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Proactive maritime safety : concepts and applications

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WORLD MARITIME UNIVERSITY
Malmö, Sweden

Proactive Maritime Safety: Concepts and Applications

By

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A dissertation submitted to the World Maritime University in partial fulfillment of the requirements for the award of the degree of

MASTER OF SCIENCE
In
MARITIME AFFAIRS
(Maritime Safety and Environmental Administration)

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DECLARATION

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

24/08/2009.

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Abstract

Even though maritime safety regulations provide an immense source of knowledge for the whole shipping industry, it is recognized that these rules have been developed reacting to serious disasters, and that their further improvements are still indispensible. Thus, in the last decade, it became clear that maritime safety should be addressed proactively rather than waiting for accidents to happen in order to elaborate regulations that help avoiding the recurrence of the same events.

Accordingly, since the end of the 20 century, new subject matters such as "Formal Safety Assessment", "Goal Based Standards" and "Alternative Design and Arrangements" continuously appear between the items of high importance in the IMO's agenda for the development of its rule-making and application framework.

The dissertation provides a review of state-of-the-art related to the "*non traditional*" regulatory framework, and makes an explanatory an exploratory study of the different concepts that materialize the proactive approach to maritime safety, it also investigates the potential benefits and contribution of risk assessment techniques to this approach. In addition, this work identifies some strengths and weaknesses of both proactive and traditional safety approaches, and presents an outlook on the ongoing work at IMO and the most recent results achieved to date.

Finally, the incentives for the development of a risk based ship inspection regime and the basic foundations for this concept are examined as an expected future step for the development of the current proactive maritime safety regime.

Keywords: Proactive maritime safety; Formal Safety Assessment; Goal-Based Standards; Alternative Design and Arrangements; Prescriptive Standards; Performance-Based Standards; Risk-Based Approach; Risk-Based Inspection.

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List of Abbreviations

ABS	American Bureau of Shipping
ALARP	As Low As Reasonably Practicable
BEA *mer*	Bureau d’enquêtes accident de mer
CAF	Cost for averting a fatality
CATS	Cost of Averting a Spill Criterion
CBA	Cost Benefit Analysis
CLC	International Convention on Civil Liability for Oil Pollution Damage
CoF	consequences of failure
DSS	Double Side Skin
EMCIP	European Marine Casualty Information Platform
EMSA	European Maritime Safety Agency
ESP	Enhanced survey program
FMECA	Failure Mode Effects and Criticality Assessment
FP	Fire Protection Sub-Committee
FSA	Formal Safety Assessment
Fund	International Compensation Fund for Oil Pollution
HAZID	Hazard Identification
HAZOP	HAZard and OPerability
HRA	Human Reliability Analysis
HSC code	High Speed Crafts Code
HSE	U.K. Health & Safety Executive Commission
GCAF	Gross Cost of Averting a Fatality
GBS	Goal Based Standards
GISIS	Global Integrated Shipping Information System
IACS	International Association of Classification Societies
ICAF	implied cost of averting a fatality
ILO	International Labor Organization
IMCO	Inter-Governmental Maritime Consultative Organization
IMO	International Maritime Organization
ISM Code	International Safety Management Code
LoF	likelihood of Failure

LTI	Lost-Time-Injuries
LQI	Life Quality Index
MARPOL	The International Convention for the Prevention of Pollution from Ships
MEPC	The Marine Environment Protection Committee
MSC	Maritime Safety Committee
NCAF	Net Cost of Averting a Fatality
NRC	US Nuclear Regulatory Commission
OECD	International Organization for Economic Co-operation and Development
PHA	Preliminary Hazard Analysis
PLL	Potential Loss of Life
PRA	Probabilistic Risk Analysis
RCM	risk control measures
RCO	Risk Control Options
RCT	Risk Contribution Tree
SMS	Safety Management System
SOLAS	International Convention for the Safety Of Life At Sea
UKOOA	UK Offshore Operators Association
UN	United Nations
UNCTAD	United Nations Conference on Trade and Development

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Chapter One

Introduction

Chapter I: Introduction

I.1. General Context

The move toward proactive and risk-based approaches in safety regulation is already well underway in most sensitive industries. At the same time, the utilization of such scientific methods in the maritime sector is still in the first stages of development and has little impact on policy formulation.

In fact, traditional maritime safety regulations have mainly grown in a reactive way, with lessons drawn up from disasters and catastrophes constituting the primary motivators for regulation improvement. These regulations still constitute an indispensible base of technical knowledge; nevertheless, it becomes less effective because of rapidly changing designs and increasingly innovative building techniques, especially for “*knowledge-intensive*” and “*safety-critical*” ships.

Hence, in the last decade, the maritime sector initiated the modernization of its regulatory framework, in order to overcome the limitations posed by the traditional safety regime. Three main objectives for the development of the maritime safety regime have been identified and will be investigated in this dissertation; they consist of:

- **Supporting the development of regulations** - *Formal Safety Assessment* (FSA): The FSA is a methodology, based on risk analysis and cost benefit analysis, adopted by the IMO in order to improve the development of maritime safety and environmental protection rules by providing a support to the decision-making.
- **Promoting the innovation** - *Alternative design and arrangements for fire protection*: SOLAS regulation II-2/17 permits the approval of Non-prescriptive designs, if it is proved that their safety level is at least equivalent to the safety level of prescriptive design.
- **Developing standards according to safety objectives** - *Goal-based standards* (GBS): a new approach which is regularly appearing on the top of the Maritime Safety Committee (MSC) meetings agenda since 2004, and which has been, very recently, developed to be introduced in the next SOLAS Convention amendments.

These objectives constitute the backbone of the new approach to maritime safety, adopted by IMO. Thus, the future development of these concepts would be crucial for the enhancement of safety levels and for improving the picture of the shipping industry, which suffered from unacceptable fatalities rates and catastrophic environmental pollution in the last decades, mainly because of unforeseen failures.

The evolution toward a proactive regime is mainly characterized by two major elements, namely greater flexibility, and more transparency in setting safety objectives. In fact, instead of defining **specific** prescriptive rules, the new approaches state, quantitatively or qualitatively, **holistic** safety objectives, goals and performance criteria. Moreover, the concept of risk is usually introduced in an explicit or implicit way, during the development and the implementation of the regulations. However, this new tendency raises a certain number of issues, mainly related to uncertainties, reduced confidence and the role of experts in the decision-making process.

I.2. Legal Background

There are various provisions in different IMO instruments and guidelines that promote the development of proactive and risk based approaches, and emphasize the use of objective and performance based alternatives *in lieu of* prescriptive regulations; the following illustrate some of these provisions:

1. The FSA process was introduced in 1999 to support the IMO rule making process. It mainly uses risk management and cost/benefits principles for evaluating various safety alternatives. Subsequently, this process is being progressively introduced at various other levels, such as evaluating safety criteria or for the approval of alternative design and arrangements.

2. The ongoing developments of the GBS at IMO would result in a new regulatory framework for shipping, especially after the expected amendments to the SOLAS Convention, which would make the GBS standards mandatory for new oil tankers and bulk carriers. These amendments will reinforce the philosophy of risk-based approaches in the design and approval of alternative arrangements.

3. Various IMO instruments permit approving equivalents and alternatives design *in lieu of* prescriptive requirements in many areas of ship design and construction, which can *pave the way* for risk-based approaches. For instance, the 2002 amended SOLAS regulation II-2/17 and MSC/Circ.1002 provide the methodology and guidelines for the approval of alternative design and arrangements for fire safety arrangements.

4. Future developments of IMO instruments are focusing on the revision of rules and methodologies, for promoting the introduction of innovative alternative design and arrangements for machinery and electrical installations and life saving appliances, which would emphasize the importance of proactive and risk-based approach for setting the future maritime safety criteria and objectives.

Thus, proactive and risk-based approaches are currently being introduced at many levels within the IMO regulatory framework. Accordingly the development of these concepts would constitute a major challenge for maritime safety for the future decades.

I.3. Objectives and structure of the dissertation

The main objectives of this dissertation are as follows:

- Identify the principle limitations of the traditional maritime safety regime and determine the incentives for new approaches;
- Investigate the safety approaches adopted in sensitive industries other than the maritime sector;
- Identify the characteristics of the proactive approach to maritime safety and their relationship with risk management principles
- Making a comparative analysis between performance based and prescriptive regulation by the examination of their respective strengths and weaknesses;
- Investigate the various aspects of the new proactive maritime safety regime (FSA process, alternative design and GBS methodologies);

- Provide a basis of knowledge, techniques and methodologies related to the various concepts of the proactive approach to maritime safety;
- Finally, presenting the incentive for the development of a risk-based ship inspection regime and drawing the basic lines that would constitute such system.

Accordingly, after this Introduction, the second chapter will discuss the limitations of the traditional safety regime and the incentives for a new safety approach. Then a comparative analysis between performance based and prescriptive regulations and the safety regimes in sensitive industries, such as the nuclear and offshore sectors will be examined in the third chapter.

The fourth chapter will be dedicated to the investigation of the role of risk principles for developing a proactive safety regime. Then the principles of the FSA process and its importance for the new maritime rule-making methodology will be critically reviewed in the fifth chapter. Subsequently, the sixth chapter will cover the proactive safety compliance concepts, such as GBS and alternative design and arrangements.

Finally, the benefits and incentives for a risk-based ship inspection regime and the basic lines for developing such system will be presented in the seventh chapter.

Chapter Two

Aspects of the traditional maritime safety

Chapter II: Aspects of the traditional maritime safety

II.1. Brief history of the sources of maritime regulation

The first recorded mentions of maritime law go back to the Babylonian Code of Hammurabi, especially related to the bottomry and collision avoidance; safety was not considered as a matter of public apprehension, and accidents were regarded to be inevitable and act of the Gods (Mukherjee, 2002). Though, the first initiatives for the regulation of maritime safety were operated within a private framework. Indeed, the first classification societies were created in the 19th century under the impulse of the maritime insurers in order to give them information on the quality of the ships and their equipment.

In this context, classification societies imagined and conceived a system of ships' inspection which allowed them to deliver class notation attesting the degree of confidence which can be granted to the ships. With the origin, these notations, rather complex, covered the hull of the boats. This system of class notation mainly covered the ship's hull, the quality of the sails and was also interested in the competence of the master and crews.

By the end of the 19th century, dialogue attempts took place between the main maritime nations, such as Great Britain and France, particularly to establish common rules for collision avoidance in the English Channel. Subsequently, the "*s/s Titanic*" catastrophe in 1912 accelerated the process for the creation of international maritime safety standards. This catastrophe promoted the first international conference on the safety of human life at sea, which led to the first International Maritime Convention, SOLAS 1914 entering into force in 1919.

However, the most important tuning in the maritime safety regulation history was marked by the adoption in 1948 of the Convention creating the International Maritime Organization IMO (originally called IMCO), through a United Nations Conference held in Geneva. This Convention entered into force on March 17th, 1958, and the new Organization was inaugurated on January, 6th 1959.

The purposes of the Organization, as described in the Article 1(a) of the Convention, are:

> to provide machinery for co-operation among Governments in the field of governmental regulation and practices relating to technical matters of all kinds affecting shipping engaged in international trade, to encourage and facilitate the general adoption of the highest practicable standards in matters concerning maritime safety, efficiency of navigation and prevention and control of marine pollution from ships (IMO, 2009).

However, tragic accidents such as the "*Herald of free enterprise*", *Scandinavian Star* and *Estonia*, together with environmental disasters "*Torrey Canyon*", "*Amoco Cadiz*" and "*Exxon Valdez*" increased the public awareness and focus on maritime safety. Consequently, the IMO endeavors to find quick and adequate solutions, which would both prevent, on a case by case basis, the same accidents to happen again and that would cure its reputation and credibility, damaged by the recurrence of accidents like those affecting bulk carriers in the nineties.

In fact, despite the great advances in maritime safety achieved since the creation of the IMO, it is continuously target of varied and severe controversial criticisms related to its standard-setting functions. For instance, it has been accused of:

- Being an administrative body where political bureaucrats outnumber technicians;
- Producing too many complicated regulations, which are difficult to implement, especially by developing countries; however, it is not given any instrument to control the implementation of the regulations by these countries;
- Failing to eradicate substandard ship's, while it is not given any possibility of action against Flag States that accept to register such vessels;
- Acting in most cases after a disaster. In fact, most of the IMO instruments have been generated after catastrophes, as illustrated in Table.1 (Boisson, 1999).

All these criticisms, amplified by the people's increased safety and environmental awareness, urged the IMO to find solutions that meet the new maritime safety challenges, mainly by modernizing its traditional rule making approaches.

Table 01: Contribution of Maritime disasters to the improvements of maritime safety

Disaster	Place / Date	Impact
TITANIC 1502 fatalities	Cape race, Newfoundland April, 1912	SOLAS Conference of 1914 1st SOLAS convention The North Atlantic Protocol on Safety Navigation; Watertight bulkhead Radiotelegraphy Lifesaving appliances
TORREY CANYON Spill of 119,000 tons of crude oil	Scilly Islands March, 18th 1967	1967: creation of the IMO Legal Committee 1969: CLC Convention 1969: International Convention related to the Intervention on the High Seas in Cases of Oil Pollution Casualties. 1971: Fund Convention 1973: MARPOL Convention
ARGO MERCHANT Oil spill: 27,000 tons	Cape Cod, Massachusetts December, 14th 1976	March 1977: announcement by the US of unilateral measures on tankers safety 1978 SOLAS Convention Protocol 1978 MARPOL Convention Protocol: segregated ballast tanks
AMOCO CADIZ Oil spill: 228,000 tons	Off Brittany March, 16th 1978	May 1978: IMO Council initiative for the improvement of tankers safety (duplication of steering gear control systems) Speeding up entry into force of SOLAS and MARPOL Protocols: May 1981SOLAS Protocol October 1983: MARPOL Protocol 1982: Paris MoU on Ports State Control
TANIO Oil spill: 11,000 tons	English channel March, 7th 1980	
HERALD OF FREE ENTEPRISE 193 fatalities	Zeebrugge March, 6th 1987	August 1987: UK measures to improve Ro-Ro ferries safety November 1987: 1st IMO resolution on Safety Management of shipping companies April 1988: 1st package of SOLAS amendments on monitoring systems October 1988: 2nd package of SOLAS amendments on damage stability
SCANDINAVIAN STAR 158 fatalities	North sea April, 7th 1990	November 1991: IMO Res. A.680 on Safety Management of shipping companies November 1993: IMO Res. A.741 on ISM Code May 1994: ISM Code becomes Mandatory after SOLAS Conference
EXXON VALDEZ Spill of 37,000 tons of crude oil	Alaska March, 24th 1989	August 1990: US Oil Pollution Act March 1992: MARPOL amendments: - Reg 13F: Double hull for new oil tankers - Reg 13G: ESP for existing oil tankers
ESTONIA 850 FATALITIES	Baltic sea September, 28th 1994	November 1995: SOLAS Conference, adoption of new regulation II-1/8-1 on damage stability for existing ferries February 1996: Stockholm agreement on specific stability requirements for ferries operating in North Europe
ERIKA Oil spill: 20,000 tons	Bay of Biscay December, 12th 1999	March & December 2000: EU ERIKA 1 and ERIKA 2 packages Phase out of single hull tankers, creation of EMSA, Reinforcement of PSC
Prestige Oil spill: 63,000 tons	Cape Finisterre, Galicia Nov. , 13th 2002	May 2003: Adoption of FUND II December 2008: EU ERIKA 3 Package, ship-owners and Flag States obligation in the event of oil pollution

Chantelauve, G. (2006). *Evaluation des risques et réglementation de la sécurité: cas du secteur maritime – Tendances et Applications*. Thèse de Doctorat : Institut National des Sciences Appliquées de Lyon

II.2. The actors of shipping industry

Catastrophes such the "*Erika*" accident, reveal the complexity of the modern shipping industry in terms of interrelation between different actors that have an influence on maritime safety. In fact, the "*BEA mer*" investigation report on this accident states that the Maltese flagged vessel was owned by a Maltese shipping company which belongs to two other Liberian companies, managed by an Italian management company in Ravenna, manned by an Indian manning company in Mumbai and chartered by a Bahamian company (*BEA mer*, 2000). The report gives much deeper details, but this example is not unique in the modern maritime business, which is completely different from the old traditional image of the sea trade, where the owner of the vessel was himself the captain and the rest of the crew were his closest partners.

Consequently, the application of international safety standards became influenced by multiple actors (see Figure 1), the following Table 2 describes the role of the main ones (Kristiansen, 2005):

Table 2: Influence of maritime safety Actors

Actors	Influence on ship safety
Ship builder	• Design of the vessel and set the technical standards
Shipowner	• Decide on the degree of application of international standards (Evasive, compliance or safety); • Decides on the crewing composition and standard; • Decision making on all organizational and operational safety policies.
Cargo owner	• Pays for the transport operation, thus decide on the quality of the selected ship for the service.
Flag State	• Overall control of the vessel, its crew and the application of national/international standards.
Classification societies	• Control of technical standards during the ship construction and exploitation; • Undertake some or the majority of Flag States' control responsibility.
Port State	• Responsible for safety in the Port and its approach; • Control the safety levels of the ships and in extreme case may detain or deny the access of a ship to its port.

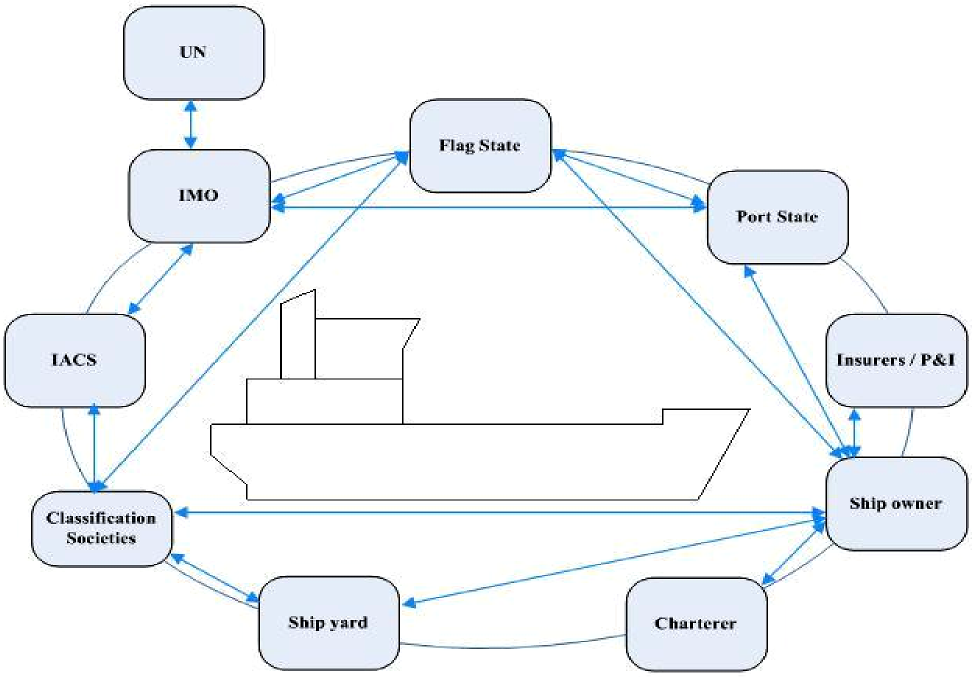

Figure 1: Principal actors of the maritime safety

II.3. Classification rules vs. statutory regulation

Because of its international character, the shipping industry is subject to a multitude of rules and regulations, technical standards and codes of best practices, either under mandatory or voluntary basis, and public or private origins. Mainly, two types of maritime safety regulations can be distinguished, namely, statutory regulations and classification rules.

➢ Statutory regulation

Historically, the purpose of the statutory regulations was, initially, the safeguard of the human life at sea and then, following several ecological catastrophes, the environmental protection. In the 21st century, the problem of terrorism and maritime security also became a subject of concern.

Flag states are responsible for the enforcement of statutory regulations which are mainly dictated by international conventions developed by the IMO. Accordingly, States can choose to exert their control related to the statutory surveys directly, or to delegate their functions (entirely or partially) to recognized organizations.

➢ Classification rules

The classification rules generally cover the solidity of the ship's structure, construction materials, principal and auxiliary machinery, control systems, electric installations, cargo installations, systems of fire detection and extinguishing and the ship stability. They cover imperative standards that constitute conditions for the class attribution, in addition to the less constraining provisions consisting in technical notes which prepare for future requirements of classification. Classification rules are mainly divided into new buildings and ships in service rules.

➢ Overlapping between statutory and classification rules

Historically, the classification rules were primarily concerned by the risk evaluation for the ship and its cargo, much more than the safeguard of the human life at sea, which was the purpose of the SOLAS Convention. It constituted the main difference between the statutory and classification rules. However, these two fields are closely dependent on each other, because the effectiveness of classification rules for the ship construction will certainly contribute to the general safety framework.

Moreover, these two fields are now much more closely dependent as the IMO imposes the recourse to classification rules, especially by SOLAS Chapter II-1 regulation 3-1, which states that "*… ships shall be designed, constructed and maintained in compliance with the structural, mechanical and electrical requirements of a classification society*". The overlapping between the classification system and some IMO Conventions is illustrated in figure 2:

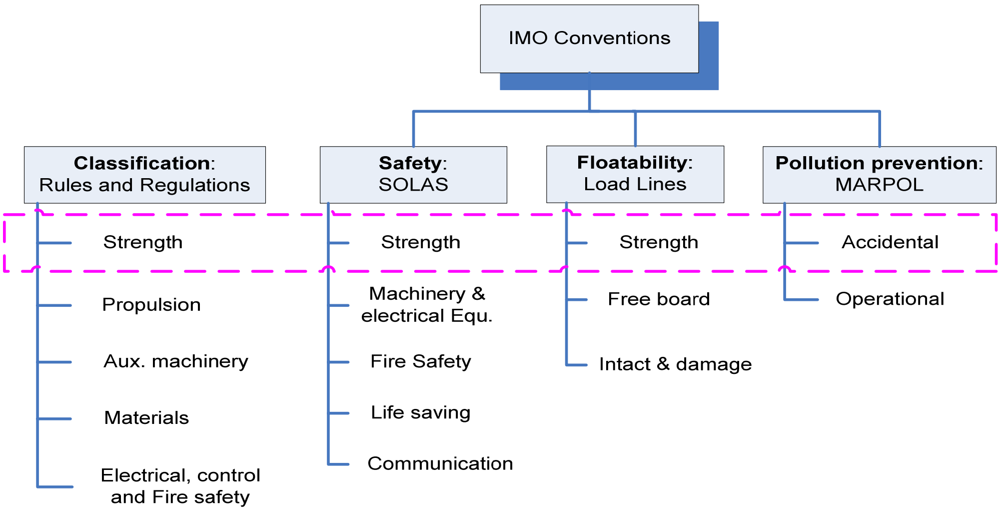

Figure 2: Overlapping between some IMO conventions and classification rules

Chantelauve, G. (2006). *Evaluation des risques et réglementation de la sécurité: cas du secteur maritime – Tendances et Applications*. Thèse de Doctorat : Institut National des Sciences Appliquées de Lyon

II.4. Problems of the traditional maritime regulation

Regulation is an indispensable factor of maritime safety. However, the international maritime regulation is heavily criticized because of its complexity, its volume, diversity and incompleteness.

➢ Volume of maritime regulation

The huge number of regulations makes them difficult for States to interpret and implement. Mainly, there are two reasons for this heavy volume of regulations.

First, after having been in competition with other UN organizations such as UNCTAD and ILO for the establishment of international maritime standards, today, the IMO find itself confronting other regional organizations in order to impose international standards. For instance, the US or the EU are not only adopting measures to interpret and harmonize the implementation of existing conventions, but they also elaborate their own mandatory directives on problems that are still not addressed on a universal scale, or even to rise the IMO standards to a higher level.

Second, the quick pace of technical progress and the huge number of problems calling for urgent solutions, made the IMO using the *tacit acceptance* regularly to keep a close eye on the technical innovation and prevent the aging of its regulations. However, this instrument does not have only benefits, but also drawbacks. For instance, on certain occasions the quick pace of rules generating, created point saturation, and it became impossible for States to implement the huge amount of standards adopted.

➢ Diversity of safety standards

International safety regulations are extremely numerous and diverse; this diversity can be observed on three levels:

- Firstly, public regulations comprise both technical and legal requirements. These two aspects require different procedures for their preparation, amendment and enforcement. For instance, an international convention may comprise both compulsory rules and recommendations which will be implemented at different degrees by States.

- Secondly, technical standards have different legal forces, depending on whether they are prescribed by conventions or resolutions. In the first case, the principle of *“pacta sunt servanda”* applies; but in the case of resolutions, some flexibility is left to the States’ legislators for the implementation process.
- Finally, regulations may sometimes be technically precise but legally vague, because the texts are often reviewed and adjusted to ensure the broadest possible agreement. Consequently, certain rules are so vague that they leave the issue of implementation open to all kinds of interpretation.

➢ Loopholes in safety rules

Several IMO instruments have wide ranges of application, depending, for instance, on the type of navigation, registered tonnage and the age of the ship. Accordingly, these aspects are now used in a commercial context, to increase the shipowners’ incomes, at the expense of safety. For instance, container ships are increasing the over-deck cargo to decrease their gross-tonnage and other ships take profit of the *“grand-father clauses”* to implement lower safety standards. These Loopholes are now put in question for their impact on safety.

In this context, Boisson (1999) states that:

> *The safety laws, so difficult to understand and interpret, so complicated to implement and enforce, raise a new set of problems for those concerned with safety. This situation is disturbing the shipping industry. The harmful effects of over-regulation and the fragmentation of rules have been denounced. Difficulties arise from the fact that the international standards governing safety at sea are heterogeneous, many in number and incomplete. Another sources of anxiety is the increasing speed at which the law changes. Despite the proliferation of regulatory organizations, certain loopholes persist in the law. Overlapping and duplication of efforts to promote maritime safety continue in the absence of global co-ordination.*

➢ Reactivity

Maritime regulations have long time been criticized because of the reactive nature of its development, generally following catastrophes, also known as "*regulation by the disasters"*. The principal limits of this approach is that taking decisions with limited range of application after a crisis, resulted both in a complex regulation and an over-regulation, which have a prescriptive aspect that typically dictates the minimal technical or competence requirements. Consequently, a "*compliance culture*" has long time regulated the maritime sector, associated with a reduced capacity of innovation and initiative taking (Chantelauve, 2006).

➢ Deterministic Principle

Also, the traditional maritime rule-making is based upon a deterministic approach that mainly addresses technical systems or human elements. However, the solutions generated by this approach often remain incomplete, because of the over-simplification made during the analysis process giving excessive weight to the technical and human factors (Boisson, 1996).

Boisson (1999) states that for over a hundred and fifty years, maritime safety mainly relied on a deterministic philosophy, assuming that every event has a cause, and that the same causes produce the same effects. Consequently, maritime safety became a set of preventive measures based on malfunctions in the shipping industry, namely maritime accidents and incidents. This attitude is now criticized for being complex, permanently out of date, constantly failing to keep up with technological innovations, thus, inadequate to meet the overall challenges of maritime safety for providing a safe, efficient, environment friendly and highly competitive transportation mode.

However, as response to such criticisms, Mr. Mitropoulos suggests that "the IMO manages to navigate a successful course between the proverbial "*rock and a hard place*" by working at whatever pace is appropriate for the issue in hand and the context within which it is being considered" (Mitropoulos, 2004). Thus, a wind of change in the safety regulations policy making was indispensible.

II.5. Chapter Conclusions

This Chapter discussed traditional maritime regulation regime. It is important to notice that in the maritime sector, the prescriptive regulations played and continue to play an important role in the safety control. Thus, the objective is not to call into question or to critisize the traditional maritime safety regulation framework, for several reasons such as:

- In spite of apparent criticisms and dysfunctions, this existing legislation is a capital source of knowledge;
- The development of such a regulation in the historical and international context of maritime safety was a necessary stage of consolidation;
- The progressive evolution of maritime safety regime should find solutions to the current and foreseeable future problems.

By reviewing the traditional maritime safety regime, the author is rather trying to identify possible dysfunctions that justify the needs for the recent evolutions.

Chapter three

The New Safety approaches

Chapter III: The New Safety approaches

III.1. general context

In the previous chapter the indispensability of regulation for the maritime safety was exposed. Also, there was an attempt to present the problematic posed by traditional safety approach and the panoply of criticisms that addressed this approach, especially with regards to its reactive and prescriptive nature. Consequently, new safety approaches have been considered to overcome these loopholes, using more scientific tools such as risk science at the stages of rules making and application.

Ideally, the new approach would at least meet the following expectations:

- Provide solutions that respond to well defined hazards;
- Incorporate the management aspects, by placing the responsibility for safety within the hands of the operators themselves;
- Make benefit from recent technological, operational and managerial advances;
- Give incentives for operators that should consider that safety is assisting them to achieve their corporate objectives (Kuo, 1999).
- Provide a holistic safety approach that gives to regulation the flexibility to adapt to the quick pace of technological innovation.

In this context, risk science has been introduced at two levels in the maritime safety regulation. First, at the stage of rule making thought the concept of Formal Safety Assessment (*FSA*) (IMO, 1997), and second, at the stage of the rules application, for instance, the introduction of the "*alternative design*" approach (SOLAS regulation II-2/17), or the Goal-based ship construction standards.

These concepts will be thoroughly reviewed, but first two other "non-maritime" alternatives to traditional safety approach have been selected in order to introduce the new regulation tendencies. Firstly, the nuclear industry, as it is the first sector using risk principles in its rule making (Lassagne, 2004), and secondly, the offshore safety approach because of the similarities between this industry and the maritime field. Then, a comparative review between prescriptive and performance-based regulations will be presented in this chapter.

III.2. Nuclear sector: “*Risk-informed*” regulation approach

When he was asked about the need to risk-inform regulations that are “*good enough*” for the safety and oversight of currently operating reactors, and even for the evolutionary and advanced reactor designs, Mr. Nils Diaz, Chairman of the Nuclear Regulatory Commission (NRC), replayed that: ““*good enough*” should not be our standard … ...when we have the know-how and the tools to create regulations that will allow us to incrementally incorporate the best scientific and technical information, and the best methods and approaches” (Diaz, 2004, p.03).

The U.S. NRC was the origin for the developments of many risk analysis techniques in the seventies. Today, it is mostly recognized as the creator of a doctrine in the risk-based rules making, which is the risk-informed regulations. This approach is defined to be a regulatory decision-making that “represents a philosophy whereby risk insights are considered together with other factors to establish requirements that better focus licensee and regulatory attention on design and operational issues commensurate with their importance to public health and safety” (U.S.NRC, 2004, p.07). It can be explained by the use of the probability and consequences of an undesirable event to influence the regulations decision-making process. The framework for risk-informing a specific regulation is explained in Figure 3.

This approach was initiated in 1995, when the NRC Policy Commission declared that the use of probabilistic risk analysis (PRA) should be increased in all regulation-making processes, in order to supplement the deterministic approaches, and reinforce the traditional defense-in-depth philosophy (U.S.NRC, 1995). In fact, even though this approach was originally used only for few specific regulations, its application has been generalized, especially after the nuclear catastrophe of three-mile Island (U.S.NRC, 2009).

Although encouraging, and being at the origin, of the use of risk analysis techniques, NRC has also insisted on their limits, especially with regard to the uncertainties. They suggest that the guiding principle is “***risk informed***” and not “***risk based***” rule making. Accordingly, the risk-informed and performance-based regulatory structure should rather be used as holistic principles, to complement the NRC’s deterministic approach and support the NRC’s traditional defense-in-depth philosophy

(Lassagne, 2004), which confirms the importance of keeping the balance right between the utilization of different techniques.

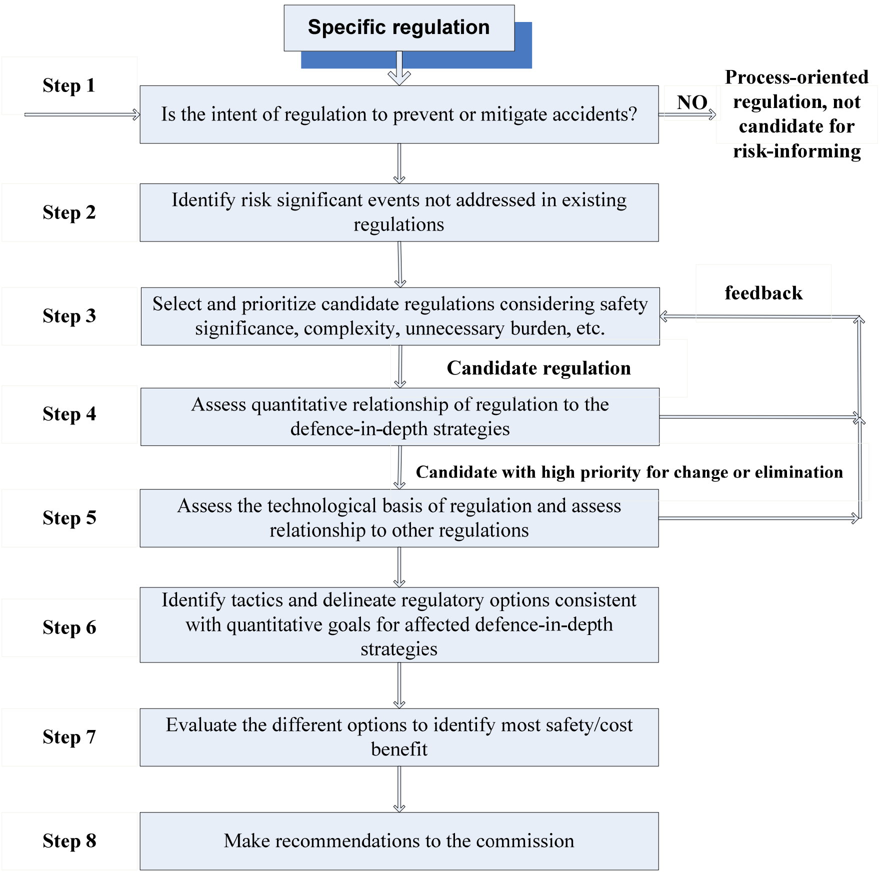

Figure 3: Framework for Risk-informing of a specific regulation

US Office of Nuclear Regulatory Research (2000, April). *Framework for risk-informing the technical requirements of 10 CFR 50*. Retrieved May 02, 2009, from the World Wide Web: http://www.nrc.gov/reading-rm/doc-collections/commission/secys/2000/secy2000-0086/attachment1.pdf

Recently, the new principles of "*realism*" and "*conservatism*" were introduced by the NRC. These principles consist of:

- The regulations are informed by "*the real world*", science, technology, the experience (Realistic approach);
- Safety margins are preserved in an effective and adequate manner (conservatism principle);
- A balanced approach must allow the protection of the public health and the safety, in ensuring that the resources are allocated the prioritized safety subjects;
- The regulation must correspond to the real risk and not to assumptions of "*worst case*" scenarios (Diaz, 2003), to avoid over-regulation and wastage of resources.

III.3. Offshore industry: the *“safety case”* approach

The UK offshore regulation approach has been marked by a significant shift in the last decades. In fact, following to Lord Cullen’s investigation into the “*Piper Alpha*” disaster in 1988, it has been proved that the compliance with prescriptive safety codes and standards was not sufficient to ensuring the safety of offshore systems (Cullen, 1990). Consequently, the regulatory trend moved away from prescriptive requirements towards performance-based systems, where the responsibility shifted to the oil/gas exploration operators, who should develop and present well reasoned arguments and evidence proving that the design and operation of their systems achieve acceptable levels of safety, in all their life cycle stages. This approach is referred to as the “*safety case*” (HSE, 2006).

Kuo (1999) states that the concept of the “safety case” has been developed and derived from the application of “systems engineering principles”, whereby the safety of systems and installations does not depend solely on previous operational experience, but rather uses all available expertise and information in a logical way. Accordingly, the principles of this approach were first adopted by the nuclear industry, and later by the chemical and offshore sectors.

For instance, if a new installation concept is generated, the safety of the project can be modeled by answering a number of fundamental questions such as the following:

Table 3: Fundamentals of the safety case concept

Questions	Tasks	Scientific terms
What aspects can go wrong?	Identifying hazards systematically	**Hazard Identification**
What are the likelihoods and impacts?	Assessing the risk levels of the hazards	**Risk Assessment**
How can they be reduced?	Reducing risk levels of selected hazards	**Risk Reduction**
What to do if an accident occurs?	Being prepared to respond to emergency situations	**Emergency preparedness**
How can safety be managed	Managing and controlling risk levels of hazards	**Safety Management System**

Kuo, C. (1999). *Managing ship safety.* London: LLP publishing

Accordingly, the use of risk management principles were generalized and progressively increased throughout the offshore industry. Pillay and Wang (2003) identified five key elements on which the "safety case" concept is based, as follows:

- Hazard Identification

Identifying all likely hazards, which would potentially endanger the system or cause a major accident.

- Risk assessment

Evaluating the risk levels associated with each identified hazard, hazards are generally grouped in three regions, namely intolerable, tolerable (As Low As Reasonably Practicable ALARP region) and negligible as shown in Figure 4.

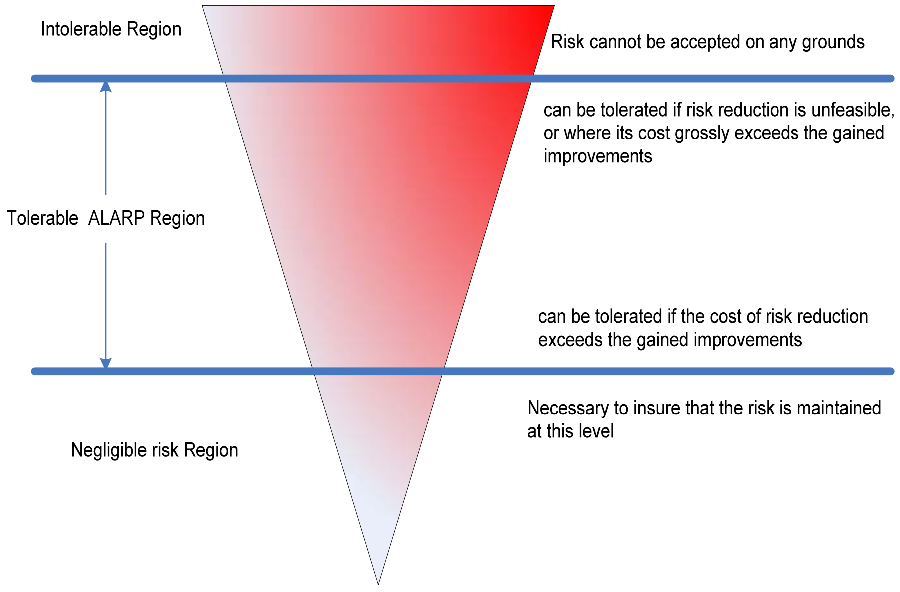

Figure 04: HSE framework for risk tolerability
Det Norske Veritas. (2002). *Marine risk assessment*. London: HSE Books.

- Risk reduction

Reducing risks associated with intolerable levels and, lowering tolerable risk if such operation can be done cost-effectively.

- Emergency preparedness

To be prepared in the event that a hazard becomes a reality, even when all necessary precautions have been taken against it, and take the appropriate measures to reduce its impacts.

- Safety management system

The purpose of the SMS is ensuring that the organization is safely and efficiently achieving its goals, without damage to the people, the installations and the environment. The SMS has five components as follows:

- Formulation of the Policy;
- Organizing the resources and communication of information;
- Implementation of the agreed policies and actions;
- Measuring the achievement of the required standards;
- Review of performance and making relevant refinement.

These five key elements on which the "*safety case*" concept is based, are presented in Figure 5 **(Kuo & Cojeen, 2000)**:

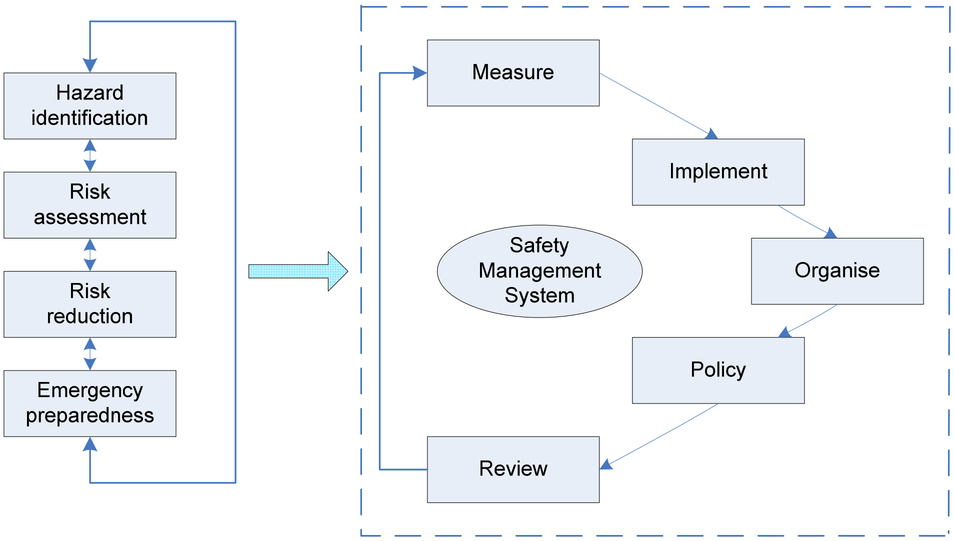

Figure 5: The Five key elements of the safety case concept

The nuclear and offshore safety concepts are considered to be pillows of the modern safety approach, and have certainly influenced the new proactive maritime approach adopted by the IMO, which will now be reviewed.

III.4. From prescription to performance:

Being proactive means identifying at early stages the factors that may affect the maritime safety and developing rules and regulations that would prevent the occurrence of such undesirable events, as opposed to the "*regulation by disaster*" that responds, on a ad-hoc basis, to a single accident (Psaraftis, 2002).

The paradigm shift toward a proactive maritime safety includes the transition from prescriptive to performance-based codes. In fact, this tendency of moving toward performance-based codes is, in part, due to the fast pace of technological innovation and the negative aspect of prescriptive regulations to respond to these scientific and engineering advances.

In contrast, performances–based codes basically set the safety objectives and criteria, and leave to the designer the conception and selection of the most effective alternatives of achieving these objectives, which allow a great degree of flexibility and encourages innovation (Hadjisophocleous & Bénichou, 2000).

Historically, the conservative prescriptive approach was synonymous of providing a large margin of safety to reduce the likelihood of accidents, and/or give the means to mitigate their consequences if they occur (Meserve, 2000). Moreover, when an accident happens, more prescriptions were generated to respond to the new causes and effects of the new event. This approach included many assumptions and oversimplification, especially because of the lack of extensive knowledge and sharp scientific and technological tools that are available nowadays.

The main difference between a performance-based approach and a more traditional prescriptive approach is finally the change from the angle of view of the studied system: the traditional approaches are more **specific** and **analytical**, while performance standards are more **holistic** and risk based.

However, this paradigm shift implies also some practical consequences. For instance, the prescriptive rules are easier to follow for the designers and manufacturers, easier to control for third parties, namely classification societies and maritime authorities, and relatively easy to implement for the legislators. Nevertheless, the fundamental difficulties related to the use of the prescriptive approaches, as well as the advances in scientific safety analysis, mainly in the risk management field, increased the interest for the performance-based approaches.

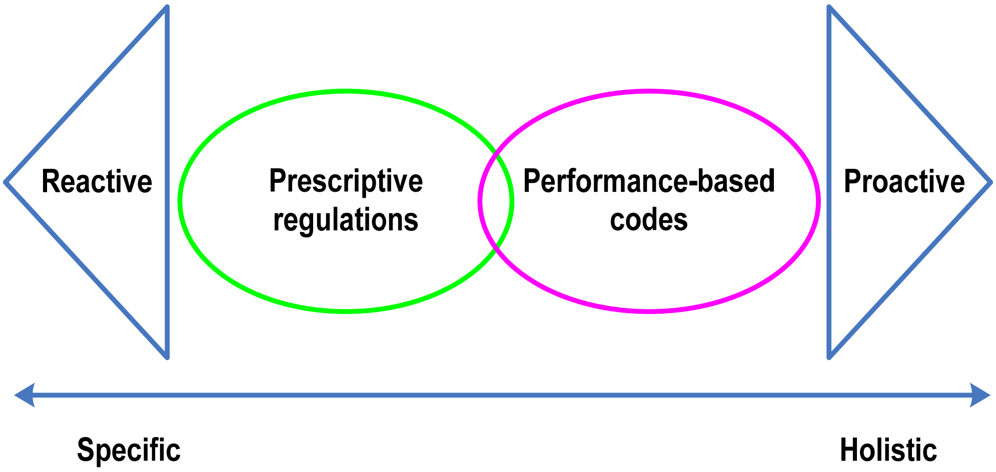

Figure 6: Paradigm shift, from prescriptive to performance-based regulations

Thus, the main characteristics associated with prescriptive regulations are: limited flexibility for architecture and reduced design optimization; difficulty of application to new concepts; taking into account of the technical systems, unbalanced and contradictory requirements of safety; little transparency; reactivity and continuous amendments.

On the other hand, the characteristics associated with performance-based codes are: flexibility; introduction of new concepts; explicit objectives of safety; pro-activity and taking into account of nontechnical aspects such as human element. These characteristics validate the preference for the performance-based approaches, and justify the critical vision of the prescriptive approaches to maritime safety.

Practically, the choice of a prescriptive or performance-based approach will have the following impacts:

- **Ships in construction: design and conformity**

From the ship-builders perspective, prescriptive rules are easy to implement, despite their complexities. They are incrusted in the shipyards building culture, and therefore allow reduced conception and design delays, resulting in increasingly shorter times of construction. The implementation of new performance-based rules requires the development of new knowledge, new tools and a new culture. The question arises concerning the times of design and construction. Thus, these new changes will be reflected on the ship-building delays. Consequently, the ship-owners needs will undoubtedly influence the degree of innovation of the yard, which will create a new factor of competition within the ship-building industry.

The situation will be identical from the under-construction classification and certification point of view. The new performance-based approach would generate new knowledge and expertise needs, which will be reflected on the delays of classification and certification.

- **Ships in service: operation and control**

With regard to the ships' crew, relatively standardized ships and working environments conform to traditional prescription create, from a first point of view, an element of safety. New concepts would certainly impose new specific familiarization, training, and competencies.

Finally, regarding the last shackle of the safety chain, the inspections and surveys of ships that do not conform to standardized prescriptive requirements can be problematic, either for statutory and classification surveys, or Port State inspections. Thus, new training needs and new surveys and inspections regimes would be required.

A comparative review contrasting the advantages and disadvantages of theses two approaches is summarized in Table 4 (Chantelauve, 2006; Hadjisophocleous & Bénichou, 2000; Kuo, 1999 ; Tavares, 2008):

Table 4: Prescriptive vs. Performance-based regulations

Regulation approaches	Merits	Drawbacks
Prescriptive	• Straightforward concept, direct analysis and interpretation, noncomplex application and evaluation. • Setting reference standards to be met by anyone who wants to build and operate a ship or marine vehicle. • No requirements for specific qualification or high levels of engineering and expertise.	• Specification of the requirements without clear statement of objectives. • Inhibits innovative alternatives and inflexibility for innovation. • Difficulties of keeping up-to-date and tends to lag behind technological advances. • Little promotion of cost-effectiveness analysis. • Complex structure and need for continuous amendments. • Assume that there is only one way to provide the required safety level, and are not much open to alternative solutions. • Once the standard requirement has been satisfied, there are little incentives for operators to achieve safety levels beyond. • Possibility of imbalance because of the influence of major disasters.
Performance-based	• Establishment of clearly defined safety objective and leaving to the engineers the freedom of defining the criteria and methodology to achieving them. • Flexibility for introducing innovative design solutions that meet the performance criteria. • Harmonization of international standards. • Reduced complexity of documents. • Facilitating the introduction of innovative technologies and knowledge • Usage of cost-effectiveness analysis, and allowing great flexibility for the designer	• Difficulty to clearly quantifying the safety levels. • Need for further education and training especially because of reduced comprehension especially during the first phases of implementation. • Difficulties to analyze and evaluate the compliance of “equivalent projects” with the established standards. • Difficulties for the validation of the methodologies and tools used for defining the quantitative criteria.

III.5. Factors influencing the choice of the regulation approach:

Both prescriptive and performance-based regulations have their merits and drawbacks; thus the real strength lies in recognizing the factors that would favor one concept or the other, and how to use both approaches in harmony. Now, an analysis of the context in which a transition in the safety regulation regime can occur will be made, and more precisely, the aspects influencing the choice of a prescriptive or performance-based safety approach.

➢ The HSE "*permissioning*" regime

The *U.K. Health & Safety Commission* (HSC/E) suggests that a new safety regime would be proposed, only where the "normal forms of regulation are not sufficient and where the extra demands imposed by the regime are justified by the benefits it brings" (U.K. HSE, 2003). It proposes that a combination of at least one criterion in A and the criterion in B will help determining the need to generate a new safety regime, called "*permissioning*" regime, which can be assimilated to the performance-based approach.

Table 5: HSE criteria for determining the need for a "*permissioning*" regime

Criteria	Description
A	• *There is a need to have regard to high, sustained and broadly based levels of societal concern, either existing or likely, over potential risks of harm (eg high levels of public dread or aversion associated with the hazard and the vulnerability of those exposed to the hazard); and/or* • *There are significant risks of multiple fatalities from a single (or linked series of) event(s); and/or* • *There are significant risks of widespread and significant adverse effects on human health.*
B	• *The proposed regime adds proportionate value in terms of risk control and/or allows specific activities (with clear benefits to society) to proceed.*

➢ The UKOOA decision-making framework

In the document submitted by Japan to the 81st MSC session, related to the safety level approach for Goal-Based new ship construction Standards (GBS), it is proposed that the *United Kingdom's Offshore Operators Association* framework for risk-based decision making (UKOOA,1999), can be used to assist in risk-related decision-making. The main purpose of this tool is evaluating different alternatives during the feasibility studies and concept stages of a given project, in relation to certain hazards such as fire, explosion, loss of stability and others (IMO, 2006a).

The framework's model takes the form of a decisions' spectrum, ranging from decisions influenced by engineering parameters to decisions where the societal values are important. At the right-hand side of the model are positioned characteristics which indicate the decisional context; to the left, are indicated the means of calibration.

This approach establishes that the evaluation of the risks that can have a significant impact for the decisions of the type B, implying uncertainties and deviations from the usual best practice and standards. While for the decisions of the type A and C, the evaluation of risk is still suitable, but has less influence on the final decision. Accordingly, it can be noted that most IMO regulations fall within the "type B" decisions category of the spectrum.

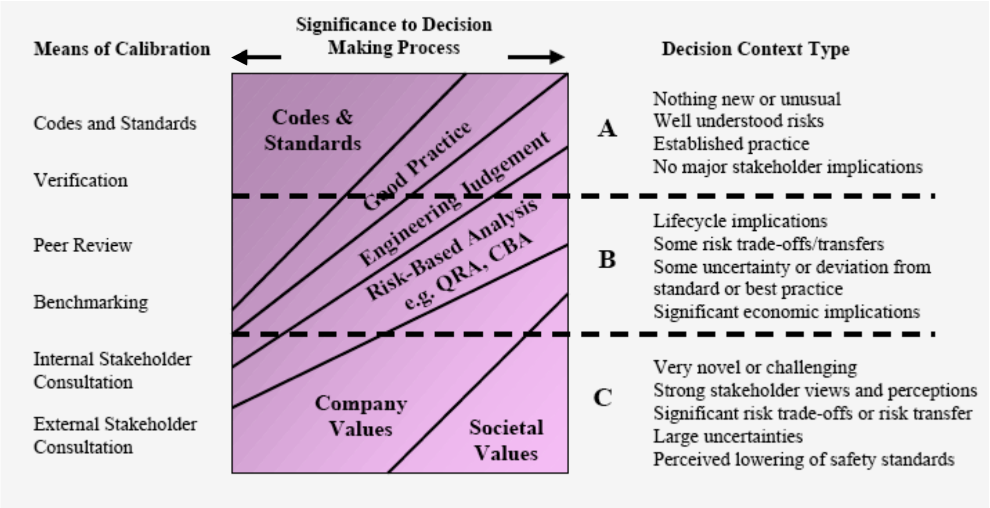

Figure 7: UKOOA decision-making Framework

International Maritime Organization. (2006a, February 5). *Goal-Based new ship construction Standards- Safety levels – Submitted by Japan*. (MSC 81/6/3). London: Author

The framework is not intended to be a prescriptive method, and can be used for a wide range of application (Yang & Al., 2001). However, its usage can be complex and its interpretation can become subjective.

➢ ISM Code: a paradigm shift

The implementation of the ISM Code is recognized to be the first and most significant paradigm shift, which was adopted by the IMO, to move toward a **proactive** maritime safety. If applying the previously analyzed theories related to the need for a transition in the regulation approach, it can be noted that, by the end of the 20th century, serious accidents continued to happen within the maritime industry, despite the application of the relevant international rules and standards on board the involved ships (Kletz, 2001), which raised great social anxieties regarding the safety levels in the maritime field.

With regard to the HSE criteria for determining the need for a "*permissioning*" regime, these conditions perfectly respond to the need for a transition toward a new safety regime. Indeed, the conditions stated in the A and B rows of Table 5 are combined in this case, which justifies the need to change the safety regime. Accordingly, more responsibility was moved to the ship operator, who became required to provide a Safety Management System that meets the safety objectives fixed by the Code, establishes safeguards against all identified risks, and provides evidence to prove the system's safety is effectively managed. This transition represented a noteworthy move toward the shipping industry self-regulation.

Chapter Four

Risk management and proactive safety

Chapter IV: Risk management and proactive safety

IV.1. Introduction

Basically, risk is incrusted in all safety aspects. If refering to the definition of the term "safety", which can be for instance "the term that is normally used to describe the degree of freedom from danger" (Kristiansen, 2005), risk is the concept that allows evaluating the levels of protection from hazards and thus the degree of freedom from danger.

Rasmussen and Svedung (2000) state that the evolution toward a **proactive** "*no-accident-is-tolerable*" policy, which improves the safety levels of any industry, can not be attained without applying adequate and effective risk management strategies. Recently, The IMO finalized the consolidated text of the Guidelines for Formal Safety Assessment, and thus, endeavors to generalize, where possible, the use of risk management theories in its rule making process (IMO, 2007a).

In this chapter, the role of risk theories in developing proactive maritime safety regime will be analyzed, and the difficulties faced by the risk-based approach will be investigated. But first, the category to which the maritime safety regulation belongs will be defined, and in the level in which it is positioned compared to other industries' safety systems will be identified.

IV.2. Categorization of safety control systems

Rasmussen and Svedung (2000) associate the risk management strategies with the related categories of accidents. Accordingly, three safety control categories can be defined as follows:

- *Empirical safety control*: focusing on safety systems where accident are frequent but with relatively small consequences. This category deals with occupational safety, where the hazards are controlled empirically by epidemiological analysis of past accidents. The level of safety is measured by the "*LTI*" index (*Lost-Time-Injuries*), mainly used in the manufacturing and other relatively non-hazardous industries.

- *Evolutionary safety control*: protecting against relatively unlikely accidents that have medium impacts. The safety of this category of systems starts from the improvement of the design reacting to the analysis of the "*individual, latest major accident*". The safety control is created by building up several lines of defense against accidents. This approach is mainly focused on the removal of the causes of a particular accident. Examples of application of this safety control approach could be the aircraft and railways safety.

- *Analytical safety control*: dealing with systems where accidents are rare, but have heavy impacts. For this approach accidents will be so rare that the modeling can not be based on empirical evidence from accident analysis. The risk is predicted and modeled using probabilistic approaches (*Probabilistic Risk Analysis* "*PRA*"), based on the estimation of likelihood of a simultaneous violation of all the designed safety barriers. This safety concept mainly concerns very sensitive industries such as nuclear or chemical sectors, where the pace of innovation is very fast and a "no-accident-is-tolerable" policy is applied (Rasmussen & Svedung 2000).

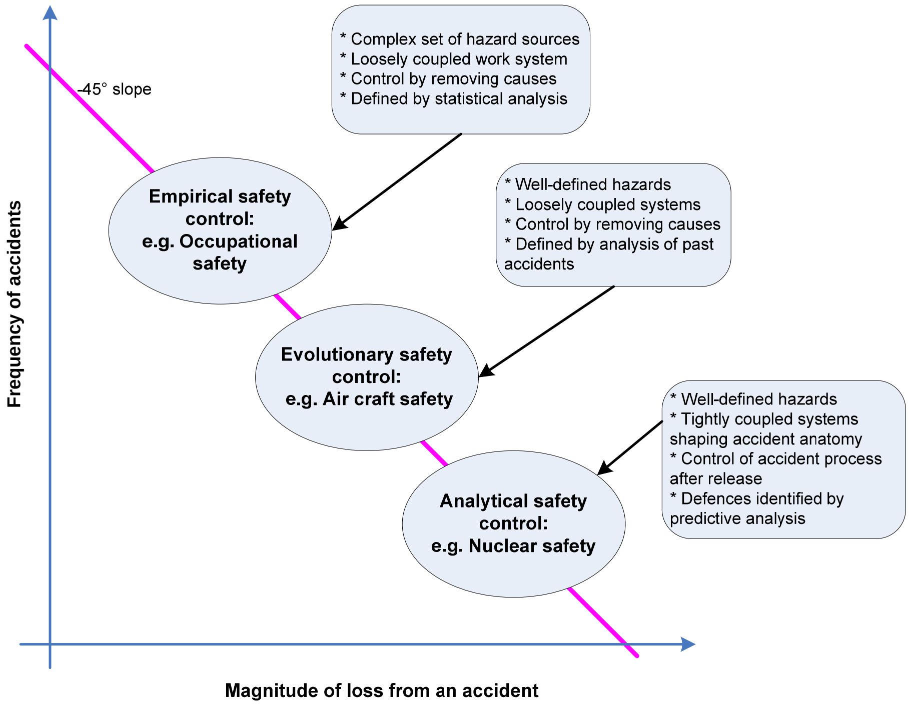

Figure 8: Rasmussen's Categorisation of safety control systems

Rasmussen, J. & Svedung, I. (2000). *Proactive Risk Management in a Dynamic Society*. Borås: Sjuhäradsbygdens

- *Safety control in the maritime sector*:

Maritime safety can be regarded as a hybrid regime that combines both empirical and evolutionary safety control approaches. Not only maritime regulation deals with the occupational safety of people on board (personnel protection, and working place safety), but also it sets the barriers that would prevent major accidents. Also, the maritime safety regulation focuses both on removing the causes of accidents, and the mitigation of their consequences in the unfortunate event they occur.

Accordingly, in its efforts to move toward a proactive safety, it is necessary for IMO to set up methodologies that will allow identifying, assessing and managing all risks associated with maritime activities. These risk-oriented methodologies would constitute the framework upon which the holistic safety regime could be developed.

IV.3. Possible configurations of safety regimes

Hood, Rothstein and Baldwin (2001) define a safety regime as being the rules, practices and ideas associated with the regulation and control of a risk or a particular hazard. The configuration of safety regimes depends upon the approaches adopted for the rule-making (deterministic or probabilistic), and the nature of the application process (prescriptive or performance-based). The probabilistic approach is intended to combine the evaluation of the frequency of an event with its level of consequence; it can therefore be considered as a risk-based approach (Lassagne, 2004).

Table 6: classification of safety regimes

Rules making →	**Deterministic**	**Probabilistic**
Rules application ↓		
Prescriptive	Traditional	Risk based
Performance-based	Risk Based	Purely risk based

Accordingly, depending on the process adopted for the rule making and the application methodologies, safety regulation can be classified in four categories as follows:

- *Traditional approach*: where the regulator prescribes technical requirements based on previous experience or deterministic calculation. This approach corresponds to the traditional maritime safety.

- *Purely risk-based approach*: where rule making process is based upon probabilistic calculation, associated with performance-based application codes, mostly used in the nuclear sector where no accident can be tolerated.

- *Risk-based approach*: in which either the performance-based rules are generated from deterministic approach, or, prescriptive rules are based upon probabilistic calculations e.g.: the regulator can impose specific technical solutions drawn up from lessons generated by risk analysis techniques, which represent the approach adopted for the proactive maritime safety.

These four principal categories can be supplemented by rules of equivalence, e.g.: a prescriptive rule can be satisfied by equivalent solutions other than the prescriptive requirements, as for SOLAS Chapter I/regulation 5.

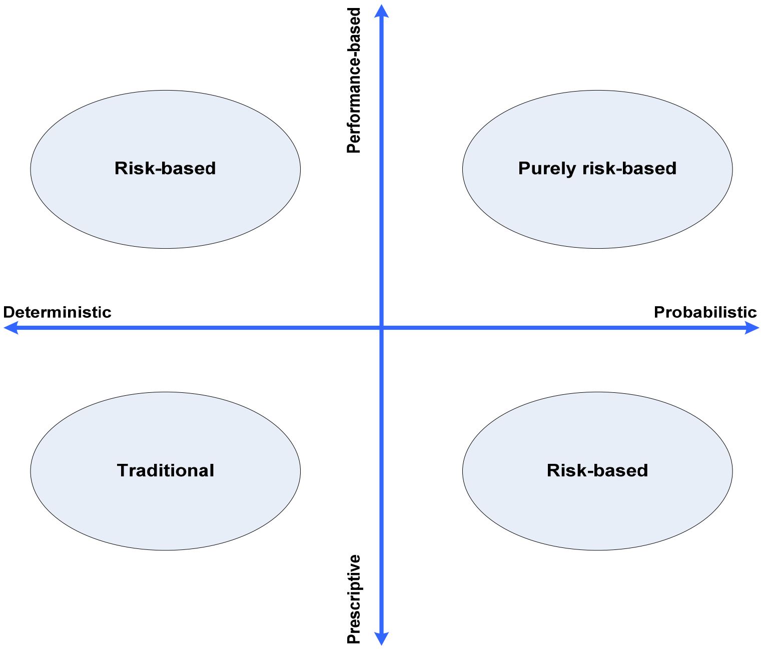

Figure 9: Possible configuration of safety regulation

IV.4. Safety and Risk management

The progressive evolution of a maritime safety regime toward a proactive approach has various aspects. First of all by the introduction of risk analysis tools in the development of prescriptive regulations, then by creating some openings within the SOLAS Convention by offering the possibility to adopt innovative solutions that provide equivalent levels of safety, also, within the framework of the rules development for the High Speed Craft (HSC) for which existing prescriptive safety requirement can not be enforced; finally, by enforcing requirements concerning the safety and security management systems.

Focusing on all these safety concepts allows noticing that risk management is a central point governing them. For instance, risk analysis will allow deciding whether the alternative solutions to SOLAS requirements, or the HSC innovative technologies, provide equivalent safety levels. Also, risk management tools are the backbone for setting and verifying the safety margins of performance-based regulations.

Many authors were interested in the description of the techniques of risk management and analysis in various sectors, such as financing, economy, banking, contingency planning and other fields. The new tendency of a proactive maritime safety regime is one of the fields of application of risk sciences, or more modestly, of the techniques of risk control and management. In order to centre the remarks, the following definitions are proposed:

- Risk analysis: a process which objective is the estimation of the risk;
- Risk assessment: confrontation of the risk levels with the criteria of risk acceptability, with the objective of formalization of the Risk Control Options;
- Risk management: the whole process including the selection of the suitable Risk Control Options and their implementation in the management of the safety of the considered activity.

The principle of risk management theory can be summarized in the Figure 10:

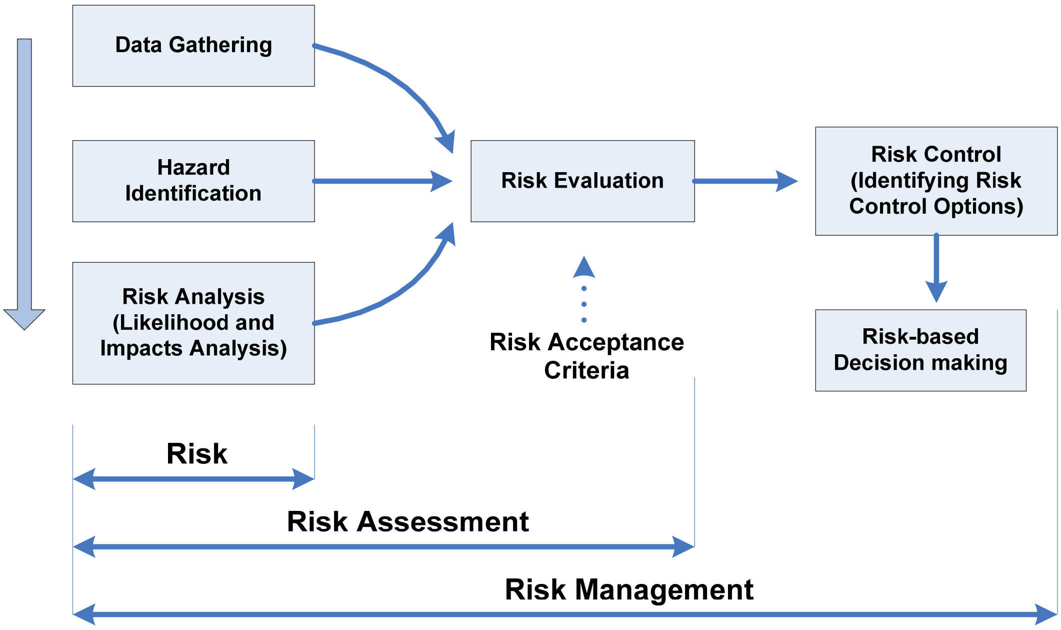

Figure 10: Risk Management System

International Maritime Organization. (2006b, September 14). *Manual on Oil Spill Risk Evaluation and Assessment of Response Preparedness - Submitted by New Zealand.* (MEPC/OPRC-HNS/TG 5/3). London: Author

Hazard identification and risk assessment are arguably the most important phases of a system safety lifecycle and often the most difficult. They are also a major source of uncertainty as they greatly dependent on experts' judgment (Moore, 2005). These concepts can be classified as follows:

- *Hazard Identification*

The identification of the hazards is mainly based on the opinion of experts, with various backgrounds, who associate each function of the considered system with the risks that result from it, the accidents to which they are exposed, the conditions likely to lead to these potential accidents, and the consequences of these accidents in the possibility where they occur. Diverse hazard identification techniques are essential to ensure that all hazards are identified. These techniques include qualitative tools such as Preliminary Hazard Analysis (PHA), HAZard and OPerability (HAZOP) or Failure Mode Effects and Criticality Assessment (FMECA), (Securius & Al., 1999).

- *Risk assessment:*

Chantelauve (2006) distinguishes the deterministic risk analysis approaches, which are interested in the consequences of an undesirable event, and the probabilistic approaches which, either, evaluate the probability of an undesirable event, or evaluate simultaneously its probabilities and consequences. It is also possible to make a distinction between the approaches which are based on the evaluation of a failure, of a cause or an impact, and approaches that make a combined evaluation of the undesirable events.

Other approaches distinguish the qualitative from quantitative analysis. The qualitative analyses mainly review the modes of failure of a system based on experts' judgments, and try to describe the magnitude of potential consequences and likelihood that those consequences will occur. The quantitative approaches aim to characterize the level of risk by extrapolating numerical values of likelihood and consequences, mainly from accidental data, and/or using various other techniques for modeling the possible outcomes of a set of events. Halfway between the qualitative and quantitative approaches, the semi-quantitative approach is mainly based on the judgment of experts and the characterization of the level of risks using ranking scales such as risks matrix. These approaches can be used jointly or separately (Shuohui, Xuejing, Shuang & Xuan, 2006).

Finally, it can be concluded that a risk analysis technique may be classified in various categories, and that the methods used generally represent a combination of various techniques.

IV.5. Example of risk-based regulation: probabilistic damage stability

Ships' stability and subdivision are covered by Chapter II-1 "Construction - Structure, subdivision and stability, machinery and electrical installations" of the SOLAS Convention. The subdivision of the ships into watertight compartments must ensure that, after a hypothetical damage of the hull, the ship remains afloat in a stable position. Two approaches exist for these problems: the "*deterministic*" approach and the "*probabilistic*" approach.

The object of the deterministic method is to ensure that ships can survive without capsizing after the flooding of a fixed number of damaged compartments. Recently, a more risk-based "*probabilistic*" concept which uses the probability of survival after collision as a measure of ships' safety in a damaged condition was adopted, and entered into force on January, 01st 2009 (IMO, 2008).

The development of this approach is based on the study of statistical data from the collision accidents analysis, which allowed establishing the probability of damages at different positions of the ship. This study generated a diagram of the damages, which can be used to make the design of the ships safer and more effective. For instance, the study reveals that the forward part of the ship is subject to the most important damages, and therefore its reinforcement will greatly improve the attained subdivision index more than the reinforcement of other ship locations, which corresponds to the Risk Assessment and Risk Control principles.

Accordingly, the new philosophy introduced by this concept is that two different ships which have the same subdivision index "A" have equal safety levels and, therefore, there is no need for special treatment of specific parts of the ship, even if they are able to survive different random damages.

This approach enables evaluating the probability of ship's survival: the evidence of compliance with the rule is attained simply if the probability of calculated survival is acceptable. This "*probabilistic*" concept, based on statistical facts of collisions circumstances, allows obtaining a much more realistic image of the endured risk for survivability after damage, as compared with the old "*deterministic*" methods whose subdivision design principles are more theoretical than practical.

However, it should be noted that, still, some deterministic "*minor damage*" principles are still used, especially for the development of passenger ships subdivision rules, in order to avoid such ships being designed with what can be perceived as "*unacceptably vulnerable spots*" in some parts of their length (IMO, 2008).

IV.6. Difficulties associated with risk-based regulations:

The evolution toward proactive risk-based regulations includes a number of difficulties that have to be overcome in order to control risks effectively. These difficulties comprise the following:

- *Control Referential*

The conformity with performance-based regulations can be more difficult to prove as compared to the more traditional prescriptive regulations. Moreover, setting a performance referential can be problematic, as the risk control options that will allow setting the adequate safety levels depend on a multitude of parameters.

This problem actually covers another dilemma related to the fact that the maritime authorities must have the adequate resources and expertise that allow, not only delivering valuable judgments concerning the effectiveness of the risk control measures and their proper implementation, but also the ability to carry analysis of the adequacy of the used safety alternatives and innovative techniques to prove whether they provide the required safety levels.

- *Increased costs for standard setting and application*

Lassagne (2004) suggests that the costs associated with risk-based regulations, paradoxically, proved to be higher than those related to the traditional simple regulations, because of the important expertise and technicality required; however, the author’s opinion is that they could never exceed the costs associated with over-regulation and prescriptive rules, once the necessary knowledge would be acquired.

This new knowledge is required at the same time from the legislator’s side, and also from the shipbuilders and ships operators parts, since they became respectively requested to provide technical solutions and safety management systems that meet the required performance and objectives.

- *ALARP concept and Public Perception*

Risk acceptance criteria are continuously subject to diverse polemics, in spite of many theoretical contributions attempting to solve this dilemma, such as the Formal Safety Assessment in the maritime field.

It is argued that setting the Tolerable, Intolerable and ALARP regions is greatly influenced by the public perception of risk. In fact, human understanding and cultures are considered to be the backbone of the risk concepts, thus the acceptance criteria will be influenced by many social factors, such as ethnic and social aspects, and even the degree of trust accorded to the experts and legislators in charge of setting the adequate protective and preventive solutions for controlling risks (Pidgeon et *al*., 2003).

Practically, Beck (2004) states that what individuals perceive as risky will depend on their values and their preferences. Thus, the ALARP border is dynamic and moves with the wellness of each country. Figure 11 illustrates, for instance, the "*Cost of Averting a Fatality*" for OECD countries. This graphic would certainly show much bigger fluctuations if developing, or other non-OECD, Countries were included.

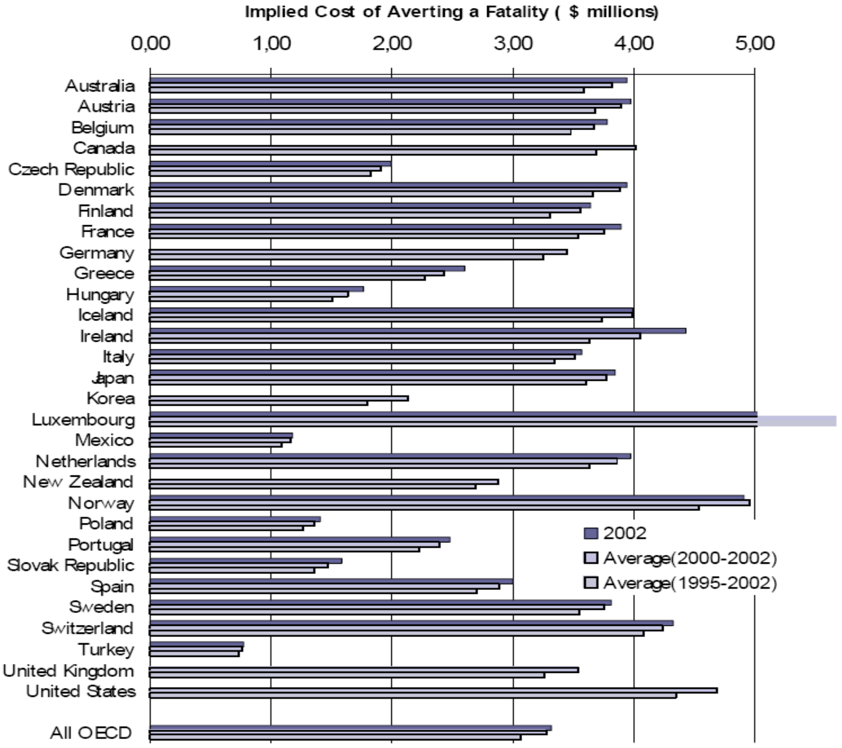

Figure 11: Cost of Averting a Fatality – OECD Countries (2002)
Kontovas C. A. (2005). *Formal Safety Assessment: Critical Review and Future Role.* Unpublished Diploma thesis. National Technical University of Athens, School of Naval Architecture & Marine Engineering, Greece

- *Dealing with uncertainties*

Aven and Vinnem (2007) define risk as being the combination of the two basic dimensions: possible consequences and associated uncertainties. Accordingly, it can be argued that if uncertainties are suppressed, there would be no risk and safety would be almost guaranteed. Nevertheless, full safety is practically unattainable, especially for the complex systems such as the maritime sector mainly because of human involvement.

Uncertainties are introduced at many levels of the development of a risk based project, for instance hazard identification and qualitative analysis are based on experts' judgments, and it is obvious that nothing is more uncertain than human opinion. Moreover, even the assignment of probability values and estimations of consequences are based on a number of assumptions and suppositions that depend on the quality and judgment of experts who often tend to make oversimplifications.

Hence, uncertainty needs to be carefully considered during the whole system safety lifecycle, and should be reflected in the decision-making process. Nevertheless, they should be progressively reduced, during the concretization of the projects, both during the risk-based rules modeling and the system engineering process. The finality is to bring the uncertainties within ALARP limits that provide acceptable confidence and reliability (Figure 12).

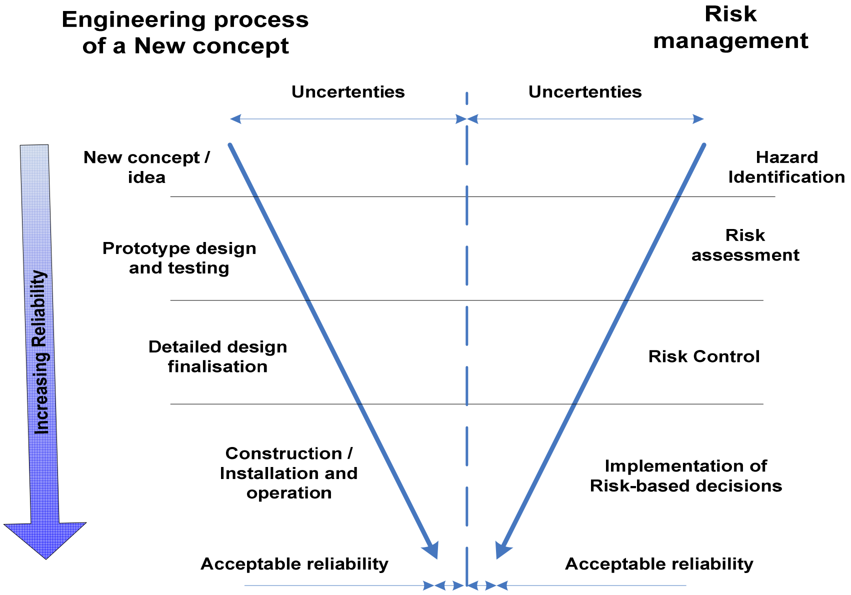

Figure 12: Evolution of the uncertainties during Risk Management and Engineering processes

IV.7. Accidental elements

Shipping is continuously subject to the risk of occurrence of accidents and incidents with significant consequences on human lives and the maritime environment. Accordingly, it is indispensable to carry out casualty investigation, in order to collect and analyse the data concerning the contributing and causation factors of the accidents, and to produce the necessary input for the foresight of threats to maritime safety.

However, casualty statistics related to ships total loss, for instance, differ from one data base to another (depending IMO, OECD, Lloyd Register and others), which distort the general image of the attained safety levels. Also, it is noted that the statistics concerning the sea events can reveal important variations, from one year to the other, as described in Figure 13 (IMO, 2005a). However, when longer periods are considered, it becomes possible to identify general tendencies, which follow a relatively decreasing trend.

Nevertheless, the new proactive concept for maritime rule-making process requires the development of unified taxonomies, and accident causation models, in addition to the common international casualty data bases, such as the "*GISIS*" developed by the IMO or the "*EMCIP*" developed by the European Maritime safety Agency (EMSA). These new approaches will allow making in depth analysis, to foresee realistic accident probabilities and impact values, which will allow reducing risk uncertainties.

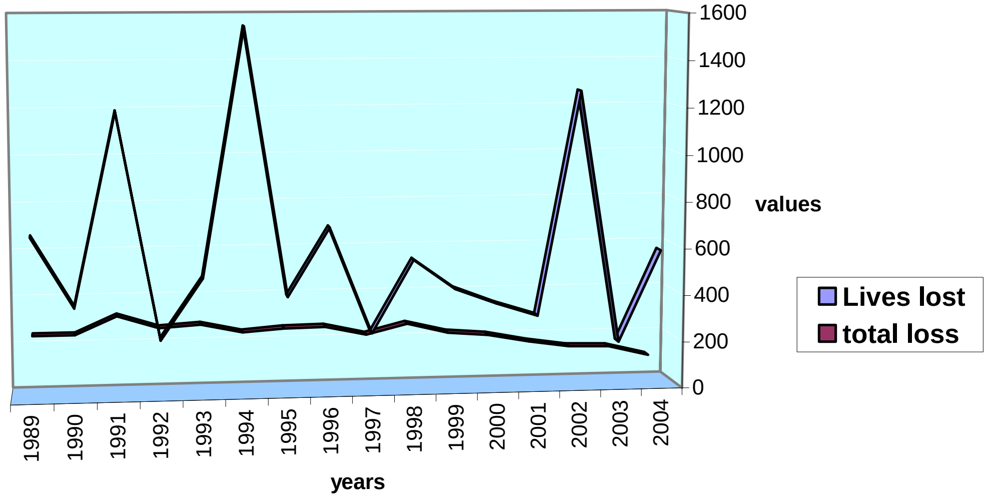

Figure 13: Total loss of ships over 100 GT and lives lost at sea 1989-2004
International Maritime Organization. (2005, February 23). *Casualty Statistics and Invistigations – Very serious casualties for the year 2003.* (FSI.3/Circ.6). London: Author.

IV.8. Chapter conclusions

This Chapter was interested in the categorization of the maritime safety regime and the contribution of risk sciences to the safety regulation.

The change from a prescriptive and deterministic approach toward an performance-based and probabilistic approach is underlined as being a shift toward proactive risk-based regulations, which represent a change from microscopic and specific approach to a more macroscopic and holistic concept.

The difficulties that would be faced by the new proactive regime were also discussed, as well as the contextual conditions that would allow apprehending the potential development of one approach or the other.

Finally, it can be argued that the regulation revolution is not perceptible in the current context; progressive evolution supported by effective training is more desirable. Thus, both traditional and risk-based approaches should continue to exist side by side and complete each other. For instance, risk management tools can be introduced in the process of elaboration of prescriptive requirements, similar to the "*risk informed*" concept related to the nuclear industry; on the other hand, prescriptive arrangement can be utilized to set the safety objectives and evaluate the conformity to the performance-based regulations.

Chapter Five

FSA: a risk-based rule making process

Chapter V: FSA: a risk-based rule making process

V.1. General context

The British initiatives following the capsizing of the "*Herald of Free Enterprise*" in 1987, led to approval, in 1997, of The Interim Guidelines for the Application of Formal Safety Assessment to the IMO Rule-Making Process "*FSA*" (MSC/Circ.829-MEPC/Circ.335), to be used within the IMO framework of rules development (IMO, 1997). Subsequently, after experimental applications such as the bulk carriers safety, the Maritime Safety Committee (MSC.74 in 2001), and the Marine Environment Protection Committee (MEPC.47 in 2002), approved the IMO "*Guidelines for Formal Safety Assessment (FSA) for use in the IMO rule-making process*" (MSC/Circ.1033-MEPC/Circ.392) (IMO, 2002), which were amended in consecutively in 2005 and 2006 (IMO, 2005b; IMO, 2006c).

The objectives of the Formal Safety Assessment process are the improvement of the maritime safety framework, including the protection of human life and the preservation of the marine environment and goods, while being based on the risk assessment and cost-benefit analysis principles. The FSA is a tool that can help evaluating new rules related to the safety of ships and the protection of the marine environment, or to carry out a comparative evaluation between existing rules and their possible amendments and improvement, in order to get the "*balance right*" between various technical and operational factors, including the human element, and the ships' safety, the protection of the marine environment and the costs effectiveness.

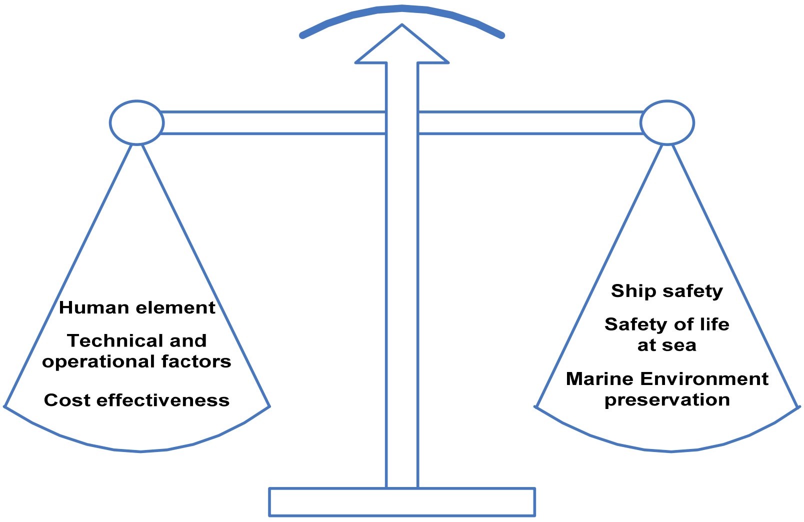

Figure 14: FSA: Getting "*the balance right*"

V.2. The FSA methodology

The FSA process consists of a structured rational and systematic methodology aiming to:

- Assess the risks related to maritime safety and the preservation of the marine environment; and to
- Evaluate the costs and benefits of IMO's alternatives for the reduction of these risks.

It comprises five steps, as illustrated in Figure 15, in addition to a preparatory stage of problem definition (IMO, 2007a). These five steps are as follows:

- Step 1: Hazard Identification (HAZID);
- Step 2: Risks Analysis;
- Step 3: Risks Control Options (RCO);
- Step 4: Cost/Benefit assessement (CBA); and
- Step 5: Recommendations for the decision-making.

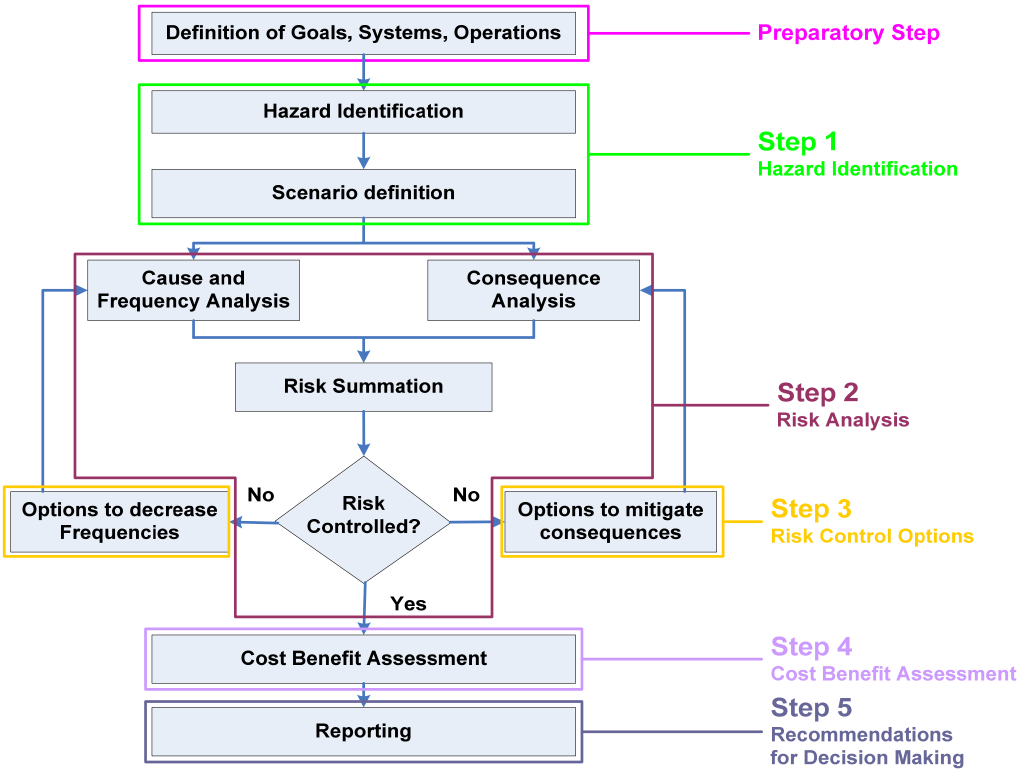

Figure 15: Illustrative flowchart of the FSA framework (IACS-MSC 75, 2002)
International Maritime Organization. (2006d, August 29). *Formal Safety assessment- Possible improvements on FSA Guidelines Submitted by Greece*. (MSC 82/INF.3). London: Author

V.2.1. The preparatory stage

The FSA process must be preceded by preliminary work to define the problem that will be assessed. It includes the definition of the type of ship to be studied, the specification of relevant constraints, and the delimitation of depth and extent of the study itself. This work will also allow gathering all available information and data related to accidents, incidents and reliability elements for the considered subject. The accuracy of this stage is fundamental for the rest of the FSA studies, as it will influence the whole rest of the project. In fact, a deficient appreciation in this stage can lead to erroneous assessments of major risks during the FSA process.

However, the consistency of the collected data, its detail and the effectiveness of the methodologies used throughout the process is often not guaranteed, which handicaps the progress of the FSA study. For instance, the FSA study on bulk carriers took about 30 months to be achieved (December 1999- May 2002) (IMO, 2006d).

In this context, in order to refine the problem and to help selecting the adequate theories and methodologies to be applied, a generic model is defined at this stage (IMO, 1998). It will not be regarded as a particular ship, but rather as a whole of systems including operation, organization, management, human factor, and equipment as illustrated in Figure 16.

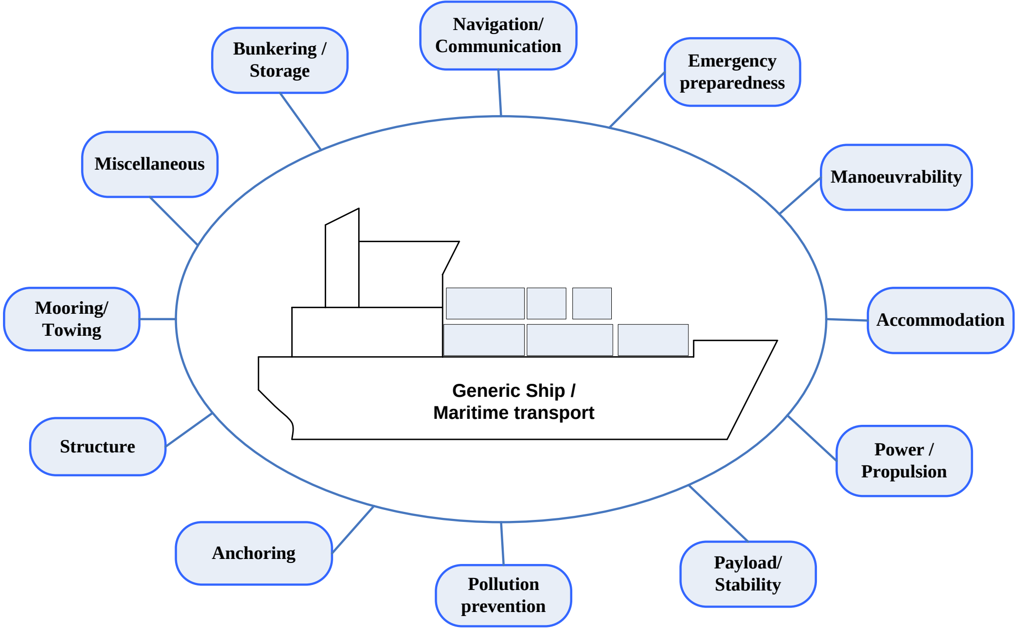

Figure 16: Principle functions related to the generic ship

Boisson, P. (1996). FSA : a new approach to safety at sea. *Bulletin Technique du Bureau Veritas*, *3*, 7-20.

V.2.2. Step 1: Hazard Identification

The object of this first step of the FSA study is to identify all potential hazardous situations related to the considered problem and to prioritize them according to their risk levels. It combines creative and analytical tools (IMO, 2006d). This combination ensures the **proactivity** of the whole process and allows avoiding the confinement to hazards that happened in the past.

This step includes two phases: a phase of identification and a phase of ranking.

- **Identification**

A Maritime Hazard can generically be defined as:

> ***Any scenario or situation that, if not contained, would present an intolerable threat to maritime safety.***

The Hazard Identification process is generally based on the opinion of a group of experts, from various fields, who associate each function of the considered system with the risks which result from it, and the accidents to which they are exposed, the conditions likely to lead to these potential accidents, and the consequences of these accidents in the possibility where they occur (Lassagne, 2004) Several standardized techniques can be used, according to the studied problem: such as HAZOP, FMECA or What If theories (see Annex A).

Kontovas, Psaraftis & Zachariadis (2007) notice that for most of the accomplished FSA studies, hazard identification has mainly, if not exclusively, been based on historical data, because it is deemed that where historical data is available, there is no need to generate scenarios in order to model the risk profile. However, the use of historical data alters the proactive philosophy behind the whole process. Thus, this tendency could not be used for innovative designs or probabilistic failures modeling, where effective scenarios have to be developed using more elaborate tools.

Finally, it can be argued that, since only the hazards that have been identified during this step would be analyzed during the whole FSA process, the accuracy and exactness of this stage are vital for the rest of the study.

- **Ranking**

The second goal of this step is developing a ranking list of the identified hazards, generally starting from the most severe scenarios, to end by eliminating the scenarios that are judged to have negligible significance. The evaluation uses qualitative tools at this stage of the analysis. The identified hazards are classified using an index of frequency vs. severity, and generally allows generating a qualitative risk matrix that represents a visual evaluation of the risk associated with each hazard.

This step is considered to be a less formal one, mainly based upon the "*know how*" of the experts and their "*good sense*". Thus, mathematical and behavioural approaches would be necessary to evaluate these opinions. Accordingly, the decision making for this step uses tools such as the "*concordance coefficient (W)*" to evaluate the correlation between the experts' estimations. This coefficient is calculated on the basis of a formula that correlates the group of experts' ranking of a number of hazards, and varies between 0 and 1. Hence, it is accepted that the experts attain good agreement where this coefficient is $W>0.7$ (IMO, 2006d). Kontovas (2005), states that, mostly, a group of 10 experts allows having a good stability of this coefficient, and that the more hazards have to be studied the less number of experts should be used.

Moreover, as proposed by Dourmas, Nikitakos and Lambrou (2007), more scientific numerical approaches such as the Bayesian network models or the fuzzy logic theory, should be developed further, to analyze and evaluate the experts' decision-making framework.

V.2.3. Step 2: Risk Analysis

The objective of this stage is to make a detailed analysis of the hazards identified in the previous step, especially the most severe ones, in order to identify and quantify the causes and consequences of the high risk areas. FSA guidelines suggest the use "*Risk Contribution Tree (RCT)*" concept at this stage. This model combines Fault Trees and Event Trees, which respectively allow displaying graphical representations of the logic combination of causes which lead to an undesirable event, and how the consequences of accidents may develop to result in different magnitude of loss. The quantification requires accidental reliability data, and any other suitable source of information, particularly, valuable expert judgments.

Also, it is recommended that risk could be expressed in two categories, namely, the "*individual risk*" and the "*societal risk*". The first category estimates the risk for a particular individual at a particular location, in order to ensure that persons who may be involved in ships' accidents are not exposed to excessive risk. The second category displays a more comprehensive picture of particular risks from ships to societies as a whole, taking into account their geographical distribution. Societal Risk is generally expressed in the form of F-N curves which represents the frequency (F) in function of a number (N), or more, of fatalities. These F-N diagrams allow displaying a more realistic picture of the societal perception of risk, as 1000 accidents that kills 1 person are not be perceived as equivalent to 1 accident which kills 1000 persons for instance (society is less willing to accept the latter case). An example of FN diagram is given in Figure 17.

Finally, it can be argued that the units used in the FSA studies submitted to IMO are mainly the Potential Loss of Life (PLL), number of fatalities, ship loss, environmental harm or frequency of casualties. This can cause some confusion, therefore a common quantification unit would be recommended in this stage; this unit could be similar to the universal unit used in the CLC or Fund conventions.

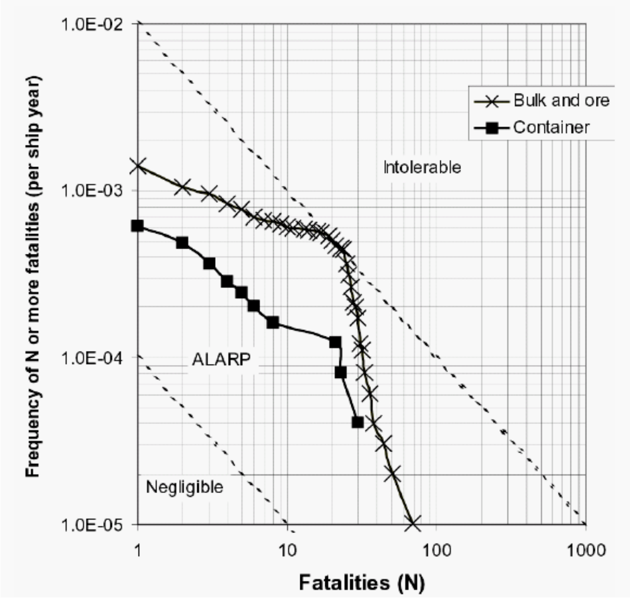

Figure 17: Example of F-N Curve for different types of ships

Skjong, R. (2002). *Risk acceptance criteria: current proposals and IMO position*. Retrieved June 25, 2009, from the World Wide Web: http://research.dnv.com/skj/Papers/SkjValencia.pdf

It can, regrettably, be noted from Figure 17 the high likelihood that the total number of crew members of bulk carriers (approximately 20 persons) looses their lives in the unfortunate event of casualty.

V.2.4. Step 3: Risk Control Options (RCOs)

According to the FSA guidelines (2007), the purpose of this step is generating: “effective and practical RCOs and comprises the following four principal stages:

.1 focusing on risk areas needing control;
.2 identifying potential risk control measures (RCMs);
.3 evaluating the effectiveness of the RCMs in reducing risk by re-evaluating step 2;
.4 and, grouping RCMs into practical regulatory options.”

Thus, this step consists in identifying possible Risk Control Measures (RCMs), and gathering them to establish practical regulatory options (RCOs). The Guidelines suggest focusing on the following aspects:

- Firstly, on prioritizing accidents for which the **risk level** is unacceptable;
- Secondly, on the **probability** for the branches of the RCTs which present strong probabilities of occurrence whatever are their consequences.
- Thirdly, on the **gravity**, by identifying the fields of the RCTs which contribute to very severe consequences; these fields have also to be evaluated whatever is their probability;
- Finally, on the **reliability**, by identifying the fields for which the RCT indicates great uncertainty with regard to the endured risk.

Subsequently, RCOs are analyzed during structured group examination, in order to estimate the risk reduction (ΔR) associated with each RCO. Dourmas, Nikitakos and Lambrou (2007) state that estimating ΔR in a numerical mode, according to historical data, cannot be proactive in the true sense of the term. Thus, it is suggested that the estimation should rather be based on the use of risk matrices and qualitative approaches to ensure the proactive aspect of the whole concept.

This step will allow generating:

.1 a set of RCOs which will be assessed for their risk reduction and cost/benefit effectiveness;

.2 a list of interested parties involved in the identified RCOs; and

.3 a list illustrating the interdependencies and possible combinations between the identified elementary RCOs.

V.2.5. Step 4: Cost Benefit Analysis (CBA)

In this stage, the costs associated with the implementation and maintenance of each RCO, generated during the previous step, will be evaluated for the whole lifetime of the vessel, as well as the benefits gained for the same time period. This step marks the end of the qualitative approach used in the previous stages, as quantitative tools will now be used to estimate and compare the cost effectiveness of each RCO, in terms of cost per ΔR unit. These calculations are the basis for the decision-making on the RCOs.

Several indexes are used to express the cost-effectiveness ratio related to the human life safeguard. Indeed, IMO prefers to use the term "*Cost for averting a fatality (CAF)*" instead of "*cost of a human life*" or "*cost of a fatality*" as human life can not be valued. Thus, indexes such as "*Gross Cost of Averting a Fatality (GCAF)*" and "*Net Cost of Averting a Fatality (NCAF)*" are used. Other indexes, such as the "*Cost of Averting a Spill Criterion (CATS)*", which are based on the damage and the impacts on the environment and installations, are also utilized for the analysis of the costs/benefits related to such questions (Kontovas, Psaraftis & Zachariadis, 2007). Subsequently, the cost effectiveness of the RCOs is calculated on the basis of such indexes. The Gross and Net CAFs are calculated as follows:

$$GCAF = \frac{\Delta C}{\Delta R}$$

$$NCAF = \frac{\Delta C - \Delta B}{\Delta R}$$

Where:

- ΔC is the cost of the considered RCO per ship.
- ΔB is the economic benefit per ship gained from the implementation of the RCO (may also include the pollution prevention and the prevention of a ship's total loss) (IMO, 2004a).

- ΔR is the reduction of the risk per ship, in terms of a number of fatalities averted, rising from the implementation of the RCO.

Francescutto (2005) proposes an alternative concept, frequently applied by the HSE in modern risk assessments, commonly called implied cost of averting a fatality (ICAF), and which expresses the risks and costs as a ratio as follows:

$$\text{ICAF} = \frac{\text{Net cost of the measure}}{\text{Reduction in fatality risks}}$$

This ratio is dimensional, e.g. using monetary units such as £ or $ spent per averted fatality. This approach avoids "losing" the valuation of risks to life within the calculation, and keeps it explicit. However, the choice of adequate ICAF must still be decided, in order to decide which RCO to adopt.

The advantages and weaknesses of the CBA analysis are summarized in Table 7:

Table 7: Advantages and weaknesses of the CBA Analysis

Advantages	Weaknesses
Makes the safety vs. cost analysis process explicit and traceable	Difficult to estimate the value of life, the process may be considered unethical and CBA results may not be widely accepted and can provoke hostile reactions.
Standardization of safety investments	Many factors cannot be adequately converted into monetary values, and should therefore be given equivalent weight in the decision-making process.
Ability to evaluate the costs and benefits of a specific measure without knowing the risks on the whole installation.	Costs for averting fatalities are based on Life Quality Index (LQI), which is dynamic and changes with the wellness of the countries, thus, ICAF should continuously be reviewed.
Gives a clear image of the investment for the implementation of each individual RCO that helps decision-makers.	Sensitive, some assumptions made during this step may greatly change the results of the whole FSA process

V.2.6. Step 5: Recommendations for Decision-Making:

In this final step of the FSA study, final recommendations are formalized and forwarded to decision makers aiming for safety improvement. The recommended RCOs should both be “cost effective” and reduce the risk to the “desired safety levels”. The review of the FSA studies presented to IMO allows noticing that they at least:

- Draw up the list of the principal hazards, risks, costs and benefits identified during the evaluation;
- Explain the basis for the important assumptions, the extent and the principal limits of the study, the models and the techniques used for the evaluations and the recommendations,
- Describe the sources, and the main uncertainties associated with the evaluation and/or the recommendations,
- Describe the composition and competences of the group of experts who were involved in the FSA study.

V.3. Human factor

The announced IMO’s objectives for the 2000s include emphasizing the importance of people for developing a maritime safety culture. Accordingly, shifting toward proactive maritime safety implies the need for better understanding the role of the human element in accident causation and consequence mitigation, in order to enhance the rule-making framework. In fact, it is stipulated in the FSA guidelines that: “*Human element issues [……] should be systematically treated within the FSA framework, associating them directly with the occurrence of accidents, underlying causes or influences. Appropriate techniques for incorporating human factors should be used*” (IMO, 2007a).

Particularly, the IACS gave great importance to the human factor and its structured incorporation into the FSA guidelines. Thus, the IACS developed a “*Draft Guidance on Human Reliability Analysis (HRA) within Formal Safety Assessment (FSA)*” (IMO, 1999) for its incorporation in the FSA guidelines. This proposal was finally integrated into the FSA guidelines (IMO, 2002).

The 2007 FSA guidelines' appendix named "*Guidance on Human Reliability Analysis (HRA)*", proposes the incorporation of the human factor into the FSA studies, by the use of Human Reliability Analysis Techniques, which were developed originally by the nuclear sector (Chantelauve, 2006). These techniques provide a support at the first three stages of the FSA methodology, as illustrated in Figure 18. The HRA process usually includes the following stages:

1. Identification and analysis of the key tasks;
2. Identification and analysis of the possible human errors; and,
3. Quantification of human reliability.

The appendix mentions that substantial benefit can be drawn up from the qualitative use of HRA techniques during the stage of hazard identification. It also recognizes that the data available for a quantification of human reliability are rare, and that the experts' judgments are the more adapted means for the quantification.

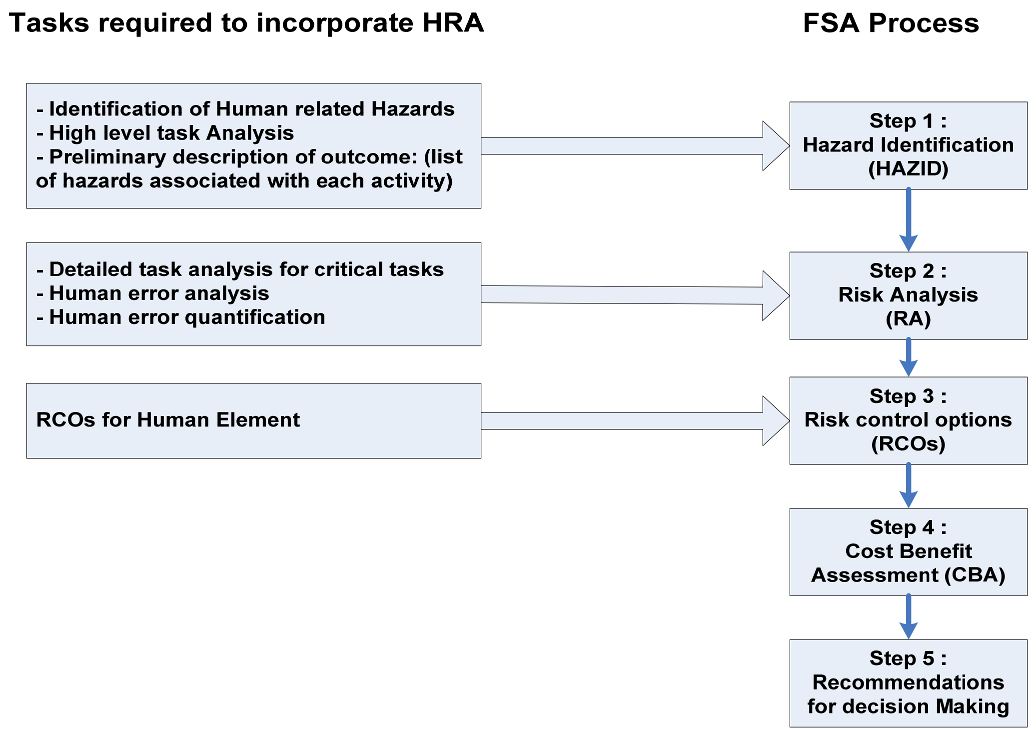

Figure 18: Incorporation of HRA into the FSA process

International Maritime Organization. (2007a, May 14). *Formal Safety assessment - Consolidated text of the Guidelines for Formal Safety Assessment (FSA) for use in the IMO rule-making process (MSC/Circ.1023−MEPC/Circ.392)*. (MSC 83/INF.2). London: Author.

V.4. Discussion and conclusions

The formal safety assessment process can be considered to be the first rational attempt of using the risk analysis approach for the IMO rule making framework. The main objective of this concept is to provide a transparent and clearly justified decision-making process, which promotes the proactive safety regulation concept in opposition to the existing system, which functioned only in reaction to accidents. Accordingly, several FSA studies were carried out, associating many partners, particularly the European Union and IACS members (for instance the SAFEDOR and HARDER projects), for different types of ships such as high speed craft, bulk carriers, container ships and LNG carriers (IMO, 2009).

These studies resulted, for some applications, in new requirements such as the amendments to the High Speed Craft Code (HSC Code), to the SOLAS Chapter XI related to safety of bulk carriers (especially the *Double Side Skin "DSS"* requirements), and the new regulations concerning the helicopter deck on board passenger ships, even though some of these regulations are still creating polemics after their adoption.

However, the whole FSA process is still meeting a number of oppositions, associated with the perception that the FSA is likely to lead to considerations which are disconnected from the reality, especially because of its dependence on experts' judgments for the Hazard Identification, Risk Reduction calculations and cost benefits analysis. In fact these steps depend on qualitative approaches, which can suffer from bias, and reduced credibility because of the associated uncertainties, and the lack of confidence inside the IMO bodies and member states.

Moreover, as opposed to the safety case, which is enforced by the UK on British offshore installations, the FSA studies would generate proactive recommendations that will be implemented on board international fleets. This aspect is problematic in itself, as it will be difficult to convince member states, which have various ethnics, diverse cultures and especially different interests, that the proposed step-forward regulations would bring the risk within acceptable limits. In fact the perception of these acceptable risk limits differs from one society to another.

Finally, it can be argued that, in spite of these oppositions, the FSA process is still an indispensable tool that can even be used in proactive safety aspects, other than the rule-making process, such the individual assessment of safety levels for performance-based regulations or to support the “Goal Based Standards” framework. In fact, the generalization of the FSA process application for these innovative maritime safety approaches, would allow identifying its limitations, which will permit reducing the uncertainties, increasing the reliability of the whole process, and essentially will promote the generation of effective improvement measures.

Chapter six

Aspects of the proactive rules application

Chapter VI: Aspects of the proactive rules application

VI.1. Introduction

In the 2000s, new performance-based concepts were introduced by the IMO for the application of its instruments. These concepts are mainly established by SOLAS regulation II-2/17 related to the Fire Safety Design and Arrangements, and the Goal Based Standards for shipbuilding. In this Chapter, a review of the regulatory framework of these concepts will be provided, and the "*state-of-affairs*" concerning the application of these approaches will be investigated.

VI.2. Alternative Fire Safety Design and Arrangements

VI.2.1. General Context

Traditional fire safety regulations, which were mainly created in response to specific accidents, hardly became applicable to innovative ship design and building technologies. Consequently, in 1998, the Fire Protection Sub-Committee (FP42) created a working group in charge of a comprehensive review of SOLAS Chapter II-2, which would consider the introduction of more performance-based instruments based on risk management theories. In this context, the revised Chapter II-2 of SOLAS Convention was adopted in 2000, and entered into force on July 1st, 2002, including a new Regulation II-2/17 related to the alternative design and arrangements.

According to this Regulation, the fire safety design and arrangements can deviate from the prescriptive requirements set out in the other parts of Chapter II-2, provided that all fire protection objectives and the functional fire safety requirements are fulfilled. It is also required that when the fire safety design and arrangements deviate from the prescriptive requirements, an engineering analysis, and an evaluation and approval of the alternative design and arrangements should be carried out.

Thus, in order to provide uniform guidance for the proper application of these rules, the Maritime Safety Committee approved, in its 74th session (2001), the Guidelines on Alternative Design and Arrangements for Fire Safety (IMO, 2001a), which were amended in 2005 (IMO, 2005c).

These guidelines give additional descriptions of the methodology to be followed when carrying out engineering analysis and approval of innovative fire safety design and arrangements which deviate from the prescriptive rules of SOLAS Chapter II-2.

VI.2.2. The new proactive fire safety framework

Since 2002, the new SOLAS Chapter II-2 "*Construction - fire protection, detection, extinction*" enables the designers to conceive arrangements which do not fulfill the prescriptive requirements. However these alternative designs should at least meet the fire safety objectives of Chapter II-2, which can be summarized as follows:

- Preventing the occurrence of the fire and the explosion;
- Reducing the risk caused by the fire to human life;
- Reducing the risk of damage caused by the fire to the ship, its cargo and the environment;
- Confining, controlling and removing the fires and explosions in the compartment of origin; and,
- Providing adequate and easily accessible means of evacuation for the crew and the passengers.

Chantelauve (2006) proposes that the fire safety objectives can be illustrated in a "*Fire Safety Tree*" Concept as follows:

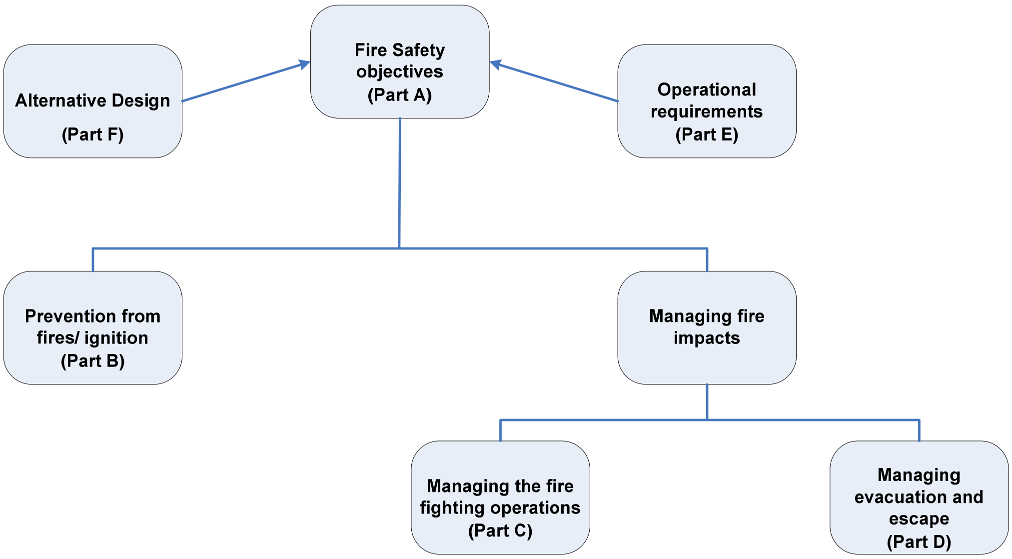

Figure 19: SOLAS Chapter II-2 "*Fire Safety Tree*"

Accordingly, in order to achieve the fire safety objectives, functional requirements are incorporated in Chapter II-2 which require:

- The Division of the ship in main vertical and horizontal zones;
- The Separation between accommodation areas and other spaces;
- The Restriction in the utilization of combustible materials;
- The Detection, confinement and extinction of fires in the zone of origin;
- The Protection of the means of evacuation and access for the fire control;
- The Availability of the extinguishing equipment; and,
- The Minimization of the possibility of ignition of flammable cargo vapors (Chantelauve, 2006).

Therefore, in order to be in conformity with the SOLAS Chapter II-2, ships have to satisfy one of the three following options:

1. Being designed and equipped in conformity with the prescriptive requirements of the whole Chapter II-2;
2. Being fully designed and equipped according to the regulation II-2/17 "*alternative Design and arrangements*", the design and the arrangements of the ship, as a whole, should be re-examined and approved according to same regulation; or,
3. Parts of the design and arrangements of the ship were re-examined and approved according to Chapter II-2/Part F Regulation 17, and the remaining parts are in conformity with the related prescriptive requirements.

VI.2.3. IMO Guidelines for the approval of Alternatives Design

The analysis intended to prove that the proposed alternative design or arrangements achieve safety levels which are, at least, equivalent to those ensured by the prescriptive regulations and standards of SOLAS Chapter II-2. The concept is based on a two stages principle: a qualitative preliminary stage and a quantitative stage. These stages are examined hereafter:

- Qualitative preliminary stage

The preliminary analysis is intended to define the concept in qualitative terms, i.e. to clearly define the area of application of the considered design and arrangement and the rules and standards related to them. It also covers the examination of the objectives and functional requirements of the regulation, in order to generate fire scenarios and any other proactive testing concepts, which should mainly be based on the risk management and control science. The testing concept should also take into consideration the external elements such as human factors, vessel operations, and management (IMO, 2001a)

- Quantitative stage

The quantitative analysis allows making a technical evaluation of the alternative arrangements and carrying out adequate tests in quantitative terms, i.e.:

- Quantifying specific fires of reference and fire scenarios (including elements such as heat transfer, smoke, flame heights and generation of toxic gases),
- Developing performance criteria based on the acceptable prescriptive performance criteria;
- Ensuring the adequacy of the selected safety margins; and,
- Evaluating the performance of the trial alternative designs taking into consideration the selected performance criteria.

Risk analysis is a major component of the alternative design approval process, both for identification of fire scenarios during the preliminary analysis, and during the quantitative analysis. The objective is not to build a design with "*zero risk*", but to achieve safety levels that are at least equivalent to the traditional arrangements.

Likewise the FSA process discussed in the previous chapter, the historical and statistical data are also of a great importance, in order to estimate the reliability of the system. Also the same techniques, such as "*PHA*", "*FMECA*", "*HAZOP*", and group of experts brain storming and judgments are used. Therefore, the FSA framework could provide an efficient analysis tool for maritime administrations and other approval bodies in charge of the analysis and approval of an innovative design or arrangement for maritime fire safety.

VI.2.4. Principal Applications of "alternative design and arrangements"

The principal applications of "alternative design and arrangements" have, until now, mainly concerned passenger ships. A review of the reports related to the subject which were submitted to the IMO, allows noticing that three categories of arrangements have been introduced as follows:

- Movable fire walls in main vertical zones

Many cruising ships have "*promenades*" and "*atriums*" containing shopping centers, public cafees, restaurants and other public spaces. These atriums extend on the full length of the ship. However According to SOLAS Convention an A60 transversal vertical bulkhead is required every 48m in order to divide the ship in main vertical zones.

The proposed solution of "***Movable fire walls in main vertical zones***", ensure the division of the ship in vertical zones, when they are in the closed position, but they cannot satisfy other prescriptive requirements, especially related to the "*Openings in Main Fire Bulkheads*", because of technical and economical feasibility reasons. Accordingly, an FSA study of the identified risks have been carried out, which included elements such as temperature, smoke, toxicity, visibility and the evacuation time. This study allowed generating the necessary recommendations and measures for ensuring that the proposed safety levels are equivalent to those specified in SOLAS regulation II-2/9.2.2.1 (IMO, 2007b).

The comparative engineering analysis of the performances shows that the alternative design provides safety levels which are equivalent to the traditional design. Thus it becomes possible to have a pleasant walk over the entire length of the ship.

- Lift with no separate machinery room

The SOLAS regulation II-2/9.2.2.5 "*Protection of stairways and top spins in accommodation area*" requires the machinery room to be separated from the lifts located within the limits of the stairways. The performance of the alternative arrangement was compared with an equivalent prescriptive design, where the machinery room is located at the top or in the lower part of the lift cage.

The comparative evaluation shows that the alternative design is better than a prescriptive design with a top machinery room, and definitely better than a prescriptive design with a bottom machinery room (IMO, 2004b), as illustrated in Table 8. The alternative design allows, also, making great profits in terms of gained space.

Table 8: Comparison of safety performance for ship's lifts arrangements

Effect	Alternative design	Commonly used acceptable prescriptive designs	
		Machinery room above	Machinery room below
Heat	Better	Reference	Worse
Smoke	Better	Reference	Worse
Toxicity	Better	Reference	Worse
Reduced visibility	Better	Reference	Worse
Evacuation time	Better	Reference	Worse

International Maritime Organization. (2004b, December 08). *International Convention for the Safety of Life At Sea, 1974 – Alternative arrangements accepted under regulation II-2/17 Lift with no separate machinery room*. (SLS.14/Circ.235). London: Author.

- Class B-15 bulkheads in cabin corridor

Ship builders try to design cabins, which are increasingly more luxurious, in order to satisfy the requests of their customers. In parallel they have to be in conformity with prescriptive fire safety requirements, such as SOLAS regulation II-2/9.2.2.2 related B-15 Bulkheads in cabin corridors. The proposed alternative arrangement provide safety levels equivalent to the prescriptive requirement of having "*continuous B-15 walls and ceiling construction (forming B-15 tunnel)*", and that give flexibility to designer for making luxurious designs (IMO, 2007c).

Therefore, it can be argued that these openings within the SOLAS Convention which allow designers to conceive innovative fire safety alternatives are still not effectively exploited. Mainly three alternatives have been developed, and become similar to traditional prescriptive regulations, as they are strictly applied by designers on new ships, even though they were developed to deviate from prescriptive regulations. Consequently, performance based regulations can be regarded as giving the designer the opportunities to develop a new kind of prescriptive regulations that fit his conception orientations, and provide equivalent safety levels.

VI.3. Goal Based Standards

VI.3.1. Background

Alternative design and arrangements are made possible under various IMO instruments, such as:

- The MARPOL Convention regulations I/5 on equivalence and I/19 related to the acceptance of alternative design of oil tanker provided that equivalent protection levels against pollution in the event of grounding or collision are provided compared to the prescriptive design;
- The latest amendments to SOLAS chapters II-1 and III (regulations II-1/55 and III/38) which will enter into force on 1 July 2010 (IMO, 2006e), related respectively to the alternative design and arrangements of machinery and electrical installations, and life-saving appliances and arrangements, in addition to the previously discussed SOLAS regulation II-2/17 related to the alternative fire safety design and arrangements; and finally,
- Articles 8 and 9 of the International Convention on Load Lines (LL 66) respectively related to equivalent arrangements and approvals for experimental purposes.

However, the most ambitious development toward a risk-based approach philosophy in the design and approval of new ship construction was proposed to the 78th MSC Committee in February 2004 jointly by Greece, the Bahamas and the IACS. This proposal is related to the development of standards for the construction of ships entirely based on performance and safety objectives, namely the "*Goal-Based Standards*" (GBS); the accent being placed for the moment on the ships' structural requirements (IMO, 2004c).

It can be argued that this proposal is a fully "***proactive initiative***" as it has not been developed to respond to a particular disaster, but rather to make use of the latest scientific tools and theories that promote innovation, and provide flexible and cost-effective ways of dealing with safety, especially for the knowledge-intensive and safety-critical ships.

VI.3.2. The five-tier GBS system

The Goal-Based Standards approach has been developed on the basis of a five-tier system, as illustrated in Figure 20. The first three tiers constitute the core of the concept and consist of:

- ***Tier I***: defining the safety goals to be achieved and controlled during the design, construction and the whole life cycle of the ship, in terms of environmental performance, structural safety and construction quality.
- ***Tier II***: identifying functional requirements that will ensure the fulfillment of safety goals described in tier I and would represent benchmarks for audits of protection against corrosion or structural and residual resistance.
- ***Tier III***: setting the criteria of checking the conformity with the safety objectives-based standards at the stages of design, validation of construction and follow-up throughout the service life of the ship, and for the certification.

Tiers IV and V respectively correspond to the technical guidelines and procedures developed by the IMO, Administrations and/or Recognized Organizations (ROs) for the design of ships to meet Objectives of tiers I and functional requirements of Tiers II; and, the industry's common standards and practices applied during ships' design and construction (Hoppe, 2005).

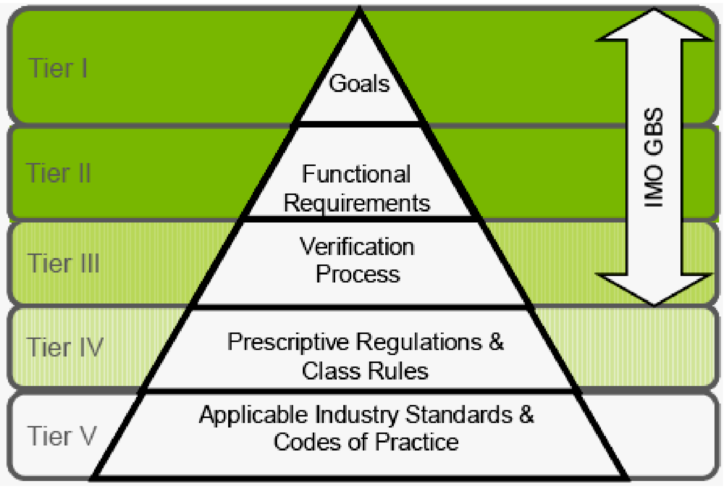

Figure 20: IMO GBS system

Papanikolaou, A. & Alissafaki, A.(2005). Introduction to the Goal-Based Standards. *Thematic Network SAFER EURORO II, Newsletter*, 5. Retrieved June 10, 2009, from the World Wide Web: http://www.safereuroro.org/restricted/SAFER_EURORO_II-Deliverable_D7-Draft.pdf

VI.3.3. Recent developments in the GBS system

In February 2009, the IMO published the "*Guidelines on approval of risk-based ship design*" for Goal-Based New Ship Construction Standards. This document contains general principles, which are intended to be used, by authorities and design teams during the process of approval of risk-based designed ships, in all areas of ship design. It is also deemed that this document provides a useful tool when dealing with the approval of alternative designs and arrangements (IMO, 2009).

More recently, the MSC approved the "*international Goal-Based ship construction standards for bulk carriers and oil tankers*", and finalized a proposal of amendments to SOLAS Chapter II-1 making the application of these Standards mandatory, to be considered at the next MSC 87th session, with a view to adoption.

The future amendments would introduce a new SOLAS regulation II-1/3-10 on "*Goal-based ship construction standards for bulk carriers and oil tankers"* for oil tankers and bulk carriers of 150 m or more. This regulation would require new ships to be "*designed and constructed for a specified design life, and to be safe and environmentally friendly, in intact and specified damage conditions, throughout their life*" (IMO, 2009).

VI.4. Comments and Conclusions

New safety compliance approaches such as the SOLAS regulation II-2/17 related to the "*alternative design and arrangements*" or the "*Goal-Based Standards*" (GBS) constitute a logical result of the initiatives undertaken for reforming the maritime safety regulation methodologies, under the new knowledge gained from advancement in technology and the great development in the field of risk analysis.

This new approach created a dynamic safety regime, capable of reacting to changes in engineering practices and evolving technologies. Thus, the IMO Goals and Performance Safety Standards should be sensitive to the technological progress and innovation, and also to the changes in public and political risk perception.

Thus, the biggest dilemma of the whole process is setting transparent and verifiable criteria that reflect the safety goals and performances, during the whole life-time of the ship.

Moreover, compliance with function and performance-based requirements, such as the GBS approach, can be a complex and "*knowledge-intensive*" process. Thus, the monitoring of the design, building and operation stages would require the involvement of highly skilled naval architect having adequate risk science knowledge. Consequently, the following options occur:

- Maritime Administration would upgrade their manpower, by employing highly skilled marine surveyors who have the necessary naval architecture and risk management backgrounds, and providing them with new control tools and equipment, necessary for the approval and monitoring of innovative safety alternatives. Consequently, surveying costs would increase and ship-owners would, probably, support these extra-charges; or,

- More responsibility would be delegated to the Classification Societies, especially the IACS members, who are major actors behind the development of these new proactive safety alternatives. In fact, IACS members already acquired great expertise in this field, and have the necessary specialized manpower able to carry out this job. Thus, it is much probable that Flag States, which already delegated statutory surveys to recognized organizations, would neither monitor new Goal-Based Standards, nor endeavor to set performance criteria that fit their real safety objectives, but rather place "*Blind*" confidence on their ROs, with all the possible consequences of this process;

An evasive attitude can also be adopted by what can be called by "*less performing*" Flags, which would use these new concepts for attracting "*Sub-standard*" ship-owners, by adopting low safety criteria and delegating the approval and monitoring processes of the Goal-Based Standards to "*2nd range*" ROs. This attitude can have dangerous repercussions on the safety levels, as Port State Authorities could not refuse safety standards that were approved under Flag State's criteria.

Thus, the whole GBS and performance-based philosophy can be threatened by these Flag States, and new instruments should be given to Port State Authorities, such as refusing the right to enter their ports to the ships built and operated under the Authority of Flag States, which have "*non-credible*" GBS or alternative arrangements approval methodologies.

Consequently, the new proactive safety approaches would require a new transparent and auditable surveying regime, which allows ensuring that ships are built and operated under reasonable safety standards, during their whole life cycle. This initiative will be discussed in the next VIIth Chapter.

Chapter seven

Risk-based Ship Inspection Regime

Chapter VII: Risk-based Ship Inspection Regime

VII.1. Introduction

The move toward a proactive maritime safety regime requires ships to be designed, built and operated according to safety goals and objectives. Accordingly, the aim of the new safety approach is defining clear performance criteria that can be measured, monitored and verified by Flag States, at any time during the whole life cycle of the ship.

Thus, designers get the flexibility to introduce concepts with a high degree of novelty, and the freedom to benefit from the latest advances in technologies and risk analysis theories, which makes today's ship design complex, and some times ahead of the traditional rules and regulations.

Nevertheless, at the last shackle of the safety chain, namely safety inspection and surveying regime, ships are still surveyed according to prescriptive requirements, dictated by relevant IMO instruments and Classification Rules. However, this prescriptive approach does not encourage the analysis of the specific threats to the ship's navigability, the consequences of damage and the risks of structural deterioration.

It also does not allow benefiting from good operating practice and managing inspection resources to focus on the areas of greatest concern (HSE, 2004). Consequently, a more flexible inspection approach using risk concepts for managing the ships' inspection plan, can be considered as an indispensable component of the proactive maritime safety philosophy.

Similar to the GBS concept, this conceptual attempt for studying a risk based ship inspection regime will be limited to the ships' structural inspection, and will mainly be based on the experienced gained in this field by the nuclear and offshore sectors.

VII.2. Motivation for Risk Based Inspections

Prescriptive inspections are mainly time-based. The periods of inspection are based upon estimation form previous experience and historical data analyzed at the time of setting the regulations. For instance, ship's structures are subject to annual, intermediate or special surveys. The scope of these surveys covers the deck, hull plating, watertight penetration, cargo and water ballast capacities and special survey such as thickness measurements. These surveys are broadly carried out independently of the level of risk caused by the failure of each individual element, or the quality of ship operational and managerial policy. Also, the outside of the ship's bottom has to be inspected in dry dock twice every 5 years with a maximum period of 36 month between two consecutive inspections, without giving consideration neither to the trading zone nor to the quality of paints and hull maintenance systems.

Nevertheless, today's technological advances offer high quality paints that can resist for periods greatly exceeding the mandatory 36 months. Further, new communication and video systems allow making in-water investigation of probable hull damages, for identifying possible failures mechanism of the immerged parts of the structure. But ship-owners who adopt these innovative technologies, or implement efficient operational and managerial safety policy, do not get any benefits from their investments, in terms of flexibility of inspection period.

Thus, it can be argued that the current prescriptive time-based inspection regime does not encourage innovation and improvement of the operational and managerial performances over the "*compliance*" levels, as the periods of inspections consider a unique empirical value of failure likelihood, which is not influenced by the adopted technological or operational systems.

Consequently, the IMO adopted resolution A.744 related to the Enhanced Survey Program (ESP) for Bulk Carriers and Oil Tanker (IMO, 1993). This resolution can be considered to be a first step forward to improve the efficiency of ships structure inspection framework. However, it can not be considered as a risk based approach because it only consider the condition of the ship for planning the survey cycle independently of other parameters such as operating practices.

Therefore, the efforts of IMO to move toward a proactive inspection regime should include the use of risk based methodologies that allow generating rational and efficient inspection plan. The progression toward a proactive inspection regime is illustrated in Figure 21.

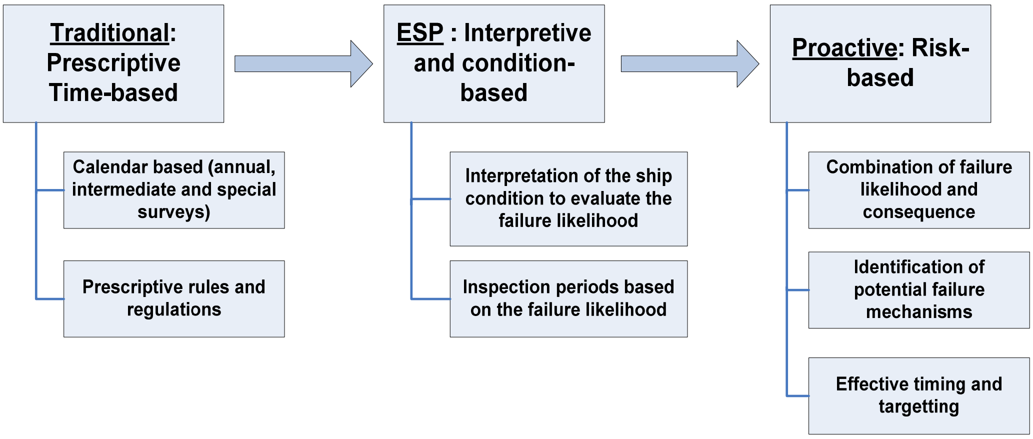

Figure 21: Evolution toward proactive Risk-Based Inspection regime

VII.3. Theoretic foundations

The purpose of ship's Risk Based Inspection can be defined as:

***Identifying the potential deterioration mechanisms, and threats to the navigability of the ship and the integrity of its structure, and assessing the likelihood and consequences of potential failures*.**

This definition comes from the proper definition of the term risk, which is mainly a combination of consequences of failure (CoF) and likelihood of failure (LoF):

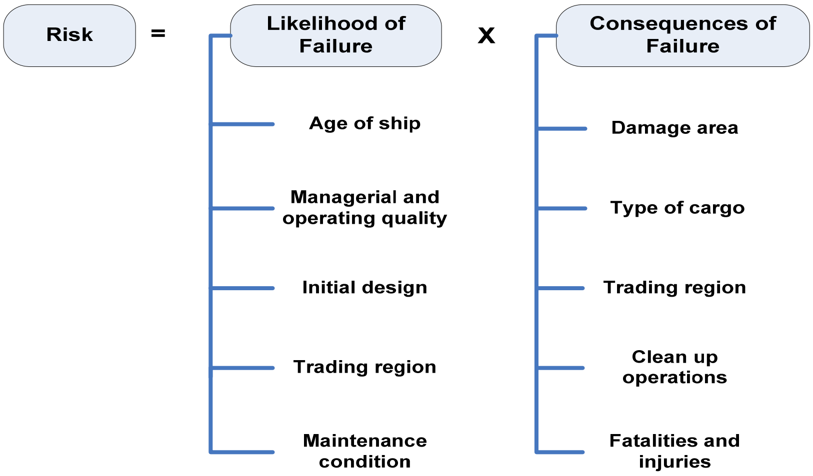

Figure 22: Risk evaluation for ship inspection

Consequently the Risk Based Inspections consist of analyzing the likelihood and consequences of a considered failure in order to generate potential failure mechanisms that will allow establishing effective inspection plan. These analyses can be as follows:

➢ Likelihood analysis

A Risk Based approaches for managing inspection would offer more flexible inspection regime. Particularly, the inspection team would not only be required to record specific damages or failures to comply with certain requirements, but also would make analysis of specific threats to the hull integrity, identify probable failure mechanisms and predict failure likelihood.

Like other risk based concepts, the first step of risk based inspections would consist of collecting and analyzing data concerning the considered system, secondly, comes the classical HAZID stage, where the different hazards to the ship's structure would be identified, for instance, severe corrosion, cracking, pitting, buckling and stress and fatigue failures.

This stage will be followed by the likelihood analysis, in which the likelihood ratio for each hazard will be expressed, depending on qualitative and quantitative appreciations. This last step will allow generating a likelihood matrix that classifies hazards in terms of their probability. An illustrative example is given in Table 12; the appreciation differs depending on various factors. The numerical value of the likelihood ratio should be dynamic, and revised for any change in the related parameters. In fact, likelihood will obviously increase with time because of the degradation of time-dependent structure materials.

Table 9: likelihood of various hazards

Failures	Quantitative appreciation	Qualitative appreciation
cracking	0 – 0,70	Low
buckling	0,70 – 0,85	medium
corrosion	0,85 – 1,00	high

This likelihood analysis will be influenced by various structure related data, such as design process information (how close to the limits the structure is initially designed), the age of the ship (time accelerates fatigue, corrosion and other damaging process), the degree of innovation, the trading zones, the maintenance conditions and the operating and managerial expertise of the ship operator.

➢ Consequence Analysis

The consequence of failure influence the risks created by each item of the ship's sub-system. Consequently, risk based inspection should consider a thorough consequence analysis to establish the ship's inspection plan. In the shipping sector, consequences can be considered in the four following categories:

- *Consequences to human life*: fatalities and injuries;
- *Consequences to the environment*: oil or noxious substances leakage and pollution;
- *Consequences to the ship*: costs caused by the damage to the ship's structure;
- *Consequences to the cargo*: costs caused by the damage to the ship's cargo.

Even though the main objectives of the IMO are the safety of the life and protection of the environment, the "*efficient shipping*" goal, introduced recently, emphasizes the importance of the protection of the ship and its cargo. However, these parameters make the consequence analysis more complex, as it will be difficult to estimate the repair value of the ship, especially when introducing parameters such as costs for immobilization or disruption of a trading contract. The complexity of the consequences analysis is also increased by the fact that structural failures cause a redistribution of forces. i.e. for instance a small initial cracking may progress and lead to the failure of considerable portions of the structure because of forces redistribution (Basu & Lee, 2006).

Despite these difficulties, consequence analysis methodologies are already employed for the development of reliability-based design standards, and performance-oriented safety criteria, especially after the introduction of GBS methodology. Thus, similar concepts can be adopted for the development of the consequence analysis methodology related to the risk based inspection framework.

Hence, the consequences of the identified hazards would be classified according to their severity using qualitative and quantitative approaches. The levels can range from minor, significant, critical to catastrophic consequences. Accordingly, the ranking of consequences would be realized depending on the previously identified impact categories (namely, the human life, the environment, the ship and its cargo).

Combination of likelihood and consequences

The combination of the likelihood and consequences analysis, will allow generating a risk ranking matrix that permits classifying the various structural elements, components and assemblies according to their criticality. Thus, the inspection efforts would be more focused on structural elements which represent high risk levels, and less finite inspection resources would be used for the areas representing lower concern.

VII.4. Application of the risk based inspection approach

For the purpose of this application, a midsection of a single skinned bulk carrier will be considered. The survey will consider the internal inspection of top side and bottom side ballast tanks (respectively the TST and BST), the double bottom ballast tanks (DBT), the side shell (SID) and the transversal bulkhead (TRB) (see Figure 24).

The first step will consist of gathering data, such as the thickness measurements, maintenance program and corrosion-prevention methods used inside the ballast tanks, the initial structural design, and the type of transported cargo. Subsequently, this information will be combined with statistical data such as the historical distribution of the structural hull failures area represented in Figure 23 (IMO, 2001b). This step will allow generating likelihood classification of the structural regions concerned.

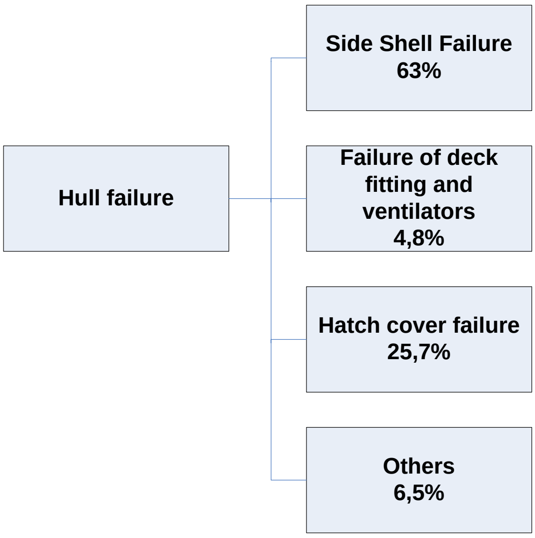

Figure 23: distribution of hull failures for bulk carriers

In the second step, the failures consequences are estimated for each area, using the four categories of consequences. An illustrative example is given in table 13, which reflects only the author's appreciation of the related failures.

Table 10: Qualitative estimation of hull failures consequences

Area	**Consequence category**			
	Human life	**Environment**	**ship**	**cargo**
TST	Significant	Minor	Critical	Minor
BST	Critical	Critical	Critical	Significant
DBT	Critical	Critical	Significant	Critical
SID	Catastrophic	Critical	Catastrophic	Catastrophic
TRB	Critical	Minor	Significant	Catastrophic

This consequence weighting illustration will then be combined with the likelihood analysis matrix, to draw up a risk ranking table, which allows prioritizing the high risk area in the inspection plan. The risk ranking matrix will use weighting coefficients, which can be as follows:

Table 11: example of Risk Ranking Matrix					
Likelihood	High	4	5	6	8
	Medium	2	4	5	6
	Low	0	2	4	5
		Minor	Significant	Critical	Catastrophic
		Consequences			

The most challenging process, will then be illustrating the risk assessment results in an adequate form that would be used for preparing the inspection plan. In this process, computer software can be developed in order to generate adequate inspection plans in function of the input data that will be entered by the surveyor, depending on the risk appreciation of each vessel.

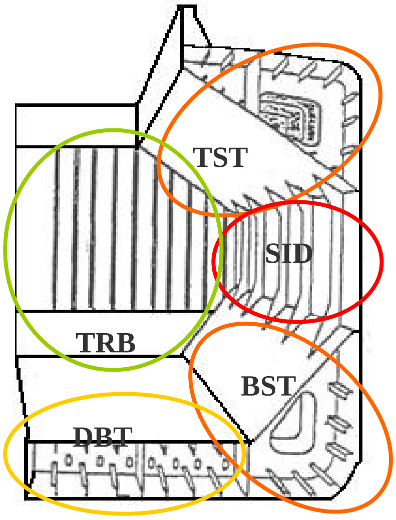

Figure 24: Cross section of a typical single skinned bulk carrier

VII.5. Benefits of the Risk Based Inspection approach:

The first benefit of adopting a risk based inspection concept, is harmonizing the approaches to the various aspects of maritime safety. In fact, the IMO already introduced various proactive risk-based approaches for the rule-making framework and the ship design and building methodologies. Thus, adopting a risk-based ship inspection regime will allow matching the last shackle of the of the maritime safety chain, namely ship surveying activity, with the new safety trend.

Secondly, the risk based inspection regime will provide more flexibility to ship-owners for planning their inspection periods, and will encourage higher quality of managerial and operating procedures, as the investment in these aspects would bring benefits in terms of inspection periodicity. Consequently, the inspections will be more targeted and the operational constraints better managed, resulting in a more optimized and cost effective inspection program, while maintaining the same level of safety (Conachey, Serratella & Wang, 2008).

Thirdly, it would allow extending the duration of ship operation between two consecutive dry-dockings, since this major maintenance operation will no longer be exclusively time-based, but rather rely on various factors, as illustrated in Appendix C.

Fourthly, the risk based inspection approach will allow generating inspection data bases that contain historical data on various ship equipment designs, damage repairs, inspection findings and failure mechanisms. This data bases will increase both the ship operators' and surveyors' knowledge of the levels of potential risk posed to every ship element.

Moreover, the risk-based inspection would allow meeting the functional requirements of the GBS methodology, which aim to monitor the condition of ships to ensure that they achieve reasonable safety performance criteria during their whole life cycle.

Finally, it can be argued that risk based inspection would increase maritime safety, because it allows identifying high risk areas of the ship, and generation inspection plans tailored for every particular ship type, operator and condition.

VII.5. Chapter's Conclusions and Recommendations:

Risk based inspection methodologies have been widely used in sensitive industries such as nuclear, chemistry and offshore sector over the last decade (ABS, 2004). The analysis of the latest developments in the maritime safety regime, which is moving toward a proactive risk-based approach, allow predicting that the future step will be adopting risk based methods to support the traditional prescriptive inspection regime.

This new inspection regime will improve the targeting and timing of the inspections, and allow generating flexible and cost effective inspection plans, to ensure that the condition of ship's equipment and structure are fit-for-service during its whole life-cycle, through the assessment and prediction of potential failure mechanism, which supports the IMO GBS objectives.

Finally it is recommended that:

- The risk based inspection should be initially introduced as recommendation for the enhancement of surveys and inspection of ships structures included in the safety management system, for the maintenance of ship condition.
- Crew should be trained for the identification and inspection of ship's regions which have high risk potential.
- The crew inspection should allow emphasizing the areas of great vulnerability, and generating Risk Control Options such as the improvement of coating or using corrosion-prevention methods, in order to mitigate failure mechanisms.
- The risk based inspection can then be generalized for the structural inspections of ships for classification and statutory purposes. The development of computer software and more sophisticated inspection equipment would be indispensable for the effective implementation of this last step.

Chapter eight

General Conclusions

Chapter VIII: General Conclusions

VIII.1. Review of the Objectives

One of major IMO objectives for the 21st century is developing a proactive safety regime that would improve the perceived picture of the whole shipping industry. Accordingly, various initiatives were adopted and experimented to ensure that hazards are identified as early as possible and are eliminated or mitigated cost effectively. These initiatives make that IMO regulations are no more "*post-disasters*" reactions, but also preventive measures against all foreseeable accidents.

The aim of this dissertation was to make an explanatory and exploratory study of the different approaches to proactive maritime safety and to investigate the contribution of risk science in these approaches.

In other words, the **scientific objective** was to prove the incentive for employing risk management techniques for the proactive maritime safety regulations, and to contribute to the demonstration of the adaptability risk-based methodologies to the context of maritime safety regulation, and the **practical objective** was to provide an analytical support and to develop a basis of fundamental knowledge, methods and techniques using risk-based principles for building a proactive maritime safety regime.

Thus, in the first part, the origins and the importance of the maritime safety regulation have been recalled. It was mainly concluded that even if the traditional configuration of maritime safety regulations (deterministic and prescriptive) is still a major source of maritime safety knowledge, certain limits such as the fragmentation, the over-regulation, the perceived incentive for unilateral or regional initiatives and the limited innovation capability, justify the necessity for a "*wind of change*" within the IMO rule-making process.

This requirement was also highlighted by reviewing the regulatory approaches of other sensitive industries such as the nuclear and offshore sectors, which emphasized the contribution of risk science in the evolution of their safety framework.

Then the study allowed making a critical review of the methods developed to meet the proactive maritime safety objectives and their relation with risk management principles. For instance, the FSA framework ***pre-use*** risk analysis concept before the development of regulations to facilitate the decision-making process, while the alternative design and arrangements and Goal-based Standards approaches ***post-use*** risk assessment principles for setting, evaluating and approving the compliance with related safety criteria. Hence, it can be concluded that risk-based methodologies are used to respond to the need for a **proactive** safety regime at multiple levels.

Subsequently, the difficulties faced by the proactive maritime safety initiatives were illustrated, for instance the new approach implies that the design of the ship becomes based on the quantification of hazards and analysis of historical and statistical data from casualty analysis, which are used for modeling the safety standards required for the intended ship's life cycle. However, until now, it is not unusual that the required data is still inaccurate mainly because of the absence of unified taxonomy and accidental database. Thus, the whole process will generate uncertainties, which need to be managed in order to avoid misleading results. Fortunately, the harmonization of casualty analysis methodologies and data taxonomy is being considered by the IMO, especially after the adoption of the mandatory Code of Casualty Investigation.

Moreover, the proactive ship design building framework pose a dilemma with regard to ensuring and monitoring that GBS-built ships comply with adequate safety criteria at the stages of design, building and during their whole life cycle. Thus, the proposed solution was the development of a Risk-Based safety regime, inspired from the nuclear and offshore inspection approaches. Accordingly, a first tentative to develop such regime was presented, and some difficulties associated with this regime were then identified.

Finally, it can be argued that this proactive trend, not only allows achieving the IMO safety enhancement objectives, but it also promotes giving to ship designers great concept flexibility that encourages innovation, and provides to ship owners more cost effective alternatives for matching their commercial goals with effective safety objectives. All these arguments *pave the way* toward a more effective integrated shipping industry.

VIII.2. Limitations of the research

After reviewing the importance of realized work, it is now essential to present the practical difficulties and to clarify the limits of the reviewed methodologies.

First, though the introduction of the risk principles would enable the development of a more balanced and flexible legislation, for the design of vessels and other equipment and arrangements, it was noted certain reluctance for their application. The first reluctance is due to the fact that the risk assessment requires structured and costly efforts in the phase of hazards identification, then the second reluctance is related to the fact that the experts' judgment of the qualitative risk analysis can be biased, which would greatly influence the study results. Fortunately, uncertainties and reluctance are diminishing and confidence is increasing due to the progressive generalization of the application of risk-based techniques at the stages of rule making and ship design.

Second, the enhancement of application of risk-based techniques within maritime safety obviously requires an intensive learning stage. In fact, the use of risk based-methods can enlarge the technological and knowledge **gap** between high-performance Flag States and classification societies from one side, and more modest maritime administration from the other side. Thus, intensive learning and knowledge acquisition is indispensible for these maritime administrations to catch the expertise and scientific advances reached by other parties and avoid a full delegation of their responsibilities to recognized organization. This aspect was not thoroughly covered by the scope of the present study.

The limitation of this study is also related to the incorporation of the human element for developing safety regulations and setting the safety criteria. Also, the benefits provided by the introduction of the ISM Code in the maritime sector for building a proactive safety culture were not comprehensively explored. Unfortunately, it was not possible to carefully explore these major safety aspects, given the importance of a detailed study exclusively dedicated to these subjects.

Finally, given the reduced level of maturity of research for the new performance and goal based standards in the maritime sector, and the scarcity of the published studies on the subject, it was decided that a comparative analysis between the application of the goal based and prescriptive standards on board specific ships would not provide reliable results. Thus, the research was limited to contrasting the theories and objectives of the traditional and new regime, and emphasizing the benefits and limitations of these two safety approaches.

VIII.3. Recommendations for further studies

After reviewing the main contributions of the present research and examining its limits, it became possible to draw up prospects for future work.

First, risk-based methodologies are used for developing regulations and promoting safer and cost effective design for ships covered by IMO instruments. Further developments of these methodologies would give great incentive to maritime administrations and ship owners to employ these approaches, on voluntary basis, for the national rule-making and the design of non-convention vessels. A comprehensive study of the applicability of these risk-based safety regimes in a national context, and for vessels that are not subject to the application of mandatory IMO instruments would provide effective solutions to the safety problems posed by this type of ships.

Second risk based methodologies are distinctly applied at multiple levels of the global maritime safety framework, such as rule making, design of safety equipment and arrangements, ship building and evaluation of safety criteria. Additional in depth studies could determine the feasibility of the harmonization and integration of all these risk-based applications for the development of an integrated maritime safety framework.

Third, clear and definite risk-based safety criteria setting and monitoring framework, and risk perception and acceptability levels identification (such transparent methods for setting the ALARP levels) should be deeply investigated, as well as their effect on the current safety regime.

Fourth, the use of performance and goal based standards should be completed by the development universal databases of ship building and safety criteria identification. These data bases would be completed by the maintenance and inspection records of these ships after the introduction of the predicted risk-based maintenance and inspection regimes.

Moreover, the introduction of goal based standards and performance based codes is still posing a dilemma with regard to the criteria of their inspection under Port State Control (PSC) activity. The author's opinion is that these risk-based designed ships should be inspected under a risk-based Port State Control regime. Thus, PSC inspection framework should be developed to meet the new safety trend by adopting a proactive risk based safety approach.

Finally, it was presented that Risk Based Inspection has successfully been employed in various sensitive industries. In the opinion of the author, these techniques can be further developed to be introduced in the maritime sector for the inspection of ship structures in a first stage, and then for the survey of various ship safety equipment.

The use of these risk-based techniques would also enable engineers to develop inspection software, which would make the inspection activity **more efficient** and **less time consuming**, especially when considering the increasingly bigger ship dimensions and the introduction of large double hulled tankers and double skinned bulk carriers.

Word count: 19939

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The International Maritime Organization web site gives further information on: http://www.imo.org

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Appendices

Appendix A

Overview of Main Risk Analysis Methods

Risk Analysis Methods	**Principles of the method**	**Common Utilization**
Preliminary hazard analysis (PrHA)	The PHA technique is a broad, initial study that focuses on (1) identifying apparent hazards, (2) assessing the severity of potential mishaps that could occur involving the hazards, and (3) identifying means (safeguard) for reducing the risks associated with the hazards. This technique focuses on identifying weaknesses early in the life of a system, thus saving time and money which might be required for major redesign if the hazards are discovered at a later date.	• Most often conducted early in the development of an activity or system where there is little detailed information or operating procedures, and is often a precursor to further hazard/risk analyses. • Primarily used for hazard identification and ranking in any type system/process.
Preliminary risk analysis (PRA)	PRA is a streamlined mishap-based risk assessment approach. The primary objective of the technique is to characterize the risk associated with significant loss scenarios. This team-based approach relies on subject matter experts systematically examining the issues. The team postulates combinations of mishaps, most significant contributors to losses and safeguards. The analysis also characterizes the risk of the mishaps and identifies recommendations for reducing risk.	• Primarily used for generating risk profiles across a broad range of activities (e.g., a port-wide risk assessment).
What-if/checklist analysis	What-if analysis is a brainstorming approach that uses loosely structured questioning to (1) postulate potential upsets that may result in mishaps or system performance problems and (2) ensure that appropriate safeguards against those problems are in place. Checklist analysis is a systematic evaluation against pre-established criteria in the form of one or more checklists.	• Generally applicable to any type of system, process or activity (especially when pertinent checklists of loss prevention requirements or best practices exist). • Most often used when the use of other more systematic methods (e.g., FMEA and HAZOP analysis) is not practical.
Failure Modes and Effects Analyses (FMEA)	FMEA is an inductive reasoning approach that is best suited to reviews of mechanical and electrical hardware systems. The FMEA technique (1) considers how the failure modes of each system component can result in system performance problems and (2) ensures that appropriate safeguards against such problems are in place. A quantitative version of FMEA is known as failure modes, effects and criticality analysis (FMECA).	• Primarily used for reviews of mechanical and electrical systems (e.g., fire suppression systems, vessel steering / propulsion systems). • Often used to develop and optimize planned maintenance and equipment inspection plans. • Sometimes used to gather information for troubleshooting systems.

Overview of Main Risk Analysis Methods (Continued)

Risk Analysis Methods	**Principles of the method**	**Common Utilization**
HAZard and Operability (HAZOP) analysis	The HAZOP analysis technique is an inductive approach that uses a systematic process (using special guide words) for (1) postulating deviations from design intents for sections of systems and (2) ensuring that appropriate safeguards are in place to help prevent system performance problems.	• Primarily used for identifying safety hazards and operability problems of continuous process systems (especially fluid and thermal systems). Also used to review procedures and other sequential operations.
Fault Tree Analysis (FTA)	FTA is a deductive analysis technique that graphically models (using Boolean logic) how logical relationships between equipment failures, human errors and external events can combine to cause specific mishaps of interest.	• Generally applicable for almost every type of analysis application, but most effectively used to address the fundamental causes of specific system failures dominated by relatively complex combinations of events. • Often used for complex electronic, control or communication systems.
Event Tree Analysis (ETA)	ETA is an inductive analysis technique that graphically models (using decision trees) the possible outcomes of an initiating event capable of producing a mishap of interest.	• Generally applicable for almost every type of analysis application, but most effectively used to address possible outcomes of initiating events for which multiple safeguards (lines of assurance) are in place as protective features. • Often used for analysis of vessel movement mishaps and propagation of fire/explosions or toxic releases.
Relative Ranking/Risk Indexing	Relative ranking/risk indexing uses attributes of a vessel, shore facility, port or waterway to calculate index numbers that are useful for making relative comparisons of various alternatives (and in some cases can be correlated to actual performance estimates).	• Extensively used to establish priorities for boarding and inspecting foreign flagged vessels. • Generally applicable to any type of analysis situation (especially when only relative priorities are needed) as long as a pertinent scoring tool exists.
Coarse Risk Analysis (CRA)	CRA uses operations/evaluations and associated functions for accomplishing those operations/evolutions to describe the activities of a type of vessel or shore facility. Then, possible deviations in carrying out functions are postulated and evaluated to characterize the risk of possible mishaps, to generate risk profiles in a number of formats and to recommend appropriate risk mitigation actions.	• Primarily used to analyze (in some detail) the broad range of operations/evolutions associated with a specific class of vessel or type of shore facility. • Analyses can be performed for a representative vessel/facility within a class or may be applied to specific vessels/facilities. • Especially useful when risk-based information is sought to optimize field inspections for classes of vessels/facilities.

Overview of Main Risk Analysis Methods (Continued)

Risk Analysis Methods	Principles of the method	Common Utilization
Pareto analysis	Pareto analysis is a prioritization technique based solely on historical data that identifies the most significant items among many. This technique employs the 80-20 rule, which states that ~80 percent of the problems (effects) are produced by ~20 percent of the causes.	• Generally applicable to any type of system, process or activity (as long as ample historical data is available). • Most often used to broadly characterize the most important risk contributors for more detailed analysis.
Root cause analysis • Event charting • 5 Whys technique • Root Cause Map	Root cause analysis uses one or a combination of analysis tools to systematically dissect how a mishap occurred (i.e., identifying specific equipment failures, human errors and external events contributing to the loss). Then, the analysis continues to discover the underlying root causes of the key contributors to the mishap and to make recommendations for correcting the root causes.	• Generally applicable to the investigation of any mishap or some identified deficiency in the field. • Event charting is most commonly used when the loss scenario is relatively complicated, involving a significant chain of events and/or a number of underlying root causes. • 5 Whys is most commonly used for more straightforward loss scenarios. • Root Cause Map is used in conjunction with any root cause analysis to challenge analysts to consider a range of possible root causes.
Change analysis	Change analysis systematically looks for possible risk impacts and appropriate risk management strategies in situations in which change is occurring (e.g., when system configurations are altered, when operating practices/policies changes, when new/different activities will be performed).	• Generally applicable to any situation in which change from normal configuration/operations/ activities is likely to significantly affect risks (e.g., marine events in ports/waterways). • Can be used as an effective root cause analysis method as well as a predictive hazard/risk analysis method
Common Cause Failure Analysis (CCFA)	CCFA is a specialized approach for systematically examining sequences of events stemming from the conduct of activities and/or operation of physical systems that cause multiple failures/errors to occur from the same root causes, thus defeating multiple layers of protection simultaneously.	• Exclusively used as a supplement to a broader analysis using another technique, especially fault tree and event tree analyses. • Best suited for situations in which complex combinations of errors/equipment failures are necessary for undesirable events to occur.

Overview of Main Risk Analysis Methods (Continued)

Risk Analysis Methods	**Principles of the method**	**Common Utilization**
Human error analysis • Error-likely situation analysis • Walkthrough analysis • Guide word analysis • Human reliability analysis •	Human error analysis involves a range of analysis methods from simple human factors checklist through more systematic (step-by-step) analyses of human actions to more sophisticated human reliability analyses. These tools focus on identifying and correcting error-likely situations that set people up to make mistakes that lead to mishaps.	• Generally applicable to any type of activity that is significantly dependent on human performance. • Error-likely situation analysis is the simplest approach and is used as a basic level of analysis for human factors issues. • Walkthrough and guide word analyses are used for more systematic analyses of individual procedures. • Human reliability analysis is used for special applications in which detailed quantification of human reliability performance is needed.

Source: American Bureau of Shipping. (2000). *Guidance Notes on Risk Assessment Applications for the Marine and Offshore Oil and Gas Industries*. New York: Author

Appendix B

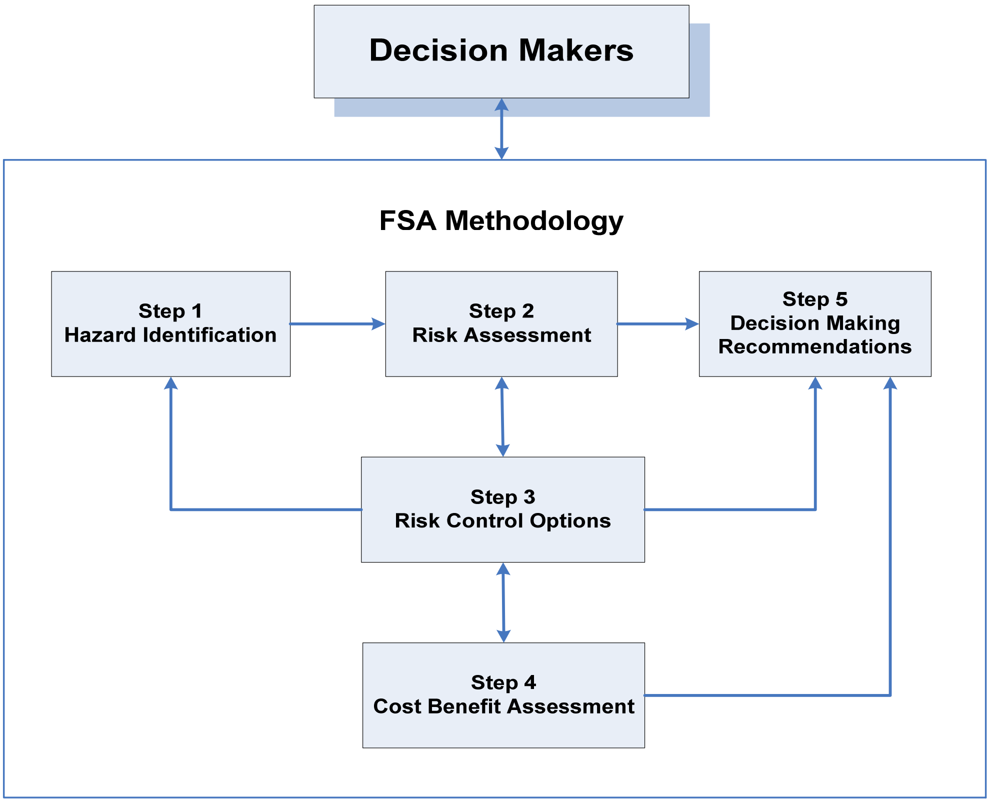

Figure 25: IMO Flowchart of the FSA methodology

International Maritime Organization. (2007, May 14). *Formal Safety assessment - Consolidated text of the Guidelines for Formal Safety Assessment (FSA) for use in the IMO rule-making process (MSC/Circ.1023−MEPC/Circ.392)*. (MSC 83/INF.2). London: Author.

Appendix C

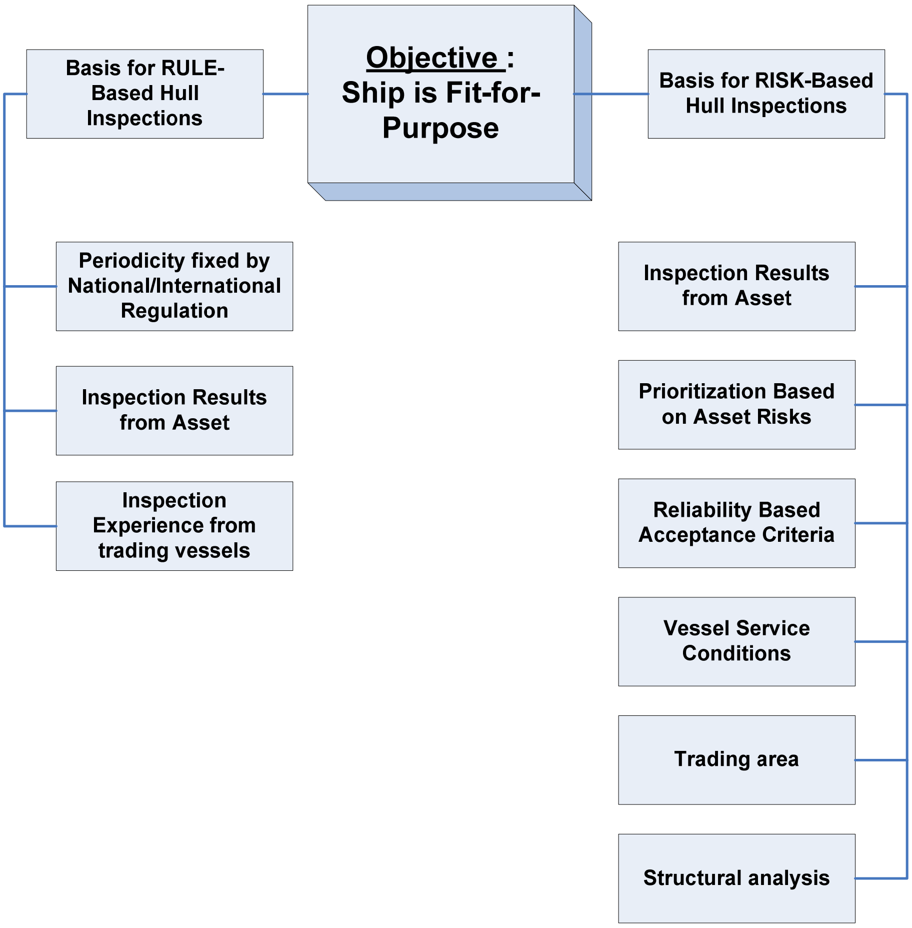

Figure 26: Comparison between RISK-based and RULE-based hull inspections.

Source: Lee, A.K., Serratella, C., Wang, G. & Basu, R. (2006). *Flexible Approaches to Risk-Based Inspection of FPSOs*. Houston: Offshore Technology Conference. Retrieved May 7, 2009, from the World Wide Web: http://www.otcnet.org/2006/tech_prog/sched/documents/otc183641.pdf

Appendix D

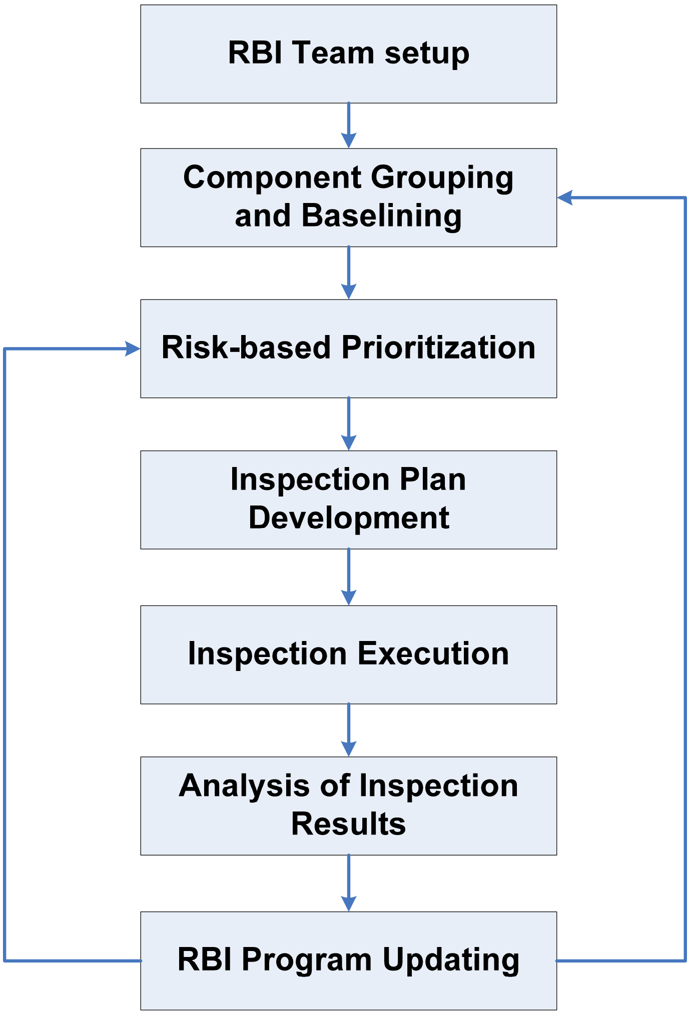

Figure 27: Main Steps in the development of an RBI Program

American Bureau of Shipping. (2003). *Guide for Surveys Using Risk-Based Inspection for the Offshore Industry*. New York: Author

Appendix E

Table 12: Pros and Cons of Qualitative and Quantitative Risk Analysis Techniques

Qualitative Analysis		***Quantitative Analysis***	
Pros	***Cons***	***Pros***	***Cons***
Captures expertise of persons most familiar with facility.	Need time commitment from qualified persons.	Can generate results based on existing data.	Need to determine which models to use and how they will be integrated with each other.
Can quickly screen out equipment or structures with no damage mechanisms or with low consequence of failure.	May fail to consider all failure mechanisms in all modes of operation, especially combination of failures.	Requires less time on part of experts during the analysis.	Expensive to build and maintain, may require software support.
Can be less costly than quantitative analysis.	Results may be difficult to defend to third party	Becomes less costly with experience in use of models.	May be high cost on initial studies.
Can be faster than quantitative study.	Inconsistent results, care must be taken to provide audit trail.	Consistent results, auditable, perception of accuracy.	Accuracy depends on data availability and accuracy.

American Bureau of Shipping. (2003). *Guide for Surveys Using Risk-Based Inspection for the Offshore Industry*. New York: Author