirements may 'end up being the main design driver, stifling innovation and producing less useful end product' (ISSC, 2006).

The diametrically opposite strategy is to set limitations directly in the performance space, formulating there the acceptance criteria. This principle provides a much wider design space and thus opens a more innovative design space that transparently complies with the normative acceptance criteria. This change of philosophy provides greater freedom to the designer, who is allowed to exploit a wider range of feasible solutions compared to the prescriptive approach.

The implication of this approach is that a 'performance function' is needed; both in the design and verification phases, in an explicit form to assure the requirements are met. In other words, a theoretical model is necessary that is able to predict all the relevant performances (i.e. all the effects occurring during the various phases of the product lifecycle).

A performance based structural design is implicitly a *risk based design* (RBD) in that the risk is the most important measure to be assessed. The objective is to move away from strict prescriptive requirements to performance-based or at least performance-oriented regulations. This general trend can be seen as a result of the increasing capabilities of reliable predictions for the performance of the engineering product.

In the maritime field, the idea of redefining rules on the basis of GBS has begun as demonstrated by the commitment by the International Maritime Organisation that began in 2002 (see ISSC, 2006). During this period, an application of the concept to ship design and construction rules has been debated in depth.

2.2 Definition of Performances

In parallel to the transition from prescriptive towards performance based design, another important trend is seen in a more holistic approach to the design. In a sense, such holistic approach can be described in terms of an increase in the dimensions of the performance space (i.e. taking into account a wider range of interactions of the product with its surroundings).

Specifications in shipbuilding have historically concentrated on performances directly related to the ship and its basic functions (capacity, speed, stability and seaworthiness). Traditionally, the objectives of safety-related requirements were to prevent damage or loss of the ship itself or of the cargo. Later, an increased social concern on the shipping industry has prompted specific requirements aimed at the safety of human life at sea (e.g. *Safety of Life at Sea Convention* (SOLAS)). More recently, liability towards third parties has been established in particular for pollution incidents (e.g. *International Convention on Civil Liability for Bunker Oil Pollution Damage*). In addition, there have been recent developments of legal obligations for the owner of the ship in particular towards the abandonment of crew as well as forthcoming amendments considered for the *International Convention on Standards of Training, Certification and Watchkeeping* (STCW).

The recent requirements and prescriptions on anti-fouling paints, water ballast treatment, and on the NO_x, SO_x and CO_2 emissions demonstrate the ever evolving societal concerns for technological impacts of human activity upon the marine environment as a whole. The concern for climate change will lead to changes in design of vessels and to change of operational speed.

In summary, current design principles and criteria in shipbuilding must be based on the holistic assessment of ship performance including interactions with the surrounding environment. A central element is the transparent quantitative assessment that facilitates weighing of various types of interactions in that environment and the establishment of suitable acceptance criteria.

2.3 Classification of Performance Indicators

In the modelling of the potential losses, we may distinguish between those phenomena that are ever present during ship lifecycle called *systemic phenomenon* (probability = 1) and those which occur rarely in the ship lifecycle called *random phenomenon* (probability < 1).

A further classification of potential losses can be defined in terms of the consequences impacting the ship (or other assets), humans (in particular the crew on board), and the environment. Examples of systemic phenomena are:

- degradation of the structure due corrosion, wear, fatigue or increased fuel consumption due to fouling, (assets);
- shipboard habitability affected by noise, vibrations or noxious emissions (humans); or
- pollutants due to anti-fouling paints or emissions (environment).

Examples of random phenomena include:

- damage or loss to the ship due to collision, grounding, or explosion (assets);
- casualty due to personal or ship accident (crew); or
- pollution due to oil spill or loss of containment (environment).

It is noted that although the systemic events occur with probability one the consequences that follows are still uncertain. Hence, without loss of generality, the systemic events may as well as the random events be treated in a risk based framework.

The matrix diagram shown in Table summarizes these relevant elements to be taken into consideration in unison. Three areas are labelled as *economics, society*, and *environment*. The risks associated with these elements are both systemic phenomenon ($p = 1$), or random phenomenon ($p < 1$). Design has conventionally been concerned with systemic economic risks (through first and operating design costs), while shipowners hedge their accidental risks via insurance. Regulation is concerned with the risks to life, the property of third parties and environmental protection. Only in recent years has the systemic risk to the environment become a significant concern, with ever increasing importance.

Table 1
Holistic Risk Matrix

Entity	**P=1 (systemic)**	**P<1 (random)**
Economic	First & operating costs (Design concern)	Loss, damage of vessel (Owner's concern hedged via insurance)
Society	Quality of Life / Corporate Social Responsibility (Regulatory concern)	Loss of Life (Regulatory concern)
Environmental	Environmental Impact "Sustainability" (New concern)	Pollution (Regulatory concern)

3. IMO GOAL-BASED STANDARDS

3.1 Introduction of Goal-Based Standards to the Maritime Industry

Goal-based standards (GBS) have been introduced by Bahamas and Greece in 2002 (IMO) to the 89th session of the IMO Council in the context of developing the IMO Strategic Plan (IMO, 2002a). This submission argued that IMO should play a greater role in determining the construction standards to which new ships are built, a role traditionally delegated to the classification societies, and that this should be incorporated into IMO Strategic Plan. After intense debate at the MSC 77, the item "Goal-based new ship construction standards" has been introduced in the agenda of the MSC 78 (IMO, 2003) and in the IMO strategic plan for the period up to 2010 (IMO, 2004a) as a high-priority item for MSC in the long-term work plan (IMO, 2004b).

From 2002 to the present date this new concept has been discussed and developed in several IMO MCS sessions and also by scientific community as reviewed by Skjong, (2005), Besse et al., (2007) and Huss, (2007).

At MSC 78 in 2004, the Bahamas, Greece and IACS have proposed in a joint submission a 5-tier Goal-Based Regulatory Framework consisting of: goals (Tier I); functional requirements (Tier II); verification of compliance criteria (Tier III); technical procedures and guidelines, classification rules and industry standards (Tier IV); and codes of practice and safety and quality systems for shipbuilding, ship operation, maintenance, training, manning, etc. (Tier V) (IMO, (2004a).

The basic idea with GBS, or otherwise called goal-based regulations, is to better organize the regulations following a functional approach. The functional requirements and safety requirement are made part of the IMO conventions but allows for different prescriptive standards or rules that are verified to comply with the conventions. In the process it is also the intention to verify the rules of the classification societies (Skjong, (2005).

Goal-based standards (GBS) were first introduced to the ISSC in the 2006 report of the Technical Committee IV.1, Design Principles and Criteria (ISSC, 2006). The primary objective of GBS was to have the International Maritime Organization (IMO) establish a framework for which it would play a larger and more significant role in determining the fundamental standards for which ships are built. IMO has not overtaken the role of the classification societies with the GBS development. IMO's role would be to set the standards (the overall general goals) that are to be achieved and leave it to the classification societies, designers, ship builders, naval architects and any other relevant body to decide how to achieve the established goals.

Following the initial proposal, a five-tier system was agreed, on the basis of a top-down approach, where very general goals are progressively revised and translated into general requirements, guidelines, procedures and codes of practice.

In principle, the first three tier levels are to be developed by IMO, whereas Tiers IV and V 'contain provisions to be developed by classification societies, other recognised organisations and industry organisations'. The underlying concept is the coherence of each level of analysis to those proceeding at upper levels, even if a specific phase of 'verification of compliance' is foreseen only at Tier III. Tier III is seen as a connection between the first two Tiers, in which the decision maker corresponds to the IMO, and the last two, in the case of non-statutory, the main actors of the process are class societies and other technical organisations, and for statutory regulations, the main actors of the process are the committees and sub committees of the IMO.

The first application of the tier III requirements of GBS to a set of Rules has just finished (see the work of the Pilot Panel on the trial application of the Tier III verification process using the International Association of Classification Societies (IACS) Common Structural Rules, Terms of Reference: MSC82/24 annex 15 (IMO, 2006a)). This trial application was done in two iterations with some refinements to GBS before the second iteration (see the report from the second iteration: IMO, 2008a). The outcome of these trials was then further reviewed and updated at the 85th meeting of the IMO's Maritime Safety Committee (see IMO, 2008b and IMO, 2008c). It is not thought there will be any further changes to Tiers I to III of GBS for bulk carriers and oil tankers.

3.1.1 Tier system - Characteristics of the various Tiers in GBS

Tier II formulations should provide functional requirements 'relevant to the functions of the ship structures to be complied with in order to meet the Tier I goals'. The functional requirements play an intermediate role between the general goals of Tier I and the 'instruments necessary for demonstrating that the detailed requirements in Tier IV comply with the Tier I goals and Tier II functional requirements', to be set out in Tier III.

Trying an exegesis of the above definitions it could be stated that Tier I should contain what the normative framework wants to achieve, in Tier II what is to be checked to achieve the goal (and possibly also why), while Tier III should contain how the checks should be performed.

The three levels correspond to a decreasing generality, which implies also that Tier III contents are likely to reflect the state of the art at a specific point in time and are prone to be changed with a certain frequency as a result e.g. of technical progress in any field, while Tier II and particularly Tier I, once established, should be more durable (even though they too are amendable in principle).

According to this interpretation, the characteristic basic principles for GBS (IMO, 2005a: paragraph 6.28) could be somehow distributed over the three upper levels of the framework as follows:

i. broad, over-arching, long-standing,
ii. clear, implementable, achievable, irrespective of ship design and technology, and
iii. demonstrable and verifiable, specific enough in order not to be open to different interpretations.

Simply stated, Tier II aims to set out the quantitative requirements where Tier III tells you how to calculate it.

3.2 Recent Evolution of GBS for oil tankers and bulk carriers

The formulation of GBS at the uppermost level (Tier I) so far has been quite stable since the first approval (see IMO, 2006b paragraph 6.14), while Tier II functional requirements have already undergone a change (see Tier II.9 below) Some items recently discussed at MSC are presented here below.

3.2.1 Tier II.3 (structural strength)

The Pilot Panel proposed a reformatting of the formulation of Tier II.3, to identify the different concepts there included. In particular sub-headings were proposed, regarding: safety margins, deformations and failure modes, general design, and ultimate strength.

During the work of the Pilot Panel, a specific discussion was held on the concept of 'net scantling' and its application to the various types of structural verification. In particular, two opinions were emerging: a minority position based on the idea that all verifications should be made with reference to scantlings not accounting for any corrosion addition (referred to as 'pure' net scantlings) and a majority position that felt that the state of the structure in terms of corrosion should be defined case by case for the various types of checks (in particular when evaluating the longitudinal strength of the ship). In commenting on the subject the report by the Pilot Panel, the IACS delivered a document supporting the majority view and proposing a new definition (IMO, 2007a) of net scantling contained in the footnote of Tier II.3 text, reading:

> *"The net scantlings should provide the structural strength required to sustain the design loads, assuming the structure is in intact condition and accounting for the steel diminution that could be reasonably expected to occur during the life of the vessel due to corrosion and wastage."*

This definition was later endorsed by the Working Group (IMO, 2007b). The Pilot Panel suggested a new text in their report presented to MSC 85:

> *"The net scantlings should provide the structural strength required to sustain the design loads, assuming the structure is in intact condition and without any corrosion margin. However, when assessing fatigue and hull girder global strength, a portion of the total corrosion margin may be added to the net scantlings to reflect the material thickness that can reasonably be expected to exist over the design life."*

The IMO Working Group at MSC 85 then further refined it to the following:

> *"The net scantlings should provide the structural strength required to sustain the design loads, assuming the structure is in intact condition and without any corrosion margin. However, when assessing fatigue and global strength of hull girder and primary supporting structures, a portion of the total corrosion margin may be added to the net scantlings to reflect the material thickness that can reasonably be expected to exist over the design life."*

Although this text is theoretically now finalised, it may well be changed further before approval and adoption of the SOLAS amendments that will bring GBS for bulk carriers and oil tankers into force.

3.2.2 Tier II.7 (structural redundancy)

A rephrasing of the text of Tier II.7 has been proposed by the Pilot Panel clarifying the concept as regards the possibility of transferring load carrying capacity from damaged elements without implying immediate collapse of larger structures at the next hierarchical level.

3.2.3 Incorporating the Human Element into GBS

In December 2006, the IMO MSC agreed to explicitly incorporate the human element into GBS standards at the Tier II level. It was incorporated through the explicit consideration of ergonomic design criteria by agreeing to the inclusion of the following Tier II functional requirement:

> ***"II.9 Human element considerations***
> *"Ships should be designed and built using ergonomic design principles to ensure safety during operations, inspection and maintenance of ship's structures.*
>
> *"These considerations should include stairs, vertical ladders, ramps, walkways and standing platforms used for permanent means of access, the work environment and inspections and maintenance considerations."*

This inclusion of this requirement is a fundamental change by the industry in the use of ergonomic design principles. These principles have been available for use by the marine industry for many years but have only seen limited use and has previously not been systematically adopted and applied.

In essence, this work has already begun through the use of ergonomic design criteria for the permanent means of access requirements under regulation II-1/3-6 of Safety of Life at Sea (SOLAS) Convention, 1974 (IMO, 2004d) although these requirements are limited in scope. "Deck-plate" ergonomic design criteria have been available to the commercial maritime industry for some time as exemplified by the American Bureau of Shipping (2001, 2002 and 2003) and more recently by Bureau Veritas (2008).

"Deck plate" ergonomics include design of items such as stairs, vertical ladders, ramps, walkways and standing platforms used for inspection and maintenance. It is believed that the application of ergonomic design criteria of these systems can reduce the incidence of slips, trips and falls that lead to costly and frequent accidents.

Some protection and indemnity (P&I) Clubs have reported that 1 out of 5 personal injuries onboard ship are related to slips, trips and falls (IMO 2002b). The ISSC TC

IV.1 was encouraged by these developments in light of the fact that human element considerations, and in particular, scientifically based ergonomic design criteria have not been adopted by the maritime industry.

Following a discussion of document MSC 83/5/7, the WG made a change in the last sentence of Tier II.9, with an explicit mention to the facilitation of operation (IMO, 2007b).

> ***"II.9 Human element considerations***
> *Ship's structures and fittings shall be designed and arranged using ergonomic principles to ensure safety during operations, inspection and maintenance. These considerations shall include, but not be limited to, stairs, vertical ladders, ramps, walkways and standing platforms used for means of access, the work environment, inspection and maintenance and the facilitation of operation."*

A similar change was also agreed in the formulation of item 3 of Tier I:

> *"Safety also includes the ship's structure, fittings and arrangements providing for safe access, escape, inspection and proper maintenance and facilitating safe operation."*

3.2.4 Proposal for introduction of Tier II.16 (Structural performance monitoring)

The Pilot Panel recommended 'continuous performance monitoring is established as a high-level requirement as it reflects all aspects of ship design, construction, survey and maintenance' (IMO, 2007c). A text was proposed (see annex 3 in IMO, 2007c) for a possible addition as Tier II.16 to the existing Tier II requirements. The Working group 'agreed that the implementation of such a requirement would be beneficial' but 'noted that performance monitoring involve more than just classification society rules and includes maintenance, operational considerations and numerous other factors, and would require substantial work to implement' (IMO, 2007b). The decision of the WG was to keep this type of considerations at the level of Tier III for the time being.

3.3 Safety Level Approach on GBS

From the beginning of the development of GBS several members advocated the application of a holistic approach which would define a procedure for the risk-based evaluation of the current safety level of existing mandatory regulations related to ship safety and consider ways forward to establish future risk acceptance criteria using FSA (i.e. safety level approach).

The GBS Safety Level Approach will provide IMO with a basis for quantifying the safety of shipping and guiding the work for improving safety (Sames, (2007). SLA will establish the comparison of the risk level for new ships with the figure for the current risk level – a benchmark for safety. The intention is to enable IMO to direct resources to where safety benefits the most and to enable the flag states to ensure and to control the risk level in the framework for safe and environmentally friendly shipping.

MSC 81 had extensive and wide ranging discussions on the safety level approach with a view to identifying what needed to be done in order to develop GBS using the safety level approach and agreed that this should include the development of a risk model and of goal-based standards guidelines; the determination of the current safety level and of the relationship between different design measures, e.g., structure, stability, maneuverability, fire protection, etc.; examination and reconsideration of the five-tier system and, if needed, appropriate adaptation to develop a structure suitable for the safety level approach; examination and, if appropriate, modification of Tier I and Tier II as developed for oil tankers and bulk carriers for use in the safety level approach; and consideration of the relationship between overall failure of the ship and the contribution of individual failure modes (see paragraph 6.38 in IMO, 2006b).

MSC 82 (IMO 2006c, annex 4) agreed on a provisional long-term work plan for the development of GBS based on the safety level approach, set out in annex 4, and included priority items in the terms of reference for the Correspondence Group on the Safety Level Approach, including: determination of the current safety level in a holistic high-level manner, further consideration of the linkage between FSA and GBS (in particular, consider risk acceptance criteria based on MSC's work on FSA) and further development of goal-based standard guidelines for the safety level approach.

3.3.1 Formal Safety Assessment (FSA)

Although the use of probabilistic methods and formal methods for risk assessment is not new in the maritime industry as reviewed by Guedes Soares and Teixeira, (2001), the most important initiatives on implementing risk assessment as a basis for regulation in shipping have occurred last decade (Skjong and Guedes Soares, (2007).

In 2002, the Maritime Safety Committee (MSC) and the Marine Environment Protection Committee (MEPC) introduced a new methodology called Formal Safety Assessment ("FSA") for its rule-making process to incorporate risk assessment techniques that have been successfully used in several other industries such as nuclear and offshore industries. FSA Guidelines (IMO, (2002a) were approved by the MSC in 2002 and the guidelines have been routinely amended to keep them up to date with the latest knowledge on the subject (IMO, (2005)b; IMO, (2006)c; and IMO, (2007)d).

The FSA is structured and systematic methodology for use in the IMO rule making process based on the typical elements of a classical *quantified risk assessment* (QRA) and provides widely application of QRA to marine transportation sector.

Adopting FSA, the decision makers at IMO will be able to appreciate the effect of proposed regulatory changes in terms of benefits (e.g. expected reduction of lives lost or of pollution) and related costs incurred for the industry as a whole and for individual parties affected by the decision.

After the first introduction of FSA, several studies have been performed using this methodology to support decisions about the implementation of international regulations. Relevant studies have been performed on bulk-carrier integrity, which was the basis of IACS' decision to strengthen the bulkheads between the two foremost cargo holds on such vessels in 1997, and later studies have included extensive FSA on bulk carrier safety, free fall lifeboats, helicopter landing areas on cruise ships, navigation of large passenger ships, and introduction of electronic chart displays and information systems.

The main conclusion is that the maritime industry has made a lot of progress, quite, in the use of risk assessment as part of the decision making process, despite the many communication problems that arises in discussing risk issues in international forums (Skjong and Guedes Soares, (2007).

3.3.2 Review of the State-of-Art of FSA applications

The FSA methodology is particularly appropriate in the regulatory regime to influence the risk levels of large ships and in the research into safer solutions for large ships and marine transportation management. The risk is expressed in the form of risk levels during the life cycle of an analyzed object, which include risks to personnel, property and the environment. Also, FSA fulfils the postulates of safety science: it treats safety as an attribute of the man-technology-environment system and applies the probabilistic approach in safety quantification. Furthermore, FSA is adapted for situations where historical data required for risk modeling are lacking and is complemented by subjective judgments.

However, FSA has some deficiencies. The verification of the FSA studies is a key issued also important in later risk based design studies for innovative designs. The FSA study on helicopter landing areas for non-ro-ro passenger ships was a case of detailed verification. The international FSA on bulk carrier safety was not verified. This study showed how weak a FSA can be. Two different groups, with two different perspectives on what had caused certain accidents, conducted FSAs into bulk carriers.

The result was that one group recommended to IMO that bulk carriers should have double hulls whilst the other group recommended that double-hulls should not be required. Not all delegations at IMO are technical and there was no way to check the credibility of either FSA. In the end IMO decided not to follow the recommendation, meaning that bulk carriers still do not have to be double hulled. It is imperative that further work into ways of checking the credibility of FSA in an objective and repeatable manner are developed (Besse et al., (2007){Besse, Boisson, et al. #5956}.

Most FSA studies presented at IMO have used standard risk models using fault trees and event trees. Vanem et al., (2008) have presented a generic, high-level risk assessment of the global operation of ocean-going liquefied natural gas (LNG) carriers.

The analysis collected and combined information from several sources such as an initial HAZID (Skjong, (2007)) a thorough review of historic LNG accidents, review of previous studies, published damage statistics and expert judgement, and developed modular risk models for critical accident scenarios in the form of event trees for different generic accident categories. In this way, high-risk areas pertaining to LNG shipping operations have been identified. This work also included a critical review of the various components of the risk models and hence identified areas of improvements and topics for further research.

More recently, these models have been adapted for situations where historical data required for risk modelling are lacking and is complemented by subjective judgements. The paper by Trucco et al., (2008) is detailing the use of Bayesian Network techniques, a method used already in FSAs related to Navigation and therefore the risk models contain many dependencies between the technical systems and the human element. For these types of modelling challenges, Bayesian Network models have proven very useful. It is also confirmed by many studies that the human operator is increasing the contribution to ship accidents, as also explained by Antão. P. and Guedes Soares, (2008), further increase the relevance of these modelling techniques.

3.3.3 Contribution of FSA to GBS - SLA

There is an ongoing debate as to the relationship between FSA and GBS. They both share the same objective of establishing a rational and transparent basis of safeguarding and enhancing safety and protecting the marine environment however other characteristics differ.

The Tier I goals of GBS are very open to interpretations and they are not quite in agreement with a risk based approach. For example, stating an objective of minimising loss lacks the typical reference to a decision criteria, whilst for example the alternative ‘minimising loss without entailing excessive costs’ would be sufficient to associate GBS with the standard FSA approach of using agreed decision parameters and the ALARP principle.

The use of the ALARP principle is agreed at IMO for use in maritime safety regulation to determine limits of what is reasonable practicable. In practice, this is done by reference to *gross cost of averting a fatality* (GCAF) *net cost of averting a fatality* (NCAF) and *cost of averting one ton of oil spilled* (CATS). The first two concepts are described in the IMO FSA Guidelines and widely used. The decision parameters relating to environmental protection (like CATS) is not yet agreed, but already used in some studies.

In fact one of the most important contributions of FSA to GBS-SLA is on the establishment of a risk acceptance criteria based on the ALARP principle. However, there are still several fundamental key issues that are not solved or solved insufficiently in the consolidated text of the guidelines for FSA, namely, the cost effectiveness measure used to evaluate risk control options and the risk acceptance criteria.

According to appendix 7 of the consolidated FSA guidelines (IMO, (2007), either the two indices (GCAF or NCAF) can be used. However, it is recommended to firstly consider GCAF instead of NCAF and if the cost effectiveness of an RCO is in the range of criterion, then NCAF may be also considered. The reason is that NCAF, may be misused in some cases for pushing certain RCOs, by considering more economic benefits on preferred RCOs than on other RCOs.

Several FSA studies have come up with some risk control options (RCO) where the associated NCAF was negative. A negative NCAF means that the benefits in monetary units are higher than the costs associated with the RCO. Additionally, when the risk reduction is small and economic benefits are large; this may result in large negative NCAF. Therefore, Appendix 7 of IMO, (2007) suggests that RCOs with high negative NCAFs should always be considered in connection with the associated risk reduction capability.

Some seem to conclude that such risk control options should be implemented in mandatory instruments, whilst others are of the opinion that there is no need to regulate, as it is reasonable to assume that the shipowner will take care of his own economic interest Skjong, (2003).

Risk evaluation criteria related to safety of human life are available in the maritime industry for some time (IMO, (2000) but only recently formally accepted by including the cost effectiveness criterion and ALARP principle into the consolidated FSA guidelines (IMO, (2007). The ALARP area is specified to define the application of cost effectiveness evaluation for risk control options.

A criteria defined in terms of GCAF/NCAF value of USD 3 million is often regarded as appropriate, and this is the value that has been proposed for use by IMO, (2000) and IMO, (2004d). This value has been used in actual FSA studies used for decision-making at IMO, in cases where a fatality is used as an indicator which in addition to representing the fatality risk also represents injures.

This criterion has been derived by considering societal indicators (refer to document IMO 2000; UNDP, (1990); and Lind, (2002). This criteria is not static, but should be updated every year according to the average risk free rate of return (approximately 5%) or by use of the formula based on the *Life Quality Index* (LQI) (Nathwani et al., (1997), Skjong and Ronold, (1998), Skjong and Ronold, (2002), Rackwitz, (2002a), and Rackwitz, (2002b). Ditlevsen and Friis-Hansen (2005) formulated and extended and more general version of the LQI, called LQTAI. The authors found empirical support of the LQTAI formulation. LQTAI allocates societal value in terms of time to avoid life shortening fatalities as well as serious injuries that shorten the life in good health (see Ditlevsen and Friis-Hansen (2007) for a full reference).

In addition to fulfilling requirements on risk to people, activities that introduce risks to the environment also need to meet acceptance criteria for environmental risks. Presently, risk evaluation criteria related to the protection of the environment are not yet agreed at IMO. A proposal for a cost effectiveness criterion related to accidental oil spills of tankers by has been by Vanem et al., (2007) based on the work performed under the EU project SAFEDOR. This paper proposed an evaluation criteria based on cost effectiveness considerations, i.e. the cost of averting a tonne of oil spilt (CATS). The rationale behind the approach suggested is in line with cost effectiveness criteria normally employed in formal safety assessments (FSA) such as Gross/Net Cost of Averting a Fatality (GCAF/NCAF).

Based on a review of available oil spill statistics and a generic, global average cost per tonne of oil spilt, Vanem et al., (2007) have formulated a criterion in terms of CATS, suggesting that options with a CATS value less than F USD 40,000 should be implemented. An exact value for the assurance factor F was not established, but it was indicated that it should take a value between 1 and some upper limit FMax. This work has also compared the proposed criteria with previous actual decisions related to the OPA 90 regulations. Overall, it was found that the proposed methodology is in general agreement with previous decisions and that the suite of OPA regulations corresponds to a CATS value of approximately US$ 63,000 showing that the proposed CATS criteria are appropriate and the overall OPA 90 regulations are sensible and associated with a reasonable degree of cost effectiveness. This would correspond to an assurance factor FMax of 1.5 for the global criterion, and would also be in agreement with previous decisions. However, further studies on the assurance parameter are recommended. Inspired by thinking behind the LQI (Friis-Hansen and Ditlevsen, 2003) formulated the Nature preservation willingness index for assessing the socio-economic cost of environmental damage.

IMO MEPC 58 discussed, based on the submission by Japan (IMO, 2008d) which contained a r study conducted by Yamada (2009), and agreed that it would be impossible to conclude during the session what the appropriate value of the “oil spill cost per unit volume” threshold might be, although a clear majority expressed the opinion that the CATS threshold should be much less than USD 60,000/tonne, and that further investigation of this matter was necessary, and that it had discussed ways to finalize this by MEPC 59.

Sames and Hamann, (2008) have contribute to the ongoing discussion on environmental risk evaluation criteria, by suggesting a societal risk acceptance criterion related to oil spills of tankers, which can be used within risk-based ship design and approval as well as for rule-making. This work has presented two approaches for setting an ALARP area for oil transport by tankers but no firm conclusion was made on its limits, showing that the presently available historic data is not sufficient to evaluate the environmental risk of oil tankers or to demonstrate the appropriateness of the proposed ALARP area.

3.4 Generic model of IMO GBS

3.4.1 Development of Generic Guidelines of IMO GBS

At IMO MSC 81 held in May 2006, Japan pointed out the necessity of developing IMO Guidelines for goal-based standards (GBS), as a tool for the IMO rule-making process, in the same manner as IMO developed the Guidelines for Formal Safety Assessment, in order to establish a transparent, understandable and agreeable goal of safety level in marine transport (IMO, 2006d). MSC81 welcome the intention of Japan to submit a draft of guidelines for GBS, which should be of a generic nature, covering issues like scope of GBS, definitions, methodology and risk model.

The Japanese National Maritime Research Institute drafted, in cooperation with some member States of IMO, a possible outline of guidelines for GBS and submitted it to MSC 82 held in December 2006 (IMO, 2006e). The draft contained basic idea of methodology for establishment of goal (Tier I) by investigation on of acceptable level of safety and/or environmental protection and fundamental requirements to reach the goal 'Tier II) by developing risk models. In this proposal, process of evaluation of rules for ships was set aside of the tier system (this process has been defined as Tier III in the GBS for bulk carriers and oil tankers), because such process is not a part of "standard" for a subject. MSC 82 agreed, in general, to the proposal and included "development of guidelines for GBS" as one of the work item for GBS.

MSC 83 held in October 2007 discussed on the issue of GBS Guidelines and agreed to continue the development a generic GBS framework based on documents IMO (2007e) (Sweden) and IMO (2006d) (Japan).

MSC 84 held in May 2008 had an extensive discussion on the development of generic guidelines for the application of GBS to support the IMO regulatory development process and agreed that the current effort to develop goal-based standards consists of three essential and related elements:

i. the GBS for the new construction of tankers and bulk carriers;
ii. the Safety Level Approach of GBS; and
iii. the development of generic GBS guidelines.

Generic GBS guidelines would link the first two elements, as well as other initiatives which may be undertaken, by providing a unifying framework to ensure a similar structure and consistent approach.

Consequently, MSC 84 drafted generic guidelines for developing goal-based standards (IMO 2008d) using the document IMO (2006e) as the basis. The draft Guidelines reflect the consensus on a number of key principles pertaining to GBS and should form the basis for any further work in this regard. It was also recognized and agreed to make distinction between "goal-based standard" and "goal-based standard framework", i.e.

"Goal-based standards" is an IMO rule making process and it would consist three tiers (Tier I: Goal, Tier II: Functional requirement for rules for ships, and Tier III: Verification of compliance of rules for ships), while "Goal-based standard framework" includes, in addition to these Tier I to III, Tier IV: Rules for ships and Tier V: Industry standards and practice for supporting Tier IV rules. Following Figure 1 shows the entire framework of IMO GBS.

MSC 84 also agreed the scope of the Generic Guidelines of GBS that:

1. The Guidelines describe the process for the development of goal-based standards (GBS) to support regulatory development within IMO. The Guidelines are applicable to IMO, Administrations, classification societies recognized by an Administration, and other parties who develop standards for ships. The Guidelines can be used to develop a GBS for new areas of concern. The application of GBS will help ensure systematic and consistent development of new rules and regulations;
2. It should be noted that the Guidelines are generic and where they use phrases such as "required level of safety", this does not imply any preference for a specific technical approach.
3. ***Goal-based standards (GBS)*** are high-level standards and procedures that are to be met through regulations, rules and standards for ships. GBS are comprised of at least one goal, functional requirement(s) associated with that goal, and verification of compliance [that rules/regulations meet the functional requirements including goals].[13] GBS establish "rules for rules".

MSC 85 saw further development of the draft guidelines for the verification of compliance with goal-based new ship construction standards for bulk carriers and oil tankers and the latest text can be found in IMO (2008b). However, these are different from the generic guidelines and should not be confused with them.

MSC 84 also developed a vision of a comprehensive set of IMO rules using the generic GBS framework as shown in Figure 2. This shows that "Rules for ship structure" by "Goal-based new ship construction standard" would be one case among various possibility of application of GBS in IMO rule making process.

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[13] The text in brackets, [ ], are to be considered further at MSC.

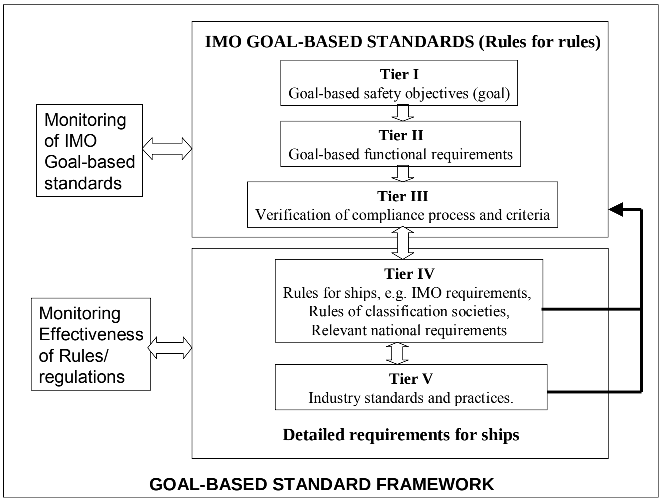


Figure 1: IMO goal-based standard framework.

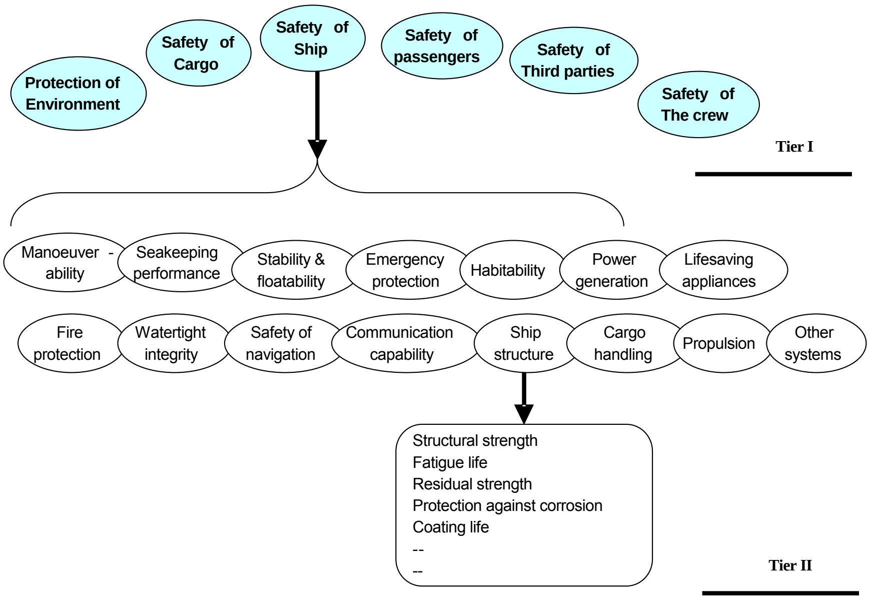


Figure 2: Whole framework of IMO rules using GBS.

MSC would further develop the Generic Guidelines of GBS aiming at finalizing it at its 86th session in May 2009. In order to make progress of such development, MSC84 established a correspondence group (coordinated by Germany) and give it a task of drafting further the Generic Guidelines of GBS.

3.4.2 Application of the Generic Guidelines of GBS

IMO Fire protection Sub-Committee had developed, in late 1990s, comprehensive revision of SOLAS Convention chapter II-2 “Fire Protection”, which has been recognized as the first case where the concept of goal-based approach was used. The regulation 2 of SOLAS chapter II-2 specifies the purpose (goal) of chapter II-2 and the fundamental and functional requirement for fire safety of ships.

IMO MSC 82 had included a new item on “Development of a new framework of requirements for life-saving appliances” in the work programme of the IMO Design and Equipment (DE) Sub-Committee with a target completion date of 2012. In February 2008, DE 51 had decided to start this work in 2009 following a goal-based approach. It would be beneficial to observe the progress made as an example for the utilization of a goal-based methodology (e.g. the Generic Guidelines of GBS).

IMO MSC has a work item of revision of International Gas Carrier (IGC) Code, where the concept of goal-based approach, thus application of the generic guidelines of GBS would be used.

3.5 IACS Common Structural Rules (CSR) and Goal-Based Standards (GBS)

During development of the Tier III verification framework for the IMO GBS, a pilot study was carried out using the IACS Common Structural Rules (CSR) for Tankers as a basis. Two trial applications were carried out in 2006 and in 2008, to test the verification framework and give proposals for improvement. A documentation package covering all the documentation requirements and evaluation criteria was prepared by an IACS Project Team, and the package was evaluated by a Pilot Panel with members selected by IMO.

The results from the pilot study were reported to the IMO Maritime Safety Committee (MSC) by the Pilot Panel in MSC (2007f) and IMO (2008a). The documentation provided by IACS in the first trial application was submitted for information in IMO (2007e).

The main findings from the trial application of how CSR meets the Tier II requirements are summarized in the following.

3.5.1 Results from Self Assessment

A self assessment was prepared by IACS to summarize the extent to which CSR meet each of the GBS Tier II functional requirements. The assessment was based on the list of evaluation criteria given by the verification framework for Tier III. A summary of the assessment is given below.

Functional requirements fully covered		**Functional requirements not fully covered**	
II.1	Design life	II.5	Residual strength
II.2	Environmental conditions	II.7	Structural redundancy

II.3	Structural strength	II.9	Human element considerations
II.4	Fatigue life	II.10	Design transparency
II.6	Protection against corrosion	II.13	Survey and Maintenance
II.6.1	Coating life	II.15	Recycling
II.6.2	Corrosion addition		
II.8	Watertight and weathertight integrity		
II.11	Construction quality procedures		
II.12	Survey		
II.14	Structural accessibility		

For the requirements which are not fully covered by CSR, the reason is found to be one or more of the following where the subject area is:

- not normally covered in class newbuilding construction rules;
- implicitly covered and not explicitly covered;
- covered by other rules or regulations; or
- only partially covered.

3.5.2 Evaluation of Functional Requirements

A short description of how each functional requirement is covered or not covered by the CSR is provided in the following.

Design life (II.1)
In GBS Tier II, the design life, as defined in Tier I, is required to be 25 years. The CSR definition of design life is essentially the same as the one provided in Tier I. A design life of 25 years is specified, and used as an input parameter for the determination of the scantling loads, fatigue loads, expected fatigue life and corrosion wastage allowances.

Environmental conditions (II.2)
Tier II requires ships to be designed in accordance with North Atlantic environmental conditions. The CSR rule text explicitly specifies that the rule requirements are based on a ship trading in the North Atlantic wave environment for its entire design life. The wave loads are derived using the sea state data given in IACS Recommendation No. 34, which gives wave data using a scatter diagram giving the probability of each sea-state. Rule formulations for wave loads are derived using numerical wave load analysis and regression analysis, calibrated with feedback from service experience and model tests.

Structural strength (II.3)
Tier II specifies that ships shall be designed with suitable safety margins for certain specified conditions, such as environmental conditions and loading conditions, and for relevant uncertainties such as loads, fatigue and buckling. It is further specified which

deformation and failure modes that shall be assessed. Certain general design requirements are given, as well as requirements to ultimate strength calculations. All items specified in II.3 are found to be covered by CSR.

Fatigue life (II.4)
Tier II states that the design fatigue life should not be less than the ship's design life and should be based on the environmental conditions required by II.2. This requirement is fully covered by CSR.

Residual strength (II.5)
Tier II requires damaged conditions such as collision, grounding and flooding to be considered. Flooding is included in the CSR as an accidental load, but only the local scantlings due to flooding pressure are checked. Requirements to residual strength are not explicitly covered by the rules. It is stated as a general principle that ships designed according to the rules will have structural redundancy to survive in a damaged condition. However, the effect of structural damage on the hull girder capacity resulting from collision or grounding is not assessed in the rules.

Protection against corrosion (II.6)
Coating life (II.6.1)
Relevant IMO instruments such as regulation II-1/3-2 of SOLAS are referred to in the Rules. In addition CSR require that all applicable statutory requirements are complied with, such as the IMO "Performance standard for protective coatings for ballast tanks and void spaces" which contains relevant requirements. In case of cathodic protection and paint containing aluminium, the Rules require additional detailed requirements.

Corrosion addition (II.6.2)
Corrosion additions are specified in the CSR, and there is a clear and direct link between the wastage allowance given during operation of the vessel and the corrosion additions used during newbuilding assessment. The actual wastage allowance numbers reflect this concept and are stipulated in the Rules.

Structural redundancy (II.7)
CSR do not have any explicit requirements to consider structural redundancy following local damage to a stiffening member. During the rule development, ship structures were considered to have inherent redundancy, since the ship's structure works in a hierarchical manner and, as such, failure of structural elements lower down in the hierarchy should not result in immediate consequential failure of elements higher up in the hierarchy.

Watertight and weathertight integrity (II.8)
Tier II gives requirements related to the watertight subdivision of the ship and to weathertight and watertight integrity of the hull. Such issues are mainly governed by relevant IMO regulations, such as SOLAS, International Convention for the Prevention of *Pollution from Ships* (MARPOL) and *International Convention on Load Lines*

(ICLL). All relevant requirements are included in or referenced to by the CSR.

Human element considerations (II.9)
In general ergonomic design principles as required by Tier II are not within the scope of classification rules for the ship hull. There exist a number of rules and regulations within the maritime regulatory framework that a designer has to consider, such as requirements of national or canal authorities and employer's liability insurance associations as well as other Tier V rules. The relations between CSR and other rules of the regulatory framework as well as responsibilities of the parties involved in ship design and construction are described in the CSR, and references to requirements of other rules and regulations are also given.

Design transparency (II.10)
The functional requirement is only partly covered by CSR. The CSR Rules require certain plans and documents to be submitted to the classification society in aid of the design appraisal. The plans and supporting calculations which need to be submitted and/or supplied on board are listed. The Rules refer to the loading conditions and design loading and ballast conditions upon which the approval of the hull scantlings is based. The matter of intellectual property rights is considered to be outside of classification matters and a contractual matter between the owner, the builder and the manufacturer, as appropriate.

Construction quality procedures (II.11)
The functional requirements of Tier II.11 are addressed in CSR and in IACS Unified Requirement Z23. In addition, CSR requires that the structural fabrication is to be carried out, in accordance with 'IACS Recommendation 47, Shipbuilding and Repair Quality Standard for New Construction' or a recognized fabrication standard which has been accepted by the classification society prior to the commencement of fabrication/construction, and lists what is required in the fabrication standard. Surveys, in general, are covered by the individual class society requirements. Neither of the documents, nor any of the classification requirements, addresses the issue of intellectual property rights.

Survey (II.12)
Survey requirements are not addressed in CSR, but are covered by IACS Unified Requirement Z23, which describes the specific activities that need to be planned for and addressed. It requires that, prior to commencing any newbuilding project; the society is to have a kick-off meeting with the shipbuilder, to agree how the activities shown are to be addressed. The meeting is to take into account the shipbuilders construction facilities and ship type, and deal with sub-contractors if it is known that the builder proposes to use them.

Survey and Maintenance (II.13)
The provision of adequate space for survey and maintenance is given by reference to SOLAS. CSR rules include explicit requirements to the access to closed spaces and the

size of access openings. Criteria for planning survey and maintenance are not explicitly included. The rules do not include requirements related to the verification of compliance with the rules during construction and operation. The shipowner and the individual classification society are responsible for maintaining the ship and verify the compliance with the class requirements in accordance with the classification society survey scheme.

Structural accessibility (II.14)
The requirements related to access to the ship's structure for inspection and thickness measurements are not covered by CSR. Means of access are covered in SOLAS and corresponding IACS interpretations, which are referenced by CSR. CSR for Oil tankers add requirements for access to specific areas such as the duct keel and pipe tunnel.

Recycling (II.15)
Recycling matters are not scope of today's classification rules. Therefore requirements regarding recycling of the ship structure are not explicitly included in CSR. Reference is made, that other national or international rules and regulations may exist, which are relevant for the particular ship.

4. COMMITTEE'S VIEWS ON CURRENT IMO GBS

4.1 Comprehensiveness of GBS

From the above brief summary of the recent developments of the upper tiers it can be said that the discussion about the content of Tiers I and II has not reached a conclusion. This regards the overall content of the two levels, as exemplified above by the proposed and (in some cases) agreed introduction of new concepts, like human factors, ergonomics, safe operation, continuous performance monitoring.

However, a considerable part of the discussions has been, and probably will be, devoted to systemise the concepts in a organised framework, in which the above recalled top-down approach can be better implemented.

In other words, it seems important to check whether the present formulations of Tier I and II reflects properly the ranking of concepts between the two levels and contains clear, identifiable concepts without un-necessary repetitions or overlapping. The subject of clearness of GBS is treated in the next paragraphs.

4.2 Clearness, conciseness and internal coherence of GBS

To assess clearness, conciseness and internal coherence of the present formulation of GBS (i.e. transparency), the following check criteria are proposed with reference to the concepts (keywords) contained in the three tiers:

a) Is every concept in Tier I adequately reflected with more specific requirements in the second or third level?
b) Do all the requirements at a given level point at a one or more of the concepts at the upper levels or do they aim at additional goals? (A negative answer would imply incomprehensiveness at the upper level)
c) Are there in Tier I concepts that represent requirements to achieve general goals or vice-versa in Tier II concepts that can be qualified as goals? (This would suggest moving goals/concepts upwards or downwards, if appropriate)
d) Are all the requirements at the various levels clearly identified or is there an overlapping of concepts in the same Tier or at different levels?
e) Is the verification process applied across all levels of the tier structure, and not limited to verification of the Tier IV (classification society/Recognised Organisation) construction standards? (e.g. verifiability may include necessary and sufficient coverage of functional requirements for any ship type concept in Tier II to attain the Goals in Tier I, and similarly comprehensiveness of prescriptive industry standards in meeting the requirement of the Tier IV stipulations.)
f) Are there in Tier I and II requirements related to the present state of the art technology in particular quantitative requirements or can they be moved to Tier III?

An exercise has been attempted starting to list the concepts (keywords) contained in Tier I. They are: life (actual and design life); operating conditions (actual, specified and ‘proper’); environmental conditions (actual and specified); damage conditions (intact and specified damage); maintenance (proper and actual); design parameters for safety (minimisation of the risk of loss of the ship and also to provide safe access, escape, inspection, maintenance and operation), environmental friendliness (minimisation of the risk of pollution to the marine environment and also selection of materials for recycling); strength; integrity and stability.

a) From what above it seems that all the goals contained in the present formulation of Tier 1 have a continuation in the lower levels.

b) As regards the second check of the list above, a couple of aspects will be recalled here. There is a point in noting that an explicit mention of the risk for the crew, for workers on board (inspectors and people from repairing companies) could be beneficial (also for passengers, should the limitation to tankers and bulkers drop). This is in line with the proposal for an inclusion of a GBS Tier I goal focussed on the ‘design of systems and functions leading to substantial reduction of work-related accidents’ (IMO, 2007g). This goal could explain why functional requirement II.9 (see section 3.2.3) is implemented.

   Another item which is probably not adequately covered in Tier I is the condition of the ship as regards degrading effects (corrosion, but also wearing and fatigue).

This aspect has the same ranking as the other ‘conditions’ (operational, environmental, damage), but has much less emphasis in the present text (and the concept of exposure is formulated as dependent from the design life).

c) The description of design parameters is spread out between Tier I and Tier II: design life, ‘specified’ conditions regarding operation, environment and damage (in Tier I); design loads, design fatigue life, design corrosion rates, design coating life, etc. (in Tier II). These are all functional requirements aimed at achieving the goals in the actual lifetime of the ship under actual conditions

d) The term ‘strength’ is, in the common use, associated to the static structural (material) response to extreme loads. When referring to the response due to a generic load, the term ‘capacity’ could be used allowing us to include the concepts of ‘stiffness’ in static structural (deflection) response and dynamic structural response which, presently are not explicitly covered in the text.

Independently from the terminology, it is noted that the capacity of a structure is assessed with reference to design loads defined by design values of environmental and operational conditions and inherent probability levels. The ensemble of these concepts, contributing to the definition of capacity or loads, defines what could be termed a scenario or a limit state equation. Both the concept of a limit state and of a scenario is lacking in the formulation of Tiers I and II where examples of limit states and of loads are given instead.

Another note regards the term ‘net scantling’. It was introduced in earlier times by IACS and can be defined as a time-invariant geometrical characteristics of the structure, obtained by deducing the whole amount of corrosion addition from the initial ‘as built’ dimensions. This characteristic was used in IACS Common Structural Rules (CSR) to check the capacity of local members, thus implying that the ‘design corrosion condition’ for that type of check corresponds to the total loss of the corrosion margin. For other types of checks (e.g. hull girder strength) different ‘design corroded conditions’ are envisaged (in the example, a reduction of 50% of the corrosion addition, with some limits).

Generalising the concept, this means that the design conditions as regards corrosion can be different for different checks. They actually represent ‘realistic’ situations, significant for the specific verification. In the former example above the scantling that is considered as ‘effective’ in sustaining loads corresponds to the ‘net scantling’, while in the latter case the ‘effective’ scantling includes a part of the corrosion addition.

What above suggest that the concept of ‘design corroded condition’ (which represents a ‘realistic’ situation as regards the decreased load carrying capacity in comparison to the ‘as built’ situation) should be decoupled from the ‘net scantling’, which represents an invariant characteristics of the structural members (and of the assembly). It can be regarded as a lower bound for the corroded condition. The long-lasting discussions on the subject within the Pilot Panel and the WG seem to be related to the attempt of identifying the two concepts.

In general the committee's view is that in a goal-based framework that stimulates innovative designs it appears misleading to enforce the net scantling thinking. It is limited to steel ships and restricts innovative thinking in considering new materials that may reduce or eliminate corrosion and thus lead to lighter ships that may lead to less fuel consumption and thus less environmental impact. The concept of net scantlings does not represent a goal based functional requirement. The concept represents a pragmatic regulatory solution approach to handle and control a complicated and important degrading mechanism during the vessels lifetime. Hence, concept of net-scantlings belongs to Tier IV.

e) Removal of quantitative or prescriptive aspects from Tier I and II. This modification of the present situation would have at least two important consequences:

- confining the duality between the safety level and the prescriptive approaches to Tier III only. In the two cases the verification of compliance would be performed on single values, or probability distributions, or risk.
- concentrating all requirements depending on the state of the art, and thus not 'irrespective of ship design and technology', to the lower of the three levels.

The task would easily be performed e.g. by downgrading the quantitative requirement of 25 years for a design life to Tier III (or Tier IV) where it rightfully belong as a pragmatic regulatory setting and moving to the same level the prescriptions about the reference environmental conditions (presently North Atlantic environmental conditions).

4.3 Measuring and monitoring GBS

4.3.1 Introduction

At the 83rd session of the Maritime Safety Committee, it was agreed that performance based monitoring would be beneficial, but would involve more than just classification society rules and included maintenance, operational considerations and numerous other factors, and would require substantial work to implement. Additionally, the Committee noted that the group could not determine the appropriate method to implement performance monitoring and, therefore, agreed that, in the short term, the concept could be considered by the Pilot Panel as part of the Tier III verification process (IMO, 2007c).

At the IMO's 84th session of the Maritime Safety Committee, work continued on developing GBS and in particular, time was spent on guidelines for the development of goal based standards. Figure 3 was included in these guidelines. Compared to previous pictorial descriptions of GBS this diagram has been extended in the verification process to include explicit references to two monitoring systems. This section will look into which monitoring and measure systems are being considered and highlight some of the pros and cons for each regime.

4.3.2 Using reliability analysis within GBS

The basis for the reliability-based code calibration was discussed in the ISSC Specialist Report VI-2 in 2006. We will not revisit this issue here, but leave reference to that document. Clearly, the described principles in that document should be used as an integrated part of the verification process of the GBS.

Formal Safety Assessment is a tool to identify hazards and to derive and quantify risk control options to improve the safety of the entire system ship. Another instrument is the structural reliability analysis (SRA) that is used for identify the safety level of a ship structure (this analysis may well be part of a FSA). In context of the GBS discussion it might be an option to demonstrate the safety level during the verification of a certain set of rules. A SRA could be an appropriate instrument to produce a neutral figure that allows comparing different approaches of rules to find out if the different rules achieve the same safety level.

For this purpose a failure probability for a system needs to be calculated using a general limit state function, where $G(\mathbf{x}) \leq 0$ represents the failure of a system. For ship structures it is common to investigate the ultimate hull girder bending capacity M_U with respect to the hull girder bending loads $(M_{SW} + M_{VW})$ that may occur. This leads to the following limit state function:

$$G(\mathbf{x}) = M_U - (M_{SW} + M_{VW}) \tag{4.1}$$

In order to evaluate the probability of $G(\mathbf{x}) \leq 0$, the possible uncertainties for the loads' side and for the resistance side need to be introduced as model uncertainty parameters into the limit state function.

$$G(\mathbf{x}) = M_{Uc} \cdot \kappa_{Rm1} \cdot \kappa_{Rm2} - (\Psi_{SW} \cdot \kappa_{SW} \cdot M_{SWc} + \kappa_{annual} \cdot \kappa_{VC} \cdot \kappa_{nl} \cdot \kappa_{envir} \cdot \kappa_{hwa} \cdot \kappa_{IACS} \cdot M_{VWc}) \tag{4.2}$$

It has to be observed that the different influential parameters have different statistical distribution functions, mean values and different standard deviation for different ship types. If SRA should be used in future to demonstrate the safety level by means of failure probabilities common agreements on several issues will be necessary such as:

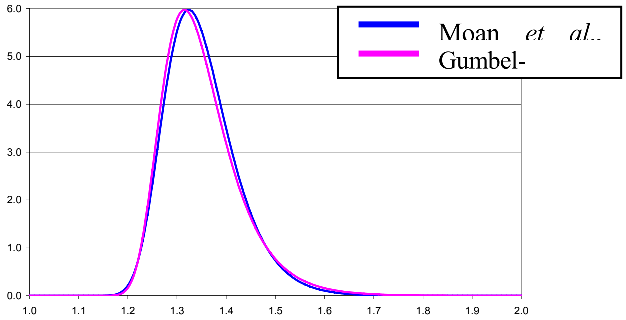
- What is an acceptable failure probability? Here some international standards exist.
- Common statistics for the influential parameters on the investigated failure mode (e.g. material properties, loads, fabrication tolerances etc.).

- Common distribution functions for the influential values.

In order to identify the sensitivity of a SRA a comparative calculation has been carried out in two ways. Published results of a reliability analysis (Moan *et al.*, 2006) were taken as a basis. A calculation was carried out using the same influential parameters except the probabilistic density function for one parameter κ_{SW} (influential factor for the distribution of still water bending moment). The following table shows the comparison of results for annual failure probabilities and the reliability index.

1) generic ship			**Sagging**		**Hogging**		
	$(M_{SW,rule}/M_{VWC})$		0,6	$0,6^{1)}$	1,0	$1,0^{1)}$	$1,1^{1)}$
k = 1,5	(Moan *et al*., 2006)	P_f	4,8E-03	1,0E-02	6,7E-05	3,7E-04	5,4E-04
		β	2,59	2,33	3,82	3,38	3,27
	GL	P_f	2,5E-03	1,0E-02	3,2E-05	1,0E-03	1,5E-03
		β	2,81	2,32	4,00	3,09	2,97
k = 2,24	(Moan *et al*., 2006)	P_f	1,9E-03	2,5E-03	2,0E-05	6,7E-05	9,3E-05
		β	2,90	2,80	4,11	3,82	3,74
	GL	P_f	2,6E-03	1,3E-02	4,8E-05	2,0E-03	2,9E-03
		β	2,80	2,23	3,90	2,88	2,76

The following figure shows the difference of the selected density functions.



In a second step a comparative calculation was carried out with individually calculated influential parameters. For a sample of 9 PANMAX container ships influential parameters for stillwater bending moment κ_{sw} and wave bending moment κ_{nl} , κ_{annual} were calculated. For the stillwater bending moment the loading manuals of the subject ships have been evaluated. For wave bending moment long term statistical computations have been carried out. Other parameters have been cross checked by own calculations and good agreement was found with the published figures, thus the remaining parameters were taken from the original publication. The following table shows the failure probability and the reliability index for 1 and 20 years.

		Sagging	**Hogging**
$\frac{M_{SW}}{M_{VWC}}$		0,55	0,55
1 year k= 1,732	P_f	8,0E-4	5,5E-6
	β	2,381	4,397
20 years k=2,865	P_f	8,6E-3	1,08E-4
	β	2,381	3,700

Due to the evaluation of the loading manuals to determine the actual stillwater bending moment for the specific design instead of the recommended rule values the ratio of hull girder moments differs from the publication (Moan *et al*., 2006). However the values may be compared with the previous and show differences. From the above it may be concluded that further work is necessary before reliability analysis may be used as a general tool for the verification of different rule codes.

To determine the influence of material properties on the ultimate hull girder strength only limited statistical data for the distribution of yield strength of shipbuilding steel are available. In the field of civil engineering some publications were found (Hou *et al*., 2000) and (Strauss *et al*., 2006) similar data bases for ship building steel should be set up and commonly used. The same is valid for the influence of fabrication tolerances. Here several fabrication standards exist in parallel to IACS recommendation 47.

Further it was found that the selection of stillwater bending moments has major impact on the failure probability. The present rules of classification societies define a minimum required hull girder section modulus. From this requirement a stillwater bending moment can be derived if we have calculated the wave bending moment from the classification rules. However this stillwater bending moment can be seen as a recommendation. The design process for a ship will start with the definition of the transportation task and the related loading condition, after definition of the hull form a set of stillwater bending moments will be available together with the wave bending moments. Having in mind that present work is still based on figures dating 10 years back (Guedes *et al*., 1996), (Östergaard *et al*., 1996) it is recommended for future reliability analyses to evaluate loading manuals of recent designs to set up a distribution functions for the stillwater bending moment rather than taking the recommended values from rules. Ivanov and Wang (2008) have drawn up this way for tankers. On the same line is the predictive model by Garrè *et al.* (2009) calibrated by operational data of a specific double hull tanker.

4.3.3 Monitoring of IMO's Goal-Based Standards

The monitoring and verification of specified GBS will require significant data collection. One suggestion is to use formal safety assessment (FSA) techniques combined with registered data to verify that the functional requirements are fulfilling the aims (see Figure 1).

A limitation of already collected maritime casualty data is the lack of quality and inconsistency, especially with respect to limited information of the causal factors in the registered data. For example, the Lloyds Register Fairplay (LRFP) does not include occupational accidents, which is a critical component to any holistic analysis. Similarly, databases that do contain occupational accidents rarely contain any detailed information on causal effects that led to the accident.

This is because LRFP records ship accidents rather than accidents involving the person. Such data and subsequent analyses from this data would not provide us with a holistic view of the relevant risk profile. Therefore, it is paramount that the core data collection is considered and structured carefully and due consideration is given to the limitations of such data.

Several models exist for structured data analysis of the occurrence of unwanted events. Most suggested models are complex and may therefore not always be easy to clearly remember. However, the “loss causation model” proposed by Bird *et al.* (2003) is attractive in its simple format. The model consists of five steps, as illustrated in Figure 3. The focus of the model is in understanding the causative factors of the incidents. Not only should the set of causative factors be understood, they should also be registered. Doing so would represent a giant step in the control of all types of losses.

In their book Bird *et al.* (2003) consistently use the “incident” for reference to an event that could or does result in unintended harm or damage. They divide the incidents into two types: No-loss incidents and Loss-type incidents. They consistently avoid using word “accident” because “it conveys an unplanned, unexplainable, random event”, which in turn lead to the impression that the event is unpredictable and hence also uncontrollable. However, the occurrence of an incident is always the result of some source of energy, and our goal in doing an investigation and in recording the relevant data is to be able to better control the source of energy, or the effect of the released energy.

The loss causation model is read and understood from the right end at the Loss. Once the sequence begins, the type and degree of loss is a matter of chance. Actions to minimize loss (such as first aid, fire fighting, repair, emergency action plans) will be activated as fast as possible. It is recognized that incidents can costs money, in some cases lots of money! The loss is not measured only in the direct (insured) cost of the loss (medical compensation, building damage, etc.), but also in the indirect costs (often uninsured) such as investigation time, deferred production, cost of replacement and training, loss of goodwill, etc.

In many incident data bases only the direct loss is registered. Some may also include a limited description of the event that precedes the loss in the database, but the in general the description of the incident is scarce. In the loss causation model, the event is called the Incident. The incident is described by the event which causes the contact or energy release that could or does cause the harm or damage. It is important to recall that any loss is the result of a release of energy, also financial losses. In almost any system actions will be implemented to minimize the amount harmful of energy released when the event occurs. The mitigating actions would focus on either diversion or absorption of the energy. These actions act as a threshold between the Incident and the Loss.

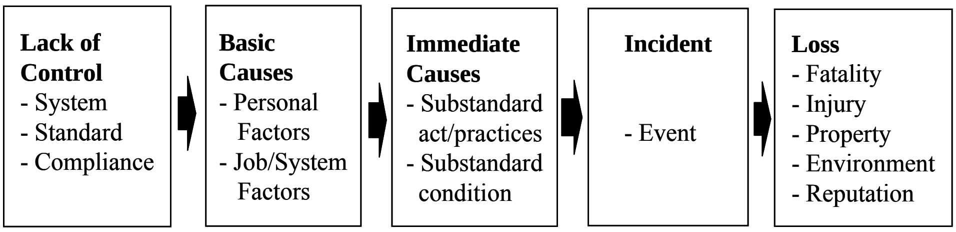


Figure 3: The Loss Causation Model. (bird *et al.*, 2003)

As an example we may take a real case where a conductor who one early sunny morning misses a red light when exciting a tunnel with his train and as a result kills a railroad worker who was doing repair on the rails. The loss is the fatality of the railroad worker, whereas the incident is the train hitting the worker because of a missed red light. At best, a database registration will result in the above registration.

To properly learn from the incident, it is necessary to dig deeper and to find the immediate causes for the incident. The immediate causes are the circumstances that immediately precede the contact. The immediate causes are grouped into substandard act/practices and substandard conditions. The terminology relates practice and conditions to standards instead of using a terminology of unsafe acts (behaviors) or unsafe conditions (circumstances). By relating practice and conditions to standards it broadens the scope of the investigation.

To continue the example we need to understand why the conductor missed the red light. It was well known that in the morning it was impossible to see whether the light was red or green. This was partly because the sunlight in the morning was shining directly into the tunnel and partly because the glass on the signal light was very dirty. Although procedures prescribe that when the conductor cannot see the light the signal should be interpreted as a red light. However, the conditions were the same every morning in sunlight and all conductors just drove ahead. In this case we see a substandard condition that transforms into a substandard act which eventually becomes a substandard practice.

Management system influences human behavior. It is important to realize that more than 85% of the mistakes people make are result of factors that only management system controls. It is therefore a fault to say that 85-95% of incidents results from unsafe acts or faults from people.

A series of questions arises immediately: Why did that substandard practice occur? Why did that substandard condition exist? What failure in the loss control system permitted that practice or condition? These questions shall be answered in the next step focus on understanding the basic causes that led to these immediate causes. The basic causes are the "diseases", the root cause of the substandard act/practices and conditions. When these causes can be identified they permit meaningful control. It is beneficial to divide the causes into real causes and indirect causes as this better will explain why the substandard act/practices and conditions exist. Was the basic cause due to no training or no knowledge? Was maintenance lacking? No maintenance results in a substandard product.

Continuing the example it should be asked: Why was the signal dirty? Why was it not kept clean? In the present case it turned out that there were no work procedures for regular cleaning of the signals. They were cleaned only when a bulb failed and was changed.

The last element in the loss causation model is the "*lack of control*". This box relates alone to the management and to its possible lack of control. The three common reasons for an organization may not have control of its incidents are 1) inadequate systems, 2) inadequate standards, and 3) inadequate compliance with standards. These three items are affected by management's commitment through responsibility, resources, willingness to invest in safety, the management philosophy, rules of the company, and willingness to make effective use of new technology.

If we want to learn properly from the incidents, then it is important to improve the model building of the casual factors that leads to identification, assessment and management of the unwanted events. Only through this we may properly learn from the incidents and improve safety.

Rarely do we find there to be only a single cause of any problem. For this reason most registered failure data are misleading as they normally only report a single or relatively few causal factors affecting an incident. Incidents are caused; the do not just happen (see Table 2). The causes of loss can be determined and controlled.

Table 2
Comparison of LRFP and the Norwegian Maritime Directorate data on the number of fatalities or injuries by accident type (01.01.1997 to 31.12.2006).

Cause	Fatalities				Injuries			
	NMD	LRFP	Overlap	Total	NMD	LRFP	Overlap	Total
Personal accident	20			20	522			522
Collision	7	6	6	7	1			1
Capsizing	11	11	11	11				
Fire/Explosion					3	1	1	3
Other accident	1	1	1	1				
Total	39	18	18	39	526	1	1	526

4.3.4 Monitoring rules

At the 83rd session of the Maritime Safety Committee (IMO, 2007f) the Pilot Panel was set up to test how GBS would work by a trial verification of the IACS common structural rules for tankers and bulk carriers has come up with some example metrics of structural performance monitoring. This monitoring is of the performance generated by the rules rather than the performance of a specific design. An example of the proposals is:

> ***"Corrosion and steel renewal assessment***
> *At least [TBD]% of ships built to the Rules should satisfy the following steel renewal target:*
>
> *Over the 25 year service life, structural steel renewal due to corrosion should not exceed [TBD]% of the hull steel weight. The hull steel weight includes all hull structure except the weight of the house and casing."*

This metric is trying to establish whether the corrosion allowance is sufficient. It does this by using the assumption that if it is sufficient steel no more the x% will need to replaced over the life of the vessel. However, this creates some problems as this metric can be read two ways: the class society is poor because its rules are insufficient with respect to corrosion allowance is insufficient or the class society is good because it insists that corroded steel is renewed.

It is certainly a concern that any criteria here could discourage safe practice by leading rule making bodies to watch the statistics rather than ensure that they take the right decisions.

4.3.5 Calibration of Rules

Rules developed under GBS need to incorporate the applicable existing prescriptive provisions in various IMO, classification society and statutory instruments to assure attainment of the desired reliability level through standard procedures, and also ensure adequacy of the design, construction and operational practises compared to the present prescriptive provisions.

An exercise in this direction was carried out by IACS during the development of the CSR rules for bulk carriers and tankers. Similarly, the IMO FP sub-committee followed this procedure through use of NFPA Standard 550 in the development of the performance based structural fire protection and fire control regulations Fire Safety System (FSS) Code and prescriptive Fire Test Procedure (FTP) Code in a systematic manner. In absence of this exercise, implimentability and comprehensiveness of the regulatory provisions under GBS regime can be questioned.

5. ALTERNATIVE FORMULATIONS OF GBS

Our present understanding of rules and the development of these is naturally rooted in the present framework in which these rules are formulated. The rules have with success been applied for years and when these were found not to be satisfactory they were modified to assure that design according to the rules did comply with desired safety level. However, the framework within which these rules were formulated has shown not to be able to guide designers when these want to go beyond legislative compliance. The objective of introducing goal-based standards is partly to solve this problem.

Although the today's formulation of GBS solves some of the problems it was intended to solve, this committee finds that the present formulation do not properly solve some of the central problems that GBS should be required solve. In section 3.2 we discussed some of the problems or deficits pertinent to the present formulation of GBS. The discussions related to the need of the Pilot Panel to continuously modify the formulations related to net scantlings under Tier II. The Pilot Panel foresee that these revisions will need to continue. This only illustrates that net scantlings should not be part of the higher level Tiers. Further, discussions in section 3.2 also related to the focus and considerations of the human element. Here it is apparent that at a top level the present GBS specifies what tools and what areas should be considered for reducing slips, trips and falls. The objective of higher level of GBS should, more importantly, be to specify what problems exactly should be solved under the GBS framework and it should not address the tools which are of the concern of the designer. This type of exemplification and guidance in specification belongs to Tier IV.

In section 3.3.3 the problem of the lacking of a clear risk based acceptance criteria formulation in the present GBS format was addressed. The obvious advantage and need for such an acceptance criteria setting is that it will fully integrate FSA into the GBS standards and in this way allow as well owners as classification societies to meet the goals of the standards transparently. This element is seen as a major problem in the present GBS formulation.

In chapter 4 we discussed the comprehensiveness and consistency of the present GBS formulation. It was noted that Tier I and Tier II should contain no quantitative or prescriptive approaches as these belongs to the lower levels. We discussed the monitoring in connection to goal based standards. Not only shall the GBS framework continuously be monitored, it shall also be possible transparently modify or update the framework when changing societal preferences dictates this. This is for instance seen in today's move towards the 'green ship'. Further, GBS should allow taking into account a more flexible maintenance and monitoring scheme, if the owner finds that this result in operational advantages and at the same time do not compromise the safety of the operation.

In this chapter we challenge the GBS formulation. By taking point of departure in the present GBS formulation we extend and modify it, such that it solves the discussed deficits and problems pertinent in the present formulation.

5.1 Introduction

IMO and ship owners world wide are facing increasing pressure to be responsible, transparent, and accountable for how they perform in relation to a sustainable development of the shipping industry. We see an increased interest by operators to apply risk management to all aspects of the operation, from compliance to legislations to managing integrity of their assets. Their focus is on operating profitably while complying with legislations; that is to ensure the best possible financial performance and the lowest practical risk (expected loss). By introducing goal based standards (GBS) within IMO we see the move towards a more holistic and transparent approach to maritime rule development that meets requirements of sustainability. In the loss mitigation we will see major owners who foresee the need to go beyond legislative compliance in addressing the societal concerns, e.g. related to environmental pollution and climate change. A benefit to the operator by introducing GBS is more freedom in arriving at more competitive, innovative, and safer design, yet still assuring the operating vessel will comply with societal requirements to sustainability, human and environment. This compliance is also known as corporate social responsibility. Hence, a far reaching objective of introducing goal based standards is to assure that a vessel has been designed according to GBS is sustainable during its lifecycle and thus assuring corporate social responsibility.

The committee objective of this section is to challenge the current formulation of goal based standard to aim at a more comprehensive risk based formulation at the higher tiers, and performance based at the lower tiers, that assures societal preferences will be reflected easily and transparently. Any move towards a new regime will always be a challenge to adapt to a new paradigm. Therefore, it is paramount that any new regulatory framework is transparent and adaptable to meet the expectations of future societal preferences.

Figure 4 illustrates the pyramid of the GBS tiers taking into consideration the concept of a ‘Tier 0’ which is the overall mission statement of the goal based standard as presented in section 5.2. The principal content of the first three tiers (0, 1, and 2) will be discussed in this section.

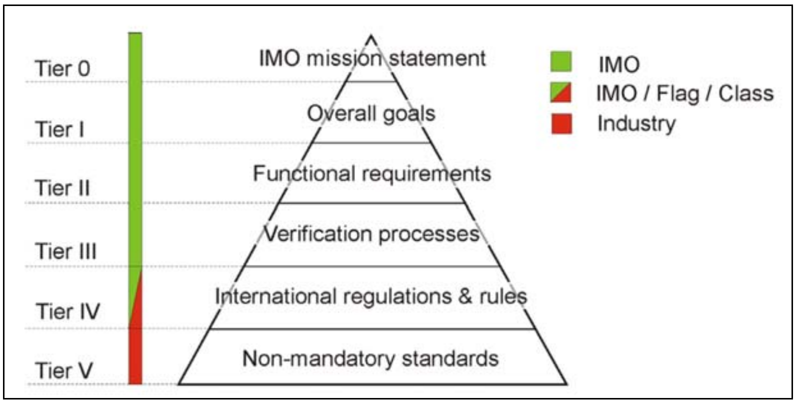


Figure 4: The pyramid illustrating the GBS tiers.

5.2 Tier 0: mission statement

Tier 0 defines a 'mission statement' not included in the earlier sections of this report nor considered within the IMO GBS framework. The mission statement should be so general that it can stand unchanged for a very long time. An important element is that the mission statement, in relation to goal based standards, shall assure corporate social responsibility of the shipping industry. There are different definitions of corporate social responsibility but for the purpose of this report, we are using the definition from Wikipedia (www.wikipedia.org) as follows:

> *"Corporate social responsibility is a concept whereby organizations consider the interests of society by taking responsibility for the impact of their activities on customers, suppliers, employees, shareholders, communities and other stakeholders, as well as the environment. This obligation is seen to extend beyond the statutory obligation to comply with legislation and sees organizations voluntarily taking further steps to improve the quality of life for employees and their families as well as for the local community and society at large."*

From the definition of corporate social responsibility, as defined above, a shipowner should be able to validate that the company's activities *provide added value to society* (improvement of quality of life). This implies that the owner at least must cover all the losses (harms) that he imposes on society by his activity (*taking responsibility for the impact of their activities*).

To a large extent, the losses imposed on society relates to intangible sources such as injury and loss of life, environmental damage to nature, effect on climate changes, sustainable development for future generations. On the other hand, society chooses to accept the losses by choosing to operate ships in trade. As a counter measure to limit the losses, society institutes controls and requirements by national flag administrations and by international bodies like IMO. If the global society wants to change something it has the mechanisms in place to implement such policy and there is also the possibility for implementing regional and national regulations.

All these intangible losses, and indeed any intangible benefits such as enjoyment of a product that would otherwise be unavailable, are political in nature and must be identified and ranked by authorities. The value setting of such intangible losses may change over time to reflect the changing priorities of society when more knowledge becomes available and new emerging risks are faced. The list of the risk item items to be included in the analysis is detailed in Tier 1.

One possible formulation for the GBS Tier 0 mission statement becomes:

> *"Goal based standards shall assure corporate social responsibility whereby the Organization is to consider the interests of society by taking responsibility for the impact of regulations on customers, suppliers, shareholders, and other stakeholders, as well as the environment and by checking that the activity under consideration*

does provide added value to society."

The advantage of this mission statement is that it clarifies the concept of the societal interest as complementary to private interest. In principle, shipowners enter the activity only if there is a reasonable expectation of a tangible return on their investment. The objective of IMO is, as the representative of world societies, to assure that the organizations (shipowners) do not cynically exploit societal interests, but operate these in a social responsible way.

On the other hand, society may suffer both recoverable and non-recoverable harm from the activity covered by the shipowner. Therefore, the society will similarly accept the activity only if it can expect a corresponding positive expectation to its benefit, although in this instance the benefit may take tangible (taxes) or intangible (see section 5.3) form. These two criteria can be combined into one single criterion that the rule maker (eventually the shipowner) can use to define acceptance limits that expectedly satisfies both owner and societal preferences.

5.2.1 Defining the principles for acceptance criteria in accordance to the mission statement[14]

When the shipowner makes decision about the general arrangement of his vessel, he will first calculate the difference between the expected income the expected operational cost. Depending upon the ship's trade, the shipowner will expect to arrive at a gross solution that meets the forecast marked need. From this solution the shipowner may calculate a net gain (g) from which all the running costs are subtracted. From this net gain all calculated expected losses (i.e. the risk) that may be caused by the occurrence of unwanted and unplanned events such as damages during storms, collisions, grounding, and fire are subtracted. Omitting any interest rates we can consider the owners decision criteria by the following equation:

$$g - \sum_{i=1}^{N} \lambda_i \, \mu_{oi} > 0 \tag{5.1}$$

where:

N is the number of considered unwanted events;

λ_i is the frequency of occurrence of unwanted event category i; and

μ_{oi} is expected loss of the owner (index o for owner) following the occurrence of unwanted event category i.

The term in the summation is the risk. The owner can pay an insurance risk premium to cover parts of any potential losses. The owner must require that the expected annual net gain minus the expected annual losses is large than zero, otherwise it will lead to bankruptcy.

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[14] This section is presented as one example of how acceptance criteria can be evaluated. Not all Members of the Committee were in agreement to the use of such an approach and requested that be noted.

As proposed with the GBS Tier 0 mission statement, the shipowners should provide an added value to society. If the society perceives a positive net benefit, the activity may be claimed to be corporate socially responsible. To formulate this mathematically we may write the corporate social responsibility criterion as (Ditlevsen, 2003 and Friis-Hansen and Ditlevsen, 2003):

$$\left(g - \sum_{i=1}^{N} \lambda_i \, \mu_{oi} \right) r_p > \sum_{i=1}^{N} \lambda_i \cdot \max\{\mu_{pi} - \mu_{oi}; 0\} \tag{5.2}$$

in which:

r_p is a (political) factor defined by society that specifies how much of the owner proceeds (yield) that may be attributed as an asset (or income) to society;

μ_{pi} is the expected loss to the society, in excess of owner's compensation, following the occurrence of unwanted event category *i*;

Note index p is used for public (society). It is noted that society's effective loss is its gross loss exclusive of what owner already may have covered. If the owner can justify that equation (5.2) holds then he has justified that he covers the societal loss and that the activity thus provides an added value to society. Hence, the owner is thus exhibiting corporate social responsibility. It should be noted at this point that the point of equilibrium of the equation will be different for each society considered. When considering the global society the equation becomes a representation of the political process that takes place at the IMO. Hence, in IMO act as the representative of the global society.

In the above, a time horizon of one year has been assumed. However, a time horizon different from one year and interest rates may easily be included in the definitions of equations (5.1) and (5.2).

No specific time horizon for the ship has been defined. Equation (5.2) may be validated for any design life period that the owner finds suitable for his vessel. If the owner investment has paid itself (including desired interest) in a (relatively) short period, then there may be an interest in having larger flexibility in investing in new ships that meet new technological demands. Society may have an interest in this in the sense that outdated vessels could be faced out at a higher speed.

5.2.2 Note on public restrictions on owners decision making

Risk acceptance criteria are often given in the form of bounds on the annual probability of failure in dependence of the consequence of failure measured as monetary costs or lives lost. Examples of such bounds together with indications of domains of experienced fatalities or lost capital are referred in (Bea 1990, ISSC 2000) and are shown in Figure 5.

The value of human rest, pleasure, felicity, etc. is outside rational reasoning and can for use in decision analysis involving anonymous people be set directly or indirectly only through a decision made by the political authorities. From the decision maker's point of view (that is, from the point of view of the owner of the capital producing operation) the concern is only the cost of the compensation (and the loss of reputation and perhaps goodwill) that matters. To prevent cynical exploitation of human lives for large benefits, the public is forced to impose restrictions that may require suitably enhanced utility losses to be used in the decision analysis in connection with loss of human lives and/or specify different types of probability bounds as for example bounds on related risk profiles.

The rationality problem of setting public acceptance criteria for the operation is essentially that there are two decision makers with partly conflicting settings of the preference ordering, the owner and the public. In a free society the owner has priority with respect to setting the preference ordering but the public specifies certain regulating rules to protect its interests, which besides the protection of human lives and welfare embraces the protection of public property, aesthetic values, culture, and environmental qualities of nature. Among the interests of the public is also that the public gets a benefit from the production activity of the owner through the creation of jobs and tax paying. Therefore the public should not impose too onerous restrictions through the acceptance criteria.

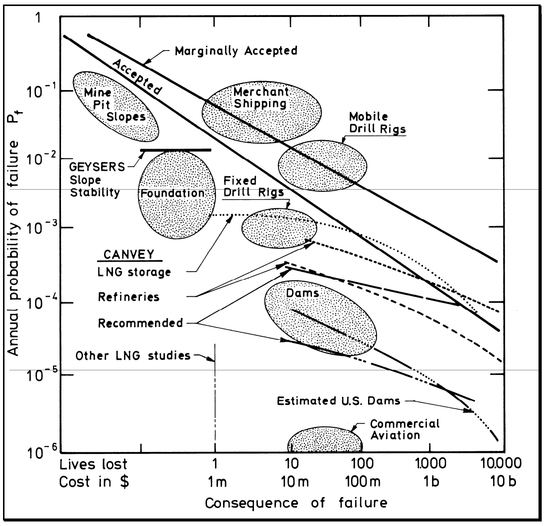


Figure 5: Domains of experienced fatalities and costs versus annual occurrence probability for different types of engineering structures.

The following considerations on basic principle illustrate a rational way to guide the setting of public acceptance criteria, (Friis-Hansen and Ditlevsen, 2003):

1) Any operation that may cause damage to a population group without a counteracting benefit or compensation to the group should not be undertaken.
2) The salaries obtained by the employees in an operation are subject to tax that

contributes to cover the expenses of the society to maintain the ordinary welfare functions of the society.

3) The damages from severe adverse events related to the operation are in principle not compensated by the salary taxes or the ordinary sale and consumption taxes. An exception is the compensation for damage caused by operations whose owners become unable to compensate or in cases where those responsible for the pollution cannot be identified.
4) Accepting the principle that the person or the body that in an operation causes the damage also must compensate for the damage, the company tax yield to the society must be sufficiently large to cover the loss of the society in excess of the owner's direct compensation (the legislative imposed compensation) after the occurrence of the damage.
5) The concept of society is independent of country borders implying that in the modelling it is not important whether the tax is paid in the one or the other country within a region that may embrace several countries. The company tax rate r as well as other parameters of the model should be considered as local or regional assessment parameters that may vary from region to region around the world.

Accordingly the model defines a procedure that in the average over all kinds of risky operations is a guide to formulate public acceptance criteria. Equation (5.2) is in accordance to the above-described basic principles.

5.3 Tier I - Goals

The mission stated in Tier 0, is to be accomplished by careful design and construction procedures, but also with proper procedures covering the other activities connected with the ship's life: operation, inspection, maintenance and decommissioning. It is noted that the present formulation of GBS covers design and construction but also touches upon those aspects belonging to the other activities that have an impact on the former two.

Tier 1 should list in detail the elements of the cost-benefit analysis outlined in Tier 0, thus defining the general goals of the analysis. Therefore, Tier1 should reflect the value setting of the losses that the shipping industry imposes upon society and the benefits generated for the society. The goals must be defined to strike a balance between the needs of the shipowner in providing these benefits to society by not being overly constrictive but at the same time ensuring that the activity is sustainable both for society and the environment. The society depends on the shipping transport and the goal setting can therefore not be completely free. Defining the overall goals is economic and political in nature. In particular as regards the costs (risks) for society, the following categories should be considered (see Figure 2 and Figure 6). The evaluation of the risk for human life, both on board and in the surroundings of the ship, including:

- evaluation of long-term damage due to prolonged exposures to unhealthy substances or actions; and
- consideration of injuries and loss of life due to accidents during construction, operation, inspection, maintenance and decommissioning of the ship.

The risk for objects including as consequences:

- damage or loss of tangible items (the ship or part of her, the transported cargo and external objects); and
- intangible items (e.g. limitations or impossibility to run activities).

The environmental risk, including consideration of pollution due to:

- the normal (systemic) activities developed on the ship during her lifetime; or
- to accidental events.

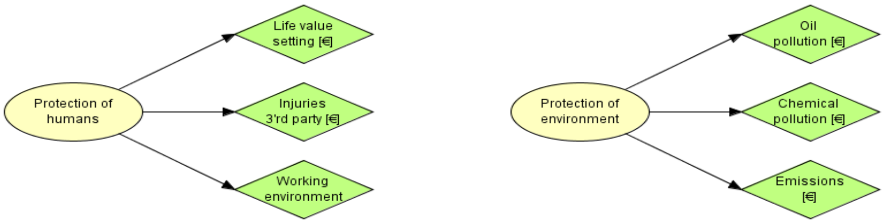


Figure 6: EXAMPLE OF Societal public losses.

As already mentioned, the value of human rest, pleasure, felicity, etc. is outside rational reasoning and can be set directly or indirectly only through a decision made by the political authorities. However, the LQI and the LQTAI principles discussed in section 3.3.3 may be used in guiding this value setting. The LQI and the LQTAI formulates a balance between the gross domestic product per capita and the work free life time (in good health). On the basis of an invariance requirement to the LQI or LQTAI the procedure arrives at a maximal social affordable life value. Hence, the principle thus implicitly accounts for benefits such as the enjoyment that may result form a product. Therefore, the acceptance principle proposed in equation (5.2) does not require an assessment of the intangible enjoyment principle. The ethical problem of needing to balance human life value and enjoyment is eliminated.

Table 4 exemplify the corresponding consequence matrices for society and the owner, respectfully. In both tables the last row presents the corresponding economic value setting of the consequences in the particular column. The societal loss is divided into two main groups: human related losses and environmental related losses. The human related losses is subdivided into the sub-groups human life value (HL), human injury value (HI), and human work environment value (HW). The environmental losses is divided into oil spill (OS), environmental damages (EM), and release of CO2 (CO2). Note that the societal loss in the table is not reduced by the possible compensation by the owner.

Similarly, the owner's consequence matrix is divided into four main groups: crew related losses, passenger related losses, material related losses, and environmental related losses. The crew related loss is divided into loss related to personal injuries (PD) and in lost work hours (LW). The passenger and the material loss only contain one group each. The environmental loss is divided into a general group labelled EM and a specific cost assessment group related to oil spill (OS). The two tables may be used in a coarse risk analysis in combination with equation (5.2).

It is noted that a problem appears when considering pollution events occurring far away from populated areas such as in the Arctic's. Rational rules to formulate public risk acceptance criteria for operations in such remote regions possibly do not exist because of the difficulty of assessing the loss of value by harming the wild life. In stead a codex of decent behaviour might be defined by ethics imposed by international conventions and laws. Possibly the value of lack of good will in the market for the products of the operation can be used as basis for the owners optimization of the level of risk?

A deeper discussion on the value setting is given in sections 6 and 7 of this report.

5.4 Tier II (functional requirements for the structural design and the construction of ships)

Tier II should include a list of functional requirements (in particular for structural design and construction, in general for design) aimed at obtaining the control of the risks listed at the upper level.

5.4.1 General concepts

The general arrangement of the structures of ships shall be aimed at minimising the interference with cargo loading, unloading and transport and at facilitating all operations performed on board, including inspection and maintenance. Ergonomic design is a means to achieve this functional requirement. Continuity in the structure shall be sought in order to avoid undue stress concentrations, creating risk of damage and degradation.

Robustness is also required to ensure that modest deviations between design and actual scenarios do not imply major differences in consequences. A means to implement robustness in the structure is to apply redundancy so that local failure of single structural elements does not propagate automatically to larger portions of the structure.

5.4.2 Structural capacity verification

In order to achieve the goals, the structural design of ships shall be performed with reference to design scenarios, which are aimed at representing realistically the most significant situations the structure will possibly experience during her lifetime. Each design scenario implies the definition of design quantities such as:

1. loads, representative of environmental and operational conditions which the ship structure is exposed to;
2. accidental damages occurred to the structure according to the scenario (including the state 'intact'= no damages);
3. degradation, as a result of environmental and operational actions occurred in the past which limit the performances of the structure;
4. capacity of the structure, which relates the loads to the response in given damage and degradation situations. Capacity is also dependent on the possible deviations of the actual scantlings of the structure from the nominal ones; and
5. performance to be achieved by the structure in the specific scenario.

Table 3
An example of a consequence matrix for society

Society		Negligible	Minor	Significant	Serious	Severe	Catastrophic	Disastrous
Consequence Class	Abbreviation	3	4	5	6	7	8	9
Human	HL				1 fatality	2-10 fatalities	10-100 fatalities	> 100 fatalities
	HI	Bruises and minor damages that do not require hospital treatment	1 injury requiring hospital treatment	Several incidents requiring hospital treatment	Several incidents requiring hospital treatment. Disabilities			
	HW	Medical treatment and first aid cases	Restricted work accidents - An accident where an individual is unable to perform normally assigned work functions for a period	An accident where an individual is unable to carry out any of his duties or return to work on a scheduled work shift on the day following the injury. 1 disabled	Several incidents requiring hospital treatment. 1 disabled			
Environment	OS		< 50 l	0.05-1.4 ton	1.4 - 44 ton	44 - 1400 ton	1400 - 45000 ton	> 45000 ton
	EM		None/negligible	Minor environmental damages. Restored within days	Serious environmental damages. Restored within weeks	Serious environmental damages. Restored within months	Critical environmental damages. Takes 1-2 years to restore	Catastrophic environmental damages. Takes several years to restore
	CO2	0-3.000 t/y	3.000 - 30.000 t/y	30.000 - 300.000 t/y	300.000 - 3 mil t/y			
Monetary value [Euro]		1.000	10.000	100.000	1.000.000	10.000.000	100.000.000	1.000.000.000
Acceptability per year		Negligible	Negligible	Tolerable	Unwanted	Unacceptable	Unacceptable	Unacceptable

Table 4
An example of an owner's consequence matrix

Owner		**Negligible**	**Minor**	**Significant**	**Serious**	**Severe**	**Catastrophic**	**Disastrous**
Consequence Class	**Abbreviation**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Crew	PD	Medical treatment and first aid cases	Restricted work accidents - An accident where an individual is unable to perform normally assigned work functions for a period	An accident where an individual is unable to carry out any of his duties or return to work on a scheduled work shift on the day following the injury. 1 disabled	Several incidents requiring hospital treatment. 1 disabled	1-10 killed	More than 10 killed	
	LW	0-1 lost work hours	1-10 lost work hours	10-100 lost work hours	100-1000 lost work hours	1 year or more lost		
Passenger	ND	Uncomfortable, insecurity	Bruises and minor damages that do not require hospital treatment	1 injury requiring hospital treatment	Several incidents requiring hospital treatment	Several incidents requiring hospital treatment. 1 disabled	1 or more killed	
Material	MK		Minor repairs that can be done immediately by own crew	Repairs that takes several days to carry out	Damages that takes weeks to repair and will affect the system	Damages that takes months to repair and cause serious consequences	Very large material damages	Significant parts of the system destroyed
Environment	EM		None/negligible	Minor environmental damages. Restored within days	Serious environmental damages. Restored within weeks	Serious environmental damages. Restored within months	Critical environmental damages. Takes 1-2 years to restore	Catastrophic environmental damages. Takes several years to restore
	OS		< 50 l	0.05-1.4 ton	1.4 - 44 ton	44 - 1400 t	1400 - 45000 t	> 45000 ton
Monetary value		100	1.000	10.000	100.000	1.000.000	10.000.000	100.000.000
Acceptability per year		Negligible	Negligible	Tolerable	Unwanted	Unacceptable	Unacceptable	Unacceptable

A structure is properly designed with respect to a design scenario if its capacity is sufficient to achieve the required performance. The scenario defines the loads and the conditions of damage and degradation that the structure should be able to sustain. All the elements of the verification can be expressed in probabilistic or deterministic terms.

The definition of the scenarios needs to be realistic and coherent. This applies in particular to the definition of loads and of degradation effects and inherent probability levels. To ensure coherence in the definition of environmental loads, reference environmental conditions are to be set in connection with design scenarios. In particular:

- Design loads will be specified with reference to design scenarios. This includes loads depending on the design environment (e.g. wave, wind, current, ice) and those depending on design operational conditions (e.g. loading condition, speed, and heading). Each type of load will be identified in terms of amplitude, number of cycles or probability level, associated to design time spans selected according to the design scenario formulation.
- The state of the structure as regards accidental damage (e.g. intact, flooded), is to be defined in connection with the other elements of the scenario, in particular loads, performances required and time reference.
- The state of structure with reference to degrading effects (e.g. corrosion, fatigue, wear) shall be set at realistic design values taking into account the selected time reference for the scenario, active and passive means to prevent degradation, the selected time reference for inspections and the reference policy for maintenance. Among the passive means to prevent corrosion, coating and corrosion additions are to be considered.
- The structural capacity of the structure is to be assessed also with reference to the possible deviation between actual scantlings and real ones, which depend on checks during construction.
- The performances required of the structure may include survival or absence of permanent damage or limit deformations as appropriate for the design scenario.

5.4.3 Functional requirements for construction

Construction procedures shall be defined in order to achieve the general goals in the construction phase. During construction, inspections are to be undertaken to ensure that, for both the single structural elements and the assembled structure, materials and geometrical characteristics are coherent with the design characteristics. The inspection policy influences the deviations between actual and nominal scantlings. This shall be taken into account in the definition of realistic conditions for evaluating the capacity of the structure.

5.4.4 Maintenance requirements

Inspection and maintenance are the means to control the degrading effects that affect unavoidably the ship's structure. They are aimed at keeping the actual degraded conditions of the ship close to the design degraded conditions in which the scantlings of the structure are checked.

The inspection plan and maintenance policies as regards the substitution of parts of the structure with advanced degradation conditions need to defined at a design phase, as they have an impact on the definition of reference conditions for the structure in the design scenarios.

The coarse risk analysis consists of the following main groups:

Fire

- Oil leakage on hot surfaces
- Explosion in crank case
- Self-ignition of racks
- Short-circuit in workshop
- Fire in main switch board
- Fire during hot work (welding)
- Catastrophic fire – escalation of one of the above
- Fire in accommodation
- Fire in galley
- Fire in ventilation shaft

Propulsion and manoeuvring

- Collision at open sea
- Grounding
- Failure of autopilot
- Failure of joystick

Delays

- Plate cooler stuffed up
- Sea filter stuffed up
- Sea boxes stuffed up
- Landing unfinished

5.5 *'Goal-Tree-Success-Tree' (GTST) Framework*

5.5.1 General application

Once the overall Goal (Tier 0), the sub-goals(Tier I) (also see Figures 2 and 5) and the Functional Requirements (Tier II) for the design, construction and operation of any ship-type are identified, it sets the basic objectives of Functional Modelling approach for a very systematic hierarchical break-down of the system requirements for the ship-type under consideration. This approach has been around for a number of years for complex industrial systems including nuclear, process and even IT industries for design of fail-safe systems incorporating supervision and control. Applications also include systematic break-down and analyses for design for producability of ships (Ring *et al.*, 2001). A proposal for using this approach was proposed in a submission from India to IMO in MSC 77 (IMO, 2004e). The basic application of GTST for Goal Based Standard can be modelled after the procedure given by Modares, 1998.

5.5.2 GTST concept

The GTST is a functional decomposition framework as indicated below in Figure 7. The main purpose of this decomposition, as in case of the GBS, is to define the physically meaningful functions, realization of which assures attainment of the designated apex goal. The goals and the functions of the system are represented by the goal tree part of the resulting model, and the physical structure and the relationships among variables (i.e. performances) are treated by the success tree part of the model.

In the GTST method, the ‘Goal-Tree’ for a system is constructed by decomposing the overall goal of the system into a set of necessary and sufficient sub-goals, and continuing the task of decomposition for each sub-goal until physical components are satisfied. At this point a success tree for that particular sub-goal begins. In order to construct the success tree, all different paths by which the sub-goal is attained need to be represented.

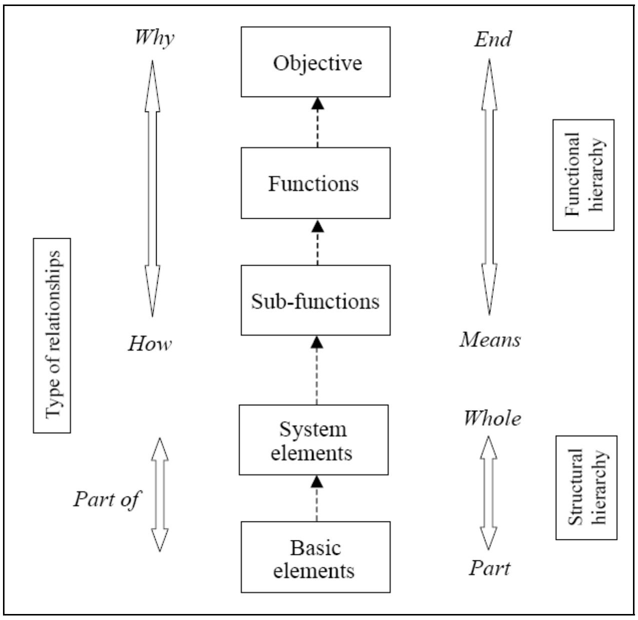


Figure 7: Conceptual GTST Framework

In the GTST model of the complex system, the degree to which each sub-function can influence the achievement of the parent function is not explicitly indicated; hence, the decomposition does not describe the ‘degree’ of the relationship, i.e. the extent to which the parent function will be achieved. This should be obtained from reliability based or heuristic formulations. However, looking up from any function / sub-function one may describe ‘why’ the function / sub-function is needed.

This underlines the need for sound understanding of physical laws, operational conditions, application of preventive/mitigating safety & security procedures, human interactions / interventions and role of parts of a complex system when developing a GTST model. The decomposition can proceed to a point where system functions have been sufficiently described such that the purpose of each physical part of the system (i.e.

human behaviour, software, equipment, components and material) can be explicitly described. In view of the design of ships involve a complex set of functional variables, it may not be possible to eliminate all uncertainty in formulating the exact relationship between sub-functional goals in realising their overall goals; however, the goal-tree part of the GTST can comprehensibly account for the understanding of the system and the relationship can be developed through heuristic or statistically corroborated expert advice.

The 'Success-Tree' describes the physical functions in achieving the target objective of the functional goal. Since, some of the basic physical aspects of the system objective can be achieved through redundancy and component reliability, the utility of the success-tree exists in decomposing the structure into its basic components. Success-tree analysis is the complement of fault tree analysis technique. Instead of determining all the possible failure scenarios, all the functions needed in order for the system to function properly are modeled in the success-tree. However, unlike in fault tree where the 'AND' and 'OR' gates are arranged to model the failure of the system, here the components are designed to achieve the 'success' objective. Therefore, the 'AND' / 'OR' gates are simply reversed in a fault-tree to arrive at the corresponding 'success-tree'. For a system to function, the series of events that have to take place are usually easier to define than all the possible failure scenarios. This can greatly simplify the process of building an adequate model with the assurance that all the important aspects of the system have been taken into account. The normal calculations involving gates of the fault-tree can be similarly carried out for the 'success-tree' as well.

In view of the complexity of the system, it is not accurate enough to decompose the system into 'Tier' structure, and a better insight can be obtained through a tree structure. This also makes it amenable to adapting risk-based or 'safety-level' inputs. The GTST model therefore takes a form described in Fig.8.

It should be pointed out that the GTST structure depicts the main functions in a ship design, construction and operation; and in terms of the current understanding, only the design & construction activities. The supporting functions e.g. training, procurement, verification (inspection) at various stages of the main functions are the facilitating functions. These activities are to be carried out for the entire hierarchy of the GTST as applicable and are dependent on the main system. The facilitating functions / activities are also decomposable into sub-functions and basic elements covering the main functional hierarchy. These are to be incorporated through a logical relationship between the main functions/elements and the facilitating functions / elements. The conceptual relationship between the main & facilitating functions are indicated in Fig. 9.

It can be readily seen that aspects of 'Allowable Stress', 'Design Transparency', 'Design Life' etc. have been duly taken out of the main function covering 'design-construction-operation'. While these issues are indeed important they constitute the verification and appraisal activities carried out by the external agency (e.g.

classification society, statutory body, insurance company, etc.). They can be modelled in their respective GTST framework thereby assuring their efficacy in the right context.

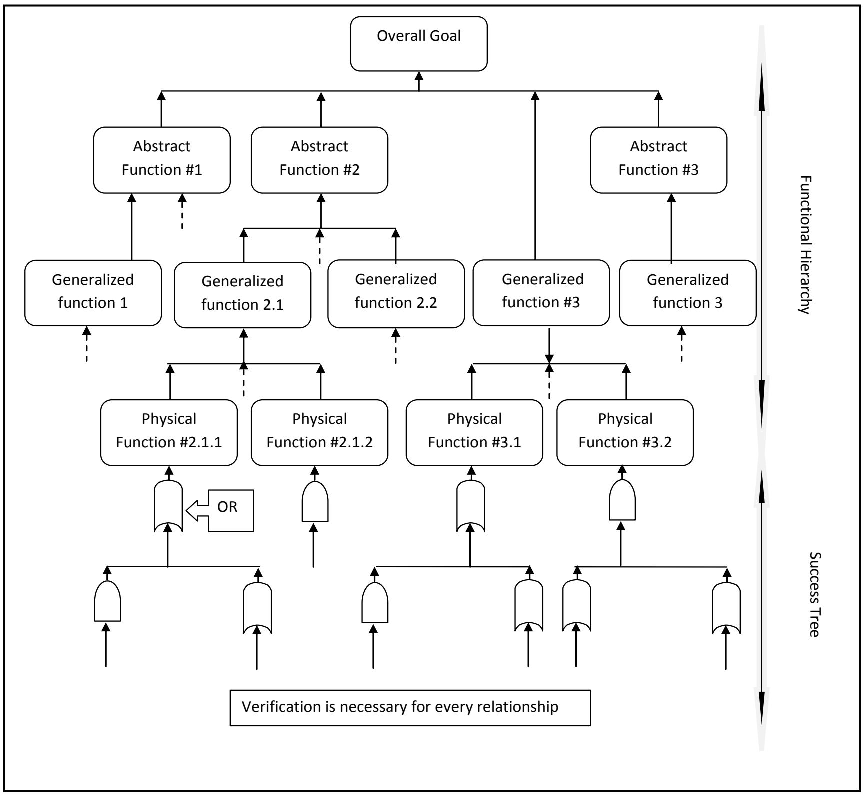
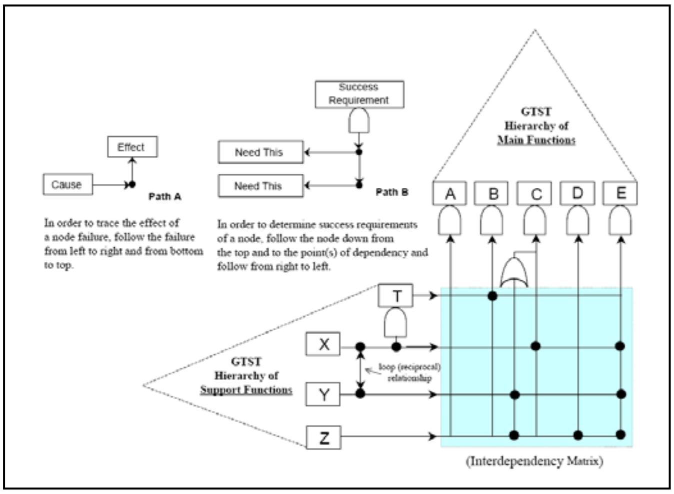


Figure 8: Typical GTST Layout. (Modares, 1998)



In order to trace the effect of a node failure, follow the failure from left to right and from bottom to top.

In order to determine success requirements of a node, follow the node down from the top and to the point(s) of dependency and follow from right to left.

Figure 9: Integrated Main Function & Support Function Framework. (Modares, 1998)

5.5.3 Benefits of the GTST framework

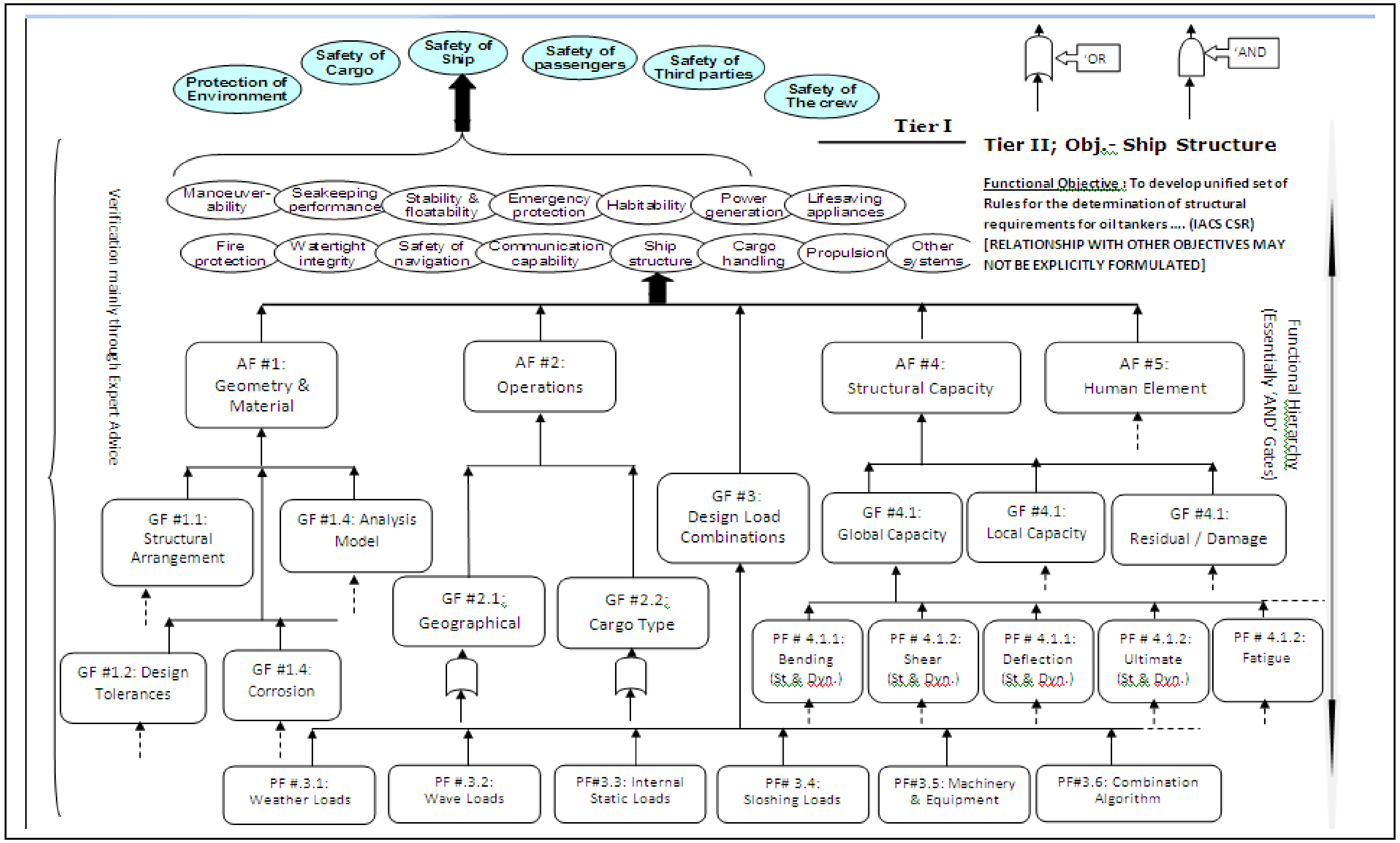
The GTST framework is more accurate and versatile than the Tier-based framework in respect of the following attributes:

i. It renders the current knowledge of the 'design-construction-operation' aspects of the regulatory provisions in a very logical framework, allowing the existing instruments to be incorporated in their appropriate context and relevance.
ii. It is immediately possible to identify the 'missing' elements of the current prescriptive provisions and incorporate them in a manner that provides the option to the either in 'preventive' or 'mitigating' usage to assure intended overall objective.
iii. By suitable assignment of the effectiveness factor of the existing basic provisions of current regulatory instruments, it is possible to ascertain the attainment of the 'Functional Objective' in clear probabilistic terms through standard calculation procedure. This helps establishing the 'bench-mark' of the existing set of regulations to calibrate the 'Functional Objective' for the GBS.

In addition, the GTST framework allows differentiation of the supporting activities e.g. classification society and statutory verification, training, legal issues etc. from the entire main function of 'design-construction-operation' aspect of product life cycle. It allows these supporting functions to be modelled in a GTST framework to examine their influence on the main function through logical intersection of their actions on the relevant relationship nodes of the main function.

The framework is in a nascent stage for maritime application for GBS, and needs to be evolved further to ensure sufficiency of this application. The attraction of this framework can be viewed in the system-based modelling and analysis, making it equally beneficial for all disciplines of ship design i.e. naval architecture, structure, machinery system, electrical and control network, noise & vibration, etc.

5.5.4 GTST application is presented based on the IACS CSR Model for a Tanker (IMO, 2007h)



6. SUSTAINABILITY: SHIPPING AND OFFSHORE

The increased concern at the impacts of industrial activity on the environment, and the widespread acceptance of the reality of climate change, is forcing the concept of sustainability to be considered in all aspects of human activity. Consideration of the sustainability of shipping is now emerging as an area of concern, it will clearly become a significant issue in the months and years ahead. Before discussing the lessons learnt from early studies in this area it is worth clarifying what is meant by sustainability. Sustainable activities are those that fulfil society's present needs without impacting on the ability of future generations to provide for their needs. It should also be recognised that although sustainability is now considered to refer to the environment, sustainable activity must also be sustainable in economic and social terms. In other words actions designed to improve environmental sustainability must also be affordable and acceptable.

Transportation is the foundation of the world's economy, and it is the shipping industry that dominates in the transportation of goods with 90% of world trade being waterborne. Of the many modes of transportation it is also shipping that is the most efficient in the use of energy, as evidenced in the updated External Cost of Transport report (Zurich and Karlsruhe, 2004) which suggests that the industry can claim it is the least in need of improvement in sustainability performance. However the sheer magnitude of the industry necessitates that in the years ahead it moves to increasingly sustainable ways of operating. The difficulty is that although the concept of sustainability is easily understood in theory, it is not easy to identify practical actions that will make a significant impact. This is because little work has been done to identify just what a more sustainable shipping industry would look like.

6.1 Current work on Ship Sustainability

At Newcastle University in the UK, one group of researchers have been working in this area for several years. They have been examining both detailed elements that can contribute to the sustainability of shipping operations, such as the use of ballast water (Cabezas-Basurko *et al.*, 2007) and more wide ranging studies on how to reduce the global impact of specific marine activities, such as recreational boating (Landamore *et al.*, 2007). The results of these studies are leading to efforts to improve the sustainability performance of specific activities, but they can also provide insights that can be generalised more widely, and these will be briefly discussed here.

Firstly the scale of environmental impact assessments has to be recognised. Sustainability studies should take account of the entire life cycle of the operation being considered, so when considering shipping it is not just the operational phase that is of concern, but the material sourcing, the construction, the operation and the decommissioning of ships that has to be considered. Risk assessment has for many years considered the impact of rare catastrophic events, such as oil spills. However, of principal interest in sustainability studies are the inevitable impacts of the full life cycle of shipping activities, including such things as: fossil fuel usage and depletion of other natural resources; emissions affecting climate change and those that are classed as respiratory organics and inorganics; land use and degradation; and eutrophication and acidification of waterways.

The effort involved in one study can be immense, but if the study is intended not just to validate an existing design or operation, but to guide the designer and operator to improved solutions, then a series of such studies need to be undertaken. As there are numerous alternatives to almost every aspect of a design or operation the number of variants that could be studied is virtually infinite. A significant challenge in attempting to improve sustainability performance is to identify a small set of alternatives that can be usefully studied within a given budget and timescale, and that will provide real answers, not just more questions. Developing methodologies to identify this 'useful' set of alternatives is an interesting research problem in its own right, and one the research groups at Newcastle around the world are advancing.

In the years ahead all industrial activity is going to be expected to develop in directions that increase sustainability. Despite the shipping industry's indispensable contribution to he global economy, and the relatively efficiency of transportation by sea, this sector will not be immune from these pressures. Sustainability studies are being undertaken in the marine sector, with the European Commission including sustainability elements in several of its recently funded projects, but more needs to be done before strategic policies and tactical approaches can be widely established. These studies have to look at all aspects of sustainability, including the analysis of life cycle costs and societal impacts, if the pursuit of truly sustainable operations is to be at the heart of future decision making.

6.2 State of the art analysis of environmental impact

6.2.1 Life cycle analysis

The impact of any activity can be divided into three elements, financial, societal, and environmental, as shown in terms of risk in Table 1. To usefully assess the impacts an analysis has to be undertaken over the entire lifecycle of the activity, and include future impacts that are felt after the culmination of the activity itself. The advantageous and detrimental impacts to society (such as loss of life) and to the environment have to be taken into account when evaluating the worth or viability of any proposed activity, however procedures to equate these impacts with the financial benefits are still being formulated.

Life cycle analysis of the financial impact of any activity, such as the construction and operation of a vessel, is well understood, with discount rates being used to take account of the time value of money. Societal impacts have also been discussed for many years, with procedures for valuing human life in monetary terms established. Full life cycle analysis of the environmental impact of any activity is also maturing with agreed procedures being established and embedded in software. However in the environmental case further work has to be done to establish procedures to combine such environmental analysis with conventional cost/benefit analysis. Environmental impacts can be local or global, and have to be considered in many ways, such as fossil resource depletion, land degradation, respiratory impact, radiation etc. The relative importance of these diverse impacts has not been agreed or formulated in a single scale, although current perception is that carbon dioxide emissions are the most significant element due to the threat of climate change. Procedures that have been developed evaluate environmental impacts in some form of ‘eco-unit’, and not in financial terms.

Environmental life cycle analysis is intended to be used to assist the decision making process regarding alternative activities, or the acceptability of an activity. However while such analysis is undertaken in isolation, and without linking it to financial analysis, only regulatory pressure can be used to ensure future activity is acceptable. Market forces will only come into play if eco-units can be given monetary value. This will then enable conventional financial analysis to include environmental impacts. Even then the fact that many impacts, and possibly the most serious, are in the distant future means that discounting procedures can make them appear trivial from the perspective of the present. However a failure to take appropriate action now will be considered reckless from a future perspective.

A simple financial analogy can be found in the alternative operational modes off pension schemes: the present generation can support today’s aged, or the present generation can invest to support themselves in the future. In sustainability terms this is the choice between paying today for the environmental of past activity, or investing today to pay for future impacts of current activity. If the second strategy is adopted then for every activity there is a real financial choice to be made: is it more economical to invest in measures that will reduce or prevent future environmental impact, or is it more economical to invest in other activities so that sufficient funds will be available in the future to compensate for the environmental impacts.

6.2.2 *Ecological footprint – Triple III*

The Inclusive Impact Index (III) or “Triple-I” was proposed by the Inclusive Marine Pressure Assessment & Classification Technology (IMPACT) Committee of the Japan Society of Naval Architects and Ocean Engineers in 2006 as follows (Otsuka, 2006):

$$III = (EF + \alpha ER) + \frac{\sum EF_{Domestic}}{\sum GDP}(\beta HR + C - B) \tag{6.1}$$

where:

EF: Ecological Footprint;
ER: Ecological Risk;

HR: Human Risk;
C: Cost;
B: Benefit;
$EF_{Domestic}$: total ecological footprint of an area or a country; and
GDP: Gross Domestic Product of an area or a country.

An Ecological Footprint[15] as defined by Wackernagel and Rees (2007) is a means of gauging humanity's impact upon the natural environment by a standardized measure of the consumption of renewable resources (or equivalents). Ecological footprints (EFs) are based on the premise that it is possible to measure humanity's reliance and impact upon the natural world through a simple accounting of the resources consumed, and more specifically the "land" from which they are derived. The ecological significance of these values derives from the fact that they make it possible to "balance the books", as it were:

$$Remainder = Biocapacity\ -\ Ecological\ Footprint \qquad (6.2)$$

where each term is in global hectares ((gha) is 1 hectare is approx. 2.5 acres) a form of area normalized for average productivity. Also, in equation (6.1), α is a coefficient that changes the units in order to express the ecological risk in gha (αER) and β is a coefficient to express the units of human risk in money (βHR).

By using the concept of Triple-I, Murai and Yoan (2008) carried out an inclusive environmental assessment for construction of an offshore airport. The study was done for the future expansion of Tokyo Haneda airport. The candidate methods of construction were a floating method and a reclamation method. The Triple-I of each option was evaluated as shown in Table 5.

As for the floating construction method, the production of the 5.89×10^5 tons of steel needed for the project and its transportation to the construction site were examined and the generated CO_2 was evaluated. The bio-capacity to consume the CO_2 was estimated to derive the EF. A similar process was carried out to evaluate the EF for the reclamation method. The EFs for the construction of the offshore airport by the two methods were compared as shown in Figure 10. For the water depth of less than 20 meters it was concluded that the reclamation method is advantageous from the viewpoint of the ecological footprint.

By constructing the offshore airport, a productive sea area is transformed to an artificial area, which means that its bio-capacity will be lost. This effect was also estimated in the assessment. CO_2 discharged from the airplanes was then estimated and was counted as a part of the ecological footprint. Human risk (HR) was estimated in terms of the expected accidents of civilian airplanes, and the risk was evaluated by using the average value of a life insurance payment. The cost of the construction of the airport

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[15] This definition of *ecological footprint* can be found at http://pthbb.org/natural/footprint/.

by the floating method and by the reclamation method was taken from the estimated costs provided by the contractors, ¥ 600 billion for both methods.

Table 5
Evaluation of the triple-I.
(Some components were evaluated as the mean value for a year.)

		Item		**Value [unit]**
III	**EF**	EF of offshore airport construction	Floating method	3.03×10^{5} [gha]
			Reclamation method	2.35×10^{5} [gha]
		EF caused by the change of the land		3.44×10^{2} [gha/year]
		EF caused by the increase of CO_2 (mainly from the airplanes)		5.64×10^{5} [gha/year]
	HR + C - B	HR		1.94×10^{8} [¥/year]
		$C-B$		-4.81×10^{9} [¥/year]
		$HR+C-B$		-4.61×10^{9} [¥/year]
		$\frac{\sum EF_{Domestic}}{\sum GDP} \to \frac{EF_{Japan}}{GDP_{Japan}}$	$EF_{Japan}=7.47\times10^{8}$ [gha/year]	1.61×10^{-6} [¥/Yen]
			$GDP_{Japan}=4.65\times10^{14}$ [¥/year]	
		$\frac{EF_{Japan}}{GDP_{Japan}}(HR+C-B)$; $\beta=1$		-7.42×10^{3} [gha/year]
		III excluding the EF by the effect of CO_2 from airplanes		-7.07×10^{3} [gha/year]
		III including the EF by the effect of CO_2 from airplanes		5.57×10^{5} [gha/year]

The life of the structure was assumed to be 100 years; from the initial construction cost and the maintenance cost, the necessary cost (C) per year was estimated. The main part of the benefit (B) was the income from the airplanes' landing fees. To obtain the Triple-I index, the total EF of Japan and Japan's GDP were used. From Table 5, it is seen that the environmental load caused by the discharged CO2 from the airplanes is significantly large and dominates the results.

To make the project feasible it is necessary to compensate for the EF component caused by the generated CO_2 from the airplanes. If we convert the EF (gha) to the unit of money by GDP_{Japan}/EF_{Japan} and divided it by the estimated number of passengers, we obtain ¥ 15,800 per passenger. This may be added as a surcharge for each passenger to compensate for the discharge of CO_2 from airplanes. Assuming that this compensation is done, the changes of the triple-I indexes over time are compared in Figure 11. The triple-I becomes negative after about 42 years from the completion of the floating airport about 33 years for the reclamation airport. This indicates that the construction of the airport is realized by "borrowing" about 40 years of bio-capacity in advance.

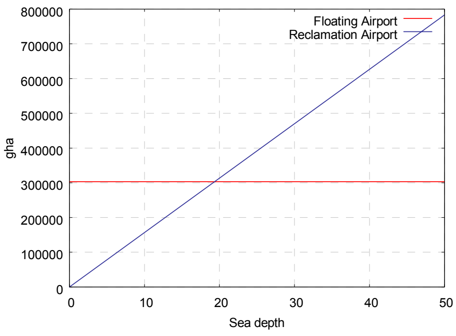

Figure 10: Change of gha by construction of an offshore airport

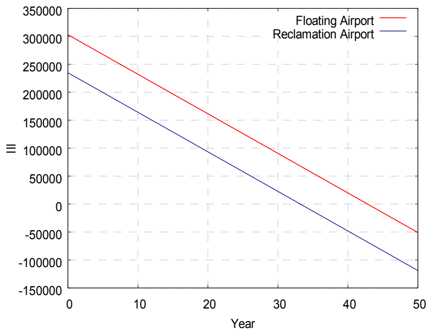

Figure 11: Change of triple-I index by the construction of the offshore airport

6.2.3 Greenhouse Gas (GHG) stabilization developments at IMO

The United Nations (UN) adopted United Nations Framework Convention on Climate Change (UNFCCC) on 9 May 1992, aiming at stabilizing greenhouse gases (GHG) in atmosphere and preventing harmful impact of human behaviours of excessive emission of such gas.

In order to pursue the responsibilities specified in UNFCCC, a mandatory framework was developed and adopted the third Conference of Parties (COP 3) in Kyoto, known as the Kyoto Protocol. Article 2 of the Kyoto Protocol states:

> *"The Parties included in Annex I shall pursue limitation or reduction of emission of greenhouse gases not controlled by Montreal Protocol from aviation and maritime bunker fuels, working through the International Civil Aviation organization and the International Maritime organization, respectively."*

This means that Parties included in Annex I of UNFCCC have responsibility to limit and reduce the emission of GHG from for maritime bunker fuels through IMO.

In this aspect, COP 3 adopted following decision that GHG emission from international trading ships shall not be included in the emission report of individual parties, but shall be reported separately, and that methodological issues related to such reporting should be developed in cooperation with IMO.

IMO Assembly, at its 23rd session in November 2003, considering the request of UN, adopted Resolution A.963 (23), IMO Policies and Practices related to the Reduction of Greenhouse Gas Emissions from Ships, which requests IMO *Marine Environmental Protection Committee* (MEPC) to develop GHG emission baseline, GHG emission indexing and the evaluation of technical, operational and market-based solutions for international trading ships.

Under this resolution A.963(23), MEPC, at its 53rd session in 2005 "Interim guidelines for voluntary ship CO_2 emission indexing for use in trials" as MEPC/Circ. 471. This would apply to existing ships in operation. MEPC also agreed to improve these interim guidelines at the 58th session of the MEPC in 2008.

IMO has noted the activities of UNFCCC, in particular at COP13 Conference (Bari Conference), that UNFCCC will develop the next binding instruments for GHG emission reduction after 2012, and recognized that IMO must bring its clear actual action plan for control and reduction of GHG emission from international trading ships to COP 15 in December 2009 in Copenhagen. Under this circumstances, MEPC agreed, at its 57th session in 2008, that it develops "new ship design CO_2 index" and possible mandatory application of the index to new ships.

The working group on GHG under MEPC met in Oslo in June and October 2008 and developed a draft of new ship design CO_2 index called the *Energy Efficiency Design Index* (EEDI), which includes the following calculation method where the attained new ship design CO_2 index can be expressed as follows (IMO, 2008d):

$$\frac{\left(\prod_{j=1}^{M} f_j\right)\left(\sum_{i=1}^{NME} C_{FMEi}\ SFC_{MEi}\ P_{MEi}\right) + \left(\sum_{i=1}^{nPTI} P_{PTIi} - \sum_{i=1}^{nWHR} P_{WHRi}\right) C_{FAE} SFC_{AE} - \left(\sum_{i=1}^{neff} f_{eff} P_{eff} C_{Feff} SFC_{MEi}\right)}{fiCapacity \ \times \ V_{ref} \times f_W} \tag{6.3}$$

where;

C_F is a non-dimensional conversion factor between fuel consumption measured in g and CO_2 emission also measured in g based on carbon content. The subscripts $_{\mathrm{MEi}}$ and $_{\mathrm{AEi}}$ refer to the main and auxiliary engine respectively;
V_{ref} is the design ship speed, measured in nautical miles per hour (knot), on deep water in the maximum design load condition of the ship;
Capacity is the design capacity of total payload of the ship as follows:

a. for dry carriers, tankers, gas carriers, container ships, ro-ro cargo and passenger ships and general cargo ships, deadweight should be used as *Capacity*; or
b. for passenger ships, gross tonnage in accordance with the International Convention on Tonnage measurement of ships 1969, Annex 1, regulation 3 should be used as *Capacity*.

P is the designed power of the main and auxiliary engines, measured in kW. The subscripts ME and AE refer to main and auxiliary engine, respectively. The summation on I is for all engines with the number of main engines (*NME*) and number of auxiliary engines (*NAE*);
$P_{ME(\mathrm{i})}$ is 75% of the rated installed power MCR for each main engine (i);
$P_{PTI(\mathrm{i})}$ is 75% of the rated power consumption of shaft motor (i);

P_{WHR} is the rated electrical power generation of waste heat recovery system at $P_{ME(i)}$;

P_{eff} is the main engine power reduction due to innovative energy efficient technology;

P_{AE} the required auxiliary engine power to supply normal maximum sea load including necessary power for machinery, systems, equipment and living on board in the condition where the ship engaged in voyage at the speed Vref under the design loading condition in Capacity;

a. for ships with main engine power of 10,000 kW or above, PAEi is defined as:

$$P_{AE(MCRME>10000kW)} = \left(0.025\ x \sum_{i=1}^{nME} MCR_{MEi}\right) + 250 \tag{6.4}$$

b. for ships with main engine power of less than 10,000 kW, PAEi is defined as:

$$P_{AE(MCRME<10000kW)} = 0.05\ x \sum_{i=1}^{nME} MCR_{MEi} \tag{6.5}$$

V_{ref}, Capacity, and P should be consistent each other, and should represent the designed sea-going condition of the ship. The parameter V_{ref}, Capacity and P will be defined and decided at the contract between the ship owner and the ship designer or shipbuilder;

SFC is the designed specific fuel consumption, measured in g/kWh, of the engines at the power output of P determined by either 6.4 or 6.5 above. The auxiliary engine Specific Fuel Consumption (SFC_{AE}) is that recorded on the Engine International Air Pollution Prevention Certificate (related to NO_x emissions) at the engine's 50% of P_{AEi} MCR power or torque rate;

f_i are corrections to account for ship specific design elements. For ice classed vessels the f_i coefficient is determined by standard f_i 'table/curve' yet to be developed;

f_W is a non-dimensional coefficient indicating the decrease of speed in representative sea conditions of wave height, wave frequency and wind speed (e.g. Beaufort Scale 6);

f_{eff} is the availability factor of any innovative energy efficient technology;

f_i is the capacity factor of any technical/regulatory limitation on capacity, and can be assumed one (1.0) if no necessity of the factor is granted; and

the reduction factors are:

f_{eff} is the availability factor of any innovative energy efficient technology;

P_{eff} is the main engine power reduction due to innovative energy efficient technology;

SFC_{eff} is the specific fuel consumption of the main engine at P_{eff}; and

CF_{eff} is the CO_2 conversion factor of the fuel used in the main engine.

The last meeting of the MEPC in October 2008 also addressed the early drafting of interim guidelines for the method of calculation of the EEDI and guidance on best practices for fuel-efficient operation of ships.

6.3 Offshore Safety Assessment

After the tragic accident at the *Piper Alpha* platform in 1988, where 167 of the 226 people present at the platform lost there lives, a public inquiry led by Lord Cullen (DOE, 1990) resulted in a change of the safety approach of offshore installations in the UK from prescriptive type regulations to a goal setting regime. Several other major offshore nations, including Norway and the Netherlands, have adopted in the mean time a similar goal setting regime. In this report we follow the UK philosophy and guidelines and procedures.

The goal setting regulations require that for each offshore development a 'Safety Case' is performed. The background, guidelines and procedures of a safety case can be found in various publications on the website of the UK Health and Safety Executive (HSE): http://www.hse.gov.uk/offshore/index.htm. An overview of the offshore safety regime and a comparison with Formal Safety Assessment procedures for ships is given by Wang (2002, 2006) and Wang and Trbojevic (2007).

The HSE framework for decisions on the tolerability of risk is based on the as low as is reasonably practicable (ALARP) principle, where there are three regions: (a) intolerable, (b) ALARP, and (c) broadly acceptable.

Offshore operators must submit operational safety cases for all existing and new offshore installations to the HSE Offshore Safety Division for acceptance. To be acceptable, a safety case must show that hazards with the potential to produce a serious accident have been identified and that associated risks are below a tolerability limit and have been reduced ALARP. It should be noted that the application of numerical risk criteria may not always be appropriate because of uncertainties in inputs. Accordingly, acceptance of a safety case is unlikely to be based solely on a numerical assessment of risk.

After several years of experience of employing the safety case approach in the offshore industry, the safety case regulations were amended in 1996 to include verification of safety-critical elements. Safety-critical elements are parts of an installation and of its plant (including computer programs) or any part whose failure could cause or contribute substantially to a major accident.

Compliance with current goal setting offshore safety regulations is achieved by applying an integrated risk-based approach, starting from feasibility studies and extending through the life cycle of the installation. Design for safety is considered to be the most important. This is achieved through stages of hazard identification (HAZID) for the life cycle of installation from concept design to decommissioning and the use of state-of-the-art risk assessment methods. In a risk-based approach, early considerations are given to those hazards that are not foreseeable to design out by progressively providing adequate measures for prevention, detection, control, and mitigation and further integration of emergency response.

The five key elements of the safety case concepts are:

1. *HAZID*. This step is to identify all hazards with the potential to cause a major accident.
2. *Risk estimation*. Once the hazards have been identified, the next step is to determine the associated risks. Hazards can generally be grouped into three risk regions known as the intolerable, tolerable, and negligible risk regions, according to the ALARP principle.
3. *Risk reduction*. Following risk assessment, it is required to reduce the risks associated with significant hazards that deserve attention.
4. *Emergency preparedness*. The goal of emergency preparedness is to be prepared to take the most appropriate action in the event that a hazard becomes a reality so as to minimize its effects and, if necessary, to transfer personnel from a location with a higher risk level to one with a lower risk level.
5. *Safety management system (SMS).* The purpose of a safety management system is to ensure that the organization is achieving the goals safely, efficiently, and without damaging the environment. One of the most important factors of the safety case is an explanation of how the operator's management system will be adapted to ensure that safety objectives are actually achieved.

The following activities characterize the development of a safety case:

- Establish acceptance criteria for safety, including environment and asset loss, if possible. These are preferably risk based but may be deterministic.
- Consider both internal and external hazards using formal and rigorous HAZID techniques.
- Estimate the frequency or probability of occurrence of each hazard.
- Analyze the consequences of occurrence of each hazard.
- Estimate the risk and compare with criteria.
- Demonstrate ALARP.
- Identify remedial measures for design, modification, or procedure to avoid the hazard altogether, reduce the frequency of occurrence, or mitigate the consequences.
- Prepare the detailed description of the installation including information on protective systems and measures in place to control and manage risk.
- Prepare a description of the safety management system and ensure that the appropriate hazard procedures are identified.

In offshore safety analysis, safety-based design/operation decisions are expected to be made at the earliest stages in order to reduce unexpected costs and time delays. A risk reduction measure that is cost effective at the early design stage may not be economically feasible at a later stage. Traditionally, when making safety-based design/operation decisions for offshore systems, the cost of a risk reduction measure is compared with the benefit resulting from reduced risks. If the benefit is larger than the cost, then it is cost effective, otherwise it is not.

To reduce risks to an ALARP level, the following hierarchical structure of risk control measures (RCMs) should be followed:

- Elimination and minimization of hazards by ‘‘inherently safer’’ design
- Prevention
- Detection
- Control
- Mitigation of consequences

Quantitative Risk Assessment (QRA) is the tool for showing risk relationships. The process of undertaking a QRA can lead to a better understanding of the important features contributing to risk and weaknesses in systems, as well as allowing a numerical estimate of residual risk to be derived. The quality of the modelling and the data will affect the robustness of the numerical estimate and the uncertainties in it must always be borne in mind when using the estimate in risk management decisions. The use of numerical estimates of risk, by themselves, can be misleading and can result in decisions that either do not meet adequate levels of safety, or overestimate the real risks. In general an approach that uses information from engineering and operational analysis, supplemented where appropriate by QRA, will lead to more robust decisions. Current safety cases are likely to make reference to the results of QRA expressed in terms of:

- *Individual Risk Per Annum* (IRPA): This is the chance of an individual becoming a fatality. An IRPA of 1 x 10^{-3} would mean for each individual, every year, there is a 1 in 1000 chance of a fatal accident.

- *Potential Loss of Life* (PLL): This is proportional to the sum of all the IRPAs. In simple terms PLL is related to IRPA by the relationship IRPA = PLL x fraction of time an individual is offshore per year/PoB. For example an installation with a PoB of 50, working 2 weeks on, 2 weeks off (fraction of time offshore per year is 0.5) with each person having an IRPA of 1 x 10^{-3} then the PLL would be 10^{-1} (10^{-3} * 50/0.5). This means that a fatality would be expected on the installation on average once in every 10 years.

Cost benefit analysis (CBA) is the numerical assessment of the costs of implementing a design change or modification and the likely reduction in fatalities that this would be expected to achieve. It suffers from the same problems as QRA when used as an input to decision-making, and therefore it should be used cautiously in support of qualitative or engineering arguments. In making this assessment there is a need to set criteria on the value of a life or implied cost of averting a statistical fatality (ICAF).

If the value of a life is set at £1 million and by implication therefore the level at which the costs are disproportionate to the benefits gained. In simplistic terms a measure that costs less than £1 million and saves a life over the lifetime of an installation is reasonably practicable, while one that costs significantly more than £1 million is disproportionate and therefore is not justified. However case law indicates that costs should be grossly disproportionate and therefore costs in excess of this figure (usually multiples) are used in the offshore industry. In reality of course there is no simple cut-off and a whole range of factors, including uncertainty need to be taken account in the decision making process.

In the offshore industry there is a need to take account of the increased focus on societal (or group) risk, i.e. the risk of multiple fatalities in a single event, as a result of society's perceptions of these types of accident. Therefore the offshore industry typically addresses this by using a high proportion factor for the maximum level of sacrifice that can be borne without it being judged ‘grossly disproportionate’; this has the effect of increasing the ICAF value used for decision-making. The typical ICAF value used by the offshore industry is around £ 6 million, i.e. a proportion factor of 6. This is approximately twice the value of US$ 3 million as proposed by IMO (2000) and IMO (2004d) for risk control options in a FSA.

Use of a proportion factor of 6 ensures that any CBA tends towards the conservative end of the spectrum and therefore takes accounts of the potential for multiple fatalities and uncertainty. Although a proportion factor of 6 tends to be used, there are no agreed standards and it is for each duty holder to apply higher levels if appropriate, for example in very novel designs.

6.3.1 Comparison Safety Case with FSA

From the description of Safety Case procedures above it is clear that there are a lot of similarities with FSA procedures for ships as described in sections 3.3.1 and 3.3.3 of the present report. The major difference is that the Safety Case is performed for each individual offshore installation and is used to optimize the safety of that particular installation or platform, whereas the FSA is applied to a generalized vessel or situation and is being used for rulemaking rather tan making decisions for an individual vessel. Reason for the difference is obvious: the number of offshore installations is small, the diversity is large and the capital investment is high, whereas the numbers of ships and similarities within one ship type are large, thus extensive safety analysis of each individual ship is out of the question.

6.3.2 Possible use of offshore experience in GBS

As the methodology and procedures used in an offshore safety case are largely in-line with procedures in a FSA for the rule-making process ship, it is proposed that the large experience gained in offshore safety cases is being considered in the development of Safety Level Approach in GBS.

6.3.3 Offshore standards

In the 2006 ISSC committee IV.1 report, a comprehensive overview is given on the development of standards for offshore structures. The harmonization as described in the 2006 report is developed further in the recent years. The work is done under the supervision of ISO / TC 67 in close cooperation with the API in the USA and these standards are publicly available[16]. Presently some 147 standards have been published (46 standards were developed in the period between 2006 and 2009) and 67 standards are under development at this moment.

All major offshore countries have agreed to adopt the ISO standards, although some nations, notably Norway, reserve the right to prescribe more stringent requirements, based on local environmental conditions[17].

The international harmonization of standards in the offshore industry is considered to be of great importance for the rationalization of the design and construction of offshore facilities, platforms and equipment.

6.3.4 Design of offshore structures

Major developments in the field of offshore structures have taken place in very deep waters, for drilling operations there is presently virtually no boundary as far as water depth is concerned and the production of hydrocarbons has reached almost a water depth of 2400 meter, and in the near future this record will certainly be surpassed. Obviously developments in these water depths can only be achieved by means of floating production platforms, and in the next sections aspects of environmental loadings and structural response of Floating Production, Storage and Offloading (FPSO) and Tension Leg Platforms (TLP) are discussed.

At the other end of the spectrum, in shallow waters, also interesting developments are taking place, in this case in the field of floating LNG (both liquefaction and offloading) plants and offshore wind farms. Rather than summarizing extensively the research reported in the last 3 years, some interesting developments are highlighted.

6.3.5 Floating Production and Storage and Offloading (FPSO)

For FPSO type platforms, especially when located in severe environmental conditions, fatigue of the hull structure and extreme loads due to green water at the bow of the

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[16] American Petroleum Institute standards: http://committees.api.org/standards/isoTC67/index.html.

[17] NORSOK standards: http://www.standard.no/imaker.exe?id=1059&visdybde=1&aktiv=1059.

vessel pose problems to the structural design.

Bergan and Lotsberg (2006) present an overview of a joint industry project, addressing the problem of fatigue capacity of FPSOs. Spectral methods are described which are becoming standard methodology for fatigue assessments of FPSOs. This methodology is well suited to numerical methods in combination with finite element representation of the global structure and structural details for response analyses. A proper link between calculated stress and fatigue capacity is required in order to achieve a reliable design. The project has generated significant amounts of numerical data as well as laboratory fatigue test data of typical ship details to improve the design basis for this.

Guedes Soares *et al.*, (2007) characterize the probability of wave impact and determining the position of impact on FPSO bow geometry. It has been found that the wave impact at the bow is highly correlated with the local wave steepness, which for very high waves incorporates second-order effects. The experimental results were used to determine how the probability of impact varies with free surface vertical velocity. It was found that the significant wave height of the sea state itself does not have significant influence on the result and a regression model was derived for the bow type in the experiments.

The proposed model for determining the probability of having an impact is based on combining distributions, adjusted a priori to the numerically generated second-order free surface vertical velocity, and the experimental probability of impact of a known certain sea state and free surface velocity. The analytical description makes it fast and easy to expand to other cases of interest and some example calculations are shown to demonstrate the relative ease of the procedure proposed. The position of the impact is determined by the nonlinear wave crests and the ship motions.

6.3.6 Tension Leg Platforms (TLPs)

The structural design of a TLP is based largely on the vast experience gained in the past decennia with semi-submersible platforms. However the design of the tendon system is relatively unexplored and requires special attention in structural research and development.

Barranco-Cicilia *et al.* (2008), present a methodology to perform a Load and Resistance Factor Design (LRFD) criterion for the design of tendons in the intact condition. The proposed design criterion considers the Ultimate Limit State (ULS) for the tendon sections, expressed in terms of the expected value of the extreme Interaction Ratio (IR), considering long-term sea states, and takes into account the dynamic load effects interaction and the statistics of its associated extreme response. The partial safety factors are calibrated through a long-term reliability-based methodology for the storm environmental conditions in the Campeche Bay, Mexico.

Different target reliability values are considered in order to evaluate the effect of this key parameter on safety factors. The results show that the partial safety factors reflect both the uncertainty content and the importance of the random variables in structural reliability analysis. When tendons are designed according to the developed LRFD criterion, a less scattered variation of reliability indexes is obtained for different tendon sections across a single or a variety of TLP designs. It is found that the target reliability value has a strong influence over the safety factor values and thus over the final size of the structural elements.

6.3.7 Floating Liquid Natural Gas (LNG) plants

With advances in liquefied natural gas technology and worldwide changing market conditions for natural gas the use of floating LNG plants is at the brink of emerging. Both liquefaction plants at large, and often remote, offshore gas fields and floating re-gasification plants near industrialized regions in the world are being engineered at the moment. As the LNG storage tanks at floating plants are often partially filled, in contrast to the tanks at conventional LNG carriers, which are either full or empty when sailing at sea, effects of sloshing in the tanks are a great concern.

Wemmenhove *et al*. (2007) and Chen *et al* (2008) present methods to describe sloshing effects and the dynamic loading on the tank structure for partially filled LNG compartments.

6.3.8 Offshore wind farms

In recent years the application of offshore wind turbines for power generation has grown rapidly, in particular in West European waters of Denmark, Germany, the Netherlands and the UK. The wind turbines are generally located in clusters (so called wind farms) in relatively shallow water depths of say 15 to 30 meters.

Zaaijer (2006) argues that the dynamic behaviour of wind turbines in combination with the support structure at offshore locations is more complex than that of either onshore wind turbines or conventional offshore platforms used in the oil and gas industry. In order to reduce the computational burden, the work presented in his paper aims at simplification of the dynamic model of the foundation, while maintaining sufficient accuracy. A stiffness matrix at the mudline is found to be the best solution for mono-pile wind turbine support structures. With respect to the required accuracy, the sensitivity of dynamic behaviour to variations in several parameters is investigated. Experimental data is used to determine whether expected accuracy is met in practice and whether modelling techniques, which are commonly used for offshore structures, can be used for wind turbines on mono-pile foundations. Comparison with full scale data showed that in most cases the results corresponded quite well.

Byrne and Houlsby (2006) investigated offshore wind farm designs developed in UK waters. They reviewed the results of a recent research programme directed towards the design of caisson foundations as an option for wind turbine foundations. The possibilities of using caissons either in the form of monopod foundations or in the form of a tripod or tetrapod arrangement are evaluated.

6.4 Offshore Risk Based Inspection[18]

6.4.1 Introduction

Ideally, design principles and in-service follow-up principles should be jointly established with the objective to determine designs and maintenance strategies which ensure economical operation throughout the anticipated service life in compliance with given requirements and acceptance criteria.

This global objective can be formulated as a Life Cycle Optimisation problem where some utility function has to be optimized under reliability or risk constraints.

a) Usually, utility function is a cost function. Objective is then to minimise the total expected cost over the lifetime of the unit. All costs have to be taken into account, including cost of design, cost of building, cost of installation, cost of maintenance including cost of inspection and cost of repair, cost of eventual failures during in-service operations and cost of decommissioning.

b) Constraints should be expressed as Risk Acceptance criteria dealing with Risk of personnel, environmental risk (pollution) and economical risk (unavailability of the unit).

Risk Acceptance Criteria are in essence directly formulated in the performance space and have to be checked on an annual basis over the whole life of the unit from the design step to the decommissioning step.

The previous global process is not yet achieved in offshore industry but some significant progress have already been achieved in the domain of in-service operations where Risk Based Inspection methodologies have been developed (Lanquetin, 2007) using the above mentioned general framework (cost optimisation under risk constraints). Guidelines and recommendations are now in the public domain and many industrial applications have been performed.

People in charge of developing “in isolation” Risk Based Inspection (RBI) strategies for in-service operations were immediately faced to design considerations. It is, as mentioned above, due to the fact the normal process is an integrated process where all steps of the units are taken into account (design, construction, operation and decommissioning). When only one step is considered (for example operational step), all other steps are nevertheless implicitly involved either as boundary conditions or as

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[18] With the Committee’s appreciation, this section was also contributed to by Mr. Jean Goyet of Bureau Veritas, Paris.

constraints.

Risk Based Inspection was developed in the last decade both for fixed steel offshore structures and Floating, Production, Storage and Offloading (FPSO) units (see Straub, 2006 for the benefits of RBI approaches). Figure 12 below gives an overview of the RBI principle.

In the following sections, general considerations are given dealing with interrelations between Risk Based Inspection as applied in offshore industry and design aspects. Items which are investigated are the following ones:

- design principles for degradation mechanisms;
- design in connection with robustness and redundancy; and
- design for use in Risk Based Inspection calculations.

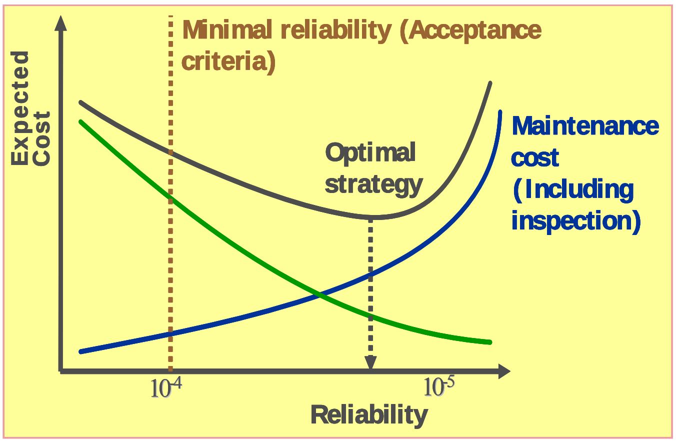

Figure 12: Risk Based Inspection principle formulated as an optimisation process.

6.4.2 Design principles for degradation mechanisms

Engineering systems such as offshore structures, ships and pipelines are ideally designed to ensure economical operation throughout the anticipated service life in compliance with given requirements and acceptance criteria.

Deterioration processes such as fatigue crack growth and corrosion will always be present to some degree. These deterioration processes are taken into account at the design stage when various assumptions are made dealing with uncertainty modelling, manufacturing, installation and operation. It is in principle assumed that uncertainty modelling is correct and the engineering system will be manufactured, installed and operated in accordance to the hypotheses adopted at the design stage. If these conditions are not fulfilled, the deterioration processes may reduce the performance of the system beyond what is acceptable.

In order to ensure that the given acceptance criteria are fulfilled throughout the service life of the engineering systems it is thus necessary to control the development of deterioration and if required to install corrective maintenance measures. In usual practical applications, inspection is the most relevant and effective means of deterioration control.

Therefore, the objectives of the inspection, expressed in the performance space, are to:

- ensure that the risks to personnel arising from structural failure are as low as reasonably practicable (the ALARP principle);
- ensure that the risks to the environment arising from consequences of leakage of hydrocarbons and chemicals are maintained below given specified limits during the lifetime of the installation;
- ensure that the physical condition of the installation remains within design limits that will allow continued safe operation in accordance with the requirements of the relevant legislation during the lifetime of the installation; and
- ensure that the target production availability is maintained or exceeded for the design life of the installation.

Even though inspections may be used as an effective means for controlling the degradation of the considered engineering system and thus imply a potential benefit, they may also have considerable impact on the operation of the system and may lead to additional costs and consequences. For this reason it is necessary to plan the inspections such that a balance is achieved (see figure 1) between the expected benefit of the inspections and the corresponding economical consequences implied by the inspections themselves. Planning of inspections concerns the identification of:

- when to perform inspections (the times of future inspections)
- where to perform inspections (the specific locations and the extent of the planned inspections)
- how to perform inspections (the inspection methods to apply)
- what actions to take based on the results of the inspections (the remedial actions to take on the basis of the results of the inspections).

As a consequence, design principles for degradation mechanisms cannot by-pass the fact regular estimation of the fatigue and corrosion states is mandatory with the objective to use experience feedback for continuously checking that risk acceptance criteria are fulfilled over the service lifetime (updating process). This means that design and operational phases have to be jointly optimized using cost optimisation procedure where a balance is achieved between the expected benefit of the inspections and the various costs (design costs and economical costs implied by the inspections), it being understood that performance criteria (the so-called RAC) expressed in the performance space have to be continuously fulfilled (this fulfilment is usually checked on an annual basis). Some units may be over-designed leading to low cost of inspection/maintenance.

On the contrary, some other units may be "under"-designed due to the fact a significant amount of inspections is planed to be done.

Over design is for example the case of some new built FPSO which are designed against the most severe conditions (North Atlantic conditions) and where inspection effort required for fulfilling risk acceptance criteria is less than usually required. Coating procedure is also an example. Due to the lack of dry-docking, owners/operators may use particular paints with the objective to avoid any strong re-coating over the service life.

Even if this global optimisation is not yet achieved in offshore industry, it is clear that Risk Based Inspection expressed as cost optimisation can be used for the selection of "alternative" concepts at the design phase. The concept leading to the cost optimal inspection plan could then be selected. For example, in the case of conversion of tankers to FPSO, RBI calculations can be done for deciding if implementation of brackets in some parts of the structure (fatigue sensitive parts) has to be decided or not.

6.4.3 Design in connection with robustness and redundancy

In the same line, design considerations in terms of redundancy and robustness (Canisius *et al.*, 2007) are increasingly used in offshore industry. When an owner/manager has to determine some inspection plan for a structure under construction or has to determine some mitigation action for justifying a damaged structure, he may takes into account structural redundancy or robustness.

In fact, various aspects are strongly interrelated:

- Owners/operators or classification societies are increasingly using Risk Based Maintenance approaches where Risk Acceptance Criteria are directly expressed in the performance space.
- Checking of risk acceptance criteria (personnel, environment and economics) require in turn increasing capabilities of reliable predictions/calculations for the performance of the engineering systems. This is because consequences analysis in terms of personnel, environment and economics require identifying structural scenarios starting from an initial event and ending by a terminal event the consequences of which are analysed in terms of safety, environment and economics. Event scenarios include in general structural system analysis (push over analysis for fixed steel offshore structures and ultimate strength for FPSO).
- Owners/operators in turn may design their units with the in-service point of view: Redundancy and robustness will be considered as design objectives because redundancy and robustness lead to less maintenance effort.

RBI analyses for fixed steel offshore structures show for example that RBI calculations do not require any inspection effort for fatigue if for example Reserve Strength Ratios

(RSR ratios) are higher than 3 or 4 or 5. In these analyses, RSR ratios are calculated for the intact structure and for the damaged structure (push over analysis of the structure where one fatigue failure is assumed). If the RIF value (ratio between the $RSR_{damaged}$ and the RSR_{intact}) is akin to 1, then failure of the component under consideration has no consequences and inspection effort is not required for this component.

This kind of approach is more and more used in offshore industry and is also included in codes, regulations, guidelines and recommendations. As one example, the American Petroleum Institute (API) is presently working (O'Connor, 2005) on an API recommendation devoted to Structural Integrity Management (SIM) where Push Over Analysis is a part of the SIM working process. As a consequence, Push Over analysis is more and more developed and used in oil & gas industry and RSR requirements may become a part of the design requirements.

Structural system analysis (Nishijima, 2009) has also been performed for FPSO using Risk Analysis Framework as formulated by the Joint Committee on Structural Safety (JCSS, 2008) and Bayesian Probabilistic Networks. In this case, a hierarchical model of the hull is built and the Bayesian Network is used for disseminate fatigue and corrosion damages on the whole structure (via the hierarchical model). Conditional probability tables are used for propagating fatigue and corrosion damages. The Conditional Probability Tables (CPT) is fitted to structural system calculations (basically ultimate strength).

6.4.4 Design for use in Risk Based Inspection scheme

Experience learnt from RBI studies show that design could take in-service considerations into account. Risk Based Inspection calculations are mainly devoted to degradation mechanisms over time and require engineering calculations as input (fatigue calculations, push over calculations). Also RBI calculations use probabilistic degradation models which are characterized by mean value (over time) and deviation around this mean value. As a consequence, good application of RBI calculations requires provisions at the design stage in terms of calculations methods and degradation models. For example, relevant RBI approaches require that fatigue calculations are performed using dynamic spectral fatigue analysis. This could become a design requirement in case where RBI study is required at the design stage. Fatigue cumulated damage calculation is another issue. RBI requires using mean value and standard deviation value. This requires that SN calculations are based on S-N curves defined by regression analysis and not by some lower bound value as it is the case in some API recommendations (lower bound value is in that case relevant for design but not relevant for RBI).

6.4.5 Conclusion

Design principles and in-service principles have to be determined jointly using a performance space which is basically active over the service life (performances dealing with personnel, environment and economics are continuously checked on an annual basis from the hook-up to the decommissioning). One has to keep in mind that design objective deal with in-service behaviour when degradation mechanisms are considered and that experience feedback (findings from surveys) has to be taking into account for updating the structural knowledge of the unit. As a consequence, design and in-service principles are two parts of a common framework which may be summarised as a life cycle cost optimisation where cost aspects may be managed in different ways. RBI studies are usually performed at the "design stage" (before the first oil or, in some particular cases, at the time of the detailed design). So, RBI can be considered as a part of the design step even if RBI requirements are not yet fully included in the design process.

7. INDUSTRY ALTERNATIVES

The cost of an accident is the financial value attached to the harm that the accident causes. An accident may cause a variety of impacts, some of which result in distinct financial transactions (e.g. repair of buckled structures) and others which do not have any financial equivalent (e.g. oil contamination in the open ocean. The harm that may be caused by a ship accident can be categorized as:

- Property - damage to the ship and other property, and associated business impacts.
- People - injuries and fatalities.
- Environmental damage - principally oil spills.

The cost of an accident is considered to be the sum of:

- Direct (or financial) cost. This is the cost incurred to return the situation to what it was before the accident.
- Indirect cost. This is the cost of people and assets being idle as a result of the accident and the business damage for the owner and other affected businesses.
- Intangible cost. These are costs allocated to types of harm that do not have market values. These "externalities" include damage to natural resources that have no commercial valve, damage to the company image that result in a loss of business, and pain, grief and suffering for people.

Table 6 shows examples of each type of cost for each type of impact from ship accidents. The combination of direct and indirect costs to the ship owner and other affected parties (e.g. ports, governments etc) and intangible costs to people and the environment are ultimately passed back to society.

Table 6
Categorization of direct and indirect costs of an accident.

	Direct costs	**Indirect costs**	**Intangible**
Property	• Repair • Cargo loss	• Off hire • Differed production (cargo owners) • Lost share value • Lost market share	• Lost reputation • New regulations
People	• Medical treatment	• Differed production (sick leave)	• Grief and suffering
Environment	• Clean up/restoring	• Lost business (e.g. tourism or fishing)	• Ongoing damage to the environment/ecosystem (loss of biodiversity)

7.1 Marine Insurance

The marine insurance industry that has the day-to-day interest in ships in operation are protection and indemnity mutual clubs and hull and machinery insurers. Protection and Indemnity (commonly referred to as "P&I") insurance provides cover to shipowners and charterers against third-party liabilities encountered in their commercial operations. Responsibility for damage to cargo, for pollution, for the death, injury or illness of passengers or crew and for damage to docks and other installations are examples of typical exposures.

Running in parallel with a ship's hull and machinery cover, traditional P&I such as that offered by the mutual P&I clubs distinguishes itself from ordinary forms of marine insurance by being based on the not-for-profit principle of mutuality where "members" of the P&I club are both the insurers and the assureds.

Hull and machinery insurance normally covers the vessel's property risk subject to the normal exclusions for wear and tear and similar causes such as lack of maintenance. Furthermore, war risks, intervention by a state power, insolvency and nuclear perils are also excluded from the standard hull and machinery insurance cover (although this cover is available through other facilities). Physical damage to parts that are defective due to error in design or faulty material is covered, subject to those parts that have been approved by the classification society.

7.1.1 Marine insurers measuring of risks

Perhaps the most influential consideration in pricing is the financial and commodity market conditions. In particular, P&I clubs generally maintain equity and bond portfolios to build reserves for payment of claims in past years as well as influence premium rates by reducing the uncertainty in future premiums. In other words, P&I clubs use these funds as a competitive edge in pricing for new fleets to join their clubs. Generally, risk profiling is viewed as less necessary during these times because clubs use the financial markets to make up for underwriting losses. Also, terms and conditions of insurance cover tend to be less stringent in areas such as deductibles, limits of insurance cover, risks covered and premiums.

In addition, the ability to apply a spread of risk amongst P&I clubs through what is called 'pooling', and reinsurance plays a significant role in P&I insurance. The International Group of P&I Clubs (IG) have a pooling of risk and catastrophic and excess of loss insurance program as shown in Figure 13. The pooling and reinsurance scheme have worked very well in providing excess of loss cover to the maritime market.

The pooling and reinsurance scheme set forth in Figure 13 is presented by the IG as follows (International Group of P&I Clubs, 2008):

> *"The Group clubs arrange a market reinsurance contract to provide reinsurance for claims which exceed US $50 million up to an amount of US $2.05 billion any one claim (US $1 billion for oil pollution claims). It is the largest single marine insurance contract. There are lower limits for claims against charterers. By bringing together in this way the risks of the great majority of the world's tonnage, the Group is able to obtain the maximum reinsurance capacity on the best terms available worldwide.*
>
> *The Group Clubs also reinsure part of their risks through a captive insurance company [Hydra]..."*

Other than financial risks, conditions for cover that are generally taken into account by marine insurers when assessing risk:

1. claims history (generally 3-5 year rolling average);
2. classification society;
3. flag State;
4. vessel type;
5. vessel age;
6. vessel trading pattern;
7. port State control record; and
8. results of vessel condition survey(s) upon entry into the P&I club.

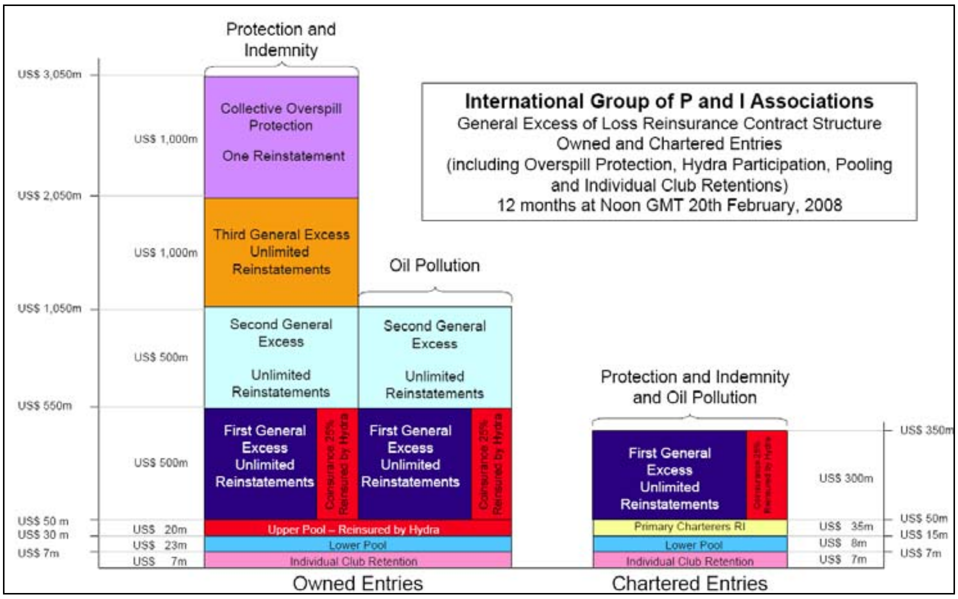

Figure 13: International Group of P&I Associations (Clubs) general excess of loss reinsurance contract structure: 20 February 2008 to 20 February 2009. (International Group of P&I Clubs, 2008)

On the other hand, hull and machinery (H&M) insurance markets work differently. Most H&M insurance companies are commercial insurers unlike the P&I clubs who are mutually assessable organizations. In other words, H&M cover is fixed price insurance cover. Also, H&M cover is provided on a 'subscription market'. In other words, the risks are spread amongst a number of insurers that take a percentage of the risks. As a rule of thumb, most H&M insurers do not take on more than a 25% risk of any one fleet/ship.

Based upon the claims records, a P&I club may consider controlling risks through higher deductibles for claims areas that are considered either frequent and/or costly. In frequency and cost; personal injury/illness and cargo claims each account for approximately 1/3 P&I claims.

Consequently, a club may choose to have higher deductible payments for bagged cargo claims in West Africa where pilferage tends to be a problem. Or a shipowner may have problems with the frequency and costs of personal injuries aboard and a club may decide to limit their ability to claim on such cases through higher deductibles, a pre-employment medical screening program or other control measures.

Nevertheless, P&I clubs use a number of measures to try to control claims through loss prevention programs, pre-employment medical screening of seafarers, surveys of ships as condition of cover and other such initiatives to control risks in unison with proper financial pricing of cover and setting reasonable deductibles.

7.2 *Ice classification*

For ice rule development an EU-funded SAFEICE project has been conducted during the years 2005-2007 (Kujala *et al*., 2007). The main findings done during SAFEICE and their possible effects on the rule development based on goal based approach can be summarized as:

- The need to update any rules, including ice class rules, stems often from performance monitoring of the rules. This performance is usually measured by damages occurred or sometimes even by catastrophes (design-by-disaster). Sometimes the advances in research make an update of rules necessary. In this case the changes in rules are not large; formulations are updated and made more elaborate. A need for an update may also stem from a change in the traffic profile. This is then main origin of the need for an update for the present Finnish-Swedish Ice Class Rules (FSICR). As the ship size of ice classed tonnage is growing when more AFRAMAX-size tanker have an ice class, the application of FSICR on these ships have revealed several points that need an update.
- The basis of the present FSICR is in the feedback from damages sustained by high ice class ships in the 1960's. At this time the year-round navigation to also the northernmost Finnish ports started and many ships had ice damage. Insurance companies found the situation intolerable and changes were required. The change in the winter navigation system was in the ice rules – these were updated based on calculation of loads causing the damages. The design point was selected on the boundary of the damage – non damage in the plots of the load carrying capacity of the shell structure versus the ship size. This is a perfectly valid approach to set the design point; it can be called a simple exercise in risk-based-design.
- At present the further major updating process of the FSICR should be based on risks, starting from deciding the design point to be used. Once the design point is set, the analysis of response must be carried out. If the design point is based on allowing some plasticity, the development of response equations especially for framing becomes a demanding task. These two tasks (design point and response formulation) must be carried out before any progress towards scantlings can be made. The SAFEICE project started to investigate both these topics. The work showed that there is much work to be done especially to reach a unified methodology. It is to be hoped that this project is continued towards developing a suitable basis for ice class rules.

8. DECISION MAKING

8.1 *Objectivity and Subjectivity*

Novel ship concepts, including advanced marine vehicles, as well as strong competition on the shipbuilding/maritime markets has created a need for full application of modern and mature design methods. Improvements required are in the fast and flexible analysis tools (of adequate fidelity) and in synthesis (multidisciplinary decision making) techniques to form a balanced design procedure. The methods should be capable of validating new concepts as well as generating competitive 'standard' designs.

This advances and applications, after the last survey for ISSC 2006, are best presented in the following Tables 7 and 8, given in the sequel. A brief summary of basic concepts (see also ISSC proceedings for 2003 and 2006) is given as an introduction to Tables. Organization of the Tables follows basic structure of the Decision support (DS) problem formulation:

Decision Support Problem Identification (columns 2, 3 and 4 in Tables 7 and 8) implies: (a) selection of design variables **x** and design criteria (constraints **g** and attributes/performance measures **a)** as a basis for mathematical formulation of the problem in design, attribute (performance) and selection sets/spaces, and (b) determination of design objectives (design attributes with direction for improvement e.g. min ai) and the corresponding measures of design robustness (rob ai).

A Decision Support Problem (DSP) methodology can be efficiently formulated after basic characteristics of designer requirements and designers' preferences are revealed. The requirements set leads to determination of the functional and physical architecture for the product which may be supplemented with technical and dynamic architecture. The latter adds behavioural characteristics of general design.

Mathematical formulation of DS problems involves: (a) DS problem manipulation into equivalent but mathematically more convenient form, (b) selection of solution strategies (e.g. optimization techniques such as MOGA, MOPSO, Evolution Strategies based on FFE, SLP, MC, etc) for the manipulated problem, (c) development of the final selection method among the generated design variants based on problem particulars, (d) sensitivity / uncertainty analysis and particularly (e) investigation of subsystem interfaces that may lead to unwanted 'emergent' behaviour. DS problem solution requires practical implementation of selected methodology through two basic calculation (mathematical) models and corresponding software modules:

(1) Design Analysis model (columns 5 and 6 in the Tables 7 and 8) is including technical evaluation models (response, weight, safety criteria) and economical (cost) evaluations models, both with balanced fidelity characteristics depending on design stage (concept, preliminary, detail). Response models M1-3 are structural, loading and response calculation models/modules. Modern approaches include, not only iteration of those basic modules but also having global iteration (loop) on improvement of design requirements.

(2) Synthesis model (columns 7 and 8 in Tables 6 and 7) is implying a preferably interactive decision-making shell with structural design utilities (optimization

and sensitivity/robustness modules, databases, graphics, etc.). Objective decision making (DM) techniques (column 7) use direct minimization or maximisation of given objective function(s). Subjective decision making techniques involve selection among generated candidates (see column 8).

The preferred (best) feasible design(s) can be determined by:

(I) lexicographical ordering of weighted priorities: among the 'best' candidates regarding the first priority select those that are 'best' regarding second priority, etc.;

(II) goal seeking is the standard method in decision making but it is possible only if a metric or 'distance' to the target design y* is generated. The introduction of metric into attribute space (spanned by design attributes) implies that all attribute values are of the same dimensions (or non-dimensional and scaled to their relative importance); and

(III) construction of value function (function of attribute functions: e.g. sum of initial cost $y_1=a_1(x)$ and maintenance costs $y_2=a_2(x, y_3)$ that are dependent on achieved safety levels $y_3=a_3(x)$) and an identification of the design with extreme value of this function. Distance norms (metrics) are often used as value functions.

To select preferred designs, by any of methods I – III, subjective criteria and designers preferences have to be revealed regarding relative importance of different attributes and also to enable realistic quality evaluation within each attribute. Number of candidates for selection can be greatly reduced by introduction of the key concept of the modern design i.e. the concept of non-dominance. It enables selection of the candidate designs from subset of feasible designs belonging to the non-dominated hyper surface (customarily called the Pareto frontier). Those designs can be identified when designers preference structure, is applied to feasible designs. Only non-dominated designs (usually only small fraction of feasible designs) are of interest to designer since they dominate all other feasible designs.

Subjectivity, basic to realistic decision-making in the final stages of DSP (methods II and III), is usually formulated via:

(1) subjective comparison of various designs for given attribute values y_i through e.g. designer constructed fuzzy functions U_i (y_i). They provide the membership grade (designer satisfaction level) $m_i = U_i(y_i)$ for each attribute in range [0, 1].

(2) determination of the subjective importance among different attributes via e.g. weighting factors wi based on the bi-attribute preference matrix whose terms are the ratios of subjective importance of those attributes.

Combination of subjectivities can be achieved as e.g. product ui(yi) = wi Ui(yi). It can be observed in Tables 7 and 8 (column 8) that many of methodologies described in the papers generate Pareto frontier directly to enable subjective selection of preferred designs.

8.2 Sensitivity, Robustness, Vulnerability and Flexibility

For technical systems the existence of solution is often guaranteed but not its uniqueness and stability. Many parameters, held constant during optimization process, are subject to uncertainties causing variations of the values in the criteria set and/or violation of constraints (unfeasible designs).

Robustness is defined as insensitivity (or stability) with respect to such changes. Design flexibility (for designs/systems with long life and subjected to change over time) is understand as ability to respond to change (Price *et al*., 2006). To distinguish between optimized designs, robust designs and flexible designs the system objectives (fixed or changing) and environment (fixed/known or changing /unknown) are to be considered.

For optimal design objectives are fixed and environment is known (usually short life-span products). Robust design, in this context means design with fixed objectives coping with changing environment. *Flexible design* has to cope with changing objectives and changing environment (usually for longer time span).

Table 7
Some references in formulation of decision support problems for ship structures.

REF.	PROBLEM IDENTIFICATION			ANALYSIS (MODELS M1-M4)		SYNTHESIS (MODELS M5-M6)	
	VARIABLES $\{x\}$	CONSTRAINTS $\{g\}$	OBJECTIVES $\{a\}$	RESPONSE (M1-M3)*	FEASIBILITY (M4)	OBJECTIVE DM (M5)	SUBJECTIVE DM (M6)
1	2	3	4	5	6	7	8
Ji (2007)	-Stiffened panel scantlings: thicknesses, spacing and type of longitudinals, (nv=21) -Oil tanker, 76 000 DWT→ midship section	IACS JTP Rules - Hull Girder Bending and Shear Strength - Local Strength	-min. structural weight	Beam theory and Analytical formulas	Analytical formulas	-Relative Difference Quotient Algorithm (RDQA)	
Jastrzebski *et al*. (2007)	-Number of web frames, girders, longitudinals → nv=8 -Container structure - partial model 7 parameters- defining spatial arrangement of structural elements	Germanischer Lloyd Rules Strength constraints -Min. distance between girders	-min. structural weight -min. length of welds -min. area of structural elements→ maintenance - min. vert. bending moment	-FEM calculation -Longitudinal strength calculation	Analytical formulas	-Parametric optimization analysis- only 11 variants were examined of total number of 12,600 possible variants.	Weighting factors for transformation of multi-objective into single objective
Klanac and Jelovica (2007)	-Longitudinal stiffened panel variables- (nv=28) -Fast ferry→ midship section	-Technological(min-max) - Geometrical (linear) - DNV Rules (yield, buckling) - 2 long. LC (crest and hollow landing)	-min. structural weight	Beam theory and Analytical formulas	Analytical formulas	-Genetic Algorithm(GA) -Scalar and vectorized problem formulation	-Pareto frontier
Klanac, *et al*. (2008)	Longitudinal stiffened panel variables- (nv=94) - Chemical tanker, 40 000 DWT→ midship section	- Technological(min-max) -Geometrical (linear) -Structural (yield, buckling) -2 load cases (crest and	-min. total structural weight -min. duplex steel weight -max. of adequacy of deck strakes	Couple Beam method + Analytical formulas	Analytical formulas	-Genetic Algorithm(GA) -Vectorized optimization problem formulation	-Pareto frontier
Nakamori *et al*. (2008)	-Number, size, spacing, angle of longitudinals in for/aft part of ship structures- nv=21	-Technological constraint (narrow working space, angle deviation) -Class NK Rules(strength, distance, angle)	-min. weight of longitudinals -min. number of knuckle joints -min. welding length-cost	Analytical formulas	Analytical formulas	-Genetic Algorithm(GA)	
Okada *et al*. (2007)	-Double bottom height, double side breadth, cross deck breadth, -Large container ship 12 000 TEU→ midship section	-Long. strength (section modulus) -Hatch opening deflection -Number of containers	-min. structural weight -min. building cost -max. number of containers -penalty function	Analytical formulas	Analytical formulas	-Genetic Algorithm(GA)	-Penalty function

Table 7 (cont.)
Some references in formulation of decision support problems for ship structures.

REF.	PROBLEM IDENTIFICATION			ANALYSIS (MODELS M1-M4)		SYNTHESIS (MODELS M5-M6)	
	VARIABLES {x}	CONSTRAINTS {g}	OBJECTIVES {a}	RESPONSE (M1-M3)*	FEASIBILITY (M4)	OBJECTIVE DM (M5)	SUBJECTIVE DM (M6)
1	2	3	4	5	6	7	8
Richir *et al.* (2006)	-Longitudinal panel scantlings (9 variables per stiff. panel, nv= 243 -VLCC ship- midship section	- technological(min-max) - geometrical (linear) - DNV structural (yield, buckling) - 8 symmetric load cases	-min. production cost	First order sensitive Analytical solution of differential equation using Fourier series	Analytical formulas	Convex Linearization And Dual Approach	
Richir *et al.* (2006)	-Longitudinal panel scantlings (9 variables per stiff. panel, nv= 600 -Passenger ship- midship section	- technological(min-max) - geometrical (linear) - BV structural (yield, buckling) - 5 symmetric load cases	-min. production cost (basic and advance cost module)	First order sensitive Analytical solution of diff. equation using Fourier series	Analytical formulas	Convex Linearization And Dual Approach	
Romanoff and Klanac (2007)	-Thicknesses of (top face, web plate, bottom face) core height, stiffener space (nv=5) - Steel sandwich hoistable car deck	-Det Norske Veritas Guidelines for laser weld sandwich panel (strength and deflection criteria) - technological(min-max)	-min. structural deck weight	Homogenized Plate Theory	Analytical formulas	-Genetic Algorithm (GA) -Vectorized optimization problem formulation -Enumeration	-Pareto frontier
Sobey *et al.* (2008)	-Stiffened FRP panel -Plate thicknesses, stiffener spacing, stiffener characteristic, (nv=8) -Composite boat hull structure	-Lloyds Registry Rules for special service craft (strength and deflection criteria) - technological(min-max)	-min. structural weight -min. building cost	-Grillage analysis for stiffeners -Third order shear deformation theory for plates	Analytical formulas	-Genetic Algorithm (GA)	-Pareto frontier
Zanic *et al.* (2007a)	-Topology parameters (size of side openings, number of trans BHD, height of long. BHD, etc.) - np=8. -Stiffened panel scantlings (plate thicknesses, stiffener spacing, stiffener and transverse frame characteristics)- nv=110 - Passenger ship-midship section	- technological(min-max) - geometrical (linear) - structural (nonlinear-yield, buckling, deflection) -2 symmetric load cases	Investigation of topology arrangement with min. stresses variation in upper decks. Scantling optimization: -min. structural weight -min. production cost -max. hull girder ultimate moment - max. structural safety	-Full ship FEM for deck efficiency coefficient -FEM- primary and secondary stresses -Analytical formulas for tertiary stresses	Analytical formulas	-Topology optimization Taguchi approach -Scantling optimization: Hybrid approach: Sequential Linear Program. (SLP) + Fractional Factorial Experiments (FFE) + Genetic Algorithm (GA)	-Pareto frontier
Zanic *et al.* (2007b)	-Stiffened panel scantlings (plate thicknesses, stiffener spacing, stiffener and transverse frame characteristics)- nv=79 -Wagon carrier - midship section	-technological(min-max) -geometrical (linear) -structural (nonlinear-yield, buckling, deflection) -3 load cases according to Russian Maritime Registry	-min. structural weight -max. structural safety	FEM- primary and secondary stresses Analytical formulas for tertiary stresses	Analytical formulas	Hybrid approach: Fractional Factorial Experiments (FFE)+ Multi-objective Genetic Algorithm (MOGA)	-Pareto frontier

Table 8
Some references in formulation of decision support problems for general structures.

REF.	PROBLEM IDENTIFICATION			ANALYSIS (MODELS M1-M4)		SYNTHESIS (MODELS M5-M6)	
	VARIABLES {x}	CONSTRAINTS {g}	OBJECTIVES {a}	RESPONSE (M1-M3)*	FEASIBILITY (M4)	OBJECTIVE DM (M5)	SUBJECTIVE DM (M6)
1	2	3	4	5	6	7	8
Jarmai *et al*. (2006)	-Stiffened and unstiffened shell scantlings	-Structural Constraints (buckling, yield) - Manufacturing constraints	-min shell production cost	Analytical formulas	Analytical formulas	- Leap-frog optimization (LFOPC) - Dynamic-Q - ETOPC algorithm - Particle Swarm Opt. (PSO)	
Pelletier and Vel (2006)	-Pressure vessel Laminate variables nv= 30 (for each laminae: fiber volume fractions, fiber orientations, and	-Structural Constraints (Tsai–Wu, stiffeners) - technological (min-max)	-max. failure pressure -max. hoop rigidity -min. areal mass density	Analytical formulas	Analytical formulas	Modified NSGA II	-Pareto frontier
Li *et al*. (2007)	Areas of 72-bar spatial truss structure – nv=16	-Structural (stress and displacements limits) -technological (min-max)	-min. weight	Finite element method (FEM)	From FEM	-Particle swarm opt. (PSO) -Passive congregation PSO (PSOPC) -heuristic PSO (HPSO)	
Hansen and Horst (2008)	Blended wing body topology (n = 6) geometry (n=4) and scantling variables (n=110)	-technological (min-max) -Structural constraints (bifurcation buckling, Von Misses Stress for metallic, Tsai Hill for composite)	-min. weight	FEM – MSC.Nastran	-FEM – Bifurcation Buckling -Analytical formulas	-Evolution Strategy (EStruct used for topo/geo opt) -NASTRAN Sol200 (gradient based – used for scantling opt)	
Kong *et al*. (2006)	Containership deck thicknesses (nv=64)	-technological (min-max) -vibrations (free and forced)	min. forced vibration response (rms value)	FEM – MSC.Nastran	FEM – MSC. Nastran	OPTSHIP (GA and R tabu)	
Sinha & Kaushik (2007)	Automotive structure thicknesses and material (nv=9)	-technological (min-max) -Structural constraints (reliability based force and deflection)	-min. structural weight -min. door velocity	-Nonlinear FEM LS-DYNA -Response surface model	- Analytical Formulas	-FORM -Generic Design Optimization Toolkit GDOT (NSGA II)	Pareto Frontier
Degertekin (2007)	Four-storey 84-member space frame areas (nv=10)	-technological (min-max) -Structural (stress and displacements limits)	-min. weight	- Nonlinear Analytical Formulas	- Nonlinear Analytical Formulas	- Simulated Annealing - Genetic Algorithms	
Filomeno (2008)	2-D wing geometrical and size variables (nv ~ 50+ fluid variables (angle of attack and velocity)	-technological (min-max) -Structural (stress and displacements limits -Lift and drag coefficient	-min. weight	-FLUENT CFD Navier Stokes and Laplace -Response surface	-Analytical Timoshenko beam	Sequential quadratic programming (SQP) MDO (All-in-one strategy)	

In a recent publication by the Joint Committee of Structural Safety (JCSS, 2008) a distinction is proposed between the direct and the indirect consequences that an exposure can cause to a structure. The suggested difference between the two classes of consequences refers to the temporal and geometrical distance from the exposure of the damage caused to the structure: direct consequences are those induced as an immediate and direct action of the exposure, while indirect consequences are the effects of an escalation of the damage, which propagates in time and space away from the directly exposed portion of the structure.

Direct and indirect risks can be derived by multiplying direct and indirect consequences by the probability of occurrence of the inherent exposures. On the basis of this distinction, two definitions are given:

Vulnerability
The vulnerability of a system is defined as the ratio between the risks due to direct consequences and the total value of the considered asset or portfolio of assets considering all relevant exposures acting in a specified time frame.

In other words, this definition of vulnerability corresponds to the part of the system construction value that it is expected to be lost as a result of 'direct' consequences of the various exposures. A conditional vulnerability may be defined as the vulnerability conditional on a given exposure.

Robustness
The robustness index of a system is defined as the ratio between the direct risks and the total risks, (total risks is equal to the sum of direct and indirect risks), for a specified time frame and considering the damage to the system due to all relevant exposure events and all relevant escalation sequences. The rational of this definition of robustness is that a high value of the index implies the damage expected in the structure not to escalate much beyond direct effects. A conditional robustness may be defined as the robustness conditional on a given exposure and/or a given damage sequence.

8.3 Concept and Preliminary Design Stages

ISSC have given definitions of concept and preliminary design stages. Here only simple additions are given. The concept design stage (phase) is characterised with the highest level questions on design at hand. Its essence is reduction to the most important issues and work with low fidelity methods, all that with a task to produce the most far fetching decisions. The iterative procedure is applied and this phase ends when satisfactory level of functionality and requirements satisfaction is .achieved. It requires the most experienced designers.

The preliminary design phase starts when design space is sufficiently well defined/constrained for the accepted concept or alternatively when all the high level questions have been answered. Most papers in Tables 7 and 8 are tackling difficult phase of concept design.

8.4 Multi-criteria Decision Making and Conflict Resolution

Most papers in Tables 7 and 8 have multiple objectives (see column 4). Comments on multiple-criteria DM is given in Section 8.1

8.5 Summary of decision support approaches for maritime structures

Introductory notes regarding each of the columns in Tables 8.1 and 8.2 are given in Section 8.1. Conclusions regarding presented works:

- *Variables* **x**: most of the contributions are dealing with small number of variables (less than forty) characteristic for concept design. Transition to larger number of variables is to be expected.
- *Constraints* **g**: structural feasibility constraints are augmented with technological constrains to obtain build able designs. Risk based constraints may be expected combining in natural way different aspects of operation and maintenance strategies.
- *Objectives (attributes)* ***a***: Most papers have multiple objectives. Minimal weight is still dominating due to parallel increase in carrying capacity. In the multiple objectives environment the cost is also considered as objective as well as safety. Safety objective can lead to safe designs with rational distribution of material when combined with cost objective.
- *Response models/modules* (M1-3): Fast analytical modules are used in parallel to the more flexible FEM approaches capable of unrestricted modeling of structural topology and geometry.
- *Feasibility models* (M4): Analytical formulae are dominating since structural parts are usually covered with high fidelity due to their regular shape.
- *Objective decision making* (M5): Genetic algorithms are considered solid, jet slow, method for Multi Attribute decision making. When Multi Objective decision making (MODM) is applied dual formulation using convex linearization or SLP is a fast alternative. Hybrid approaches are fast and reliable way to combine speed and fidelity. FFE are also used, as well as neural networks, to speed up design process.
- *Subjective decision making* (M6): Pareto frontier in multiple objective cases is considered a reliable way to use for selection of preferred designs in all cases.

9. CONCLUSIONS

In the report of the 2009 ISSC TC IV.1, there are three interrelated underlying primary concepts that we have addressed. Each of these concepts, if explored independently, would warrant much further study on their own merits: *Goal-based standards* and in particular the *Safety Level Approach*; *Sustainability*; and *Corporate Social Responsibility*.

However, there is a strong interdependence between the three areas in order for each to succeed in bringing relevant change to the marine industry from a perspective of design principles and the associated criteria that are a result of those principles.

In essence, the global society, through its appointed representatives, must show a commitment to corporate social responsibility in order to have the commercial and moral compass to consider the needs of industry and society when establishing goal based standards. These goal based standards would best be considered with a safety level approach that looks at the vessel in a holistic fashion.

In addition, corporate social responsibility also has an impact upon the commitment to developing and providing a sustainable marine industry. In turn, sustainability is a critical element to consider holistically within the safety level approach of goal based standards.

Recommendations for future work by the ISSC on subjects reflected in this report include:

1. GBS and the Safety Level Approach. Since the onset of the 2009 TC IV.1 Committee in October 2006, the development of goal based standards have been evolving and seem destined to become a permanent fixture to the rule making process at the International Maritime Organization. However, it is the opinion of the Committee that the current focus upon the development of GBS for the construction of tankers and bulk carriers is too narrowly focused and does not take a proper holistic view of setting goal based standards.

   It is therefore the recommendation of the Committee that the ISSC further consider development of concepts and methodologies in the safety level approach to GBS and, if possible, provide guidance to the industry on the application of safety level concepts to future GBS initiatives.

   It would be necessary to investigate the possibility and way forward to the development of technology for “ship and offshore structural design” based on risk-based and safety- level-based approach, including for global and local strength (both in intact and damaged conditions) and fatigue. In other words, these technologies should be described in terms of probability (not deterministic).

   Some of these possibilities have been presented at IMO at annex to IMO (2008f) as follows:

   CONCEPT FOR INTRODUCTION OF GBS-SLA TO SHIP HULL STRUCTURE

   1 Safety of ship hull utilizing GBS-SLA is examined. Although it would be hard to *relate specific risk (an index of SLA) and rules of local panel, stiffener and so forth, it is important for rules of hull girder ultimate strength, which is considered to be important transcendently, to be developed utilizing GBS-SLA, because damage, which is caused by a lack of hull girder ultimate strength, leads to a serious accident.*

2 In this way, it should be possible to establish GBS-SLA which is a standard to form a connection between "Goals" and "Rule for Ships" for hull girder ultimate strength by means of the risk as an index of SLA. In this case, the risk can be evaluated by multiplying probability of failure and consequence together. Consequence can be evaluated based on the statistical data of casualties and incidents. Probability of failure can be evaluated by means of the logical method such as structural reliability analysis. This composition may be applicable when utilizing GBS-SLA for other rules. In terms of development of rules for prevention of capsizing of ship, the risk, which connects between "Goals" and "Rule for ships", can be evaluated by multiplying capsizing probability under a certain sea state and consequence together. It is important to develop GBS-SLA taking such compositions into consideration.

3 From the technical point of view, probability of failure, which is evaluated by means of the structural reliability analysis, is merely a notional index. Therefore, we have to pay attention to analytical tools and input data (e.g., wave data), which have effects on the evaluated probability. This means that we have to evaluate probability of failure by means of the unified analytical tools and input data. It is also important to develop "Rules for rule", which define the methodology of evaluation."

2. Sustainability. Perhaps the greatest challenges to the marine industry and society in general in the coming millennium will be to become a sustainable society. Only the basic concepts of the sustainability concepts were explored in this 2009 TC IV.1 report. We believe that developing sustainable resources an in that it is a newly developing area of the industry.
   Particular technical areas of sustainability concepts that can be considered by the ISSC are as follows:

   i. ship and marine structure lifecycle design criteria to establish and maintain sustainability;
   ii. sustainability design concepts for decommissioning (ship recycling) of ship and offshore marine structures; and
   iii. construction of sustainable ships and marine structures.
3. Corporate social responsibility. This is an overarching principle that should be a driving force in of design principles. Although corporate social responsibility might not warrant further work by the ISSC, it should be a major principle in consideration of future work of at least the TC IV.1 as well as any other relevant ISSC technical and specialist committees.

4. In section 6.1, the Committee introduced the latest updates on setting standards for the stabilization of GHG as currently proposed within IMO. It is the recommendation that the ISSC further consider this initiative in consideration of the upcoming a meeting to take place in Copenhagen in December 2009 for the purpose of forging a successor regime to the Kyoto Protocol.
5. It is expected that the arctic shipping will increase remarkably in the near future when the oil and gas exploration moves to the arctic areas. The present ice strengthening principles are based on deterministic approach without proper analysis of the environmental effects together with the statistical nature of the ice induced loads and structural response. In future also the ice strengthening should be based on the risks, starting from deciding the design point to be used and continuing to the analysis of response and finally aiming to the proper GBS type approach.

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