18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)

Proceedings to be purchased at http://www.stg-online.org/publikationen.html

18$^{th}$ INTERNATIONAL SHIP AND
OFFSHORE STRUCTURES CONGRESS

09-13 SEPTEMBER 2012
ROSTOCK, GERMANY

VOLUME 1

COMMITTEE IV.1

# DESIGN PRINCIPLES AND CRITERIA

## COMMITTEE MANDATE

Concern for the quantification of general economic, safety and sustainability criteria (as there are reliability, availability, maintainability, dependability) 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 the implementation, and to their potential for success in achieving their aims taking account of possible differences with the safety and sustainability standards in ISO and similar standards developed for the offshore and other maritime industries and of the current regulatory framework for ship structures. The IMO-related work shall be performed at a time scale consistent with that necessary for submission of documents to the relevant IMO committees.

## COMMITTEE MEMBERS

Chairman: Edzard Brünner
Richard W. Birmingham
Eirik Byklum
Yingqiu Chen
Yuk F. Cheng
Jyotisman Dasgupta
Gennadiy Egorov
Jeppe Juhl
Byeoung S. Kang
Dale Karr
Yasumi Kawamura
Alan Klanac
Sean O'Neil
Enrico Rizzuto
Angelo Teixeira
Koichi Yoshida

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)


**KEYWORDS**

Economics, maritime transport, human life, health, sustainability, noise, goal based standard, GBS, formal safety assessment, FSA, greenhouse gas, GHG, common structural rules, CSR, offshore wind turbines

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)


## CONTENTS

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



## 1 INTRODUCTION

Looking at discussions in public about industrial activities people can observe a shift of focus. Whereas discussions in the past were mainly focussing on the technological aspects and progress of development, now discussions concentrate on the consequences of technological development to humans, the environment and the economy. In other words the sustainability of industrial activities is the focus. The mandate for this Committee, which has been assembled for its second report period, emphasised this development.

OECD has spent much effort in recent years to analyse the condition of the seaborne transport industry and to give recommendations for its future development. The first report on The Environmental Effect of Freight in 1997 analysed seaborne transportation and found it to be comparatively environmentally friendly, however further OECD reports dealing with the maritime industry were less positive. The list of OECD reports specifically related to maritime shipping starts with Endresen (2008), continues with a study on the effects of the shipbuilding industry itself (OECD, 2010b) and ends with a report on the role of ports (OECD, 2011) which describes the impact on the environment around bigger international ports and the consequences for local authorities.

Further the International Maritime Organisation (IMO) has taken onto its agenda strategic directions that initiate activities to reduce the environmental impact of shipping and to improve the sustainability of all aspects of shipping, from shipbuilding, through ship operations to ship dismantling (IMO, 2010d).

As a consequence of the concerns outlined above the major part of the report of this Committee deals with methods used to assess the sustainability of the maritime industry, and covers aspects such as economic impact, impact to humans and impacts to the environment. Along with the usual literature review some methods are described in more detail.

Further, this report tries to describe the regulatory framework that is dominated by a dual system, consisting of on the one hand of classification requirements and on the other of international legal requirements (from the IMO and flag states), but is now being extended by yet a third interest group, the port state authorities, who are raising further requirements. Intending to differentiate between random impacts like sea loads and the respective responses and systemic impacts like emissions from ships to the environment the following two sections are titled control of random impacts and control of systemic impacts.

During the last years, especially in Europe, many activities started to install offshore wind energy plants, as a consequence attention has been paid to some aspects the offshore wind energy industry which is contributes its part to a sustainable utilization of natural resources.

The next important development for the maritime industry is the IMO's Goal Based Standards which were adopted during the 87th session of the Maritime Safety Committee (MSC 87) in May 2010. In continuation of this Committee's previous work this Report discusses the possible consequences of future development of Rules and Regulations in the maritime sector.

## 2 THE GLOSSARY

Within this report a few terms will be used that have different meanings in different contexts. To allow a common understanding within this context a glossary will list the

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)

Proceedings to be purchased at http://www.stg-online.org/publikationen.html



Table 1: Categories of losses and examples

| | | Humans | Environment | | Assets |
|---|---|---|---|---|---|
| Systemic | Loss generated by a certain event (probability of occurrence = 1) | Fatalities, injuries, permanent or transient disabilities (health, disease problems), physical or psychological disturbances | permanent or transient loss of biodiversity, utilisation of fossil resources | GHG emissions from a ship | failure, damage, unavailability of assets, operating costs, building costs |
| Random | Loss generated by a random event (probability of occurence $< 1$) | | | oil spill from a tanker ship | |

definitions as used in the context of this report. In the context of the present report all definitions are to be interpreted as applied to the field of structural design

*Sustainability:* An activity is sustainable if it is proved that it adds value to the society, i.e. it improves the quality of life of the members and does not prevent future generations to achieve similar improvements. The expected value of the impact of a sustainable activity on the long term needs to be positive, i.e. the benefits should overcome the losses. The reference time range for the evaluation of single terms of the balance above mentioned should be set in order to capture all possible implications (with an intergenerational perspective, if applicable).

"Companies are being encouraged, and will increasingly be forced, to take 'cradle-to-grave' responsibility for their products, which of course includes shipping" (Landamore and Campbell, 2010).

*Corporate Social Responsibility:* Attitude of a corporation to pursue sustainable activities

*Loss:* Any adverse impact of a structural system, it may include terms regarding humans, environment or assets. Depending on the probability of occurrence of the events at the basis of the losses they can be divided into systemic and random.

The total expected loss is meant as an integral in the time and probability domain of the various contributions.

*Accident:* Random event generating losses

*Safety:* A structural system is safe if it does not impair sustainability through an excessive expected loss due to accidents (i.e. to random events).

*Risk:* Expected loss due to random events (probability times consequences)

*Regulatory framework:* In the existing practical applications of regulatory frameworks, different sets of requirements address specific performances. They, all together, should pursue sustainability in a specific field (in particular shipbuilding and ship operation)

*Performance:* Performance of a structural system in this context is a quantity that allows to assess if the system is sustainable. Benefits and losses for the society are respectively positive and negative performances. Summed together they provide an assessment in terms of Sustainability, which is the ultimate performance. (A positive value of sustainability is the final target to be aimed at).

*Performance based rules vs. prescriptive rules:* In principle, a performance based rule should always refer explicitly to the final target for the assessment (positive sustainability, in the present report). In all practical implementations of Rules the final target is broken down into partial targets of different levels of generality. The less general is

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



the target, the lower degree of freedom is allowed in the choice of the design solution. It is to be noted that this practical way of constructing a regulatory framework may have the effect of neglecting solutions that do not satisfy a specific target, but may be able to achieve the final goal.

A performance-based set of Rules implies a 'calibration' of lower level targets to targets at a higher level (and ultimately to the final target: sustainability). If this calibration is not performed, the term 'prescriptive Rules' applies, as the requirement is introduced in an 'axiomatic' way (i.e. without a proper justification in terms of achievement of the final target).

In the IMO context 'Goal Based Standards' can be seen as a synonymous of 'Performance Based Rules'

*Functional requirement:* In the practical implementation of a regulatory framework, specific targets can be set, represented by functional requirements. Such targets can be set at different levels. In the framework of the development of performance based rules it should be proved that their fulfilment implies to improve Sustainability.

*Full Cost Accounting:* In the context of this report, FCA is a synonymous of sustainability assessment.

## 3 THE CONCEPT OF DESIGN PRINCIPLES AND CRITERIA

### *3.1 Design Principles and Criteria in Context*

The principles guiding the design of vessels, and therefore the criteria used to develop the best designs, have evolved over time. It is useful to consider that evolution in order to understand the focus of design today, and how society's concern for sustainability can be identified in the evolving design principles and criteria.

There are many definitions of sustainability (see the Glossary), however it is now widely accepted that the concept has three pillars: economic, societal, and environmental. The evolution of design can be shown to have sequentially added each of these three areas, or pillars, to the required criteria, such that now it can be considered that we are striving to achieve 'design for sustainability'. This analysis was first introduced in the 2009 Design Principles and Criteria Report (from ISSC Committee IV.1), where a matrix diagram was presented that illustrated this analysis. A version of the matrix diagram is reproduced in Figure 1.

In this diagram the costs associated with the three areas of sustainability (economic, societal and environmental), are divided into two categories: costs that are an inevitable part of the operation, and can therefore be considered systemic; and potential costs that are possible if an unintended event occurs, and so can be considered accidental.

The chronology of the embedding of these six categories of concern into the design process has been as follows:

- Economic principles and critieria: design has always focused on minimising the cost of constructing a vessel, and of operating it - these economic concerns must have been present even before the theory of economics itself had been devised. Subsequently criteria were developed that sought to prevent the costs being incurred due to accidental loss of the vessel and cargo, an early example being the minimum freeboard mark.

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



| Sustainability Pillar | Systemic Costs: Continuous and Inevitable | Accidental Costs: Spasmodic and Potential |
|---|---|---|
| Economic | Initial & operating costs (Owners, Designers' and Builders' concern) | Loss of vessel (Owners and Insurers' concern) |
| Societal | Health and Safety of Life (Societal concern) | Injury and Loss of Life (Owner and societal concern) |
| Environmental | Environmental Impact (Recent societal concern) | Pollution (Owner and Societal concern) |

Figure 1: The matrix of concerns that comprise Design for Sustainability (from the Impact Matrix presented in ISSC 2009, Report of Committee IV.1)

- Social principles and criteria: the safety of those aboard the vessel, crew and passengers, grew as a concern in the 19th century, eventually being formalized in the first SOLAS convention in 1914. These concerns initially concentrated on the loss of life due to accidents, however during the 20th century an increasing emphasis has been placed on health as well as safety, and so requirements have been introduced to ensure that in the normal operation of any commercial activity the health of the operators (and the public) is not compromised.
- Environmental principles and criteria: environmental concerns first focused on the damage suffered by nature as a result of accidental pollution form events such as the loss of a tanker. It is only in the last few decades that it has been widely recognized that commercial activity can not be allowed to routinely damage the environment as an unavoidable part of the operation of any system.

This brief (and simplified) description of the chronology of the evolution of concerns that underlie the design of ships is reflected in the diagram below. It can be seen that it is the relatively recent realization (or at least widespread acceptance) of the environmental impact that human activity is having around the globe that has led to a change in society's priorities. The ongoing development of the principles and criteria reflect society's desire that sustainability considerations drive the design of ships and offshore structures. In this chapter the current methods for the analysis of the three pillars of sustainability are described.

### *3.2 Analysis Methods for the Economics of Maritime Transport*

Recent research advances in the economics of maritime transport discuss issues related to the value of ships, design methods to maximize this for stakeholders, shipbuilding as a service, ship speed etc. Here the way these concepts reflect on ship design principles and criteria will be discussed. First however, some statistics on the economics of maritime transport will be provided.

Observing the world trade figures (UNCTAD 2011) we can clearly state that without the seaborne shipping, world trade would not be possible on the scale necessary for the modern world to functions. Around 90 % of world trade is carried by the international shipping industry and this accounts for 4.5 trillion USD of exported goods. According to the same statistics, this figure brings 380 billion USD in freight rates, which is equivalent to about 5 % of total world trade.

These figures indicate the efficiency of shipping. The ratio between the total freight rates and goods transported leads shows that on average less than 10 % of the value of goods transported is required undertake that transportation using the shipping of the world. Even if the annual investment in newbuilding is add to this, in the order of 100 billion USD (SAJ, 2010), the overall system is still very lean.

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)




### *3.2.1 Economics of Shipbuilding*

Modern shipbuilding demands a new approach that accounts for the opinions of multiple stakeholders. Traditionally, "ship designs were often developed by a stove pipe [i.e. isolated] design organization without the direct, early participation of the future ship's builder, ship owner, operators and maintainers" (Gale, 2003). In contrast, modern design teams employ Concurrent Engineering principles, which require the consideration of all the stakeholders' preferences. It indicates that the ship valuation should be approached from the perspectives of different parties involved in the shipbuilding process.

The conventional ship value assessment adopts the Net Present Value (NPV) (Stopford, 1997) approach, which only measures the tangible aspects of the ship, including ship's features and functions, discounted through time. NPV therefore fails to capture the importance of partnership and cooperation between the stakeholders of the shipbuilding industry.

Forsström (2005) studied the importance of the relationship between the shipyards as sellers, and the owners as buyers and turnkey suppliers, and concluded that interdependency triggers stakeholders to continue the relationships, recognising that they can to create more value together than independently.

Wang (2008), building on this, found that currently there is insufficient understanding of the value of a ship by the ship owner and shipyard. A more complete understanding will enable designers to reduce the problems of over and under-engineering, prevent ship owners from making unrealistic requirements and avoid shipyards doing inappropriate things such as installing poorly performing equipment. The author also concluded that for unique and sophisticated ships, like cruise ships, successful building was only possible if there was a strong relationship between the stakeholders that allowed flexibility to bridge all technical challenges. Less sophisticated ships, like bulk carriers or tankers, are built strictly according to specifications, and any demands for alterations are met with resistance. The dominant factor of value for these kinds of ships is price, while for the sophisticated ships, the value is held in the passenger experience and the uniqueness that the ship has in the market.

This fact led many yards building cruise ships to extend their business activities to support the owner in the post delivery phase, offering to their clients not just a product, i.e. a ship, but a shipbuilding service. This service would include a maintenance service for the ship, but the primary objective was to engage in the refitting and enlargements of vessels in order to rejuvenate them after a certain period of time, perhaps 10 to 15 years.

Klanac *et al.* (2011) studied the aspect of a "true service yard", in which, following the modern business paradigm of production companies as service companies, a shipyard would get involved in providing transportation capacity. Instead of selling its product, i.e. the ship, it would offer it on the charter market. The benefits of this business model are found in the increased asset value of the yard, longterm production planning, which enables innovation, continuous inflow of income, reduced requirements for cash backup etc.

### *3.2.2 Economics of Ship Operations*

Noticing the shipping industry's trend toward the reduction of operating speed due to the rising oil prices and reduced economic activity in 2010 and onwards, Klanac *et al.* (2010a) performed an analysis to identify optimal speeds dependence on freight

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



rates. Following the premise of economic equilibrium, it was possible to draw a functional relationship between the optimal ship speed and the freight rates, assuming constant transport capacity. Further to this, the relationship was also established with the cost of ship operations. Considering that the biggest cost in operation is the fuel, it is possible to estimate the optimal ship speed and the corresponding freight rate for a given price of fuel. Extending the result of this analysis into the present day situation of rising oil prices, or the addition of $CO_2$ taxes, we can expect that the ship speed will need to be further reduced if the economic equilibrium is to be maintained. Only a rise in the world economy could reverse this trend, but if the requirement to reduce the $CO_2$ emissions from shipping is accepted then maintaining the slow speed steaming and building more ships might in the long term build a more sustainable approach to 'greener' shipping industry.

#### *3.2.3 Economics of Maritime Accidents*

The circumstances surrounding a spill incident are complex and unique. Predicting the per-unit costs of a spill response is a highly imprecise science since the factors impacting cost are as complex as the factors impacting the degree of damage the spilled oil will cause. Clearly, one universal per-unit cost is meaningless in the face of these complex factors, see Schmidt Etkin (1999, 2000).

On the other hand, the spill response, or the clean up is a minor part of the costs. The major part of the costs relates to the socio-economic damage to the community affected by pollution, and in this way a lot of variations can be averaged, so building a model with confidence. In this respect Friis-Hansen and Ditlevsen (2003), using previously reported spill damages (Grey, 1999) established a probabilistic model. Klanac *et al.* (2010b) updated the model with figures related to reported major accidents from 2000 to 2008 (IOPC, 2009).

Klanac and Varsta (2011) studied the international legal framework of IOPC fund (IOPC, 2005), and considered how it impacts on the overall pollution damage. They found that risk distribution is unbalanced as a result of the scheme of liabilities determined according to the maritime conventions, namely the CLC 1992 and the IOPC 1992 fund. An additional imbalance amongst stakeholders is due to the distribution of influence on risk management. The public has a very low influence on risk management, principally setting only the minimum requirements through the actions of its representatives in the IMO or their Flag States. The biggest influence and responsibility is on the yard designing and building the structure, while the influence of


Figure 2: Principal distribution of the environmental risk of spillage among stakeholders for a small to medium tanker (40 to 75 thousand tons DWT), and the influence of these stakeholders on risk management (Klanac and Varsta, 2011).

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)




ship and cargo owners on risk management are inversely proportional to their share of the risk. Figure 2 interprets this statement graphically, although it assumes that ship structural design as the sole risk control option. Klanac *et al.* (2007) and Klanac and Varsta (2011) propose this ship structural design method based on multi criterion decision-making to minimize the negative effect of this unbalanced distributions of risks.

#### *3.2.4 Economics of Ship Dismantling and Recycling*

EC (2007a) performed a comparative study amongst others on the economic options of ship dismantling to avoid careless and "illegal" beaching in India and Bangladesh. From the results of the case analysis the most attractive alternative to beaching in Asia is dismantling at Turkish sites. The second-best alternative seems to be the procedure of pre-cleaning of hazardous material in Europe and then dismantling in Asia. The high cost of European labour coupled with the cost of complying with all workers' health and safety and associated environmental regulations in Europe is the reason why the scenario with full green dismantling in EU is the least attractive alternative.

In their study for the US Navy, Hess *et al.* (2001) analysed among other common dismantling strategies the reefing of naval ships (i.e. creating artificial reefs with the vessel). They concluded that reefing is the only option that has the potential to create revenue in the form of taxes from businesses associated with reef usage beyond the ship-disposal costs.

Recently, Classification societies started to implement Green Passport to the ship's class notation to distinguish ship which posses onboard Inventory of Hazardous Material (IHM). Following the convention of IMO (2009), this notation has been established partly to safeguard life onboard, but predominantly to safeguard the life of the personnel involved in ship dismantling and recycling. IHM contains the list of all hazardous materials permanently stored onboard, inside of ship hull and accommodation, and the ship equipment. Any changes in these subsystems should be also noted in the IHM in such a way that IHM permanently represents the actual status of hazardous material onboard. Gaining Green Passport notation provides strong marketing for the owner on the second hand ship market. There is a common understanding also that in the phase of ship dismantling, better price can be gained for a vessel carrying a Green Passport.

### ***3.3 Analysis Methods for Human Life and Health***

#### *3.3.1 Approaches to the Valuation of Human Life, Health and Safety*

During engineering projects such as shipbuilding projects decisions have to be done how the performance of a system and namely its safety can be improved. This goes along with changes of costs of the project, may it be increased or decreased costs. As a consequence the engineer needs a support to determine the consequences of an option, as this may be a risk control option in the terminology of formal safety assessments, to improve the performance with regard to the costs. In this context one of the most difficult issues in examining different risk control options for making engineering design decisions and policy formulation is the valuation of human life, health and safety in monetary terms which have meanings in pricing decisions. However in the fields of technology, medicine and insurance decisions are taken that sometimes also involve the possibility of human suffering or death. These decisions are usually made by politicians, taking into account the aversion towards human suffering in an intuitive way. An analysis of these decisions shows, however, that the implicit value of a human life is always finite.

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



The economic aspect of the problem is, that the scarce national means have to be divided over many investments, among which are a number of possible investments in health and safety. Any rational decision mechanism must therefore be able to weigh the probability of profit against the probability of saving lives and enhancing health. The growing application of risk based design methods makes it necessary to estimate the value of a human life, health and safety in addition to an assessment of the economic damage involved with failure of the system under design.

Generally the most common approach is to conduct a cost and benefit analysis. One such analysis is to study the outcomes of political or societal decision processes, the investments made in a society to enlarge the probability of saving an extra life. The cost, or investment made in practical cases to save an expected extra life (the investment divided by the decrease in expected number of casualties due to the investment) is denoted by CSX. This CSX value seems to be able to serve as a valuation of human life, as it indicates the willingness to pay for the saving of a life. The problem with this approach is that the resulting CSX values differ widely. The values reported in literature, see Brookshire (1980), Crouch (1982) and Ramsberg (1997), ranges from $1,000 for investments in sport and recreation to $100,000,000 for investments in the nuclear industry. In the marine industry it is generally assumed the value to be $3,000,000. Many authors mention this wide range as an indication that decisions concerning the protection of human life are irrational. The tacit assumption is that the CSX value should be a constant number. However it would be even more difficult to monetize health and safety. Most insurance policies do attach a monetary value to "physical" damages to human body.

Holland (2002) and Kelman (2005) contend that the characteristic value monism of cost-benefit analysis renders the practice inadequate for guiding environmental policy formation: not all choices are tradeoffs made on quantitative assessments of preference satisfactions, Holland (2002), and some goods human life among them cannot and should not be measured in monetary terms. Economist Robert Solow (2005) contends that cost-benefit analysis need not necessarily operate by "monetizing everything from mother love to patriotism". Amartya Sen (2001) notes that a foundational component of cost-benefit analysis is "broadly consequentialist evaluation", i.e. a decision is evaluated based on the costs and benfits of its consequences. At a basic level, cost-benefit analysis can include within the scope of its reasoning diverse goods - including so-called "human costs," such as rights and duties, and environmental costs. Sen acknowledges that cost-benefit analysis is not fully compatible with a deontological ethical framework, but he notes that it can accommodate in its calculations respect for rights and duties, safety, health, environmental, and other concerns.

If, despite ethical objections, a price has to be put on a human life, an objective number is the present value of the Net National Product (NNP) per head of the country under study (Net National Product = Gross National Product (GNP) minus Depreciation). The consequence of this approach is that the value of human life in a developing country is considerable lower. This may seem strange and unethical, but it actually accentuates one advantage of the economic optimization of safety, that is, the proposed investments in safety are affordable in the context of the national economy.

Another method is the Life-Quality Index approach (LQI) which is another means of applying the cost benefit analysis approach. The LQI is a tool for the assessment of risk reduction initiatives that would enhance safety and quality of life. The LQI is a substantial improvement for rationalizing the process for setting safety standards (Nathwani *et al.*, 1997; Pandey *et al.*, 2006). It is a tool for the assessment of risk

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)

Proceedings to be purchased at http://www.stg-online.org/publikationen.html



reduction initiatives that would support the public interest and enhance safety and quality of life. The LQI is equivalent to a multi-attribute utility function being consistent with the principles of rational decision analysis. It is further refined to consider the issues of discounting of life years, competing background risks, and population age and mortality distribution.

Rackwitz (2002, 2004a,b) and Rackwitz *et al.* (2005) expanded the LQI framework and applied it to determine optimal safety levels in civil engineering infrastructures. Maes *et al.* (2003) applied LQI for optimising the life-cycle cost of structures. The LQI model has also been applied to the cost-benefit analysis of air quality standards and nuclear safety design practices by Pandey and Nathwani (2003).

If economists, ethicists, and policy-makers alike seek methods of cost benefit analysis that are more adept, then the practice can be retained as an evaluative and decisional tool that can explicitly and helpfully facilitate the decision-making process. Kelman (2005) criticizes cost-benefit analysis for its characteristic inability to take into consideration rights and duties as things that have prima facie moral validity. He also contends that we should not always readily assign monetary values to non-marketed goods such as human life, health, and environmental stability. Holland (2002) similarly contends that cost-benefit analysis, at least in its cruder forms, lacks the capacity to grasp adequately the value of goods - both marketed and non-marketed - and to take into account how the value of goods and relative weights are formed. The above analysis reflects on cost-benefit analysis as an evaluative and decisional tool that is marked by explicit evaluation, broadly consequentialist reasoning, and additive accounting. Within the restrictions that these three principles bear for the practice of cost-benefit analysis, the discipline is surely limited. Other conventional structural and valuational features such as non-iterative and non-parametric valuation and market-centered valuation (including reliance on willingness to pay, and exclusion of social choice options) are common but not in themselves essential to the practice of cost-benefit analysis. Various approaches to cost-benefit analysis can be adopted. Monetary commensurability is not always required, thus value pluralism can be introduced. Market-centered and willingness-to-pay valuation are conventional but can be practiced in conjunction with other methods of valuation. Goods can be weighed on non-monetary scales of value and social choice options can be considered. Economists can use iterative valuation and value parameters and thereby keep the process open to changes in value assessments and qualitative judgments. Simple arithmetic alone does not have to determine the process. We can develop or improve the method of cost-benefit analysis rather than discard it as inherently morally inadequate.

### *3.3.2 Occupational Health*

In its strategy IMO has focused on the development of Goal Based new ship construction Standards (GBS), where a more holistic approach towards the ship and its systems is applied. The second approach has a more risk-based and holistic attitude and is called the safety level approach (GBS-SLA), included the safety of seafarer (occupational health), passengers and safety of third parties. Juhl (2007) investigated common ideas and problems of vessels' crew occupational health and safety (OHS). The intention with GBS - and in this respect especially with regard to SLA - is that the standard is an overarching and holistic approach which covers all functions and systems on board. The argument is that if there were a safety standard in place for all systems and workplaces on board, it would indirectly reflect positively on the health and safety of the crew, i.e. the OHS. To the author's opinion, communication between

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



ships' design and ships' ergonomics has been non-existent, and it is overdue for the working environment and the prevention of personnel accidents to be taken into consideration in the construction phase, where it is both cheaper and more efficient to create the solutions that efficiently prevents work-related accidents.

Permanent means of access to spaces that require surveys are commonly comprised of walkways, platforms, ramps, ladders, and hatches (see McSweeney *et al.*, 2007, ABS, 2009). Each form of access is unique in design, construction, and arrangement including the potential hazards associated with their use. These hazards include falling over guardrails, off walkways or ladders, stepping into or falling through deck openings, climbing on ladders that are damaged or slippery, or head strikes against overhead obstacles or surfaces. Recently, IMO amended the SOLAS requirements for means of access to vessel tanks and holds. In response, IACS developed Unified Interpretations to provide vessels owners with guidance about how to meet the intent of the SOLAS amendments.

For example, ABS ergonomics approach used for developing ABS own guideline ABS (2003) is described. Recognizing that much of the access criteria could be refined/enhanced by the application of ergonomics criteria, ABS has prepared the Guide for Means of Access to Tanks and Holds for Inspection with an associated notation (PMA+). The PMA+ notation combines the IMO means of access requirements with ergonomics criteria. It is believed that this additional guidance will provide vessel owners with a means to enhance personnel safety associated with survey and inspection activities.

Postural stability is one of the key topics for the maritime sector, Nocerino *et al.* (2011), as wave induced ship motions make the maintenance of upright stance demanding and moving in a controlled manner very difficult, negatively affecting safety of personnel working onboard. Mariners have to concentrate on standing upright while performing the allotted task, avoiding risk of potential injury. Crew members of fishing vessels, navy craft, and supply vessels all experience conditions of work that are different from those faced by workers in other sectors. The fatality rate for fishers is typically several times higher than for other employees, making fishing a very hazardous activity. For validating theoretical models aiming to simulate the postural behaviour of working personnel a possible method is the execution of trials onboard full-scale ships. Nocerino *et al.* (2011) describe an innovative motion acquisition system that is usable onboard ships while accomplishing the daily mission. The system integrates different techniques (photogrammetry, inertial measurements, global positioning system) for acquiring both ship and human motions. Its core is an own-developed low-cost motion capture system fundamental in analysing and understanding the measurements from the inertial sensors. Preliminary laboratory tests and results from measurement campaigns onboard are also presented.

#### *3.3.3 Maritime Labour Convention*

The International Labour Organization (ILO) provides legal instruments aimed at protecting and improving working conditions, including those of seafarers. Recently, the ILO produced the Maritime Labour Convention, 2006 (MLC).

The MLC provides a comprehensive code regarding seafarers' rights, and the obligations of States and vessel Owners with respect to these rights. The MLC incorporates the fundamental principles of many ILO Conventions and updates standards of 68 existing ILO Conventions into one document. The MLC comprises three different but

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)




related parts: the Articles, the Regulations, and the Code. The Articles and Regulations set out the core rights and principles and the basic obligations of Members ratifying the MLC. The Code contains the details for the implementation of the Regulations. The Regulations and the Code are organized into general areas under five Titles:

- Title 1: Minimum requirements for seafarers to work on a ship.
- Title 2: Conditions of employment.
- Title 3: Accommodation, recreational facilities, food and catering.
- Title 4: Health protection, medical care, welfare, and social security protection.
- Title 5: Compliance and enforcement.

Title 3 of the MLC, "Accommodation, recreational facilities, food and catering" addresses issues related to quality of life at sea, including the physical design of seafarer accommodations and the characteristics of the ambient environment which seafarers are exposed to during work, rest, and recreation.

Guidance for complying with the Title 3 requirements is provided in ABS (2010a). This Guide is based on ABS' interpretation of the intent of the Part A requirements and on what ABS considers satisfactory compliance with the Part A requirements. This Guide provides the assessment criteria and measurement methodology for obtaining an ABS Maritime Labour Convention (MLC) Accommodations (ACCOM) notation (MLC-ACCOM). This Guide focuses on five categories of design criteria addressed in MLC. These categories are accommodations design, whole-body vibration, noise, indoor climatic variables, and lighting.

#### *3.3.4 Noise Impact*

The subject of noise impact is here considered as an example of systemic impact on humans. The subject is covered not because it is believed to be more important than others, but because noise impact has been only recently been recognised to be important and some efforts are presently being devoted to analyse its effects. The relatively recent development of the analysis, however, gives additional problems in inserting this element in the global evaluation of sustainability.

The impact of noise produced by transportation means it takes the double aspect of emissions towards the inner part of the vehicle and towards the external space. This is a common feature of road vehicles, trains, airplanes and ships.

In the specific case of surface marine vehicles, external acoustic pollution is represented by airborne and waterborne emissions (the latter being typical of this type of vehicle) while the internal transmission is represented by airborne as well as structure-borne noise transmission. The propagation of noise both inside and outside ships features peculiar aspects in comparison with other transportation means because of the dimensions and the complexity of the vessel source (external radiation in air and the sea), because of the medium involved in transmission (waterborne emissions) and to the specific features (stiffness/mass characteristics) of the ship structure.

On a global scale, from the point of view of a sustainability assessment of the shipping process, all these types of radiation have a negative impact and are to be considered as negative terms (losses) in the balance of sustainability. The subject of the quantification and control of the noise impact of ships is being studied by the SILENV project within the 7 Framework Programme of the European Union (www.silenv.eu).

The impact that noise radiation has in the three fields above mentioned has quite various features, regarding different categories of receivers and different perspectives

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)




within the same category. The noise internal to ships affects the crew members and (if applicable) the passengers of the ship. The time duration of the exposure to noise and the psychological attitude towards it (both influencing the quantification of the impact) are different for the two classes of persons, which are both part of the transportation process.

External noise radiation into air may, on the other hand, affect third parties: inhabitants of areas surrounding ports, channels and coasts impacted by intense shipping traffic. In this case, the exposure time may vary from a few minutes for the ship sailing to a few hours for the ship charging or discharging at port. The frequency content and the main sources generating the noise signal differ from the case of the noise internal to the ship and differ also if the ship is sailing or in harbour.

Finally, noise emissions in water affect the marine ecosystem and its inhabitants, with effects that can vary greatly according to the type of animals (with sensibilities very much different from each others), geographical areas and situations. This subject will be covered in the next section.

A proper quantification of the effect of noise radiation from ships should therefore take into consideration all these aspects. From the point of view of the control of the noise impact the various situations differ considerably, too.

When considering the noise internal to ships, all the elements of the 'acoustic circuit' (source-transmission path-receiver) are located in the vessel. The performance to be assessed (negative effects of noise) is therefore depending entirely on characteristics of the ship and can be predicted and controlled at a design stage of the ship, with little or no influences from other elements.

On the contrary, the impact of the external radiation of airborne noise depends not only on the source (ship as a whole) but also on the characteristics of the surrounding areas (e.g. port, channel or coast geography, orography, meteorological conditions, distribution of buildings and inhabitants in the area, etc.). A quantification of the impact, therefore, involves consideration of element external to the ship and not controlled at a design stage.

*Impact of Noise and Vibration Onboard*

As mentioned for example in Badino *et al.* (2011a), the problem of health and comfort for crew and passengers on board has been considered for a few decades, leading to quite a structured and detailed framework of Norms and Requirements: several Regulatory Bodies dealt with this problem. Among them:

- The ILO (International Labour Organisation): Given the very broad mission of the organization, the aspect of noise and vibration for workers is treated in very general documents, covering also a large number of other issues, but not in a quantitative way. This applies in particular to the documents relevant to the maritime sector, references ILO (2006), ILO (2007a) and ILO (2007b).
- IMO (International Maritime Organisation): The IMO normative framework gives a more quantitative evaluation of noise effects, setting precise objectives for noise control. The key document in this respect is the IMO Noise Code (IMO, 1981, see also IMO, 1974 and IMO, 1975). For the purpose of the present report, it is interesting to note that two types of requirements are set:
  - limits on the instantaneous sound pressure levels in various locations on board (levels in dB(A)). By instantaneous is here meant a value that is obtained from a short term average, of the order of minutes. Such levels

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)




can be interpreted as limits in the sound power perceived by the human ear, (the characteristics of the human hearing apparatus being represented by the A-filtering)

– limits on the total exposure to noise (in principle in all the locations visited by the seafarer during the 24 hours), expressed in equivalent levels: $L_{eq}(24)$, see eq. (1). This can be seen as a limit on the total perceived sound energy during the typical day.

$$L_{eq}(24hours) = 10\log_{10}\frac{1}{24h}\int\limits_{24h}\left(\frac{p_A(\tau)}{p_0}\right)^2 d\tau \tag{1}$$

where $p_A$ is instantaneous A-weighted sound pressure; $p_0$ is reference pressure.

Even though not explicitly stated, the former type of requirement is meant to prevent 'immediate' effects of noise on the seafarer, ranging from permanent to transient impairment of hearing capabilities (in case of higher noise levels), to masking effects of signals or communication, to stress due to noise inducing underperformances while performing duties. The second type of requirements is devoted to the prevention of accumulation of damage in time for workers exposed for long periods to noisy environments. The two classes of requirements correspond therefore to different classes of consequences.

- Class Societies (Comfort Class notations): The aim of these additional (voluntary) notations is to evaluate the shipboard habitability and to assess with an independent certification the comfort of crew and passengers on board all kind of ships following noise and vibration criteria. Comparing the noise limits with the IMO ones (as regards crew spaces, the only ones treated in IMO, 1981) it is noted that the dB(A) limits of the lower comfort grade are close to the IMO original limits while in the higher grades limits are lower. No provisions are set in the Comfort Classes for long term exposures (using indicators like the $L_{eq}(24)$ or others).

For more detailed comments on the normative framework for the noise internal to ships, the reader is addressed to the relevant literature. In particular in Badino *et al.* (2011c) it is noted that acoustic comfort is one of the most important factors that passengers and crew usually consider to assess their on board wellness. However, at present, rules mostly refer to merely energetic indexes, as the A-weighted sound level, not considering elements with great impact on the acoustic annoyance, such as the spectral composition of noise or the repetition over time. The paper proposes a few enhanced acoustic criteria and methods to value the noise annoyance on board ships, derived from civil engineering context and notes that such criteria seem able to improve the present indicators for comfort evaluation classes, taking into consideration low frequency sound or relevant tonal components.

In addition to the literature devoted to the definition of noise requirements, a number of technical papers are found on the subject of practical means to analyse noise transmission and achieve an effective noise control on board:

- Beltran *et al.* (2011) describe a model and onboard investigation of two Ro-Ro vessels of environmental impact Noise and Vibrations on board. Correlation between theoretical and test data is discussed.
- Incel *et al.* (2009) presents a case study conducted by two sister ships, one with special noise insulation materials while the other without any special treatment.

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



Noise reductions have been conducted for the base ship and special noise reduction techniques such as floating floors, visco-elastic insulations etc. have been applied to comply stringent noise levels. The prediction method and efficiency of the special noise insulation material effects are demonstrated both by calculations and by full scale measurements. Full scale results are in good agreement with the noise levels at the lower decks. However the agreements between predictions and measurements are low at the upper deck levels. This may originate due to the noise from air conditioning, ventilation and the funnel. Differences between two ships on the noise spectrum clearly indicate that higher frequencies are affected more from the visco-elastic noise reduction measures. Lower frequencies may even be resulted in noise increase.

- Cotta *et al.* (2011) discusses a practical application of Comfort Class Notation. It introduces the main characteristics of a Comfort Rule on Board, presents the general testing conditions and also highlights additional requirements for passenger ships greater than 65 m length. The main features that each Register requires today to classify a ship with a Class Notation are presented. From the comparison between Rules Notations and Technical Specification Limits (TSL) it is possible to note how in passenger areas maximum accepted limit values are close to the best comfort class in every conditions analyzed, on the contrary noise and vibration values accepted in crew cabins and accommodations have maximum limits close to the lower Class Notations. Probably this discrepancy is related to the difficulties to have a homogeneous definition of comfort on board.

*Impact of External Airborne Noise Emissions from Ships*

As mentioned in Badino *et al.* (2011b,d), the characterisation of the whole ship as a source of airborne radiated noise is in itself a challenging task, due to the dimensions of the ship, the directivity of the emission, the dependency on the operating conditions (sailing or at quay: i.e a moving or a stationary source for a receiver ashore). The subject is covered in part by ISO Standards for the case of inland waterways (ISO, 2000) and for recreational crafts (ISO 2007, 2009). These standards deal with measurement procedures, but do not contain limits. In EU (2003b) limits for airborne noise are given for recreational crafts in function of the engine power. Such limits are to be measured according to ISO (2007), ISO (2009).

Limits and measurement procedures for this topic are being studied within the SILENV project (http://www.silenv.eu/)

When evaluating the impact of the noise emitted, it is to be noted that, as above mentioned, the actual emission patterns are highly dependent on the local characteristics of the surrounding area: obstacles, reflecting surfaces (hills, buildings) even meteorological situation. On top of this, the receiving positions (location and distribution of inhabitants with respect to the ship) are also much dependent on the local characteristics.

Indicators that can be used as units for describing the impact of noise emission from ships are on the other hand available from other engineering fields, but need to be adapted.

Two main European directives deal with the problem of industrial airborne noise: the European Directive 2002/49/EC (EU, 2002) and the European Directive 2003/44/EC (EU, 2003b). The first one applies to environmental noise to which humans are exposed in particular built-up areas, in public parks or other quiet areas in urban agglomerations, in quiet areas in open country, near schools, hospitals and other noise-sensitive

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)




buildings and areas. The indicators used are $L_{\text{den}}$ and $L_{\text{night}}$ (day-evening-night levels), that are equivalent levels defined as follow:

$$L_{\text{den}} = 10lg\frac{1}{24}\left(12 \cdot 10^{\frac{L_{\text{day}}}{10}} + 4 \cdot 10^{\frac{L_{ev.}+5}{10}} + 8 \cdot 10^{\frac{L_{\text{night}}+10}{10}}\right) \tag{2}$$

where $L_{\text{day}}$, $L_{\text{evening}}$ and $L_{\text{night}}$ are A-weighted long-term average sound level as defined in ISO 1996-2: 1987.

As apparent, in the above definition, the noise energy in the different periods of the day is weighted differently to build up a 'weighted equivalent level'.

The aim of these indicators is to correlate the measurement of sound pressure level and the percentage of people who have negative effects on their health due to a prolonged exposure to an examined noise source. The original target of such indicators are continuous noise emissions from industrial plants or similar. The application to the case of ships, passing by or at anchor, may require some adaptations, due to the comparatively short exposure time.

In Badino *et al.* (2011d) some negative conclusions were drawn about the present normative situation, which appears to be fragmented and not very well defined in terms of design emission values for ships. In the same paper, however, the Noise Strategic Mapping is identified as a useful tool to set up a control methodology for noise levels in maritime ports. As it implies the definition of an evaluation methodology of the noise levels produced by ports activities in general and by ships in particular, it can very well be used to assess the impact in terms of number of people affected and inherent noise levels (or equivalent levels, possibly weighted).

Still the question of how to weight, in monetary or other terms the exposure to noise (however evaluated) remains open.

*Comments on the Evaluation of Ship Noise Impact on Human Life*

In the preceding sections, the impact of noise on humans has been addressed separating the effects on people involved in the transportation process (crew and passengers inside the ship) from third parties. The classification to some extent is based on the absolute levels of noise to which the various categories are exposed: the crew on board is in more close contact with sources and for longer periods, passengers are less exposed both in terms of levels and time, external people are likely to be subjected to lower levels (even though not necessarily for shorter times). The differences in acceptable levels and also the indicators that are used to quantify the effects reflect the different roles played by the various categories. The limits have also different targets, ranging from the prevention of body damage due to short and/or long term exposures to avoidance of direct/indirect interference with working activities to the enforcement of less easily defined feelings of 'comfort' or 'well being'.

From the point of view of a proper evaluation of the balance between design efforts to prevent noise and benefits of reducing it, it can be said that extreme consequences (body damages) and inherent scenarios are more easily defined than lighter consequences. This is reflected also in the time sequence in which the various aspects have been addressed by the regulatory bodies: the first norms for crew health date back three decades, Comfort Classes were issued in the 90thies and most norms for outdoor noise have been delivered in the last decade.

In principle, however, all classes of consequences should be identified and weighted for their impact on human life.

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



## *3.4 Analysis Methods for the Environment*

### *3.4.1 Recent Concerns on Environmental Analysis of Ships*

The Environment can be taken to refer to any one of a number of areas: the effect of shipping as an industry on marine life and ecosystems, impacts of routine operation such as the leaching of coating systems like TBT, the impact of ship borne noise and vibration; or one off accidental emissions such as an oil spill. It can also refer to effects on the global environment as a whole, the contribution of $CO_2$ emissions to global warming, or other life cycle impacts such as the depletion of non-renewable resources such as iron and oil.

Over the past ten years, interest in these impacts from all spheres of human activity has increased, and this is reflected in the existing literature on the subject, authors such as Bebbington (Baxter *et al.* 2003, 2004a,b; Bebbington, 2007a,b; Bebbington *et al.*, 2001, 2006, 2007; Bebbington and Frame, 2003; Bebbington and McGregor, 2005; Bebbington and Thomson, 1996); Cabezas-Basurko (Cabezas-Basurko, 2010; Cabezas-Basurko *et al.*, 2007), Corbett (Corbett *et al.* 2007; Corbett and Koehler, 2003, 2004); Fet (2002) and Landamore (Landamore *et al.* 2006, 2007a,b, 2008, 2009, 2010), along with others, have carried out research aimed at better understanding the true environmental impact of ships and shipping, and how best to mitigate this, thus ensuring a sustainable industry model, that is one which can continue to operate profitably now and in the foreseeable future.

### *3.4.2 Impact of Greenhouse Gas Emissions*

Although International shipping contributes only about 3 % of global $CO_2$ emissions (IMO, 2008a, Endresen *et al.* 2008), according to the EU targets (EC, 2007) the GHG emission need to be reduced by 50 – 85 % in 2050 compared to today's level (IPCC, 2007) and, therefore, there is an ongoing debate regarding how much the sector could be expected to reduce emissions and how the reduction could be achieved (Van Dender and Crist, 2008, Gehring, 2008).

Substantial work has been developed in recent years on the study of the environmental impact of the shipping activity as reviewed by Gaspar and Balland (2010). Two recent conferences exemplify the concern of the sector in the theme, namely the International Symposium on Ship Design and Construction - Environmentally Friendly Ship in Tokyo (ISSDC 2009) and the Ship Design and Operation for Environmental Sustainability in London (RINA 2010).

Gaspar and Balland (2010) have suggested an approach towards the integration of environmental performance in the early stages of ship design, focusing on energy efficiency and air emissions. The integration process consists in 5 tasks to be performed during the conceptual phase, in which methods are applied to estimate economical, technical and environmental key performance indicators (KPI), creating thus trade-offs and evaluating as soon as possible the pros and cons of the design.

Several technical and economical measures lead to changes in the environmental factors, such as the hull optimization (Hochkirch and Bertram, 2008) or the machinery system configuration (Gaspar *et al.*, 2010). However, a balanced full cost/benefit analysis of the operation is required if the true cost to society, industry and the environment is to be accurately measured, so as to ensure that efforts to reduce emissions to air from shipping do not unnecessarily prejudice another area of sustainability. In this way options for reducing the impact of shipping can be properly compared and

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)




the most beneficial to a sustainable future can be assessed (Landamore and Campbell, 2010).

Eide *et al.* (2009) have proposed a methodology for assessing the cost-effectiveness of technical and operational measures for reducing $CO_2$ emissions from shipping, through the development of an evaluation parameter called the CATCH (Cost of Averting a Tonne of $CO_2$-eq Heating) and a decision criterion for the implementation of measures, against which the evaluation parameter should be evaluated. The methodology proposed is in line with the Intergovernmental Panel on Climate Change (IPCC) and with regulatory work using Formal Safety Assessment at the IMO.

The decision parameter for emission reduction CATCH has been established using the same approach adopted in the development of the decision parameter, NCAF (Net Cost of Averting a Fatality), already included in the FSA guidelines (IMO, 2007, 2004), and the similar parameter for assessing measures for oil spill reduction, CATS (Cost of Averting a Tonne of oil Spill) (Skjong *et al.*, 2005).

Eide *et al.* (2009) suggested that CATCH $< 50\,\$/T$ $CO_2$-eq should be used as a decision criterion for investment in GHG emission reduction measures for shipping. A number of specific technical and operational measures for reducing CO2 emissions has been analysed for selected ships showing that several measures are cost effective according to the proposed criterion. Assuming independence between the measures, the cost effective measures (not including speed reduction) considered by Eide *et al.* (2009) add up to an emission reduction in the order of 30 % for the bulk carrier, and 40 % for the container vessel.

Alvik *et al.* (2010) present a similar study about the cost benefit of several measures to diminish the $CO_2$ emissions, indicating that 30 – 60 % of the current emissions level can be diminished by 2030 if all the measures were included in the design/operation process. Shi *et al.* (2009) discuss the return of investment for design and operational energy saving measures for a container ship without, however, defining a methodology to calculate it.

#### *3.4.3 Impact of Noise Radiated into the Water*

A systemic impact on humans due to airborne noise has been considered in this report (above). Here is added the systemic impact on the environment due to underwater noise radiated by commercial vessels is analysed. Once again it is a type of impact produced by shipping activities that has gained attention in recent times.

There has been a rising concern about the negative effects that underwater radiated noise (URN) has on the marine wildlife in general and in particular on marine mammals. In these animals, acoustic communication and perception has acquired a privileged role compared with other senses and other zoological groups (see Andrè *et al.*, 2011).

The topic has become officially an object of discussion within IMO since 2001. In the last years a Correspondence Group on "Noise from commercial shipping and its adverse impact on marine life" has been active and issued several documents, containing also a ranking of quieting strategies (IMO 2009e, 2009f, 2010d).

As mentioned in Andrè *et al.* (2011) the technical problem of the evaluation of the mentioned environmental impact of ships' URN, includes, as always in acoustical terms, quantification of the source levels, of the transmission losses and of the receivers' perception of noise. The cited paper examines the role of noise emissions from shipping

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)




and explores how the emissions can be surveyed and how their impact can be quantified, in order to establish a target for the control of such emissions. The paper builds on the first results of the project SILENV, funded with the 7th Framework programme of the European Union (www.silenv.eu).

As reported in the mentioned paper, two standards have been recently issued for the characterisation of underwater noise signature by commercial vessels, respectively by the American National Standards Institute together with the Acoustical Society of America (ANSI/ASA, 2009) and by DNV (within the Silent Class Notation: DNV, 2010).

The problem of the characterisation of the ship source is strictly linked to the propagation loss issue: surveys are taken at a certain distance from the ship (of the order of few hundreds of meters), and therefore reflections from the sea surface (depending on the sea state) and from the bottom (depending on the composition) are to be taken into account in the processing of data, as well as possible uncertainties related to the actual relative position of hydrophones with respect to the ship. In some cases, also sound celerity profile in the water column may affect results. The same phenomena (with different relative influences) affect also the propagation of noise from the ship to the receivers, making the transmission problem much influenced by local parameters. A further complication in the impact assessment is represented by the extreme variety in the types of animals affected with different sensitivities and reactions to noise.

With reference to marine mammals, two main types of impact from shipping noise have been identified in Andrè *et al.* (2011): behavioural changes (abandoning their habitat or alter their feeding or living habits) and disruption in long range communication (noise masking their vocalisms). Unfortunately, a proper evaluation of these effects for the mysticetes family (the largest marine mammals, with the highest ecological value) is not possible, because audiograms for these large animals are not available as well as information about the critical band-width of their hearing apparatus.

On the basis of the above, it is clear that a regulatory framework on this aspect can only be based (and this is the foreseeable trend) on the enforcement of technology-based limits, i.e. on limits on the radiated pressure levels inspired by good practice rather than by the actual 'needs' of the receivers (unknown, for the time being).

As regards practical issues regarding investigations about the environmental impact due to Underwater radiated noise, Beltran *et al.* (2011) describes models and surveys performed onboard of two Ro-Ro vessels. Correlation between theoretical and test data is discussed.

### *3.5 Synthesis of the Analysis Methods*

As is common in maritime research, it is useful to look to other industries for existing models and best practice; in safety and human life and health (social impacts) the benchmark is often set by the aviation industry, while in environmental mitigation it is the automobile (encompassing all road-borne transport) industry which has faced the most scrutiny, and therefore invested the most in research, in recent years. That is not to say that, for example, the rail industry does not also have lessons from which the maritime industry can learn. Economic realities underpin all business decisions, and as such are a key to any realistic model which hopes to assess impact.

The concept of a full cost account (Landamore and Campbell, 2010; Bebbington *et al.*, 2001) of a business, industry or process attempts to consider all the facets of influence of that system and assigns them all equal significance; by aping the format

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)




of a profit and loss account (balance sheet), this method of assessment reduces all these competing spheres of influence to a common base line – that of their economic cost – not only those incurred directly by the company (for example) in question, but all external costs, whoever actually bears them within the system. Whilst still an incomplete model, it does encourage dialogue underpinned by the true realities of the system's level of sustainability.

#### *3.5.1 Sustainability, Indicators and Indices*

The importance that the term sustainability has gained between policy makers and scientific researchers can be attributed to its use in the Brundtland Commission's report, Our Common Future (UNWCED, 1987), which linked the term to development. This report emphasized the economic aspects of sustainability by defining sustainable development as "economic development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs."

Sustainable shipping is a new concept that is now emerging as an area of concern (ISSC, 2009). Cabezas *et al.* (2008) have defined sustainable shipping or a sustainable waterborne transport as "a cost-effective commercial activity, in which the environmental load is not bigger than that which the environment can currently and in the future bear, and that the social community (directly and indirectly) in contact with it is not being negatively affected".

In the last decade several sustainability assessment methodologies have been proposed (e.g. Cabezas *et al.*, 2008; Singh *et al.*, 2009; OECD, 2010; Ness *et al.*, 2007). These are used to develop integrated policies which take full account of the three sustainable development dimensions: economic, social, and environmental, and which include cross-cutting and short and long-term considerations.

To achieve and maintain sustainability, policy-makers require timely information which demonstrates whether a system is generally becoming more or less sustainable, and specific information on which characteristics need the most improvement. In this context sustainability indicators and indices have been proposed and developed to measure and monitor the performance of the system in terms of each sustainability stream.

A number of global, national, regional, and sectorial indicators and indices related to environmental performance or sustainability have been developed by governmental sectors, scientific research institutions and non-governmental organizations (NGOs), as recently reviewed by Singh *et al.* (2009).

An indicator is a variable that describes one characteristic of the state of a system, usually through observed or estimated data. Some indicators may give information about the position of the system relative to particular sustainability boundaries or goals ("distance-to-target" indicators).

When many indicators are used, they are either presented in a framework of categories, or aggregated into an index (also called composite indicator). An "index" is a quantitative aggregation of many indicators and can provide a simplified, coherent, multidimensional view of a system. Sustainability indices have been developed specifically to help policy-makers in these respects. Indices usually give a static overview of a system, but when calculated periodically, they can indicate whether the system is becoming more or less sustainable, and can highlight which factors are most responsible for driving the system. Sets of sustainability indicators, and aggregation of these indicators into indices, are increasingly used to make policy decisions (Hezri and

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



Dovers, 2006) and it is critical to understand index strengths, weaknesses, biases, and scale dependence when using them (Mayer, 2008; Ness *et al.*, 2007).

The need for an integral systematic approach to indicators definition and measurement is recognised in order to give well-structured methodologies, easy to reproduce and to assure that all important aspects are included in the measurement. However, before developing the methodology and the indicators what is needed is the clear definition of the policy goals towards sustainability.

Ness *et al.* (2007) developed a holistic framework for sustainability assessment tool. It consists of three umbrellas or general categorisation areas; these areas are (1) indicators and indices, which are further broken down into non-integrated and integrated, (2) product related assessment tools with the focus on the material and/or energy flows of a product or service from a life cycle perspective, and (3) integrated assessment, which are a collection of tools usually focused on policy change or project implementation.

A new holistic methodology for sustainability analysis of ships has been also proposed by Cabezas *et al.* (2008). The procedure consists of itemising the ship into different systems that are separately analysed and assessed taking a life cycle approach in order to see its pollution through its life time, and its life cycle costs and social implications in order to get a numerical sustainability index. The next stage of this research is to model environmental, economic and social performances of ships in order to obtain reliable data about the level of sustainability.

Although there are various international efforts on measuring sustainability, only few of them have an integral approach taking into account environmental, economic and social aspects. In most cases the focus is on one of the three aspects. Although, it could be argued that they could serve supplementary to each other, sustainability is more than an aggregation of the important issues, it is also about their inter linkages and the dynamics developed in a system (Singh *et al.*, 2009).

Composite indicators may conduct to misleading, non-robust decisions if they are poorly constructed or misinterpreted. Typically correlations among indicators and compensability between indicators are two critical issues that are not taken into consideration. Indicators of sustainable development should be selected and negotiated by the appropriate communities of interest and composite indicators must be constructed within a coherent framework.

One specific example of a Sustainability Index and its application in several diverse cases is given in detail in the next section.

#### *3.5.2 Triple I (III) – Inclusive Impact Index for Assessment of Sustainability*

Triple I (III: Inclusive Impact Index) is the index to evaluate sustainability of the human activity, which is developed by the Inclusive Marine Pressure Assessment & Classification Technology (IMPACT) Committee of the Japan Society of Naval Architects and Ocean Engineers. The basics and the application of the concept have already been described by one example in the previous report of this committee. Here some examples of sustainability assessments using Triple I published during the period of this committee will be given.

Yuzui and Kaneko (2011) applied the Triple I to inclusive environmental impact assessment for single-hull and double-hull tankers with the same dead-weight ton. They firstly applied the method of Life Cycle Assessment (LCA) to evaluate *EF* by calculating $CO_2$ emission at each stage such as building, navigating (25 years), demolition,

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)




and recycle(production of stretching steel). They found that *EF* of double-hull tanker increases by about 4.6 % compared with that of single-hull tanker. Secondly, they estimated the Human Risk (*HR*) from the fatality risk by accidents during navigation by using Lloyd's Register Fairplay (LPFP) casualty data. They found that *HR* of double-hull tanker is a quarter of that of single-hull tanker. Note that they use $\beta$ in the equation of Triple I as 3 million US$ per fatality, which is used as the maximum cost to avert a fatality in cost benefit assessment of safety FSA. Thirdly, they calculated Ecological Risk (*ER*). Only the risk from oil spills resulting from accidents during navigation is considered. Though compensation cost at oil spill accident, such as clean-up cost, property damage and tourism damage, is considered as environmental risk in the FSA of IMO, they consider them in the cost term ($C$) in equation (1) in their evaluation of Triple I. Instead, *ER* is estimated as polluted productive area by diffusing oil. They found that *ER* of double-hull tanker is a 1/18 of single hull-tanker. Figure 3 shows the computed Triple I for single-hull and double-hull tankers. They concluded that Triple I for double-hull tanker is about 1/5 of that of single-hull tanker. This means that double-hull tanker is a more beneficial system than single-hull tanker. Finally, they proposed that the concept of Triple I is used for cost benefit assessment to propose effective Risk Control Options (RCO). In the case of cost benefit assessment by safety or environmental FSA, cost-effectiveness of an RCO is evaluated by the index called GCAF (Gross Costs of Averting a Fatality) or CATS (Cost of Averting a Ton of oil Spill). Because the Triple I can be the index which considers risks both safety and environmental, they proposed the following $\Delta III$ for cost benefit assessment.

$$\Delta III = \gamma \left( \delta \Delta ER_{cats} + \beta \Delta HR + \Delta C \right) \qquad (3)$$

where $\Delta HR$ is the change of *HR* due to the optional RCO, $\Delta C$ is the cost to install the RCO and $\Delta ER_{cats}$ is oil spill reduction of a RCO. They concluded that $\Delta III_C$ is effective as the index which considers safety FSA and environmental FSA at the same time.

Yoshimoto and Tabeta (2011) assessed the environmental impact of an artificial up welling technology using a seabed mound by the Triple I. In the calculation of EF, direct environmental impacts by $CO_2$ emission due to construction of the seabed mound is estimated using the environmental input-output analysis. Also indirect effect, such as reduction of environmental impacts by the increased production of fish, is also considered which could be several times larger than the direct effects. It is concluded that Triple I indicates that the artificial up welling technology will be sustainable when the indirect effect is considered.

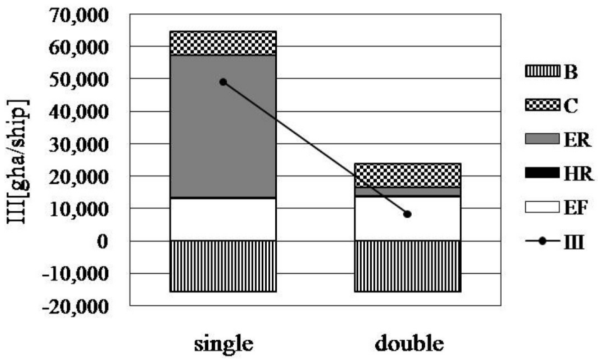


Figure 3: Triple I of single-hull and double-hull tanker (Yuzui and Kaneko, 2011)

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



Ohtsuka (2011) assessed the sustainability of the ocean nutrient enhancer which fertilize ocean by up welling deep ocean water (DOW) and can enhance marine primary production. Triple I of both the prototype of ocean nutrient enhancer, TAKUMI, and the large enhancer designed for commercial use is calculated. They conclude that the large enhancer designed for commercial use is adequately sustainable because it can up well large quantities of DOW from greater depth, though the prototype is unsustainable.

To mitigate the global warming, ocean sequestration of $CO_2$ has been proposed. Because the technology has risks on deep ocean ecosystems, its implementation needs public acceptance through environmental impact assessment. Omiya and Sato (2011) presents a methodology to calculate Triple I for the $CO_2$ ocean sequestration (COS) and compared with the effect of ocean surface acidification (OSA) and its consequent impacts in the deep ocean. Because ecological risk ($ER$) is not easy to obtain in many cases, sometimes Triple I without $ER$ and $HR$ as shown in equation (3), which is called "Triple I light", is used for simplicity. However, this study particularly focuses on the quantification of ecological risk ($ER$). $ER$ is defined by the production of quantified damage of an endpoint and its occurrence probability. The end point $ER$ is assumed to be the extinction of a particular species. The extinction probability was estimated as the occurrence probability of the reduction rates in the number of species caused by either OSA or COS, by using expert questionnaire and statistical semi-quantification method. Based on the computed Triple I, it is concluded that the $CO_2$ ocean sequestration technology is positively admitted as effective.

Duan *et al.* (2011) assessed sustainability of the water purification technologies for the Tokyo Bay. The self-cleaning technologies of artificial tidal flat creation, and eelgrass field restoration were assessed together with the external load reduction technology of the sewage treatment enhancing. A numerical model is employed for simulating the environmental and ecological impact. Because estimation of ecological risk ($ER$) is the bottleneck in calculating the Triple I, this paper also focused on a scheme of estimating the ecological risk ($ER$) where the risk of extinction of species is considered. The final assessment results on the water purification technologies suggest that the effort in seaside are the more effective than those in landside; and the artificial tidal flat creation can get larger effect than the eelgrass field restoration.

Since the global sustainability is the most important for human society, the ocean has been expected to play an essential role by providing food, energy and space. However, large scale developments with utilization of ocean need to be carried out in harmonious with the environment to ensure the sustainable and promising future. For the purpose, an inclusive impact assessment, such as assessment by using Triple I, during the planning period for the development becomes more and more important.

### *3.5.3 Developments in Full Cost Accounting*

Landamore and Campbell (2010) identify and discuss some of the methodological challenges facing the development of a model for environment-focused full cost accounting with an international shipping context. The focus is on forming the framework within which a simplified system for assessing the sustainability of shipping, which still reflects all the most important facets of the industry. For what is a new thought experiment in the GHG management of the shipping industry, this study introduces the context, reviews the relevant literature and then discusses the methodological approach that might be adopted and utilised. Specifically, they introduce the full cost accounting sustainability assessment model (SAM), which, although designed for assessing the

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



impact of an individual project, is adapted and applied to the shipping industry as a whole. Importantly, Bebbington *et al.* (2001) argue that full cost assessment is not an end itself but a "means by which market prices can be corrected ... to create an economic system that is more likely to deliver sustainable development". In this respect, the paper places FCA within its broader context whilst exploring some of the issues involved in its implementation.

UNCTAD's (2009) Expert Meeting on Maritime Transport and the Climate Change Challenge highlighted that timeframe was a real concern:

> "Current trends in terms of energy consumption and carbon path suggested that if no action were taken within the following two years ... the world would forever miss the opportunity to stabilise emissions at "manageable" levels [and] a global and concerted solution was urgently required. ... [N]egotiations towards regulation of $CO_2$ emissions from international shipping should be pursued with all due speed."

If the shipping industry is to effectively and sustainably reduce its environmental impact, a model for assessing that impact against a cost base is required (Landamore and Campbell, 2010).

Environmental analysis of ships and shipping is a relatively new activity. Recent moves by IMO, particularly the Marine Environment Protection Committee (MEPC) (IMO, 2010b), to consider the Greenhouse Gas Emissions (GHG) of ships and shipping (IMO, 2010), coupled with the political shift towards a focus on reducing the impact of activity on climate change mean that for the first time ship owners, operators and designers are seriously considering the emissions generated by their operations. Currently the IMO are using two methods for the primary assessment (and eventual control) of emissions from shipping, the Energy Efficiency Design Index (EEDI); and the Energy Efficiency Operational Index (EEOI); (IMO, 2009b, 2009d) which assess the design and operational performance of a ship against a curve of achievable performance generated from the existing ship population (Landamore and Campbell, 2010).

EEDI calculates an assessment of the efficiency of the ship design, it is meant to stimulate innovation and technical development of all the elements influencing the energy efficiency of a ship, thus making it possible to design and build intrinsically energy efficient ships of the future. EEOI works on a similar principle, but it considers the operational emissions of the ship, thereby gauging the effectiveness of any measures adopted to reduce energy consumption. It has been applied by IMO Member States and the shipping industry on a trial basis; it provides a figure, expressed in grams of $CO_2$ per tonne mile, for the efficiency of a specific ship, enabling comparison of its energy or fuel efficiency to similar ships (Landamore and Campbell, 2010). Many other models have been developed to compare the carbon emissions of different methods of transporting a specified cargo (e.g. Kühlwein and Friedrich, 2000; Corbett and Koehler, 2003, 2004; Corbett *et al.*, 2007; Endresen *et al.*, 2003; MOSES Project, 2007; IAPH, 2009a,b,c; Faber *et al.*, 2010; Browne *et al.*, 2009; Leonardi and Browne, 2009; ESPO, 2009; McKinnon, 2010) and some (e.g. Ademe, 2009; VNF, 2008) have included measures of wider impacts such as noise pollution and congestion. Simplified assessment of the emissions from shipping has often followed on from research in rail and road transport (e.g. TRL, 2010; Argonne National Laboratory, 2009; ARTEMIS Project, 2009), and is therefore rarely tailored to the characteristics of maritime operation.

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)




Whilst the impact of the whole activity (whole life) on all aspects - social and economical as well as environmental, needs to be considered if the sustainability of the operation is to be assessed, from an environmental point of view, the emissions during transit generally dwarf other impacts (Landamore and Campbell, 2010). A life cycle analysis (LCA; Frankl and Rubik, 1999; West and Manta, 1996) carried out on a short sea container ship (port to port) operating across the North Sea by the CREATE3S project (Landamore *et al.*, 2009, 2010) assessed the emissions deriving from the burning of fuel to power the ship as almost 90 % of the overall life cycle emissions of the ship. While the operational profile of this type of ship and cargo means this is likely to be an extreme example, it is clear that a significant factor for shipping is emissions to air from the engines, hence the IMO focus thus far on this aspect.

A number of full-cost accounting (FCA) approaches have been developed and applied by academics, non-governmental organisations and corporations, with the most sustained period of inquiry having been since 1990. However, the overall number of publications in the public domain remains small, and most applications have tended to be ad-hoc, experimental and incomplete in nature, with little consistency in application, although the Sustainability Assessment Model (SAM) offers some hope (Davies, 2009). See Table 2 for a summary of the key FCA applications and associated literature to date.

The Sustainability Assessment Model (SAM) was initially developed to assess the economic, resource, environmental and social impacts of a single project over its full life cycle and translates all impacts into monetary amounts using a damage cost approach. Figure 4 shows a notional SAM signature (see Baxter *et al.*, 2003) for details of the original model; for application of the SAM (see Baxter *et al.*, 2004a,b; Bebbington and Mcgregor, 2005; Bebbington, 2007a,b; Bebbington and Frame, 2007; Bebbington *et al.*, 2006 and 2007; Xing *et al.*, 2007 and 2008).

Bebbington *et al.* (2001) also report that implicit within, and underwriting, the European Commission's call for FCA are two assumptions: that current prices do not reflect the 'eco-logical truth', that is they do not reflect the true cost to society or the planet of the product, process or service; and secondly that if the market price of a product, for example, were to reflect accurately the environmental cost of that product, then market forces would encourage consumers to switch to 'more ethical' choices through financial incentives.

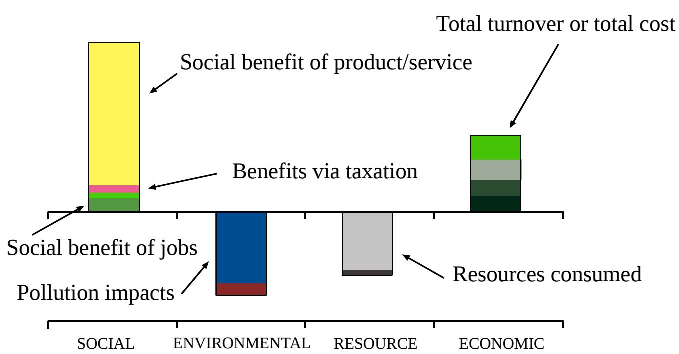


Figure 4: The SAM signature. Source: Bebbington *et al.* (2006)

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)

Proceedings to be purchased at http://www.stg-online.org/publikationen.html



Table 2: Summary of the development of FCA (by literature): reproduced from Davies (2009)

| Date of publication of relevant literature: | Type of literature (by author): *Literature explaining applications:* | *Concept development literature:* | Overview of applications sorted by major characteristic: Costing focus: Stream 1 Avoidance/ restoration costs | Stream 2 Damage costs | Stream 3 Balance sheet/ other focus |
|---|---|---|---|---|---|
| 1992 | Huizing & Dekker | Rubenstein, Gray | BSO/Origin | | |
| 1993 | | Gray et al | | | |
| 1994 | Rubenstein | Gray | Rubenstein | | Rubenstein's green balance sheet |
| 1996 | USEPA | | | Ontario Hydro | |
| 1997 | | Boone & Rubenstein | | | |
| 2000 | Atkinson | | | Powergen | |
| (Forum 2000-03) | Howes | | Forum's ECA: Interface Europe Anglian Water | | |
| Ongoing | Wessex Water | | Wessex Water | | |
| Ongoing | Water UK | | Water UK | | |
| 2001 | Bebbington & Gray | | The SCC & Landcare Research | | |
| 2001 to date | Figge et al (multiple) | | | | Figge & Hahn Sus'l Value |
| 2002 - ongoing | Bebbington/ Bebbington et al | Bebbington/ Bebbington et al | | BP Sustainability Assessment | |
| | Frame & Cavanagh | Brown & Frame | | Model (SAM), and | |
| | | Bebbington & MacGregor | | the construction and | |
| | | Xing et al | | UD SAMs | |
| 2003 | Jones | | | | Jones' natural inventory valuation model |
| 2003 (to 2006) | Richardson & Bent | | Forum's Sustainability Accounting methodology: | | |
| | Bent | | AlcCo | AlcCo | |
| | Taplin et al | | ChemCo | | |
| 2004 | Antheaume | | Antheaume | Antheaume | |
| 2005 | Herbohn | | | Herbohn | |
| 2007 | | Antheaume | | | |

# 4 REGULATORY APPROACHES TO SUSTAINABILITY AND SAFETY IN THE MARITIME INDUSTRY

## *4.1 Development of the Regulatory Framework in the Maritime Industry*

### *4.1.1 International Regulations*

The present regulatory framework for the maritime industry is a dual system where on the one hand the classification societies set up technical requirements and on the other hand the flag states set up a combination of legal and technical requirements.

The goal of requirements of the classification societies is to achieve a technically safe ship structure, propulsion plant and equipment that allow a safe operation of the ship. The present scope of classification rules and their development is further described below.

Driven by prominent accidents IMO and its predecessors developed requirements for

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



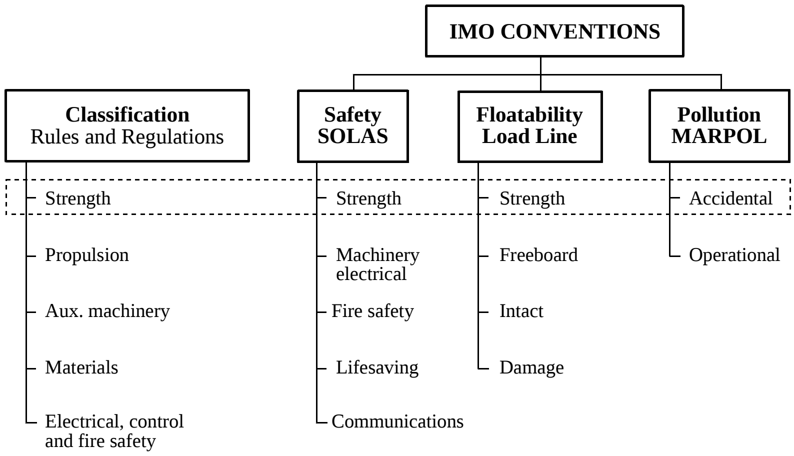


Figure 5: Scope of Classification Rules and IMO conventions

Construction (subdivision, fire protection), Life saving appliances, Radio communication and Nautical equipment of ships in the international trade. Later on oil pollution was recognized as a matter of concern and regulations for the prevention of oil pollution and other kinds of pollution were developed. Other Codes developed by IMO are the Intact Stability Code, which is not mandatory, the ISM Code, the ISPS Code and the MODU Code (which is not mandatory).

Again driven by major accidents IMO developed requirements which are overlapping the rules of the classification societies as there are general strength requirements, requirements for the strength and tightness of hatch covers and other closing appliances. Figure 5 shows the scope of both regulatory regimes and in dotted lines the overlaps.

The link between the rules of classification societies and the international regulations is given by SOLAS Chapter II-1, Regulation 3-1 which says that classification is required as a statutory requirement:

> "*Structural, mechanical and electrical requirements for ships:* In addition to the requirements contained elsewhere in the present regulations, ships shall be designed, constructed and maintained in compliance with the structural, mechanical and electrical requirements of a classification society which is recognized by the Administration in accordance with the provisions of regulation XI/1, or with applicable national standards of the Administration which provide an equivalent level of safety."

The latest IMO mission statement for the period 2012 to 2017 (IMO, 2011b) reiterates that IMO will not only work on safety issues but also on sustainability and environmental issues: "The mission of the International Maritime Organization (IMO) as a United Nations specialized agency is to promote safe, secure, environmentally sound, efficient and sustainable shipping through cooperation. This will be accomplished by adopting the highest practicable standards of maritime safety and security, efficiency of navigation and prevention and control of pollution from ships, as well as through consideration of the related legal matters and effective implementation of IMO's instruments with a view to their universal and uniform application."

The resolution identifies general trends which, among others, require IMO to identify activities that could have adverse impact on the environment and to contribute to

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



reduce the atmospheric pollution of shipping. Further a "cradle to grave" concept for new ships will be developed and implemented to allow environmentally friendly recycling of ships in the future. From these trends several strategic directions have been derived and laid down in IMO (2011b).

#### *4.1.2 Regional Requirements of Port Authorities*

In addition to the above internationally accepted regulatory regime regional or national requirements exist which tend to diverge due to different political acceptances of occupational risks or environmental impacts caused by ships.

OECD (2010c,d,e,f and 2011) give an overview of the different approaches to reduce the environmental impact of ports with regard to land consumption, noise impact or air pollution. All reports describe how development of ports is affected by environmental aspects and what kinds of environmental impact assessments have to be carried out in context of possible port expansions. It can be observed that requirements developed by some port authorities will have an impact on future ships' designs especially with regard to any kind of emission.

The activities of the ports of Los Angeles and Long Beach are described in OECD (2010c). The report gives an impression how national and local regulations on avoiding air pollution and water pollution may overlap. Both ports have developed a Clean Air Action Plan to improve the air quality in that area. The ports have committed to use pollution-based impact fees so that polluters pay their part to improve air quality. The ports agreed to develop tariff-based incentives and requirements, such as vessel speed reduction incentives and port-mandated fuel requirements and committed to work with the air quality regulatory agencies (AQMD, CARB and EPA) to establish San Pedro Bay air quality standards. Further the ports intend to provide shore based electric power supply to ships within five years from 2010.

The requirements regarding pollution of water are set up by various authorities either national or local. These requirements are complex, often overlapping, and sometimes conflicting. As an example, California state law currently prohibits the discharge of liquid wastes except for sewage from many vessels. Whereas, the U.S. Environmental Protection Agency is currently in the rulemaking process to establish non discharge zones that would make sewage discharges a violation of federal law.

Regulation of all sources of water pollution from vessels operating in California is at least comparable with that of other countries. The zero living organisms limit on ballast water discharges that becomes effective in 2020 is as stringent as possible. The ports are developing best management practices manuals to deal with port housekeeping.

Vancouver follows a similar approach to incentive ship owners to reduce air pollution (OECD, 2010d) by introducing a Harbour Dues Program being rolled out in 2010. It establishes harbour dues which are payable for the first five visits by a particular vessel during the calendar year, within three air emission standards named "Gold", "Silver" and "Bronze" which are bound to class notations of classification societies for environmental protection measures. Depending on the degree of exhaust gas cleaning measures one of the three tariffs apply where "Gold" represents the lowest due to be paid for the highest degree of exhaust gas cleaning.

In context of a planned expansion of the port areas environmental organisations have taken legal action against the Port of Rotterdam Authority (OECD, 2010e). To solve these disputes, alliances were concluded with two environmental organisations in the

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)

Proceedings to be purchased at http://www.stg-online.org/publikationen.html



context of the environmental impact of the construction of Maasvlakte 2. These organisations stopped their legal actions against the Port Authority in exchange for environmental projects.

The following summarises the most relevant activities of the Port of Rotterdam which will affect seagoing ships. There will be an environmental differentiation regarding $NO_X$ and $SO_X$ emission of port dues which is being discussed under the revision of the current port due system. The reduction target set is 50 % in 2025 compared to 1990. As a start shore-side electricity for inland barges is being introduced. A pilot project will be up-scaled to all inland berths in the Rotterdam port area. (Measures affecting the port infrastructure or the hinterland traffics were not taken over from the original source)

Due to increased cargo volume to be handled at the port of Busan and its increasing impact on the environment the Korean government decided to develop Busan New Port 25 $km$ from the city centre intending to convert the old port Busan North into a residential area later. In OECD (2010f) plans and measures are described how to reduce the environmental impact by improving the infrastructure for hinterland traffic, optimizing the cargo handling within the port, reducing $CO_2$ emissions by using electric rail mounted gantry cranes in the port or offering electric power supply for ships in the port.

Further to the regulations of MARPOL, from 1 January 2012, the sulphur content of fuel oil will be regulated in Korea as follows:

- The sulphur content of diesel is to be less than 1.0 %, however, the sulphur content of diesel used in ships operating only in territorial water and EEZ is to be less than 0.05 %,
- The sulphur content of heavy oil A, heavy oil B, heavy oil C is to be less than 2.0 %, 3.0 % and 4.5 % respectively.

The Marine Environment Management Law of Korea stipulates that fuel oil suppliers should submit the samples of fuel oil with the specification of fuel oil to the ship-owner. And the Korean Government officials will carry out ship inspections to check the oil samples and specification.

## *4.2 Control of Random Impacts*

As mentioned in the introduction the impacts influencing a ship design can be divided into random impacts and systemic impacts. For each category tolerable values of responses of a structure are defined. These tolerable values can be allowable stresses, deformations with regard to structural strength, a defined safety against the ultimate collapse of the hull girder or ship accelerations or healing angles with regard to ship motions. In view of this assumption one can say that class rules deal with random impacts.

### *4.2.1 Class Rules*

The purpose of a Classification Society, as put forward in the IACS Charter (IACS, 2009a), is to provide classification and statutory services and assistance to the maritime industry and regulatory bodies as regards maritime safety and pollution prevention, based on the accumulation of maritime knowledge and technology. The classification society verifies the structural strength of the ship hull as well as the reliability and function of the machinery systems, through the development and application of own rules and by verifying compliance with international and/or national statutory regulations on behalf of flag Administrations.

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



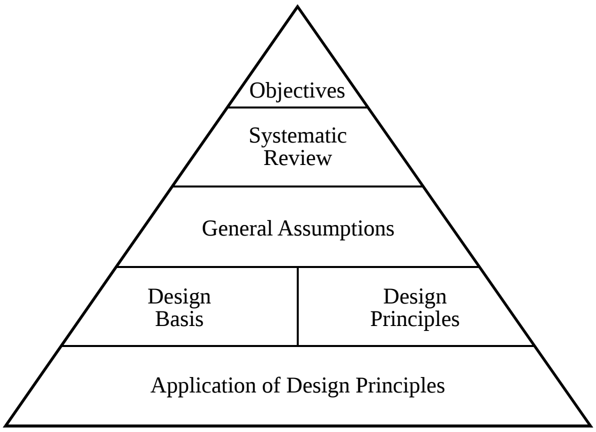


Figure 6: Rules framework

Classification Rules have been developed over many years by each classification society through extensive research and development and service experience and are subject to constant refinement. With the large number of ships in the world, the classification societies have had a very large amount of data to base the rule development on, and the safety level has been continuously increasing. In addition, Unified Requirements have been agreed by IACS Members and transposed into the individual members' rules. Statutory requirements developed at IMO are incorporated into class rules when appropriate, and where necessary Unified Interpretations of them are adopted by IACS.

However, to base the requirements for new ships on the experience from old ships does not necessarily promote innovation in ship design. With the introduction of goal-based standards, it is the role of the classification societies to develop specific rules that will meet the goals and functional requirements specified by IMO. It is the intention that the goals prescribed by IMO may be achieved by alternative designs that offer an equivalent level of safety, while promoting new technology and greater innovation within the shipping industry.

The CSR rules (IACS, 2006a,b) were the first attempt to develop new rules which would meet the objective of the Goal Based Standards. The CSR were developed based on a set of top-level goals and objectives, and a framework was made to show how the rule requirements would ensure that ships built in compliance with the rules meet the top-level goals and objectives, Figure 6. The framework of the Rules represents a 'top-down approach' that provides transparency and ensures that the structural requirements developed reflect the overall objectives.

The levels of the Rule framework address the following issues:

- the Objectives state the clear and unambiguous goals of the Rules with respect to safety and performance aspects. These objectives provide the basis for deriving the detailed structural acceptance criteria.
- the Systematic Review identifies and evaluates the hazards due to operational and environmental influences and the likely consequences of these on the structure of a ship, in order that these can be addressed in the Rules and thereby minimised.
- the General Assumptions specify aspects that are beyond the scope of the Rules,

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)




but affect the application and effectiveness of the rules. These include references to other international regulations and industry standards, e.g. SOLAS.

- the Design Basis specifies the premises that the Design Principles of the Rules are based on, in terms of design parameters and the assumptions about the ship operation.
- the Design Principles define the fundamental principles used for the structural requirements in the Rules with respect to loads, structural capacity and assessment criteria, to meet the hazards identified by the systematic review.
- the Application of the Design Principles describes what criteria are used to demonstrate that the structure meets the Objectives. It includes definition of load and capacity models, and corresponding acceptance criteria.

#### *4.2.2 Rule Development*

In order to demonstrate in a general way how classification societies should develop ship rules to meet the philosophy behind IMO Goal-Based New Ship Construction Standards, IACS recently developed a new Guideline for hull structural rule development (IACS, 2009b), which was submitted to IMO at MSC 86. The objective of the Guideline is to provide guidance, for any classification society that is a recognized organization, on the development of ship structural classification rules, by specifying general principles to be followed in the rule development process, as well as general design principles and requirements that should be considered when developing rules. The IACS Guideline provides a recommended process for classification structural rule development that will contribute to its consistency and transparency. The Guideline can be used to support new rule development and has been developed with the view that the rules should be in compliance with relevant aspects of Tier I and Tier II of the GBS.

The guideline also describes the relation between the class rules and the Maritime Safety Regime. The boundaries and relationships between rules and the Maritime Safety Regime follow a safety hierarchy with the Maritime Safety Regime at the top level. This regime regulates the design, construction and operation of ships through a diverse set of requirements including international and national Regulations and industry Standards, which may influence the ship structure rules.

The guideline emphasizes the importance of a systematic rule development process, where the overall safety objective is clearly identified before starting the development of the actual rule requirements. This should be followed by a Formal Safety Assessment (FSA), as described in the IMO Guidelines for Formal Safety Assessment (IMO, 2001) or a Systematic Review, which can be considered as a reduced version of a full FSA. The process generally follows from the complexity of the issue to be addressed in the rules, but should as a minimum include the following steps:

- Hazard identification
- Consequence evaluation
- Critical hazard management

According to the guideline, the rules are to be developed based on the following overall basic principles, where requirements to transparency, modularity and consistency are applied whenever possible:

- Structural safety can be demonstrated for all hazards identified for each design situations in the systematic review
- The structural safety can be demonstrated by utilising limit state methods

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)




- The design complies with the Design Basis
- Consistent load scenarios are applied to all aspects of the structural assessment
- Structural requirements with respect to loads, capacity models and assessment criteria are presented in a modular format, and each component is clearly identified
- Material properties are documented for high criticality class elements exposed to loads and service temperatures enhancing the risk for brittle fracture

The guideline specifies that the rules are to be based on the commonly known principles of limit state design. A limit state can be defined as a condition beyond which the structure, or part of a structure, no longer satisfies the requirements. The structural performance of the hull or components of it should generally be described with reference to a specified set of limit states that separate desired states of the structure from undesired states.

The rule requirements may be presented in various formats, or a combination of formats, depending on the nature of the specific requirement. Typical rule formats follow typical design methodologies. The working stress design (WSD) format is a practical format which has been used as the main method to verify the structural design in the rules. For certain critical failure modes, the Partial Factor Format (PFF) is used in order to increase the consistency of the safety level, and determine the actual safety margins with more accuracy. In the CSR Rules (IACS, 2006a,b), the PFF is used for the Ultimate Hull Girder Strength check. During the development of the rules, the partial safety factors were calibrated by Structural Reliability Analysis (SRA).

Rule requirements are usually expressed as a combination of prescriptive requirements and direct calculation requirements. The prescriptive requirements are in the form of minimum requirements and load-based prescriptive requirements. The minimum requirements are to a large degree developed based on experience, and are to cover effects that are not explicitly covered by other rule requirements. The load-based prescriptive requirements are normally used for most of the structural members, while direct calculation may be required for members where the load and structural response is difficult to assess accurately by simplified formulations.

Although ship rules are to a large degree prescriptive in the format, it is a basic principle that safety equivalence may be applied. Hence, innovative designs or alternative calculation methods may be accepted provided that calculations are carried out to demonstrate that the safety level is at least equivalent to a standard, well proven design.

### *4.2.3 Other Class Aspects*

Traditionally, classification rules have been mostly concerned with the ship structural integrity, while safety for humans has been covered by regulatory requirements, in particular SOLAS requirements. However, there is not always a clear line between the two, and sometimes requirements related to human safety also affect the ship structure. Examples are requirements to Permanent Means of Access (PMA), bulwarks and guardrails.

There is also an ongoing discussion about how climate change may affect future ship traffic and ship design. Class Rules need to continuously include state-of-the art knowledge about meteorological (temperature, pressure, wind) and oceanographic (waves, current) conditions. Ship standards have been discussed increasingly by industry and academia in the last decades in several international forums. There are potential safety,

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)




economic, and environmental advantages in utilizing the recent knowledge about meteorological and oceanographic conditions (met-ocean conditions) and investigating its implication for design and operation of marine structures. Bitner-Gregersen *et al.* (2011) concluded that observed and projected changes in wave climate may have large impact on tanker design practice, and that class rules may need to be updated to reflect this. However, further studies are called for to describe and quantify potential implications of climate change on safe design

#### *4.2.4 Rational Treatment of Accidental Scenarios for Hull Girder Verification*

Accidental loads can also be categorised as random impacts. In context with the introduction of the Goal Based Standards class rules for the main types of ships will most probably be reformulated taking accidental scenarios into account. First steps are made with the Common Structural Rules (CSR) for oil tankers (IACS, 2010b) and bulk carriers (IACS, 2010a).

This important evolution can be seen as part of a wider trend towards the adoption of Performance Based Design (PBD) criteria, taking place also in other fields of engineering (see e.g. Rizzuto, 2009). In the development and assessment of the design, PBD criteria imply a clear identification of the objectives for the design itself and a consistent formulation of the checks that explicitly aim at attaining those objectives. These characteristics of the new formulations imply also the possibility of alternative check procedures by means of direct computations, based on the same explicit framework.

A key aspect of the performances identification is in fact the identification of the conditions in which the structure is meant to operate during its life, which are represented at a design level by design scenarios. Such design scenarios represent in principle in a discrete way the continuous spectrum of actual situations the structure will experience: in order to be effective, they need to be realistic and representative of significant situations.

When defining a reference scenario for structural checks, it is necessary to set a series of characteristics that later need to be quantified in terms of design scenario. These elements of the scenario should allow quantifying the strength and loading quantities that are at the basis of the check.

Design scenarios (or design situations, as they are named in CSR-Tankers: IACS, 2010b) have always been behind the formulation of structural checks in Rules for ship construction. However, only in the recent formulations of Class Rules and in conjunction with the Goal Based reconsideration of the normative framework in ship design at IMO, an explicit identification of design scenarios started to appear in Rules (see Rizzo and Rizzuto, 2007). The trend can also be seen as connected with the increasing use of direct computations and direct applications of first principles to the design process, which in turn are aspects of the implementation of Performance Based Design criteria (Rizzuto, 2009).

For an intact tanker ship, design scenarios for hull girder checks are quite well defined in IACS (2010b). Even though the single elements of this reference scenario can be improved in terms of details and/or in terms of realism, a framework for the scenario description is present and direct computations coherent with the scenario can in principle (and in practice) be performed.

Checks for the hull girder strength in accidental conditions are also covered in the recent CSR, even though without reference to a precise scenario. In the text, however, accidental conditions are always associated to flooding.

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



In IACS (2010b), the effects of the flooding on the hull girder still water bending moments are evaluated by considering the cargo holds as being individually flooded up to the equilibrium waterline in all the loading conditions on which the design of the ship has been based. The envelope obtained for any combination of considered loading conditions and flooded cargo holds is assumed for the check. Wave loads are modelled with 80 % of the intact ship design bending moment, corresponding to the IACS UR S11 (IACS, 2001).

No particular justification is provided for this quantification of the wave load, which would correspond to a return period of about half year for the intact ship. The scenario includes therefore a realistic static load and a not negligible, but notional, dynamic load. The capacity to be checked is the intact one.

No specific check is available for the longitudinal strength of damaged tankers, according to the provisions of section 9-1 in CSR-Tankers (IACS, 2010b): only static local loads corresponding to the draught in the flooded condition are applied in this scenario (see also section 2-4.2.7 of IACS, 2010b).

The variety of damage states, depending on type, location and extension of the damage enlarges considerably the space of possible accidental conditions that in principle need to be considered in the design. A natural evolution in the definition of the damage state is the adoption of probabilistic models that can weigh the various scenarios according to their probability of occurrence.

In shipbuilding, accidental conditions are since long included in the verification of buoyancy and stability performances of the ship. The concept itself of subdivision of the hull in watertight compartments is based on a damage scenario, and, as known, the first Design Norms on this subject date back to the establishment of IMO and the first issue of the SOLAS convention. Also the introduction of probabilistic methods was earlier realised in the framework of the assessment of damage stability of ships and has later spread to the assessment of the environmental impact due to accidents. Curiously enough, a probabilistic description of the accidental scenarios is still lacking in structural design, where, on the opposite, probabilistic methods have a long-standing tradition in the assessment of intact systems (probabilistic definition of loads and reliability assessment of structures).

The problem of a proper characterization of a design scenario in accidental conditions for the hull girder verification has been recently discussed by Luís *et al.* (2009), Teixeira and Guedes Soares (2010) and Rizzuto *et al.* (2010). In particular Rizzuto *et al.* (2010) have examined the various elements that an effective characterisation of a design scenario for a ship in damage conditions should include, highlighting the need for a proper accounting of the relationships among such elements. The dependencies on the damage extension and position of the corresponding static and dynamic loads and of the residual structural capacity of the ship were discussed, as well as the key point of the correlation between the environmental conditions during the accident (and in the immediate aftermath). Such a complexity has been illustrated by means of Bayesian Networks (Jensen, 2001) that have also provided quantitative results for comparative evaluations in a very specific scenario.

Even though the specificity of the analysis developed by Rizzuto *et al.* (2010) did not allow any firm conclusion on the selection of a design scenario for grounding events, the work intended to give a contribution from a procedural point of view for a better treatment of accidental situations in the formulation of design checks in accidental conditions.

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



#### *4.2.5 Stability*

Requirements to stability have to large extent been developed following accidents. Stability requirements concern the relevant requirements to the intact ship and requirements to the ship when subject to damage and subsequent flooding.

The requirements to intact stability shall ensure that the ship does not capsize under any circumstance of normal operation and environmental conditions that might be expected. The intact stability was traditionally handled by IMO as a Code which in effect was voluntary as it was outside the scope of the Conventions. Its applicability was therefore subject to the decision of the flag state. This could lead to different standards depending on the flag state, and IACS introduced in 1988 compliance with the IMO Intact code as a Unified Requirement. From 2009 the IMO Intact code has been made mandatory by amendments to SOLAS and the International Convention on Load Lines (ICLL).

Damage stability has traditionally been part of the conventions. In the earliest versions of SOLAS there were damage stability requirements to passenger ships and later this was followed by requirements to cargo ships having a reduced freeboard in accordance with the ICLL. All mandatory damage stability requirements up to 1992 were of the deterministic type, i.e. requirements in the form of specific damage extent assumptions and corresponding criteria for survival.

Given the stochastic nature of e.g. a damage following a collision the deterministic requirements can in theory not be seen as to cover a known safety level.

By introduction of the probabilistic rule concept for cargo ships in SOLAS from 1992 there was in place a methodology that could reflect the capability of the vessel to survive a damage following a collision without setting deterministic requirements to location of bulkheads. In the probabilistic concept the ships attained index $A$, shall then be greater than the required level $R$. The attained index $A$ is the sum of all possible damage cases, having a probability factor derived from statistics multiplied with their respective probability for survival. The level of $R$ has been based on calculations carried out of sample ships of different size and types. The probabilistic concept was introduced to passenger ships by SOLAS amendments coming into force in 2009 following the work of the HARDER project (Rusaas, 2003).

The EU funded project GoalDS started up in 2009. GoalDS is an acronym for **Goal** based **D**amage **S**tability. In the EU funded project SAFEDOR, Formal Safety Assessments were carried out for several ship types including Cruise ships and Ro-Pax. This was also reported to IMO, see ref. (IMO, 2008b) and (IMO, 2008c). In these reports it was concluded that the safety level of both ships types could be increased by implementing Risk Control Options cost efficiently in accordance with the FSA guidelines, and this was one of the motivations for establishing the GoalDS project.

The GoalDS project consists of the following major parts:

- Characteristics of collision and grounding damages (statistical distribution)
- Probability for survival collision and grounding damages
- Standard risk models for collision and grounding
- Propose level of required R based on cost benefit analyses
- Following a careful validation of results forward proposal to IMO

The basic probability distribution for extent of damage due to collision or grounding has been established by search in accident databases and class records. The probability for survival has been based on numerical simulations and model tests.

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)




In order to have a basis for proposing the level of R as new rules it is necessary to have sample of ships that is representative for the range of size and types that the proposed rules shall cover. Additionally, yard's and operator's experience are of invaluable importance in order to estimate cost and benefits of Risk Control Options.

*Freedom in Design*

The cruise and Ro-Pax ship segment covers a big variation in size and designs. There are clear benefits for the operator when a set of rules that represents a safety level instead of prescriptive requirements can be applied. The ship can be designed to reflect the intended needs for a specific operation. Damage stability requirements based on the probabilistic concept are very well suited to fit into a risk based rules. This would however not rule out that prescriptive requirements in addition introduced in order to account for a specific hazard.

*Future Development*

A project such as GoalDS can also be repeated for ship types other than Cruise and Ro-Pax. Following the IMO FSA Guidelines ensures a transparent process in the rule development process and should eliminate that some decisions are taken that are not properly based on the relevant considerations of risks.

### *4.3 Control of Systemic Impacts*

Acceptance of systemic impacts has changed during the last years all over the world. As a consequence regulatory bodies have implemented regulations to control these impacts caused by ballast water and air pollution. The recent regulatory activities of the IMO regarding energy efficiency can be seen under two aspects. Firstly the decreasing reserves of fossil fuels force us to minimize their consumption secondly the reduction of fuel consumption leads to a reduction of air pollution. The following three subsections will describe measures to control these impacts

#### *4.3.1 Ballast Water*

Invasions of marine species to new environments are often aided by human activities among which the shipping industry is one of the major, but unintentional, vectors. Ships can provide suitable platform for transportation of marine species in the form of attaching to the ship's hull/sea chest and also being transported, at different life cycle stage, through ballast water (Bax *et al.*, 2003; Anil, 2006). Research on the subject showed that shipping, on average, is responsible for 25 % and 52 % of introductions of Non-indigenous species (NIS) into European waters (Stretaris *et al.*, 2005) and coastal waters in the North America (Fofonoff *et al.*, 2003) respectively. Cleaner ballast tanks, increased ship's transit speeds and improved management of ports have made ballast tanks of commercial ships a hospitable means of transport throughout the world (Bax *et al.*, 2003). It has been estimated that approximately 3.5 billion tonnes of ballast water are transported annually (Endresen *et al.*, 2004). There is, therefore, a vital need for mitigating technology to be developed to manage/prevent this constant movement of organisms to new areas, where they are establishing populations to the detriment of the local flora and fauna.

The major advancement in managing ballast water came in 2004 when the 'International Convention for the Control and Management of Ships' Ballast Water and Sediments' was formed by the IMO. Two key standards were determined as part of this convention: the Ballast Water Exchange Standard (Regulation D-1) and the Ballast Water Performance Standard (Regulation D-2). Regulation D-2 (D-2 discharge

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



standard) states the limit of the allowable number of viable organisms that can be discharged from the ships (IMO, 2004b). The determination and publication of Regulation D-2 was extremely important in terms of developing new ballast water treatments as the industry was given an efficiency standard to meet. This convention will enter into force 12 months after it has been ratified by 30 states which represent 35 % of the world's merchant shipping tonnage (IMO, 2004b). However, 33 states representing approx 26.5 % of the world's tonnage have currently (Feb. 2012) ratified the convention.

Since adoption of the Convention, research and industry have been working to find effective systems capable of meeting the D-2 discharge standard for when the convention enters into force. There are two generic types of technology (Figure 7) used in ballast water treatment. Since mid 2001, Newcastle University has been extensively involved in the ballast water treatment research through two European funded projects, MARTOP and BaWaPla, under the 5th and 6th framework programmes. The main aim of these projects was to promote the knowledge and help related industry in the development of sustainable ballast water treatment system.

By 2010 nine treatment systems have received IMO type approval certification and it is also expected that nine other treatment technologies to receive their type approval by 2012 (Lloyds Register, 2010).

Although there are several type approved treatment technologies available in the market, but some challenges such as online measurement of the performance of treatment systems, sampling regime that is representative of discharged ballast water and enforcement of the Convention, do exist and need to be attempted.

Compliance with standards is essential for effective implementation of any environmental regulation. Sampling, as well as adequate inspection and monitoring, are

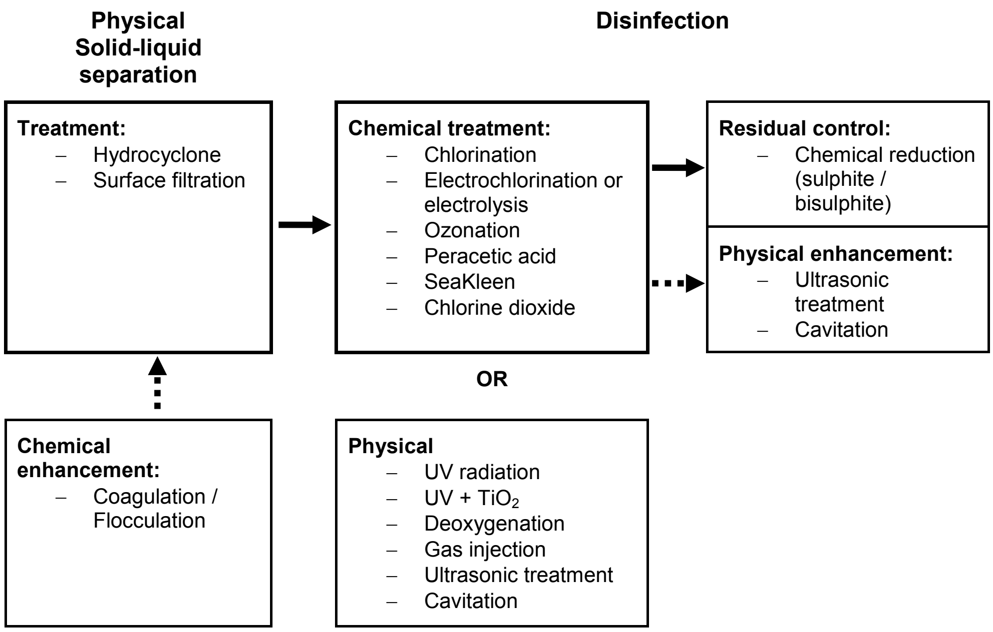


Figure 7: Generic ballast water treatment technology process option (Lloyds Register, 2010)

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



equally essential in any environmental pollution control or prevention policy (RCEP, 1998). To ensure ships ballast discharges meet Regulation D-2, sampling is required to determine the number of viable organisms present in the ballast water (Pazouki *et al.* 2009). In addition according to the G2 guideline of the Convention those samples, used to determine a ship's compliance, must be 'representative' of the 'whole' ballast water to be discharged (IMO, 2008d). Representativeness of ballast water samples has not, however, yet been discussed clearly and while G2 guideline states that representative samples are required it does not provide clear guidelines on how to obtain these samples. Pazouki *et al.* (2009) have defined and acknowledged in their work that the samples collected for the enforcement of the Convention must be both statistically and biologically representative. Obtaining samples which fulfil both of these objectives is extremely difficult to achieve. Basurko and Mesbahi (2011) and Miller *et al.* (2011) have proposed, using different statistical approaches, to determine the volume of water required for statistical representation. The results in each study, however, vary widely, highlighting the lack of standard approach.

Currently, organisations from the UK, BE, NL, DE, DK, NO and SE are involved as partner or sub-partner in a project for regional cohesion, innovation and future strategies in ballast water policies and management. The aim of the project is to focus on Coherence and harmonisation for implementation, monitoring and enforcement of the ballast water Convention as well as development of future strategies to reduce ship-borne biological invasions.

#### *4.3.2 Air Pollution by Ships*

Marine engines, in order to be cost effective, operate on extremely low-grade fuel with high sulphur and aromatic content. Other form of transportation both land and air based systems use quite different and better quality fuels. Burning low quality fuel causes harmful emissions from ships, which eventually leads to acid rain, global climate change, particularly over oceans and damaging public health for those communities living near major port areas (Pazouki, 2002).

An important step in the control of emissions from ships came in May 2004 with the ratification of Annex VI of the MARPOL 73/78 Convention and subsequently entered into force in 19th of May 2005. The regulations in the annex set limits on sulphur oxide and nitrogen oxide emissions from ship exhaust as well as particulate matter and prohibits deliberate emissions of ozone depleting substances. From May 2005, all large ships built after January 2000 trading in international waters have to use marine fuels containing no more than 4.5 % sulphur, or no more than 1.5 % sulphur in SECA (Sulphur Emission Control Areas), and comply with the IMO Tier I $NO_X$ limit valid for nominal engine speed (CNSS website and references therein).

Despite of the concerns about emissions from ships, demand for global shipping has steadily risen as international trade has increased. From 2000 to 2007, the volume (in tons) of world exports increased by 5.5 %, on average, annually. Interestingly, over 80 % of that trade has been transported via shipping (WTO, 2008; UNCTAD, 2008).

While legislation is in force, the increasing trend in transportation of goods by shipping will offset the positive environmental impact of enforced regulations and will lead to further growth in ship emissions. In this respect, in 2008 IMO agreed on stricter measures that can significantly reduce ships' emissions, Table 3 shows the first and recent regulations for $NO_X$ and $SO_X$ of annex VI (IMO, 2008e).

Climate change is the other concern of regulatory bodies and environmentalists. Maritime shipping is estimated to represent around 3 % of worldwide GHG emissions.

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)




Table 3: MARPOL ANNEX VI Regulations for $NO_X$ and Sulphur (IMO, 2008e)

| NOx – Regulations | | | | Sulphur Regulations | | |
|---|---|---|---|---|---|---|
| | Diesel engines installed on ships | Engine speed (n) in *rpm* | Max. allow. $NO_X$ emissions in $g/kWh$ | | SECA | Global |
| Tier I (engine based controls) | 1 Jan. 2000 to 1 Jan. 2011 | $< 130$ | 17.0 | 2000 | 1.5 % | 4.5 % |
| | | $130 \leq n \leq 2000$ | $45.0 \cdot n^{-0.2}$ | 2010 | 1.0 % | |
| | | $n \geq 2000$ | 9.8 | 2012 | | 3.5 % |
| Tier II (engine based controls) | After 1 Jan. 2011 | $< 130$ | 14.4 | 2015 | 0.1 % | |
| | | $130 \leq n \leq 2000$ | $44.0 \cdot n^{-0.23}$ | 2020 [a] | | 0.5 % |
| | | $n \geq 2000$ | 7.7 | [a] Alternative date is 2025, to be decided by a review in 2018 | | |
| Tier III | After 1 Jan 2011 when operating in ECA | $< 130$ | 3.4 | | | |
| | | $130 \leq n \leq 2000$ | $9.0 \cdot n^{-0.2}$ | | | |
| | | $\geq 2000$ | 2.0 | | | |

Due to the expected growth of international trade, maritime emissions are expected to increase by a factor of 2-3 in 2050 if no action is taken.

The European Union has committed to a 20 % reduction in GHG emissions by 2020, compared to 1990, and the Commission also gave its commitment to reduce shipping emissions by 40–50 % by 2050, compared to 2005 in the recently published transport White Paper (EC, 2011).

Currently there are some measures and mitigating technologies available that reduce the ships' emissions. In Table 4 an overview of different measures and their reduction

Table 4: Measures for the reduction of air pollutants from ships and their reduction potential (http://cleantech.cnss.no)

| Category | Technology aimed to reduce | $NO_X$ | $SO_X$ | $CO_X$ | PM |
|---|---|---|---|---|---|
| | $NO_X$ | | | | |
| Water addition | Direct Water Injection | max. 60 % | | +0-2 % | Max. 50 % |
| | Exhaust Gas Recirculation | 20-85 % | | | |
| | Humid Air Motors | 20-80 % | | | |
| | Combustion Air Saturation System | 30-60 % | | | |
| | Water in fuel (e.g. 20 % emulsion) | 20 % | | | 40-60 % |
| Engine modification | Internal Engine Modification | | | | |
| | - slide valves | 20 % | | | Probably reduced |
| | - advanced measures | 30-40 % | | | Probably reduced |
| After treatment | Selective catalytic Reduction | 90-99 % | | | 25-40 % |
| | $SO_X$ | | | | |
| | Scrubber | | 90-95 % | | 80-85 % |
| (Alternative) fuels | Low Sulphur Fuel 2.7 %S to 0.5 %S | | 80 % | | 20 % |
| | Both $NO_X$ and $SO_X$ | | | | |
| | LNG | 60 % | 90-100 % | 0-25 % | 72 % |
| | Onshore Power Supply (in harbour only) | 90 % | 90 % | Depending on energy source | 90 % |

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)

Proceedings to be purchased at http://www.stg-online.org/publikationen.html



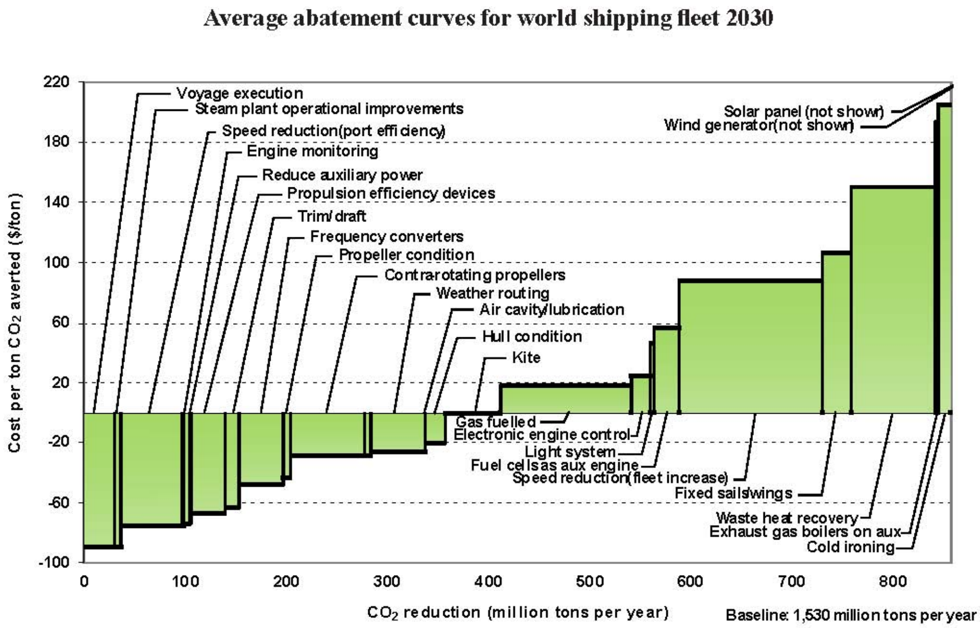


Figure 8: Overview of potential measures and reduction costs (DNV, 2010)

potential is shown. Not every technology is fully developed and ready to be applied on a large scale. Some technologies are still expensive to install or face practical barriers. Figure 8 also shows the $CO_2$ reduction potential of the 17 technical and 8 operational measures, including the cost of $CO_2$ reduction.

Currently, 18 partners across the countries around the North Sea region are involved in a project called Clean North Sea Shipping (CNSS). The aims of project are:

- Reduction of air pollution and GHG emission from shipping
- Research and application of existing and new technologies, methods and infrastructure
- For cost-effective and cleaner energy supply and usage for ships

The outcomes of this project are:

- To inform regional policy building - promote “clean shipping” Technology.
- To provide input to the implementation of EU, national and regional regulations.
- The promotion and implementation of Environmental Ship Index and incentives for “Clean Shipping Technology”.

### *4.3.3 Energy Efficiency*

As already mentioned above, MEPC made further progress in developing measures to improve the energy efficiency of ships in order to reduce GHG emissions from international shipping.

Currently IMO has developed two technical and operational measures for the primary assessment (and eventual control) of emissions from shipping, the Energy Efficiency Design Index (EEDI); and the Energy Efficiency Operational Index (EEOI) which assess the design and operational performance of a ship against a curve of achievable performance generated from the existing ship population.

The EEDI establishes a minimum energy efficiency requirement for new ships depending on ship type and size and is a robust mechanism to increase the energy efficiency

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)




of ships in the future (IMO, 2009a,b). The EEDI is a non-prescriptive, performance-based mechanism that leaves the choice of technologies to use in a specific ship design to the industry. As long as the required energy-efficiency level is attained, ship designers and builders would be free to use the most cost-efficient solutions for the ship to comply with the regulations. Thus EEDI will stimulate innovation and technical development of all the elements influencing the energy efficiency of a ship.

However, as is common practice in all IMO technical standards, EEDI will affect only new buildings and therefore, as the economic life of a ship can be 25–30 years it may take decades for the policy to sort any effect on the sector's GHG emissions (Faber *et al.*, 2009).

On the operational side, a mandatory management tool for energy efficient ship operation, the Ship Energy Efficiency Management Plan (SEEMP), has been developed by IMO (IMO, 2009c). The SEEMP establishes a mechanism for a shipping company and/or a ship to improve the energy efficiency of ship operations. The SEEMP provides an approach for monitoring ship and fleet efficiency performance over time using the EEOI as a monitoring tool and serves as a benchmark tool (IMO, 2009d). The SEEMP urges the ship owner and operator at each stage of the plan to consider new technologies and practices when seeking to optimize the performance of a ship. The Second IMO GHG Study 2009 indicates that a 20 % reduction on a tonne-mile basis by mainly operational measures is possible and would be cost-effective even with higher fuel prices than those currently experienced.

Development of the technical and operational measures is a very important step in ensuring that the global shipping industry has the necessary mechanisms to reduce its GHG emissions. However, these measures would not be sufficient to satisfactorily reduce the amount of GHG emissions from international shipping in view of the growth projections of world trade. Therefore, market-based mechanisms have been considered by MEPC.

A market-based mechanism would serve two main purposes: 1) off-setting in other sectors of growing ship emissions (out of sector reduction); and 2) providing an economic incentive for the maritime industry to invest in more fuel-efficient ships and technologies and to operate ships in a more energy-efficient manner (in sector reductions).

At present, several market-based measures are under discussion within MEPC, recently analyzed by Miola *et al.* (2011). In particular ten proposals for market-based measures have been discussed in MEPC 61on the basis of an assessment carried out by an Expert Group that has evaluated the proposals on the basis of nine criteria such as environmental and cost-effectiveness, impacts on trade innovation and technological change, etc (IMO, 2010). However, no decision was officially taken. The IMO GHG Working group will report on its conclusion on market-based measures during the MEPC 62.

# 5 RECENT DEVELOPMENT OF THE IMO GOAL BASED STANDARDS (GBS)

## *5.1 Present State of GBS Implementation at IMO*

### *5.1.1 Goal Based Standards for Tankers and Bulk Carriers*

During the work of this committee the discussion of GBS continued at the Maritime Safety Committee (MSC) of IMO. The progress will be described in the sequence of MSC sessions.

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



During MSC 86 (IMO, 2009e) the process of verification of rules, as defined under Tier III, for their compliance with the goals was discussed. First discussion of the related guideline and the assignment of responsibilities took place during that session. Further possible consequences regarding costs of the verification process, the resource implications of the process were discussed. In this context a legal aspect raised in (IMO, 2009f) is worth to be mentioned. Who will be responsible for the rules? It is mentioned that rule developers might shift their responsibility for the rules towards the IMO after IMO have approved the rules being compliant with the GBS which were developed by IMO. This leads to another supporting argument that IMO should only assess the self-assessment and the rule developing process of the rule developers in the course of an audit.

Further the possible content of the Ship Construction File is a matter of concern regarding the intellectual property rights; see (IMO, 2009g). The intention of the ship construction file (SCF) is to provide information about the design of the ship to ensure a safe operation and maintenance of the ship during the ship's lifetime and the information shall be available in case of emergency situations. As this information possibly give an insight into the design criteria of the shipyards including their approach how to design the structure including the load assumptions and their calculation methods the shipbuilders during the discussion raise concerns that their intellectual properties might be violated if too many detail information would be available on board. To take care of the concerns a workgroup was formed to balance the interests of the industry stakeholders. The document provides a progress report on a cross industry project that may assist the finalization of Guidelines for information to be included in a Ship Construction File, taking into consideration the protection of intellectual property. A future guideline for the SCF shall be based on following principles:

- The SCF is a mandatory set of documents linked to the ship from delivery until the recycling.
- Ship owners must have access to documentation for safe operation of the vessel, including maintenance, repair and for emergency situations.
- The concept of property (with regard to intellectual property), its importance and impact shall be recognized.
- The SCF provisions must address safe operation of the ship and the concept of property, as above.
- All necessary structural safety information shall be available throughout the lifetime of the vessel, along with the obligation of respecting the IP protection principles.
- Availability of supplementary structural information, not related to the safe operation, maintenance and repair of the ship may be subject to commercial agreements.

During MSC 87 the GBS for oil tankers and bulk carriers were adopted (IMO, 2010d). Accordingly newly-constructed vessels will have to comply with standards conforming to functional requirements developed by MSC. This is the first time that IMO has set up standards for ship construction. The GBS were formally adopted as an amendment to SOLAS, the new regulation II-1/3-10.

During the same session MSC adopted guidelines that establish procedures to be followed in order to verify that design standards or classification rules of recognized organisations submitted to IMO conform to the GBS (IMO, 2010e). The verification process consists of two elements: self assessment of the rules by the submitting or-

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)




ganization, followed by an audit of the rules and the self assessment, carried out by experts appointed by IMO.

In continuation of the discussions at MSC 86, MSC 87 approves the Guidelines for the information to be included in the Ship Construction File (IMO, 2010f) aiming at providing additional guidance on the application of the requirements in SOLAS regulation II-1/3-10. For details of the discussion of intellectual property rights see also (IMO, 2010g,h)

According to the guideline the SCF should remain with the ship and, in addition, be available to its classification society and flag State throughout the ship's life. Where information not considered necessary to be on board is stored ashore, procedures to access this information should be specified in the onboard SCF. The intellectual property provisions within the SCF should be duly complied with.

The appendix of the resolution lists all the information to be included in the SCF related to 14 Tier II functional requirements of the GBS. Among those are requirements regarding design, construction, in-service considerations. The information regarding structural strength of the ship is listed in Table 5 and gives an impression of the degree of detail. With this IMO for the first time have set standards on the information to be kept on board

#### *5.1.2 Safety Level Approach*

This section gives an overview of developments related to the Safety level approach in a wider sense. First the status of the ongoing IMO activities on goal based standards is described. Because risk based designs and their approval can be seen as part of the safety level approach and formal safety assessments (FSA) are mentioned as possible methods to determine the risk level of a given system and to evaluate the effectiveness of risk control options both will be described under this section.

Preceding the adoption of the GBS for Tankers and Bulk Carriers which are of prescriptive nature there was a discussion of the safety level approach (SLA) as a possible alternative to the prescriptive GBS. At MSC 87 it was agreed to continue working on the GBS and to further develop the SLA.

Proposals how to develop the SLA were made by Germany and Korea by submitting two papers to MSC 88 (IMO 2010i,j)) which supplement each other. Both papers propose to continue the work on the SLA and describe the importance of the determination of the current safety level of existing rules and regulations, determination of target safety levels for future regulations and the monitoring thereof. Formal safety assessment and structural reliability analysis are seen as tools to support the development of safety level based regulations. Continuation of the work of MSC shall lead to Guidelines for GBS to a degree suitable for the preparation of regulations for future safety-level based standards within current or future review processes (definition of goals and functional requirements, etc.), taking into consideration recent experiences, e.g., in the discussions of the IGF Code and the International Code of safety for ships operating in polar waters. Further it is to be clarified how the acceptable safety level should be specified and to specify the model to determine the safety level of standards. In this context target safety levels for all the failure modes of ship structures, limit state equations for their failure modes are to be defined and probabilistic characteristics of random variables and guidelines for defining the characteristics of random variables.

MSC 88 also acknowledged that this would be a longer term project during which a number of unresolved issues needed to be considered, such as the role of FSA in the

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)

Proceedings to be purchased at http://www.stg-online.org/publikationen.html



Table 5: Content of the SCF (IMO, 2010f)

| Tier II item | | Information to be included | Further explanation of the content | Example documents | Normal storage location |
|---|---|---|---|---|---|
| 3 | Structural Strength | | | | |
| 3.1 | General Design | • applied Rule (date and revision)<br>• applied alternative to Rule | • applied design method alternative to Rule and subject structure(s) | • SCF-specific | on board ship |
| 3.2 | Deformation and failure modes | • calculating conditions and results;<br>• assumed loading conditions<br>• operational restrictions due to structural strength | • allowable loading pattern<br>• maximum allowable hull girder bending moment and shear force<br>• maximum allowable cargo density or storage factor | • capacity plan | on board ship |
| | | | | • loading manual | on board ship |
| 3.3 | Ultimate Strength | | | • trim and stability booklet | on board ship |
| 3.4 | Safety Margins | | | • loading instrument instruction manual | on board ship |
| | | | | • operation and maintenance manuals | on board ship |
| | | • strength calculation results<br>• gross hull girder section modulus<br>• minimum hull girder section modulus along the length of the ship to be maintained throughout the ship's life | • bulky output of strength Calculation<br>• plan showing highly stressed areas prone to yielding and/or buckling | • strength calculation | on shore archive |
| | | | | • areas prone to yielding and/or buckling | on board ship |
| | | | | • general arrangement | on board ship |
| | | | | • key construction plans | on board ship |
| | | • gross scantlings of structural constituent parts<br>• net scantlings of structural constituent parts | • structural drawings<br>• rudder and stern frame<br>• structural details of typical members | • rudder and rudder stock | on board ship |
| | | | | • structural details | on board ship |
| | | | | • yard plans | on shore archive |
| | | | | • dangerous area plan | on board ship |
| | | • hull form | • hull form information indicated in key construction plans | • lines plan | on shore archive |
| | | | • hull form data stored within an onboard computer necessary for trim and stability and longitudinal strength calculations | or equivalent | on board ship |

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



Table 5: Content of the SCF (IMO, 2010f) – continued

| Tier II item | | Information to be included | Further explanation of the content | Example documents | Normal storage location |
|---|---|---|---|---|---|
| 4 | Fatigue life | • applied Rule (date and revision)<br>• applied alternative to Rule | • applied design method alternative to Rule and subject structure(s) | • SCF-specific | on board ship |
| | | • calculating conditions and results;<br>• assumed loading conditions | • assumed loading conditions and rates | • structural details | on board ship |
| | | • fatigue life calculation results | • bulky output of fatigue life Calculation<br>• plan showing areas prone to fatigue | • fatigue life calculation<br>• areas prone to fatigue | on shore archive on board ship |
| 5 | Residual Strength | • applied Rule (date and revision) | | • SCF-specific on board ship | |

context of GBS, the availability of relevant data and statistics and the expansion of the scope beyond structural requirements. A GBS/FSA Working Group is established to discuss the development starting from a summary of the preceding discussion of SLA at various MSC meetings (IMO, 2011).

As a result of this discussion MSC 89 approves generic guidelines (IMO 2011a) that for the first time provide a process for the development, verification, implementation and monitoring of goal-based standards (GBS) to support regulatory development within IMO. In addition to the agreed system of tiers of the GBS the guideline clearly describes the scope of the verification process and the scope of documentation necessary for the verification process. Further a system of monitoring the effectiveness of goals and requirements is introduced together with the responsibilities for their monitoring.

There will be two monitoring processes, the monitoring of the effectiveness of single rules/regulations on the one hand and the monitoring of the effectiveness of the goals (Tier I) and the functional requirements (Tier II) on the other hand.

According to the guideline the monitoring responsibilities should be assigned as follows: For Tier I, the monitoring (including data collection), the analysis lies with the IMO the evaluation with the committees. For Tier II the monitoring (including data collection), analysis and evaluation lies with the Sub-Committees. For Tier IV the responsibility for monitoring and analysing the Rules and requirements lies with the rule maker under supervision of the IMO. Requirement under Tier IV developed by IMO will be monitored and analysed by IMO/Sub-Committees. The Monitoring will be based on the collection and evaluation of statistical data that are representative for the maritime industry.

With this guideline a unified structure for future regulations developed by IMO is introduced for the first time. Possible differences in the structure may be regarded as editorial difference only. However, in order to achieve a homogenous structure of future goal-based regulations, a section is added to the Guidelines providing generic guidance for the revision or development of IMO regulations, in particular considering the generation of goals and functional requirements as well as a generic structure.

Earlier in this discussion a guideline on approval of risk based ship designs was sub-

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)




mitted to MSC (IMO 2009h) which can be seen as the first document comprehensively describing the process of the risk analyses and the approval. It presents a high level process which can be well adjusted to the individual type of analysis. The document considers all parties involved as there are shipyard, producer, owner, risk analyst and the flag state, it describes their tasks and it gives advice at which step of the process each party should be active in the process. It recommends that flag state and design team clearly specify the scope of the risk analysis based on a first design review. Experience with risk analysis projects shows that this recommendation had not been followed with negative impact on the result and acceptance of the analysis. Further the guideline gives support on how to estimate the scope of the analysis depending on the degree of innovation of the proposed design. The guideline generally assumes that a risk analysis consists of two parts (one for the first design, the second for the final design) and that the design team (shipyard, owner, producer, risk analyst) do a hazard identification and a quantitative risk analysis.

In practical application of the process some times one of the steps might be omitted. However, that seems to be not a problem for the proposed process. The process described in the guideline seems to be flexible enough to cover such kind of deviations, thus one can say the process is sufficiently robust to be adjusted to individual analysis tasks.

During the previous period of this committee 5 FSAs, one each for Container Vessels (IMO, 2007b), LNG Carriers (IMO, 2007c), Cruise Ships (IMO, 2008b), Ro-Pax Ships (IMO, 2008c) and Crude Oil Tankers (IMO, 2008d) were submitted to MSC and MEPC for their consideration. An extensive FSA on General Cargo Ships followed in 2010 (IMO, 2010c). Following the submission MSC established the FSA Expert Group in which three members of this committee participated. The Expert Group, according to the following terms of reference, had to

- consider whether the methodology was applied in accordance with the FSA Guidelines and the Guidance on the use of HEAP and FSA;
- check the reasonableness of the assumptions and whether the scenarios adequately addressed the issues involved;
- check the validity of the input data and its transparency (e.g., historical data, comprehensiveness, availability of data, etc.);
- check whether risk control options and their interdependence were properly evaluated and supported by the assessment;
- check whether uncertainty and sensitivity issues have been properly addressed in the FSA study;
- check whether the scope of the assessment was met in the FSA study; and
- check whether expertise of participants in the FSA study was sufficient for the range of subjects under consideration.

The Expert group comes to the result that the FSA were done in accordance with the guidelines in general and show no major deficiencies. However, it can be observed that the recommended risk control options are similar in each case regardless of the ship type and mainly recommend improvements of the navigational equipment or training of personnel. As a consequence the discussion of the Expert Group is dominated by a discussion of the quality of available casualty data which form the basis of the hazard identification. Major concern is raised regarding the documentation of the root causes of accidents. Further to the above the degree of detail of the documentation of the risk analysis or the selection of experts participating in HAZID sessions are a matter

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



of discussion. The report of the Expert Group (IMO, 2010k) finally recommends that a revision of the FSA guidelines should cover the following matters:

- description/discussion of experts participation in FSAs (i.e. expansion of specification for 10.1.5 of the FSA Guidelines);
- description of the structure, selection and composition of the project team, HAZID team and any other team, if established for taking any decision making (i.e. expansion of specification of 10.1.5 of the FSA Guidelines);
- information and analysis on root causes and details of casualties, with a view to obtaining RCOs focused on prevention rather than mitigation;
- development of risk models;
- unification of terminologies;
- reporting the method and justification for the final selection of RCOs;
- indices for cost-benefit analysis for risks other than safety of life;
- clarification on the use of NCAF and GCAF;
- methodologies to analyse possible side effect of RCOs;
- methodologies for sensitivity and uncertainty analysis;
- consideration of the human element (to have more detailed and specific guidance);
- methodologies to reach the consensus or agreement as well as reporting the degree of agreement, or concordance;
- how to present reports; and
- how to review FSA studies.

Following this report MSC establishes a Correspondence Group which work is still progressing at the time this report is written.

### 5.2 IACS Implementation of GBS (Ongoing Development)

The members of IACS are currently working on the harmonisation of the Common Structural Rules (CSR) for Oil Tankers and Bulk Carries. The CSR published in 2006 have been two sets each to be individually applied for Tankers or Bulk Carriers. In the context of the development of GBS this can be seen as a first step towards a single set of Rules that contain the basic principles for both ship types together with the individual requirements for both ship types. According to the five tier approach of GBS these rules have to be verified for compliance with the goals and functional requirements as defined as defined under tier 1 and 2. The Rules will be submitted to IMO for verification by the end of 2013 together with a set of background documentation describing the compliance with the GBS. An audit team consisting of experts nominated by the IMO member states will then carry out the review until May 2016. Finally the GBS will enter into force and will have to be applied for new designs of tankers and bulk carriers of 150 $m$ in length and above:

- For which the building contract is placed on or after 1 July 2016;
- In absence of a building contract, the keels of which are laid or which are at a similar stage of construction on or after 1 July 2017; or
- The delivery of which is on or after 1 July 2020.

#### 5.2.1 Ultimate Hull Girder Strength

In order to ensure sufficient structural safety for a ship structure throughout the lifetime, it is necessary to carefully identify all the threats the ship may encounter (IACS, 2006b, Sect. 2). A systematic review is carried out to identify hazards that may cause structural failure or lead to increased chance of additional hazards and

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



progressive collapse. In risk based rules the proper balance between probability of failure and consequences of failure is sought for. High consequences of failure call for a low probability of failure whereas low consequences allow for a higher probability.

Failure of the hull girder, which is the top level of the ship structural hierarchy, is the most critical failure mode for a ship, and an explicit check of the hull girder ultimate strength is therefore included in the CSR. It turns out that in most cases sufficient hull girder strength is already obtained after the local strength requirements for structural elements at lower levels in the hierarchy are met, including fatigue. However, with increasing ship lengths and/or changes in the design, a verification of the hull girder check is clearly important.

The hull girder check was calibrated by the use of structural reliability analysis (SRA), ref. (IACS, 2006b, Sect. 9.1). This was done to:

- Ensure a consistent safety level for the ships designed according to the rules; i.e. minimise the scatter in safety level between ships
- Support the choice of design equation; i.e. the formulation of strength being greater than the load effects
- Support the specification of the characteristic values in the design equation; i.e. wave moment, still water moment and the ultimate bending moment capacity with its calculation procedure.
- Support the magnitude of the partial safety factors applied to the characteristic values, so that the associated uncertainty is properly reflected and the desired structural safety obtained.

The absolute value of the failure probabilities is a nominal value, and will generally not reflect the frequency of failure. The target failure probability used in the rule calibration was therefore mainly taken from that of existing ship structures, were in-service experience had proven satisfactory strength. In Horte *et al.* (2007b), the target failure probability from a cost benefit analysis was also evaluated, and confirmed a similar target.

#### *5.2.2 Residual Strength*

Residual strength checks are included in certain classification societies' rules, such as ABS and DNV, while the hull girder check in CSR is at present limited to failure of an intact ship in bad weather. Following the implementation of GBS, IACS identified the residual strength of a damaged ship as one gap in the CSR versus GBS, and it was decided to include a residual strength criterion in the new, harmonized CSR rules. Damages in this context are due to collision or grounding. This was studied by IACS using SRA in 2011 which will be published with the technical background of the harmonized CSR, following the principles as outlined in the following.

The failure of an intact ship in open sea occurs if the loads in terms of wave and still water bending moment exceed the hull girder ultimate bending capacity. Damage will lead to changes in these parameters, see Figure 9:

- The still water bending moment may increase or decrease, depending on location of damage and flooding or outflow.
- The wave bending moment is likely to be significantly lower than for unrestricted service in North Atlantic conditions due to short exposure time and lower waves where most damages take place.
- The ultimate bending moment will be reduced at the location of the damage; however, note that damages near the ship ends will not reduce the capacity amidhips.

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



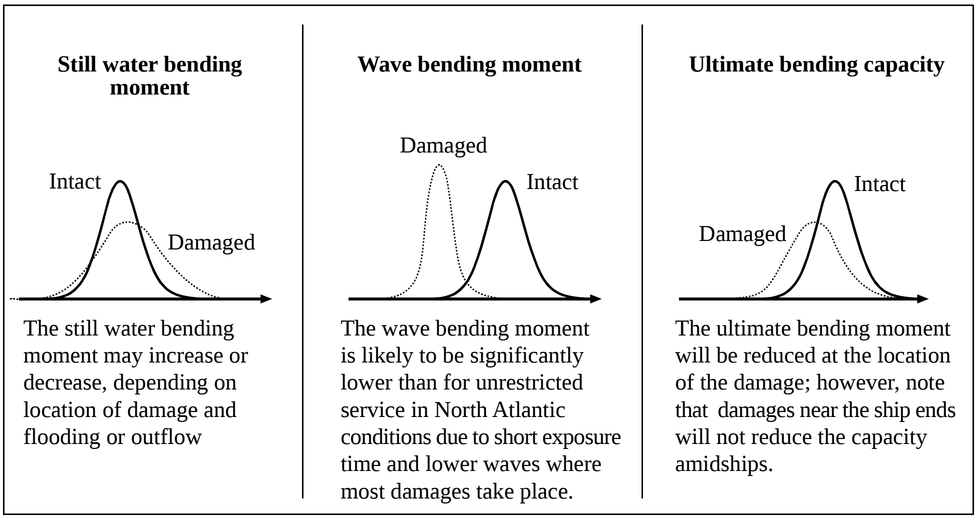


Figure 9: Effect of damage on loads and capacity

A qualitative criticality evaluation with these considerations in mind was made, and failure of a bulk carrier in sagging after collision damage was used in a case study.

### *5.2.3 Uncertainty Modelling*

The uncertainty model for the intact case is reported in (IACS, 2006b, Sect 9.1) and Horte *et al.* (2007a). Here the differences between the uncertainties for the intact versus damaged cases are described.

- Still water bending moment in the damaged case was conservatively assumed to increase by a deterministic value corresponding to the still water moment increase from flooding of the most unfavorable compartment. This was considered conservative since the chance of hitting the most unfavorable compartment was then effectively set to 1.0, and so was the probability of flooding of an empty hold.
- The wave bending moment was significantly reduced due to short exposure time (assume one week after collision) and lower waves since these events are more likely in costal areas and not in the North Atlantic environmental conditions. World wide conditions were used, with sensitivity results using observed wave conditions at collision events taken from (Rusaas, 2003).
- The ultimate bending moment capacity was reduced due to the damage. This reduction in strength was implemented as a deterministic function of the damage size, where the damage size was modeled as a random variable.
- Finally, the probability of the collision event to occur was taken as 0.01, which is somewhat conservative compared to IMO (2010c).

The structural reliability analysis was used on a comparative basis between hull girder failure of intact ship and hull girder failure of the ship following a collision or grounding damage. The following analyses were made, see Figure 10:

- Calculate the failure probability of the intact ship; and use this as the target failure probability
- Calculate the conditional failure probability for the ship, given that the damage event has occurred

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



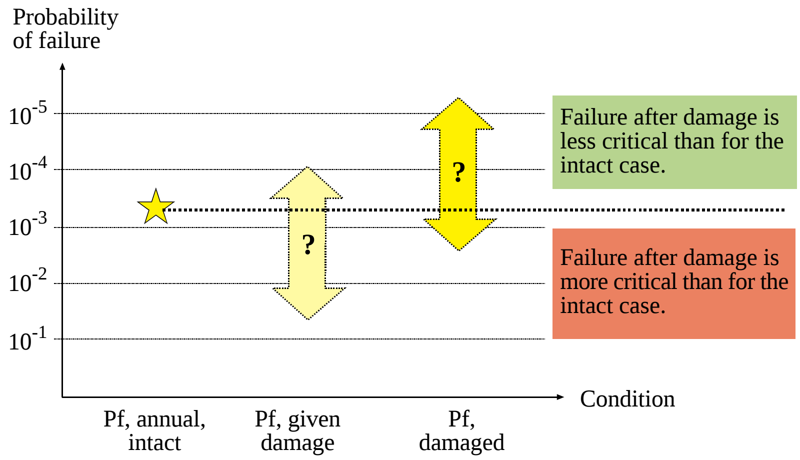


Figure 10: Illustration of comparative approach

- Calculate the failure probability for the damaged case, accounting for the probability of the damage event to occur; i.e. the conditional failure probability times the probability of damage occurrence

For the selected case, the probability for the damaged case was found to be lower than of the intact case. This could be taken as an indication that the residual strength criterion is unnecessary, i.e. not dimensioning. However, irrespective of the comparison between the intact and damaged failure probabilities, the SRA was used to support the specification of a residual strength criterion. This was done as follows:

- First the intact ship strength was modified so that the failure probability in the damaged case became equal the target failure probability from the intact case.
- Then the “design point”; i.e. the most likely value of all the random variables in the SRA that give failure was examined. The purpose of this examination was to see if a proposed residual strength criterion would be reasonable compared to what one would expect to be the most likely failure situation in real life.

The ”design point” from the SRA showed fairly good correspondence with the product of characteristic values and partial safety factors as well as the damage size specified in the proposed criterion. The criterion was found to be on the conservative side, hence providing lower failure probabilities for the damaged case than for the intact case. However, even with this conservatism compared to the intact case it is unlikely that the criterion will be dimensioning and cause any increase in scantlings for conventional designs.

### *5.3 Potential for Success Associated with GBS*

At the very beginning of the discussion of GBS at MSC there were two approaches, the prescriptive and the safety level approach. With regard to tankers and bulk carriers the more prescriptive approach has been chosen. However the discussion and development of the safety level approach continues at MSC.

As evidence for the success one can mention the decision of IMO to develop new regulations in the sense of GBS. Recent examples are the development of the code for life saving appliances, the Polar Code and the IGC. The decision at IMO to use formal safety assessments as a tool to develop the justification for new requirements supports this.

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



The GBS for tankers and bulk carriers under Tier 3 require a verification of classification rules for compliance with the functional requirements laid down under Tier 2. This is a new situation for the classification societies. At first sight it seems that classification societies lose their independence to some extent as they have to repeatedly submit their rules to the expert group of IMO for verification after changes of the content of the rules.

Yet it is not clear how often and after what kind of modification the rules have to be submitted. The present practice of classification societies foresees a yearly update and improvement of their rules based on experience and damage analysis. These amendments to their rules have been carefully developed and discussed in the governing bodies (namely the technical committees) of the classification societies which consist of representatives from the industry stakeholders. This procedure already assured a development of the technical requirements taking into account the weighted interests of the stakeholders.

If these regular rule developments should be submitted to IMO in any case, continuation of this practice would cause extensive effort for the IMO on the one hand and changes to the procedures of classification societies on the other hand, namely extended lead times before publication of new rules which in turn might impair the up-to-dateness of rules. As for the time being the classification societies and IMO discuss how to deal with this. Publications regarding this are yet not available. The maritime community shall carefully observe how this new regime affects the progress of rule development.

# 6 APPROACHES IN OFFSHORE INDUSTRY AND AVIATION INDUSTRY

## *6.1 Design Criteria for Ice Action on Offshore Wind Turbines*

Because the present report mainly deals with aspects of sustainability of the maritime industry and how the maritime industry can contribute to a sustainable use of the maritime environment the focus of this section is put on offshore wind turbines and related developments.

There is an immense global potential for wind generated electrical power (Lu *et al.*, 2009, Leung and Yang, 2012). Because of considerations such as space usage, adjacency to population centres and favourable wind speeds, developments of offshore wind farms are on the rise world-wide (Bilgili *et al.*, 2011, Markard and Petersen, 2009, Musial and Ram, 2010, and Zhixin *et al.*, 2009). The offshore oil and gas industry has of course for many years dealt with harsh ocean environments with some hard-earned lessons, particularly in the Arctic (Blanchet *et al.*, 2011, and Ghoneim, 2011). The development of offshore wind energy structures will have similar challenges to overcome with coupled forcing from ice, winds, waves and currents now influenced by turbine dynamics and other forces (Graveson *et al.*, 2001, Hacıefendioğlu and Bayraktar, 2011 and Volund 2003).

In 2001, the Danish Energy Agency (DEA 2001) issued recommendations for approval of Offshore Wind Turbines (OWT) with considerations for static and dynamic ice loads. In 2010, Germanischer Lloyd published a revised edition of the Guideline for the Certification of Wind Turbines (Woebbeking, 2010), which updates their 2005 guidelines (GL, 2005a) and complements their 2005 Guideline for fixed offshore installations in ice infested waters (GL, 2005b). Also in 2010, the American Bureau of Shipping (ABS, 2010b) Standard "Offshore Wind Turbine Installations" was released

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



in December. Det Norske Veritas issued its new Offshore Standard in September, 2011 (DNV, 2011b). These new standards refer to criteria established in the American Petroleum Institute's Recommended Practice 2N (API, 1995), the International Standard ISO 19906 (Karna *et al.*, 2011), the Petroleum and natural gas industries - Arctic offshore structures (ISO, 2010), and Annex E of IEC 61400-3:2009 (IEC, 2009). These standards establish design considerations for static and dynamic ice loading which, for the most part, were developed for Arctic offshore oil and gas structures.

Static ice forces or actions on offshore wind turbines to be considered, as commonly mentioned in the standards, are normally generated by temperature fluctuations or changes in water level in a fast ice cover. Dynamic loads are caused by moving ice interactions with the support structure as the ice impacts, fails, and clears around and past the structure.

Quoting from the new ABS Guide (ABS, 2010b):

> "For an offshore wind turbine intended to be installed in areas where ice hazards may occur, the effects of sea ice or lake ice on the Support Structure are to be taken into account in the design. Depending on the ice conditions at the site, the Support Structure may encounter with moving ice and fast ice cover... Statistical ice data of the site are to be used as the base for deriving the parameters such as ice thickness, ice crushing strength and pack ice concentration, etc., which are required for determining the ice loads. Impact, both centric and eccentric, is to be considered where moving ice may impact the Support Structure. Impact of smaller ice masses, which are accelerated by storm waves and of large masses (multi-year floes and icebergs) moving under the action of current, wind ... is to be considered in the design. The interaction between ice and the Support Structure produces responses both in the ice and the structure/soil system, and this compliance is to be taken into account as applicable."

For lower speeds, forces slowly build until the ice strength is reached and ice fails resulting in a "quasi-static condition" where the frequency of the forcing is about an order of magnitude lower than the response of the structure (Eranti *et al.*, 2011). For intermediate speeds, the ice failure response can be coupled with the structural response, resulting in a "lock-in" response where the ice feature failure period and the response period of the structure coincide (Huang and Liu, 2009, Hetmanczyk *et al.*, 2011). A third important response regime occurs at high speeds of encounter in which brittle fracturing of the ice feature in contact with the structure occur in a more or less random pattern which results in random vibration excitation of the structure (Karna *et al.*, 2010).

These three conditions are specifically addressed in the ISO standard 19906:2010 for consideration in the design of offshore structures. A special consideration of lock-in vibrations is required due to the detrimental effects of such response with regard to fatigue and foundation/soil response. Additional conditions are also of importance for transitional depth structures which may have multiple and battered piles: sloping structures may allow the ice feature to fail in bending, rather than crushing; and, multiple piles add additional complexity of ice pressure distribution and non-simultaneous failure. A final important consideration is impact of drifting ice floes encountering the platform with a sudden increase in forces which results in high-amplitude transient vibrations of the structural system.

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)




For compliance with the ISO standard 19906:2010, the following conditions should be considered: quasi-static actions, where inertial action effects within the structure can be neglected; dynamic actions due to level ice, where inertial action effects within the structure are influential; and impacts from discrete features such as first-year ice features.

Also according to ISO standards, the following limiting mechanisms shall be considered for global ice actions:

a) Limit stress, which is the mechanism that occurs when there is sufficient energy or driving force to envelop the structure and generate ice actions across its total width.
b) Limit energy, which is the mechanism that occurs when the interaction is limited by the kinetic energy of the ice feature and is generally characterized by the absence of surrounding ice.
c) Limit force, which is the mechanism that occurs when the interacting feature is driven against the structure the actions are insufficient for the ice to fail locally and envelop the structure.

Furthermore as specified in the ISO standard are considerations for:

For *local ice actions* consideration must be given to the design of sheet piling, plates, stiffeners, and frames and bulkheads.

For *dynamic ice actions*, the time-varying nature of ice actions and the corresponding ice-induced vibrations shall be considered in the design. The potential for dynamic amplification of the action effects due to lock-in of ice failure and natural frequencies shall be assessed. Particular attention shall be given to dynamic actions on narrow structures, flexible structures and structures with vertical faces exposed to ice action. Structural fatigue and foundation failure as a consequence of dynamic ice actions shall be considered.

It is quite natural for structural design of offshore wind turbine structures to initially turn to the successes of offshore oil and gas industry and land-based turbines. Certainly the lessons learned in that regard are to be valued, however from a structural analysis standpoint, the offshore wind turbines are dynamical systems by routine. A thorough description of the structural response of the blades, tower, substructure, and foundation requires an integrated, dynamical systems approach (Petrini *et al.*, 2010). An OWT is subjected to wind, ice, and wave loadings of approximately equal severity rather than predominantly wave forcing for oil and gas platforms and predominantly wind for land-based units. A key factor is of course water depth, and while there is proven success at shallower water depths using concrete gravity and steel monopile structures, there are greater challenges for establishing economical designs in deeper waters when construction, operation and maintenance costs create additional system optimization challenges in cold regions (Zaaijer, 2009).

### *6.2 Approaches to Safety the Aviation Industry*

The committee would like to make specific reference to the publication (De Florio, 2011) which provides a single reference on the subject of Aircraft Certification.

The committee has used the book to highlight issues of interest to the ISSC on the systematic aviation industry approach to flight safety, safety assessment and fatigue strength. The book is a comprehensive review of airworthiness requirements, type certification and production of products, certificates of airworthiness and continued airworthiness and operations. Approaches to sustainability and the regulatory environment in the aviation will not be further described

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



#### *6.2.1 Flight Safety*

The publication specifically deals with safety related to aeronautical activities, starting by considering what has been defined as the main conventional flight safety factors. These are: man, the environment and the machine.

1. *Man* is intended as an active part of the flight operations, i.e. after the aircraft is designed and built, e.g. the pilots, maintenance manpower, air traffic controllers and others.
2. The *environment* covers all the external factors that can have an influence on the flying of an aircraft, meteorological conditions, traffic situations, communications, correct meteorological information, rules for the vertical and horizontal separation of the aircraft, suitable aerodromes, and so on.
3. The *machine* refers to a "project" i.e. the aircraft, its sound construction and its efficiency in relation to the operations to be carried out. Also, as with the Maritime Industry, National States entrust special public bodies with the responsibility of assuring that the aircraft (project) construction, and the operating instructions comply with flight safety requirements.

The three safety elements above act in series and not in parallel. They are three links of a chain representing flight safety. The failure of a single link is sufficient for an accident to happen. E.g. a pilot's error can put the best aircraft in jeopardy, and the best pilot cannot compensate for a serious failure in an aircraft.

#### *6.2.2 Safety Assessment*

The book presents the following rationale of how the aviation industry identifies an acceptable safety level. The definition of an acceptable safety level implies the definition of an acceptable accident rate; this cannot be defined as abstract wishful thinking, but on the basis of what is practicable. What is practicable for the future can be forecast by the analysis of past accident rates. Starting from the arbitrary hypothesis that a commercial large aircraft could present some 100 hazards (potential failure conditions) leading to a catastrophic effect, it follows that, for each system, the acceptable probability of a catastrophic failure is less than $1 \cdot 10^{-9}$ flight hours.

*Failure conditions*
Failure conditions are defined as effects on the aircraft and its occupants, both direct and consequential, caused or contributed to by one or more failures, considering relevant adverse operational or environmental conditions. Failure conditions are classified according to their severity as follows:

*Minor:* Failure conditions that would not significantly reduce aircraft safety and which involve crew actions that is well within their capability.

*Major:* Failure conditions that would reduce the capability of the aircraft or the ability of the crew to cope with adverse operating conditions to the extent that there would be, for example, a significant reduction in safety margins or functional capabilities, a significant increase in crew workload or in conditions impairing crew efficiency, or discomfort to occupants, possibly including injuries.

*Hazardous:* Failure conditions that would reduce the capability of the aircraft or the ability of the crew to cope with adverse operating conditions to the extent that there would be (a) A large reduction in safety margins or functional capabilities (b) Physical distress or higher workload such that the flight crew cannot be relied on to perform their tasks accurately or completely, or (c) Serious or fatal injury to a relatively small number of the occupants.

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



Table 6: Categories of failures for a large aircraft

| | | | | |
|---|---|---|---|---|
| 1 | Minor failures | Become | Probable | |
| 2 | Major failures | Become | Remote | $P = 1 \cdot 10^{-5}$ |
| 3 | Hazardous failures | Become | Extremely remote | $P = 1 \cdot 10^{-7}$ |
| 4 | Catastrophic failures | Become | Extremely improbable | $P = 1 \cdot 10^{-9}$ |

*Catastrophic:* Failure conditions that would prevent continued safe flight and landing.

As an example: A single aircraft might fly a total of $5 \cdot 10^4$ hours and a large fleet of 200 aircraft (same type) might then accumulate a fleet total of $1 \cdot 10^7$ hours.

1. A catastrophic failure condition (at worst $1 \cdot 10^{-9}$) would be unlikely to arise in the whole fleet's life.
2. A hazardous failure condition (at worst $1 \cdot 10^{-7}$) might arise once in the whole fleet's life.
3. A major failure condition (at worst $1 \cdot 10^{-5}$) might arise once in an aircraft's life and would arise several times in the whole fleet's life.
4. A minor failure could arise several times in the aircraft's life.

The safety assessment of equipment, systems, and installation is a very important part of aircraft design. It is of paramount importance to start the assessment from the very beginning of the design. A late assessment could bring result in expensive design changes.

### *6.2.3 Fatigue Strength*

The airworthiness standards essentially consider two types of structure:

1. Single load path structures, where the applied loads are eventually distributed through a single member, the failure of which would result in the loss of the structural capability to carry the applied loads.
2. Multiple load path structures, identified with redundant structures in which (with the failure of an individual element) the applied loads would be safely distributed to other load-carrying members.

In the first case, the structure must result in *safe-life,* that is, be able to sustain a certain number of events such as flights, landings, or flight hours, during which there is a low probability that the strength will degrade below its design ultimate value due to fatigue cracking. In the second case, the structure must be of damage-tolerance design, that is, be able to retain its required residual strength for a period of unrepaired use after the failure or partial failure of a principal structural element due to fatigue, corrosion, accidental damage, and bird strikes. Such a structure is defined as *fail-safe.*

For large aircraft, the relevant airworthiness standards require *fail-safe* structures, unless this entails such complications that an effective damage tolerant structure cannot be reached within the limitations of geometry, inspection, or good design practice. Under these circumstances, a design that complies with the *safe-life* fatigue evaluation requirements is used. A typical example of a structure that might not be conducive to damage tolerance design is the landing gear and its attachments.

In the case of loads and loading spectra, the assumptions made for fatigue assessment are as follows for large aircraft. The principal loads that should be considered in establishing a loading spectrum are flight loads (gust and manoeuvre), ground load and pressurization loads. The loading spectra are based on measured statistical data derived from government and industry load history studies and, where no sufficient

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



Table 7: Relationship between probability and severity of failure conditions

| | | | | | |
|---|---|---|---|---|---|
| Effect on aircraft | No effect on operational capabilities or safety | Slight reduction in functional capabilities or safety margins | Significant reduction in functional capabilities or safety margins | Large reduction in functional capabilities or safety margins | Normally with hull loss |
| Effect on occupants excluding flight crew | Inconvenience | Physical discomfort | Physical distress, possibly including injuries | Serious or fatal injury to a small number of passengers or cabin crew | Multiple fatalities |
| Effect on flight crew | No effect on flight crew | Slight increase in workload | Physical discomfort or a significant increase in workload | Physical distress or excessive workload impairs ability to perform tasks | Fatalities or incapacitation |
| Allowable qualitative probability | No probability requirement | Probable | Remote | Extremely remote | Extremely improbable |
| Allowable quantitative probability | No probability requirement | $< 10^3$ | $< 10^5$ | $< 10^7$ | $< 10^9$ |
| Classification of failure conditions | No safety effect | Minor | Major | Hazardous | Catastrophic |

data are available, on a conservative estimate of the anticipated use of the aircraft. In assessing the possibility of serious fatigue failures, the design is examined to determine probable points of failure in service. In this examination, consideration is given, as necessary, to the results of stress analysis, static and fatigue tests, strain gauge surveys, tests of similar structural configurations and service experience.

Fatigue test programs for large aircraft can last years; hence, it is not generally possible to complete them before the aircrafts' type certification is issued. It is therefore required that at least 1 year of safe operations must be demonstrated when the type certificate is issued. Subsequently, to maintain the validity of the type certificate, the fatigue life substantiation must always exceed the number of cycles/flight hours reached by the "oldest" aircraft (lead aeroplane).

## 7 CONCLUSIONS

During the period of this report the committee focussed the report on questions regarding sustainability with regard to economic consequences of the shipping industry and the industry's impact on the environment and human life. Analysis methods of the impacts are presented in four subsections. The section regulatory approaches to sustainability and safety in the maritime industry presents methods, set up by several bodies, how to control the adverse impacts be it of random or systemic nature.

According to the mandate the committee spent time to discuss the present state of the development of the GBS and their implementation by both IMO and IACS classification societies. It lies in the nature of things that the present implementation of GBS focuses the prescriptive character of the GBS. The development of the safety level approach is still in progress at IMO and the future committee should investigate and document its implications for the work of classification societies and their respective rule development. It is recommended that the future committee should spend time to further document the progress on the implementation of risk based methods

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)

Proceedings to be purchased at http://www.stg-online.org/publikationen.html



in ship structural design, which might have impact on design methods and on rule development.

Unfortunately the committee lacked of persons having sufficient expertise in the offshore sector of the maritime industry. For that reason the section deals only with the very specific issue of design requirements for offshore wind energy plants. There must have been significant development especially in the field of offshore energy production during the last three years. This may be the case for the offshore installations themselves but also for the ships necessary to install the offshore installations in great numbers. With regard to wind turbine installation vessels there have been several concepts developed lately which have to prove their practicability. It can be expected that during the following three years more publications will be available which should be reviewed by the future committee.

A comparison with the aviation industry is presented very briefly focussing on design criteria only. It was found worth to present the hierarchy of failure consequences and their associated levels of probability. This is a well established approach in the aviation industry. Future committees should discuss whether a similar systematic approach could be adapted to shipbuilding. For the sake of keeping page limitation of this report the regulatory environment of the aviation industry was not presented here.

The committee formally met once in Newcastle and two times in Hamburg, two informal meeting were held in parallel to PRADS in Rio and at MARSTRUCT conference in Hamburg.

## 8 REFERENCES

ABS (2003). Guidance notes for the application of ergonomics to marine systems ABS, Houston, TX, USA.

ABS (2009). Guide for means of access to tanks and holds for inspection ABS, Houston, TX, USA.

ABS (2010a). Guide for Compliance with the ILO Maritime Labour Convention, 2006 Title 3 Requirements ABS, Houston, TX, USA.

ABS (2010b). Guide For Building And Classing Offshore Wind Turbine Installations.

Ademe (2009). Rapport final efficacité energetique et environnementale de transport maritime, April 2009, available at www.ademe.fr, accessed on 17/03/2010

Alvik, S., Eide, M.S., Endresen, Ø., Hoffmann, P. and Longva, T. (2010). Pathways to low carbon shipping - abatement potential towards 2030, Det Norsk Veritas – DNV, February 2010.

Anil, A.C. (2006). A perspective of marine bioinvasion". In *Multiple dimensions of global environmental change*, pp. 203-313, TERI Press, India.

ANSI/ASA (2009). Quantities and Procedures for Description and Measurement of Underwater Sound from Ships- Part1: General Requirements, ANSI/ASA S12.64-2009/Part 1.

API (1995). API RP 2N: Recommended Practice for Planning, Designing, and Constructing Structures and Pipelines for Arctic Conditions.

Argonne National Laboratory (2009). The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model available at www.transportation.anl.gov/modeling_simulation /GREET/index.html accessed on 26/03/2010.

ARTEMIS Project (2009). Assessment and Reliability of Road Transport Emission Models and Inventory Systems (ARTEMIS), Boulter, P.G., McCrae, I.S. (Eds), final report, ISBN 978-1-84608-747-9.

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



Badino A., Borelli D., Gaggero T., Rizzuto E. and Schenone C. (2011a). Normative framework for noise emissions from ships: present situation and future trends Advances in Marine Structures, Guedes Soares & Fricke (eds.), Taylor & Francis Group, London, pp. 593-602, ISBN978-0-415-67771-4.

Badino, A., Borelli, D., Gaggero, T., Rizzuto, E., Schenone, C. (2011b). Acoustic impact of ships: Noise-related needs, quantification and justification, 'Sustainable Maritime Transportation and Exploitation of Sea Resources', Taylor & Francis Group: London, pp. 961-969.

Badino, A., Borelli, D., Gaggero, T., Rizzuto, E., Schenone, C. (2011c). Criteria for noise annoyance evaluation on board ships, 'Sustainable Maritime Transportation and Exploitation of Sea Resources', Taylor & Francis Group: London, pp. 971-980.

Badino, A. , Borelli, D., Gaggero, T., Rizzuto, E., Schenone, C. (2011d). Analysis of airborne noise emitted from ships, 'Sustainable Maritime Transportation and Exploitation of Sea Resources', Taylor & Francis Group: London, pp. 1001-1010.

Basurko, O.C., Mesbahi, E. (2011). Statistical representativeness of ballast water sampling. *Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment*, 225: pp. 183-190

Bax, N., Williamson, A., Aguero, M., Gonzalez, E., Geeves, W. (2003). Marine invasive alien species: a threat to global biodiversity. *Marine Policy 27*: pp. 313-323

Baxter, T. Bebbington, J. Cutteridge, D. Harvey, G. (2003). The Sustainability Assessment Model (SAM) – Measuring Sustainable Development Performance, SPE Paper 83986 presented at Offshore Europe, Aberdeen, Scotland, September 2003.

Baxter, T. Bebbington, J. Cutteridge, D. (2004a). Sustainability Assessment Model: Modelling Economic, Resource, Environmental and Social Flows of a Project, in Triple Bottom Line – does it all add up? Ed. A. Henriques and J. Richardson, Earthscan.

Baxter, T. Bebbington, J. Cutteridge, D. Harvey, G. (2004b). The Sustainability Assessment Model (SAM) – Measuring Sustainable Development Performance, *6th Journées Scientifiques et Techniques*, Algiers, Algeria, June 2004

Bebbington, J. (2007b). Changing organisational attitudes and culture through sustainability accounting, in Unerman, J., Bebbington, J., & O'Dwyer, B. (eds), 2007, 'Sustainability Accounting and Accountability', Oxon: Routledge.

Bebbington, J. (2007a). Accounting for Sustainable Development Performance, London: CIMA Publishing/Elsevier.

Bebbington, J., Frame, B. (2003). Moving from SD reporting to evaluation: the sustainability assessment model, available at www.nzbcsd.org.nz/_attachments-/Sustainability_assessment_model.doc accessed on 20/03/2010.

Bebbington, J., McGregor, B. (2005). Modelling and Accounting for Sustainable Development, RICS Foundation, London.

Bebbington, J. Brown, J. and Frame, B. (2006). Accounting technologies and sustainability assessment models, *Ecological Economics, 61* (2007) pp. 224-236

Bebbington, J. Brown, J. Frame, B. and Thomson, I. (2007). Theorizing engagement: the potential of a critical dialogic approach. *Accounting, Auditing & Accountability Journal*, 20 (3), pp. 356-381.

Bebbington, J. Gray, R. Hibbitt, C. and Kirk, E. (2001). Full Cost accounting: an agenda for action ACCA Research Report No. 73, Association of Chartered Certified Accountants, London

Bebbington, J., Thomson, I. (1996). Business Conceptions of Sustainability and the Implications for Accountancy, London: ACCA.

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



Beltran, P., Salinas, R. (2011). An international reference vessel, from a noise and vibration point of view, in the framework of the SILENV project, 'Sustainable Maritime Transportation and Exploitation of Sea Resources', Taylor & Francis Group: London, pp. 1019-1028.

Bilgili, M., Yasar, A., and Simsek, E. (2011). Offshore wind power development in Europe and its comparison with onshore counterpart, *Renewable and Sustainable Energy Reviews, 15*, pp. 905-915.

Bitner-Gregersen, E. M., Hørte, T., Skjong, R. (2011). Potential impact of climate change on tanker design, *30th International Conference on Ocean, Offshore and Artic Engineering (OMAE 2011)*, Rotterdam, The Netherlands.

Blanchet, D., , McKenna, R., and Thomas, G. (2011). ISO 19906: An International Standard for Arctic Offshore Structures, *OTC Arctic Technology Conference*, Houston, TX, USA.

Brookshire, DS. (1980). Methods development for valuing hazards information, Technical report, Institute for Policy Research, University of Wyoming, Laramie, 1980

Browne, M., Rizet, C. Leonardi, J. and Allen, J. (2009). Analysing energy use in supply chains: the case of fruits and vegetables and furniture, available at greenlogistics.org accessed on 17/03/2010

Cabezas-Basurko, O. (2010). Methodologies for Sustainability Assessment of Marine Technologies, Thesis submitted in support of PhD qualification, Newcastle University, September 2010

Cabezas-Basurko, O., Mesbahi, E. and Moloney, S.R. (2007). Holistic Analysis of Ship's Sustainability, Proc. of MARSTRUCT 2007, *1st International Conference on Marine Structures*, Glasgow, UK, 12-14th March 2007. pp. 513-521.

Cabezas-Basurko, O., Mesbahi, E., Moloney, S. R. (2008). Methodology for sustainability analysis of ships, *Ships and Offshore Structures, vol. 3, No. 1*, pp. 1-11.

Corbett, J., Winebrake, J., Green, E., Kasibhatla, P., Eyring, V., Lauer, A. (2007). Mortality from Ship Emissions: A Global Assessment Environ, Science Technology, in publication.

Corbett, J.J., Koehler, H.W. (2003). Updated emissions from ocean shipping, *Journal of Geophysical Research, vol. 108*, NO. D20, 4650, 2003.

Corbett, J.J., Koehler, H.W. (2004). Considering alternative input parameters in an activity-based ship fuel consumption and emissions model: Reply to comment by Øyvind Endresen et al. on "Updated emissions from ocean shipping", *Journal of Geophysical Research, vol. 109*, D23303, 2004.

Cotta, A., Tincani, E.P. (2011). Impact of comfort class requirements in a new building ship and possible advantages for owners, 'Sustainable Maritime Transportation and Exploitation of Sea Resources', Taylor & Francis Group: London, 1012-1018.

Crouch EAC (1982). Risk/benefit analysis, BallingePubl. Co., Cambridge, Ma., 1982

Danish Energy Agency (DEA 2001). Recommendation for Technical Approval of Offshore Wind Turbines, an annex to Technical Criteria for Type Approval and Certification of Wind Turbines in Denmark.

Davies, J. (2009). The application of Full Cost Accounting in a Higher Education context – development of a methodological approach, ACCA.

Dender, K. van, Crist, P. (2008). Policy instruments to limit negative environmental impacts from increased international transport: an economic perspective, *Global Forum on Transport and Environment in a Globalising World*, November, Guadalajara, Mexico.

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



DNV (2010). Det Norske Veritas: Rules for Classification of Ships, Silent Class Notation, Part 6, Chapter 24.

DNV (2011a). Rules for Classification of Ships.

DNV (2011b). Design of Offshore Wind Turbine Structures, Offshore Standard, DNV-OS-J101.

Duan, F., Yamaguchi, H., Kawabuchi, M. (2011). Inclusive Environmental Impact Assessment for Water Purification Technologies, *The 21st International Offshore (Ocean) and Polar Engineering Conference 2011*, Hawaii, USA, June 19-24.

EC (2007). Presidency Conclusions - Brussels European Council (EC) 8/9 March 2007, 7224/07.

EC (2007a). Ship Dismantling and Pre-cleaning of Ships, Final report.

EC (2011). European Commission, White Paper on transport - Roadmap to a single European transport area - towards a competitive and resource-efficient transport system, Luxembourg: Publications Office of the European Union

Eide, M.S., Endresen, Ø., Skjong, R., Longva, T. and Alvik, S. (2009). Cost-effectiveness assessment of $CO_2$ reducing measures in shipping, *Journal of Maritime Policy and Management*, Taylor and Francis Group, Vol. 36, no. 4, 367–384.

Endresen, O., Sørgard, E. Sundet, J. Dalsøren, S. Isaksen, I. Berglen, T., Gravir, G. (2003). Emission from international sea transportation and environmental impact, *Journal of Geophysical Research, vol. 108*, NO. D17, 4560, 2003.

Endresen O, Behrens HL, Brynestad S, Andersen AB, Skjong R (2004). Challenges in global ballast water management, *Marine Pollution Bulletin 48*, pp.615-623

Endresen, Ø., DalsØren, S., Eide, M., Isaksen, I. S., SØrga ,R.D. (2008). The environmental impacts of increased international maritime shipping, past trends and future perspectives, *Global Forum on Transport and Environment in a Globalising World*, 10–12 November, Guadalajara, Mexico.

Florio, F. de (2011). *Airworthiness -An Introduction to Aircraft Certification*, Elsevier Butterworth-Heinemann, Amsterdam, Jan 2011

Eranti, E. , Lehtonen,E., Pukkila, H. (2011). A Novel Offshore Windmill Foundation For Heavy Ice Conditions. *30th International Conference on Ocean, Offshore and Artic Engineering (OMAE 2011)*, Rotterdam, The Netherlands.

ESPO (2009). Port Environmental Review, available at www.ecoports.com/-ContentFiles/EnvironmentalReview2009_Brochure1.pdf, accessed on 16/03/2010

Faber, J., Rensema, K. (2009). Left on the High Seas. Global Climate Policies for International Transport, CE Delft, Delft.

Faber, J., Markowska, A., Eyring, V., Cionni, I., Selstad, E. (2010). A global maritime emissions trading system, available at http://www.ce.nl/, accessed on 23/03/2010

Fet, A.M. (2002). Environmental reporting in marine transport based on LCA. Journal of Marine Design and Operations PART B (B1), *Proceedings of the Institute of Marine Engineering, Science and Technology*, pp. 1476-1556, 2002

Fofonoff, P.W., Ruiz, G.M., Steves, B. and Carlton, J.T. (2003), "In Ship or on Ships? Mechanisms of transfer and Invasion for non-native Species to the Coasts of North America", In Invasive species; Vectors and Management Strategies, Edited by Gregory M. Ruiz and James T. Carlton, ISLAND PRESS, Chapter 7, pp. 132-182

Forsström, B. (2005). Value Co-creation in Industrial Buyer-Seller Partnerships Creating and Exploiting Interdependencies, An Empirical Case Study, PhD. Thesis, Åbo Academy University Press.

Frankl, P., Rubik, F. (1999). Life Cycle Assessment in Industry and Business, Springer, 1999

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



Friis-Hansen, P., Ditlevsen, O. (2003). Nature preservation acceptance model applied to tanker oil spill simulations, *Structural safety, 25*, pp.1-34.

Gale, P.A. (2003). The Ship Design Process, in Lamb, T. (eds), Ship Design and Construction, The Society of Naval Architects and Marine Engineers. Vol.1, Sheridan Books.

Gaspar, H. M., Balland, O. (2010). Approaching Environmental Performance in Conceptual Ship Design , *11th International Symposium on Practical Design of Ships and Other Floating Structures*, Rio de Janeiro, Brazil, pp. 870-880.

Gaspar, H. M., Grimstad, A., Neumann-Larsen, E., Erikstad, S. O. (2010). "Efficient design of advanced machinery systems for complex operational profiles", *9th International Conference on Computer and IT Applications in the Maritime Industries.*

Gehring, M. (2008). Policy instruments to limit negative environmental impacts from increased international transport - constraints and opportunities in international law, *Global Forum on Transport and Environment in a Globalising World*, November, Guadalajara, Mexico.

GL (2003). Germanischer Lloyd, Rules for Classification and Construction of Seagoing Ships.

GL (2005a). Guidelines for the Certification of Offshore Wind Turbines.

GL (2005b). Guideline for the Construction of Fixed Offshore Installations in Ice Infested Waters, Rules and Guidelines, IV Industrial Services.

Ghoneim, G.A. (2011). Arctic Standards - A Comparison and Gap Study, *OTC Arctic Technology Conference*, Houston, T, USA.

Graveson, H., N.J. Tarp-Johansen, Volund, P. (2001). Combined Loads from Wind, Waves and Ice on Offshore Wind Turbine Foundations, *European Wind Energy Conference*, Copenhagen, Denmark.

Grey, C.J. (1999). The Cost of oil spills from tankers: An analysis of IOPC fund incidents, Proceedings *International Oil Spill Conference*, Seattle, 1999.

Hacıefendioğlu, K., Bayraktar, A. (2011). Effect of Ice Sheet on Stochastic Response of Offshore Wind Turbine–Seawater–Soil Interaction Systems Subjected to Random Seismic Excitation, *Journal Cold Reg. Eng. 25*, 115.

Hetmanczyk, S., Heinonen,J., Strobel, M. (2011). Dynamic Ice Load Model in Overall Simulation of Offshore Wind Turbines. *The 21st International Offshore (Ocean) and Polar Engineering Conference 2011*, Hawaii, USA, June 19-24.

Hess, R., Rushworth, D., Hynes, M.V., Peters, J.E. (2001). Disposal Options for Ships. RAND Corporation MR-1377.

Hezri, A.A., Dovers, S.R., (2006). Sustainability indicators, policy and governance: issues for ecological economics, Ecol Econ, 60, pp. 86-99.

Hochkirch, K., Bertram, V. (2008). Slow steaming bulbous bow optimization for a large containership", *8th International Conference on Computer and IT Applications in the Maritime Industries,* Liege, Belgium.

Holland, A. (2002). Are Choices "Tradeoffs" in Economics, Ethics, and Environmental Policy: Contested choices,Eds. Daniel W. Bromley and Jouni Paavola. (Malden, MA: Blackwell, 2002), 18.

Hørte, T., Wang, G., White N. (2007a). Calibration of the Hull Girder Ultimate Capacity Criterion for Double Hull Tankers, *10th International Symposium on Practical Design of Ships and Other Floating Structures ( PRADS),* Houston, USA.

Hørte, T., Skjong, R., Friis-Hansen, P., Teixeira, A.P., Viejo de Francisco, F. (2007b). Probabilistic Methods Applied to Structural Design and Rule Development. Pro-

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)




ceed. RINA Conference "Development of Classification & International Regulations". 24-25 Jan. 2007, London.

Huang, G., Liu, P. (2009). A dynamic model for the ice-induced vibration of structures, *Journal of Offshore Mechanics and Arctic Engineering, Vol. 131.*

IACS (2001). Unified Requirement S11: Longitudinal Strength Standard.

IACS (2006a). Technical background documents for Bulk Carrier CSR, access via www. IACS.org.uk/publications.

IACS (2006b). Technical background documents for Oil Tanker CSR, access via www.IACS.org.uk/publications.

IACS (2009a). CHARTER, Adopted at a meeting of Council on 27 October 2009, access via www. IACS.org.uk.

IACS (2009b). Rec. 106, IACS guideline for rule development - ship structure.

IACS (2010a). Common Structural Rules for Bulk Carriers (consolidated version July 2010), www.iacs.org.uk/publications/.

IACS (2010b). Common Structural Rules for Double Hull Oil Tankers (consolidated version July 2010), www.iacs.org.uk/publications.

IAPH (2009b). Toolbox for GHG, available at http://iaphtoolbox.wpci.nl, accessed on 14/03/2010.

IAPH (2009c). Carbon footprinting guidance document, available at http://www.wpci.nl/articles/ carbon_footprinting_doc.php, accessed on 14/03/2010

IEC (2009). Wind turbines – Part 3: Design requirements for offshore wind turbines, IEC 61400-3:2009.

ILO (2006). International Labour Organization, MLC Maritime Labour Convention.

ILO (2007a). ILO Convention No.188 concerning work in the fishing sector.

ILO (2007b). ILO Recommendation No.199 concerning work in the fishing sector.

IMO (1974). International Maritime Organization, SOLAS International Convention for the Safety of Life at Sea. Chap II-1 Reg.36

IMO (1975). Resolution A.343(IX) Recommendation on Methods of Measuring Noise Levels at Listening Posts.

IMO (1981). Resolution A.468(XII): Code on Noise Levels on Board Ships.

IMO (2001). MSC 74/WP.19, Guidelines for Formal Safety Assessment for the IMO Rule Making Process.

IMO (2004). MSC 78/19/1 Experience with formal safety assessment at IMO, Submitted by the International Association of Classification Societies (IACS).

IMO (2004b). International Convention for the Control and Management of Ships' Ballast Water and Sediments, International Maritime Organisation, 2004

IMO (2007a). MSC/Circ. 1023-MEPC/Circ. 392, Note by the Secretariat, MSC 83/INF.2. Formal Safety Assessment – Consolidated text of the Guidelines for Formal Safety Assessment (FSA) for use in the IMO rule-making process.

IMO (2007b). MSC 83/INF.8, Formal Safety Assessment, FSA – container vessels, Details of the Formal Safety Assessment, Submitted by Denmark.

IMO (2007c). MSC 83/INF.3, Formal Safety Assessment , FSA - Liquefied Natural Gas (LNG) Carriers, Details of the Formal Safety Assessment, Submitted by Denmark.

IMO (2008). Report of the Marine Environment Protection Committee, Annex 3: Resolution MEPC. 173(58) - Guidelines for ballast water sampling (G2). International Maritime Organisation, London

IMO (2008a). Updated Study on Greenhouse Gas Emissions from Ships: Phase I

Report, MEPC 58/INF.6, International Maritime Organization (IMO) London, UK, 1 September.

IMO (2008b). MSC 85/INF.2, FSA - Cruise ships Details of the Formal Safety Assessment. Marine Safety Committee of the International Maritime Organisation.

IMO (2008c). MSC 85/INF.3, FSA – RoPax ships Details of the Formal Safety Assessment. Marine Safety Committee of the International Maritime Organisation,

IMO (2008d). MEPC 58/INF.2, Formal Safety Assessment, FSA – Crude Oil Tankers, Submitted by Denmark.

IMO (2008e). Resolution MEPC.176(58), Revised MARPOL Annex VI

IMO (2009). SR/CONF/45, Hong Kong International Convention for the safe and environmentally sound recycling of ships, 2009.

IMO (2009a). Interim Guidelines on the method of calculation of the Energy Efficiency Design Index for new ships, MEPC.1/Circ.681, August, 2009 (annex 17 to MEPC 59/24).

IMO (2009b). Interim guidelines for voluntary verification of the EEDI, MEPC.1/Circ.682, August, 2009, (annex 18 to MEPC 59/24).

IMO (2009c). Guidance for the development of a SEEMP, MEPC.1/Circ.683, August, 2009, (annex 19 to MEPC 59/24).

IMO (2009d). Guidelines for voluntary use of the ship EEOI, MEPC.1/Circ.684, August, 2009, (annex 20 to MEPC 59/24).

IMO (2009e). MEPC 59/19, Noise From Commercial Shipping and its Adverse Impacts on Marine Life.

IMO (2009f). MEPC 60/18, Noise From Commercial Shipping and its Adverse Impacts on Marine Life.

IMO (2009g). MSC 86/5/14, Goal-Based New Ship Construction Standards, Guideline for ship construction file implementation, A cross-industry approach to balance design transparency and intellectual property protection, Submitted by CESA, ICS, INTERCARGO, INTERTANKO, BIMCO, OCIMF and IACS.

IMO (2009h). MSC 86/5/3, Goal-Based New Ship Construction Standards, Guidelines on approval of risk-based ship design, Submitted by Denmark.

IMO (2010). Reduction of GHG Emissions from Ships—Full Report of the Work Undertaken by the Expert Group on Feasibility Study and Impact Assessment of possible Market-Based Measures, Note by the Secretariat, MEPC61/INF.2.

IMO (2010b). Prevention of Pollution by Oil, available at imo.org, accessed on 12/04/2010

IMO (2010c). MSC 88/INF.8, General Cargo Ship Safety, "IACS FSA study – Summary of Results", Submitted by IACS.

IMO (2010d). MEPC 61/19, Noise From Commercial Shipping and its Adverse Impacts on Marine Life.

IMO (2010d). Resolution MSC.287(87), Adoption of ihe International Goal-Based Ship Construction Standards for Bulk Carriers and Oil Tankers.

IMO (2010e). Resolution MSC.296(87), Adoption of the Guidelines for Verification of Conformity with Goal-Based Ship Construction Standards for Bulk Carriers and Oil Tankers.

IMO (2010f). MSC.1/Circ.1343, Guidelines for the information to be included in a Ship Construction File.

IMO (2010g). MSC 87/5/4, Goal-Based new Ship Construction Standards, Guidelines for Ship Construction File implementation, A cross industry model for SCF imple-

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



mentation, Submitted by CESA, ICS, INTERCARGO, INTERTANKO, BIMCO, OCIMF and IACS.

IMO (2010h). MSC 87/5/5, Goal-Based new Ship Construction Standards, Proposed amendments to the Guidelines for Ship Construction File implementation, Balancing design transparency and intellectual property protection, Submitted by CESA, ICS, INTERCARGO, INTERTANKO, BIMCO, OCIMF and IACS.

IMO (2010i). MSC 88/5/1, Goal-Based new Ship Construction Standards, A proposal for the further development in consideration of the future safety-level based standards, Submitted by Germany.

IMO (2010j). MSC 88/5/2, Goal-Based new Ship Construction Standards, Information on long-term considerations for the continued development of GBS, Submitted by the Republic of Korea.

IMO (2010k). MSC 87/18, Formal Safety Assessment, Report of first intersessional meeting and the correspondence group of the Formal Safety Assessment (FSA) Experts Group, Submitted by the Chairman of the FSA Experts Group.

IMO (2011). MSC 89/5/Add.1, Goal-Based new Ship Construction Standards, Documents submitted to previous sessions of the Committee.

IMO (2011a). MSC.1/Circ.1394, Generic Guidelines for developing IMO Goal-Based Standards.

IMO (2011b). Resolution A.1037(27), Strategic plan for the Organization (For the six-year period 2012 to 2017)

Incel, M., Helvacioğlu, İ.H., Ünsan, Y., Tang, A.S.T. (2009). Noise Predictions for Shipboard Accommodations, *13th Congress of Intl. Maritime Assoc. of Mediterranean (IMAM 2009)*, Istanbul, Turkey.

IOPC (2005). Liability and Compensation for Oil Pollution Damage: Texts of the 1992 Conventions and the Supplementary Fund, IOPC.

IOPC (2009). Annual report 2008. International oil pollution compensation funds, London.

IPCC (2007). Emissions of long-lived GHGs, IPCC 4th assessment report - Synthesis Report, http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf.

ISO (2000). International Standards Organization, Measurement of airborne sound emitted by vessels on inland waterways and harbours, EN ISO 2922:2000.

ISO (2007). Small craft – Airborne sound emitted by powered recreational craft – Part 2: Sound assessment using reference craft, EN ISO 14509-2:2007.

ISO (2009). Small craft – Airborne sound emitted by powered recreational craft – Part 1:Pass-by measurement procedures, EN ISO 14509-1:2009.

ISO (2010). Petroleum and Natural Gas Industries, Arctic offshore structures, ISO19906:2010.

ISSC (2009). International Ship and Offshore Structure Congress Technical Report of Comm.IV.1: Design Principles and Criteria ISSC 2009 Seoul (KR) Aug. 2009 ISBN 9788995 473016 vol.1 pag.587-688.

Jensen, F. (2001). Bayesian Networks and Decision Graphs, Springer-Verlag, New York.

Juhl, J. (2007). Occupational health and safety - an item on the "Goal based standards" agenda Proc. of the International Conference: Human Factors in Ship Design, Safety & Operation, Royal Institution of Naval Architects, London, UK.

Karna,T., Frederking, R., Shkhinek, K. (2011). Ice Actions in ISO 19906 – Overview, *OTC Arctic Technology Conference*, Houston, TX, USA.

Karna,T., Gravesen, H., Fransson, L and Loset, S. (2010). Simulation of multi-modal

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



vibrations due to ice actions, *The 20th IAHR Symposium on Ice*, 14. - 17. June 2010, Lahti, Finland.

Kelman, S. (2005). "Cost-Benefit Analysis: An ethical critique," in Economics of the Environment: Selected readings, eds. Robert Stavins, 5th edition. (New York: W. W. Norton and Co., 2005), 269.

Klanac, A., Jalonen, R., Varsta, P. (2007). Multi-stakeholder decision-making in the risk-based design of a RO-PAX double bottom for grounding, *Journal of Engineering for the Maritime Environment, Vol. 221*, No. 1, pp. 1-15.

Klanac, A., Nikolic, P., Kovac, M., McGregor, J. (2010a). Economics and environmental impact of ship speed reduction, Proc. SORTA, Split.

Klanac, A., Duletić, T., Erceg, S., Ehlers, S., Goerlandt, F., Frank, D. (2010b). Comparative analysis of the environmental risk of collision for enclosed seas: Gulf of Finland, Adriatic, and implications for tanker design, *5th International Conference on Collision and Grounding of Ships*, June 14th – 16th 2010, Espoo, Finland.

Klanac, A., Rebic, N., Golik Klanac, N. (2011). True service yard: New business model for shipyards to advance from the 'subsidised' model, Presented at The Economist: Ideas Economy Conf, Berkeley.

Klanac, A., Varsta, P. (2011). Design of marine structures with improved safety for environment, *Journ. Reliability System Safety, 96*, pp. 75-90.

Kühlwein, J. and Friedrich, R. (2000). Uncertainties of modelling emissions from road transport, *Atmospheric Environment Vol. 34,* 2000, pp. 4603-4610.

Landamore, M., Wright, P., Birmingham, R., Downie, M. (2006). Investigation of Sustainable technologies in the Leisure Craft Sector, *Transactions Royal Institution of Naval Architects (RINA)*, 2006, B2(148), pp. 41 - 54.

Landamore, M., Birmingham, R. Downie, M. (2007a). Establishing the economic and environmental life cycle costs of marine systems: a case study from the recreational craft sector, *Marine Technology 2007, 44(2)*, pp. 106-117.

Landamore, M., Birmingham, R., Downie, M.,Wright, P. (2007b). Sustainable Technologies for Inland Leisure Craft, *Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment 2007, 221(3)*, pp. 97-114.

Landamore, M., Cabezas-Basurko, O. Downes, J. Mesbahi, E. (2007c). Design for Environmental Safety and Sustainability: The adoption of a risk-based approach *Proceedings of the Design for Safety Conference*, Berkeley, USA, September 2007.

Landamore, M., Cabezas-Basurko, O., Wright, P., Birmingham, R., Reichel, M., Kremer, F. (2008). CREATE3S: An outline of the concept and overview of possible solution routes for the hullform, *5th International Congress on Maritime Technological Innovations and Research 2007*, Barcelona.

Landamore, M., Phan, S., Aghatise, O., Mesbahi, E. (2009). Deliverable 4.3 Part Two: Environmental Assessment of the CREATE3S Class III design, Deliverable to the EC FP6 Project "CREATE3S", not publicly available).

Landamore, M., Phan, S. Aghatise, O. (2010). Environmental Assessment of Alternative Ship Designs to Improve European Short Sea Shipping Efficiency: CREATE3S, *11th International Symposium on Practical Design of Ships and Other Floating Structures (PRADS 2010)*, Rio de Janeiro, Brasil.

Landamore, M.J., Campbell, D.J. (2010). Low Carbon Shipping - A Systems Approach: Conceptualising a Full Cost Environmental Model for Sustainable Shipping, *11th International Symposium on Practical Design of Ships and Other Floating Structures (PRADS 2011)*, Rio de Janeiro, Brazil, pp. 665-673.

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)




Leonardi, J., Browne, M. (2009). Method for assessing the carbon footprint of maritime freight transport: European case study and results, available at http://www.greenlogistics.org.uk, accessed on 17/03/2010.

Leung, D., Yang, Y. (2012). Wind energy development and its environmental impact: A review, *Renewable and Sustainable Energy Reviews, 16*, pp.1031-1039.

Lloyds Register (2010). Ballast water treatment technology - Current status, *Lloyd's Register of Shipping*, London

Lu, X., McElroy, M., Kiviluoma, J. (2009). Global potential for wind-generated electricity, *Proceedings of the National Academy of Sciences, PNAS*, Vol. 106 no. 27, pp. 10933-10938.

Luís, R. M., Teixeira, A. P., Guedes Soares, C. (2009). Longitudinal strength reliability of a tanker hull accidentally grounded, *Structural Safety, 3, Vvol. 31*, pp. 224-233.

Maes, M.A., Pandey, M.D., Nathwani, J.S. (2003). Harmonizing structural safety levels with life-quality objectives, *Canadian Journal of Civil Engineering, 30(3)*, pp. 500-5 10.

Markard, J., Petersen, R. (2009). The offshore trend: structural changes in the wind power sector, *Energy Policy, 37*, pp. 3545–56.

Mayer, A.L., (2008). Strengths and weaknesses of common sustainability indices for multidimensional systems, *Environment International, 34*, pp. 277-291.

McKinnon, A. (2010). Product-level carbon auditing of supply chains: Environmental imperative or wasteful distraction? *International Journal of Physical Distribution & Logistics Management Vol. 40*, No. 1/2, 2010, pp. 42-60.

McSweeney, K.P., McCaferty, D.B. (2007). Using ergonomics to improve permanent means of access, Proceedings of the International Conference: Human Factors in Ship Design, Safety & Operation, Royal Institution of Naval Architects, London, UK.

Miller, A.W., Frazier, M., Smith, G.E., Perry, E.S., Ruiz, G.M., Tamburri, M.N. (2011). Enumerating sparse organisms in ships' ballast water: why counting to 10 is not so easy. *Environmental Science and Technology 45*: pp. 3539-3546

Miola, A., Marra, M., Ciuffo, B. (2011). Designing a climate change policy for the international maritime transport sector: Market-based measures and technological options for global and regional policy actions, Energy Policy, Elsevier Ltd.

MOSES Project (2007). Motorways of the Sea – European Style: EC FP7 funded project available at http://cordis.lu, accessed on 26/03/2010

Musial, W., Ram, B. (2010). Large-Scale Offshore Wind Power in the United States: Assessment of Opportunities and Barriers. NREL/TP-500-40745. NREL: Golden, CO.

Nathwani, J.S., Lind, N.C., Pandey, M.D. (1997). Affordable Safety By Choice: The Life-Quality Method. University of Waterloo, Institute for Risk Research, Waterloo, Ontario, Canada.

Ness, B., Urbel-Piirsalu, E., Anderberg, S., Olsson, L. (2007). Categorising tools for sustainability assessment, *Ecol Econ, 60*, pp. 498-508.

NK (2011). ClassNK, Noise and vibration Guideline.

Nocerino, E., Menna, F., Ackermann, S., Del Pizzo, S., Scamardella, A. (2011). High-flexible multi-technique acquisition system for human postural stability tests onboard ships, 'Sustainable Maritime Transportation and Exploitation of Sea Resources'. Taylor & Francis Group: London, 737-745.

OECD (2010). Guidance on Sustainability Impact Assessment, Organisation for Economic Co-operation and Development.

OECD (2010b). Council Working Party on Shipbuilding (WP6), Environmental and Climate Change Issues in the Shipbuilding Industry, November 2010, Organisation for Economic Co-operation and Development.

OECD (2010c). Working Party on National Environmental Policies, Working Group on Transport, Environmental impacts of international shipping – The role of ports, Case study of the ports of Los Angeles and Long Beach, Organisation for Economic Co-operation and Development.

OECD (2010d). Working Party on National Environmental Policies, Working Group on Transport, Environmental impacts of international shipping – The role of ports, Case study of the port of Vancouver, Organisation for Economic Co-operation and Development.

OECD (2010e). Working Party on National Environmental Policies, Working Group on Transport, Environmental impacts of international shipping – The role of ports, Case study of the port of Rotterdam, Organisation for Economic Co-operation and Development.

OECD (2010f). Working Party on National Environmental Policies, Working Group on Transport, Environmental impacts of international shipping – The role of ports, Case study of the port of Busan, Organisation for Economic Co-operation and Development.

OECD (2011). Environmental Impacts of International Shipping: The Role of Ports, Organisation for Economic Co-operation and Development.

Ohtsuka, K. (2011). Inclusive Impact Index Triple I and its Application for Ocean Nutrient Enhancer, *The 21st International Offshore (Ocean) and Polar Engineering Conference 2011*, Hawaii, USA, June 19-24.

Omiya, T., Sato, T. (2011). A proposal of methodology to calculate Triple I intended for CO2 ocean sequestration, *The 21st International Offshore (Ocean) and Polar Engineering Conference 2011*, Hawaii, USA, June 19-24.

Pandey, M.D., Nathwani, J.S. (2003). Canada wide standard for particulate matter and ozone: Cost-benefit analysis using a life quality index, *Risk Analysis, 23*, pp. 55-67.

Pandey, M.D., Nathwani, J.S., Lind, N.C. (2006). The derivation and calibration of the Life-Quality Index (LQI) from economic principles, *Structural Safety, 28(4)*, pp.341-360.

Pazouki, K., (2002). Air Pollution from Ships, Impact to the communities and Concerned Regulation, *Proceedings of 5th International Conference on Coasts, Ports and marine Structures*, Ramsar, Iran

Pazouki, K., Basurko, O.C., Mesbahi, E., Kemp, J. (2009). The control of spread of non-indigenous species through ballast water. *Part B: Ballast Water Sampling: Methods, Analysis, Representativeness and Legal issues. MCA*, RP577- Part B

Petrini, F., Manenti, S., Gkoumas, K., Bontempi, F. (2010). Structural Design and Analysis of Offshore Wind Turbines from a System Point of View, *Wind Engineering 34*, No. 1, 2010.

Rackwitz, R. (2002). Optimization and risk acceptability based on the life quality index, *Structural Safety, 24(2-4)*, pp. 297-331.

Rackwitz, R. (2004a). Discounting for optimal and acceptable technical facilities involving risks, *HERON, 49(2)*, pp.139-170.

Rackwitz, R. (2004b). Optimal and acceptable technical facilities involving risks, *Risk Analysis, 24(3)*, pp. 675-695.

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)




Rackwitz, R., Lentz, A., Faber, M. (2005). Socio-economically sustainable civil engineering infrastructures by optimization, *Structural Safety, 27(3)*, pp.187-229.

Ramsberg, J., Sjoberg, L. (1997). The cost of life saving interventions in Sweden, *Risk Analysis*, 1997.

RCEP (1998). Setting environmental standards. Royal Commission on Environmental Pollution, HMSO, London.

RINA (1999). Registro Italiano Navale, Rules for the Evaluation of Noise and vibration Comfort on Board Pleasure Vessels Lloyd's Provisional Rules, Passenger and Crew Comfort.

RITE (2009). Analyses on Mid-term Targets of Major Countries, Research Institute of Innovative Technology of Earth, www.rite.or.jp (in Japanese).

Rizzuto, E. (2009). Recent evolutions in the normative framework for civil engineering and shipbuilding, Proc. of NAV 2009 Intern. Conf., Messina (Italy).

Rizzuto, E., Teixeira, A., Guedes Soares, C. (2010). Reliability assessment of a tanker in damage conditions, *11th International Symposium on Practical Design of Ships and Other Floating Structures (PRADS 2010)*, Rio de Janeiro, Brasil.

RS (2011). Russian Register, Rules of classification and building of sea-going vessels, St.-Petersburg, Russia.

Rusaas, S., (2003). Final Publishable Paper, HARDER Consortium Doc. Ref. No. 0-00-X-2003-03-0, 2003-08-31.

SAJ (2010). Shipbuildng statistics. The Shipbuilder's Association of Japan.

Schmidt Etkin, D. (1999). Estimating cleanup costs for oil spills, *Proc. Int. Oil Spill Conf.*

Schmidt Etkin, D. (2000). Worldwide Analysis of Marine Oil Spill Cleanup Cost Factors, Proc. Arctic and Marine Oil Spill Program, Technical Seminar.

Sen, A. (2001). The Discipline of Cost-Benefit Analysis," Cost-Benefit Analysis: Legal, economic, and philosophical perspectives, eds. Matthew D. Adler and Eric A. Posner. (Chicago: Univ. of Chicago Press, 2001) (Sen, 2000), 100-01.

Shi, B., Huang, W., Tang-Jensen, P., Michel, K. (2009). Explorations beyond the design norms for eco-friendly container ships, International Symposium on Ship Design and Construction - Environment Friendly Ship, 1 - 2 September 2009, Tokyo, Japan.

Singh, R. K., Murty, H. R., Gupta, S. K., Dikshit, A. K. (2009). An overview of sustainability assessment methodologies, *Ecological Indicators, 9(2)*, pp.189-212.

Skjong, R., Vanem, E., Endresen, Ø. (2005). Risk evaluation, SAFEDOR deliverable 4.5.2, Integrated project 516278 in the 6th framework programme of the European Commission.

Solow, R. (2005). Reply to Steven Kelman, Cost-Benefit Analysis: An ethical critique." in Economics of the Environment: Selected readings, eds. Robert Stavins, 5th edition. (New York: W. W. Norton and Co., 2005), 273.

Stopford, M. (1997). Maritime Economics, 2nd edition, Routledge, London.

Taylor, S. et al. (2010). Local Design Pressures for Structures in Ice: Analysis of Full-Scale Data, *Journ. Offshore Mech. Arct. Eng. Volume 132*, 3, 031502.

Teixeira, A., Guedes Soares, C. (2010). Reliability assessment of intact and damaged ship structures, Advanced Ship Design for Pollution Prevention, Carlos Guedes Soares & Josko Parunov (Editors), ISBN-10: 0415584779, CRC Press.

TRL (2010). Sustainable Transport Research and Development: Vehicle Emissions Database available at http://www.trl.co.uk accessed on 26/03/2010.

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2012 Schiffbautechnische Gesellschaft, Hamburg, ISBN 978-3-87700-131-{5,8}
Proceedings to be purchased at http://www.stg-online.org/publikationen.html



UNCTAD (2008). United Nations Conference on Trade and Development (UNCTAD), ”Review of Maritime Transport”, 2008

UNCTAD (2009). UNCTAD Multi-year expert meeting on transport and trade facilitation: maritime transport and the climate change challenge, 16th – 18th February 2009, United Nations Commission on Trade and Development, Geneva, CH.

UNCTAD (2011). Review of Maritime Transport 2010, United Nations Publications.

UNWCED (1987). Our Common Future, World Commission on Environment and Development, Oxford Univ. Press, Oxford.

VNF (2008). Eco calculateur, available at www.vnf.fr, accessed on 17/03/2010.

Volund, P., et al. (2003). Ice Loads on Offshore Wind Turbine Foundations, Final Report, Energi E2, Document No. DOCS 15822.

Wang, J. (2008). Understanding value in the shipbuilding industry, TKK-AM-1, Espoo.

West, G.A. Manta, J.G. (1996). ISO 14001: An Executive Report, Government Institutes, US

Woebbeking, M. (2010). The New Guideline for the Certification of Wind Turbines, Edition 2010, Germanischer Lloyd Industrial Services GmbH, Renewables Certification (GL).

WTO (2008). World Trade Organisation (WTO), ”International trade Statistics”, 2008

Xing, Y., Horner, R. El-Haram, M., Bebbington, J. (2007). A Framework Model for Assessing Sustainability Impacts of a Built Environment. In International Conference on Whole Life Urban Sustainability and Its Assessment M. Horner, C. Hardcastle, A. Price and J. Bebbington, eds., Glasgow, Scotland.

Xing, Y., Horner, R.M.W., El-Haram, M.A., Bebbington, J. (2008). A Framework Model for Assessing Sustainability Impacts of Urban Development. To be published in Accounting Forum.

Yoshimoto, H., Tabeta, S. (2011). A Study on the Scaling of Ecological and Economic Values in the

Yuzui, T., Kaneko, J. (2011). Development of Cost Effectiveness Index of Oil Tankers based on Triple I, *The 21st International Offshore (Ocean) and Polar Engineering Conference 2011*, Hawaii, USA, June 19-24.

Zaaijer, M.B. (2009). Review of Knowledge Development for the Design of Offshore Wind Energy Technology, *Wind Energy, 12*.

Zhixin W., Chuanwen J., Oian A., Chengmin W. (2009). The key technology of offshore wind farm and its new development, China. *Renewable and Sustainable Energy Reviews, 13*, pp. 216–222.