NATIONAL TECHNICAL UNIVERSITY OF ATHENS
School of Naval Architecture & Marine Engineering

NTUA Maritime Transport

Division of Ship Design and Maritime Transport

Formal Safety Assessment
Critical Review and Future Role

Diploma Thesis

Christos Alex. Kontovas

July 2005

Supervised by Prof. Harilaos N. Psaraftis

Formal Safety Assessment
Critical Review and Future Role

Christos Alex. Kontovas

SCHOOL OF NAVAL ARCHITECTURE AND MARINE ENGINEERING
NATIONAL TECHNICAL UNIVERSITY OF ATHENS, GREECE

2005

I would like to dedicate this thesis
to the loving memory of my father, Alexandros.

Acknowledgment

This thesis is submitted as a partial fulfilment of the requirements for the Diploma of Naval Architecture and Marine Engineering. The study was supervised by Professor Harilaos N. Psaraftis to whom am truly grateful for his support and encouragement.

My first contact with FSA was through a course, Economics of Maritime Transport III: Environment and Safety Analysis, taught by Prof. H. Psaraftis, Associate Prof. K. Spyrou, Assistant Prof. D. Lyridis and Mr. N. Ventikos (Post-Doctoraral Associate).
I wish to thank them as well.

I am, also, very thankful to Associate Prof. Kyriakos Spyropoulos of the Dept. of Electrical and Computer Engineering, to whom I have been of assistance, for his support throughout my studies.

Finally, I would like to thank my mother, my sister and my girlfriend for their support, patience and understanding.

Christos Alex. Kontovas
Athens, July 2005

Synopsis (in greek)

Μία από τις βασικές ανησυχίες στο χώρο της Ναυτιλίας ήταν πάντοτε η ασφάλεια των πλοίων στη θάλασσα. Η έλλειψη αυτής πάντα θα έχει μεγάλο κόστος είτε αυτό μετριέται σε ανθρώπινες ζωές είτε σε ζημιές στο περιβάλλον ή στο φορτίο. Όλοι οι εμπλεκόμενοι στο χώρο πάντα επιζητούν τρόπους να αποφύγουν τις παραπάνω ζημιές. Όμως, πάντοτε η Ναυτιλία βρίσκονταν και βρίσκεται ένα βήμα πιο πίσω από τις άλλες όπως η πυρηνική και η αεροπορική βιομηχανία

Όλες οι εξελίξεις στο χώρο γίνονταν, σχεδόν, πάντα μετά από ένα μεγάλο ατύχημα και κυρίως για να μετριαστούν οι αντιδράσεις του κοινού. Όμως, σήμερα, βρισκόμαστε κοντά στο να γίνει η Ναυτιλία ο χώρος όπου οι κανονισμοί θα είναι ένα βήμα πιο μπροστά από τα ατυχήματα. Αυτό γίνεται με μελέτες που εκτιμούν το ρίσκο για δραστηριότητες και πρακτικές στις θαλάσσιες μεταφορές.

Οι μελέτες αυτές χρησιμοποιούν μια νέα μέθοδο στο ναυτιλιακό χώρο ,την μέθοδο της **«Τυπικής Αποτίμησης Ασφάλειας» (Formal Safety Assessment, FSA)** .

Η Επιτροπή Ναυτικής Ασφάλειας (Maritime Safety Committee, MSC) του Διεθνούς Ναυτιλιακού Οργανισμού (International Maritime Organization, IMO) ήδη από το 1997 ενέκρινε κατά την $68^{η}$ Συνεδρίαση του την μέθοδο της FSA ως «μια δομημένη και συστηματική μεθοδολογία με στόχο την ενίσχυση της ναυτικής ασφάλειας συμπεριλαμβανομένων της προστασίας της ανθρώπινης ζωής και υγείας, του θαλάσσιου περιβάλλοντος και της περιουσίας με τη χρήση ανάλυσης ρίσκου και ανάλυσης κόστους-οφέλους» (MSC/Circ.1023).

Η FSA έχει χρησιμοποιηθεί, ήδη, ως εργαλείο για την εκτίμηση νέων κανονισμών και αρκετές μελέτες έχουν γίνει χρησιμοποιώντας αυτή τη μεθοδολογία, όπως φαίνεται και στο παραπάνω σχήμα. Αυτό μας δίνει την ικανότητα να μπορούμε, πλέον, να έχουμε μια καλή εικόνα για το πώς χρησιμοποιείται η μέθοδος αυτή άρα και να εντοπίσουμε πιο εύκολα τα «τρωτά» της σημεία.

ΑΝΑΛΥΣΗ ΤΗΣ ΜΕΘΟΔΟΥ

Σε κάθε μελέτη FSA το πρώτο πράγμα που γίνεται είναι να διευκρινιστούν τα σημεία στα οποία ακριβώς θα εστιάσει η μελέτη καθώς κα να συλλεχθούν όλα τα απαραίτητα στοιχεία από την ομάδα των ειδικών η οποία και θα διεξαγάγει την μελέτη.

Από το σημείο αυτό και έπειτα ακολουθείται η μεθοδολογία που προτείνει ο IMO στο έγγραφο MSC/Circ.1023.

Τα πέντε Βήματα της εφαρμογής της FSA είναι :

1. Αναγνώριση Κινδύνων

Στο στάδιο αυτό, η ειδική ομάδα των εμπειρογνωμόνων καταλήγει σε μια λίστα κινδύνων που μπορούν να εμφανιστούν στο υπό μελέτη σενάριο χρησιμοποιώντας ειδικές τεχνικές και πολλές φορές βασίζονται σε στοιχεία από παλαιότερα ατυχήματα αλλά κυρίως τις εκτιμήσεις και στην εμπειρία τους. Τέλος, κατατάσσουν τους κινδύνους με βάση το ρίσκο και τη σημαντικότητα των επιπτώσεών τους

2. Αποτίμηση του Ρίσκου

Στο βήμα αυτό γίνεται εκτίμηση του «μεγέθους» του ρίσκου καθώς και αποτίμηση του με βάση ποσοτικά και ποιοτικά, κυρίως, κριτήρια. Η ποσοτική εκτίμηση του ρίσκου γίνεται, κυρίως, με την αρχή ALARP (As Low As Reasonable Practicable), δηλαδή τη σύγκριση του ρίσκου με αποδεκτά όρια. Η μοντελοποίηση του ρίσκου σε αυτό το στάδιο γίνεται εφαρμόζοντας συγκεκριμένες τεχνικές με αυτή των «Δέντρων Συμβολής στο Ρίσκο» (Risk Contribution Trees, RCT) να εμφανίζεται περισσότερο στις μελέτες που έχουν πραγματοποιηθεί έως σήμερα.

3. Επιλογή Μέτρων Περιορισμού του Ρίσκου

Στο βήμα αυτό επικεντρώνεται η προσοχή στους παράγοντες που έχουν υψηλό ρίσκο ή μεγάλη πιθανότητα εμφάνισης και αναγνωρίζονται τα πιθανά μέτρα περιορισμού. Το βασικότερο είναι ότι στο στάδιο αυτό γίνεται επανατροφοδότηση του $2^{ου}$ βήματος και υπολογισμός των νέων επιπέδου ρίσκου.

4. Εκτίμηση Κόστους – Ωφέλειας

Το βήμα αυτό είναι και το πιο σημαντικό καθώς σε αυτό γίνεται η αποτίμηση με οικονομικά, κυρίως, κριτήρια. Ακόμη και η ανθρώπινη ζωή στο στάδιο αυτό είναι σα να αποκτά χρηματικό ισοδύναμο. Έτσι όλα τα παραπάνω μέτρα που μπορούν να περιορίσουν το ρίσκο εξετάζονται με διάφορα κριτήρια με βάση το κόστος για να ληφθούν αυτά και τις αντίστοιχες ωφέλειες μεταφραζόμενες πάντα σε χρηματικές μονάδες.

Για την αποτίμηση των μέτρων προτείνονται και χρησιμοποιούνται κριτήρια όπως οι δείκτες Gross και Net CAF (Cost of Averting a Fatality, «Κόστος Αποφυγής μιας Ανθρώπινης Απώλειας») ή ακόμα τα διαγράμματα F-N που είναι διαγράμματα Συχνότητας N ανθρώπινων απωλειών σε συνάρτηση των απωλειών αυτών.

5. Προτάσεις για Λήψη Αποφάσεων

Τέλος, με βάση τα παραπάνω η ομάδα των ειδικών συντάσσει μια έκθεση με τις προτάσεις-υποδείξεις της προς πιθανή χρήση. Και σε αυτό το βήμα αξιολογούνται όλα τα προτεινόμενα μέτρα με βάση τα αποτελέσματα των προηγούμενων βημάτων και με βάση κριτήρια όπως το ALARP που αναφέρθηκε παραπάνω.

<u>ΣΚΟΠΟΣ ΤΗΣ ΕΡΓΑΣΙΑΣ</u>

Η διπλωματική, αυτή, εργασία εντοπίζει τα αδύναμα σημεία της διαδικασίας και μέσα από προτάσεις που έχουν υποβληθεί στην Επιτροπή Ναυτικής Ασφάλειας (MSC) του IMO καθώς και από συνήθεις πρακτικές που χρησιμοποιούνται σε άλλες βιομηχανίες γίνεται μια προσπάθεια για τη βελτίωση της διαδικασίας και, όπου είναι εφικτό, για την εξάλειψη των αδυναμιών.

Τέλος, πολύ αναλυτική μελέτη γίνεται όσον αφορά τα κριτήρια αποδοχής ρίσκου και της αποτελεσματικότητας των μέτρων που προτείνονται για την εξάλειψή του. Η αποτίμηση της ανθρώπινης ζωής είναι κάτι ανήθικο για τους περισσότερους επιστήμονες. Για τις ανάγκες της ανάλυσης, όμως, γίνεται ο υπολογισμός της αξίας αυτής (ICAF) μέσα από δείκτες που έχουν προταθεί στη βιβλιογραφία και, μάλιστα, χρησιμοποιούνται τα πιο πρόσφατα στατιστικά δεδομένα.

Επιπλέον, εκτός από τα παραπάνω γίνεται μια αναλυτική μελέτη του δείκτη συνταύτισης των απόψεων της γνώμης των ειδικών (expert judgment).

Τα παραπάνω αποτελούν, μάλιστα, πρωτότυπη δουλεία και, αναμφίβολα, μπορούν να συνεισφέρουν στην έρευνα γύρω από τη μέθοδο FSA.

Abbreviations

Abbreviations used in this thesis are generally explained when first introduced and their meaning will, normally, be apparent from context.

ABS	American Bureau of Shipping (USA)
AFR	Annual Fatality Rate
ALARP	As Low As Reasonably Practicable
CAF	Cost of Averting a Fatality
CBA	Cost-benefit analysis
CCPS	Center for Chemical Process Safety
CMPT	Centre for Maritime and Petroleum Technology
DNV	Det Norske Veritas (Norway)
ET	Event Tree
ETA	Event Tree Analysis
FAR	Fatal Accident Rate
FMEA	Failure Modes and Effects Analysis
FMECA	Failure Modes, Effects and Criticality Analysis
FN	Frequency-Number of fatalities
FSA	Formal Safety Assessment
FT	Fault Tree
FTA	Fault Tree Analysis
GBS	Goal-based Standards
GCAF, NCAF	Gross / Net Cost of Averting a Fatality
GDP	Gross Domestic Product
HAZID	Hazard Identification
HAZOP	Hazard and Operability Study
HMSO	Her Majesty's Stationery Office (UK)
HRA	HRA human reliability analysis
HSE	Health & Safety Commission (UK)
IACS	International Association of Classification Societies
ICAF	Implied Cost of Averting a Fatality
ICCL	International Council of Cruise Lines
IEC	International Electrotechnical Commission
IMO	International Maritime Organization

IR	Individual Risk
LMIS	Lloyd's Maritime Services' Database
MAIB	Marine Accident Investigation Branch (UK)
MCA	Marine Coastguard Agency (United Kingdom)
MEPC	Marine Environment Protection Committee (IMO)
MSC	Marine and Safety Committee (IMO)
NASA	National Aeronautics and Space Administration (US)
NCR	Nuclear Regulatory Commission (USA)
PLL	Potential Loss of Life
QRA	Quantitative risk assessment
RCM	Risk Control Measure
RCO	Risk Control Option
RCT	Risk Contribution Tree
RI	Risk Index
RID	Regulatory Impact Diagram
RINA	Royal Institution of Naval Architects (UK)
SWIFT	Structured What-IF checklist Technique
TOR	Tolerability of Risk Framework (HSE)
UK	United Kingdom
UKOOA	United Kingdom Offshore Operators Association (UK)
UNCTAD	United Nations Conference on Trade and Development
US / USA	United States of America

List of Figures

CONTENTS ×

List of Tables

Contents

4. FSA STEP 1 – IDENTIFICATION OF HAZARDS

5. FSA STEP 2 – RISK ANALYSIS

6. FSA STEP 3 – RISK CONTROL OPTIONS

7. FSA STEP 4 – COST BENEFIT ANALYSIS

8. FSA STEP 5 – RECOMMENDATIONS FOR DECISION-MAKING

9. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER WORK

REFERENCES

Chapter 1

Introduction

CHAPTER 1.

INTRODUCTION

1.1 Overview and Background

Members of modern societies are aware of and sensitive to the discomforting reality that the benefits of technology come at high cost in safety and money.
More and more people demand control over risk to which they are exposed. The complexity of most activities in engineering requires a cooperative effort made by specialists to model the uncertainties of risk and to seek measures of reduction. This urgent need to deal with the problems of risk led to the development of risk-related disciplines like Risk Analysis, Risk Assessment and Risk Management.

In the maritime industry, the only international regulatory body recognized by most of the key players is the International Maritime Organization (IMO). The way that IMO implements the principles of Risk Management and, in general, of a safety culture, is through a systematic process called Formal Safety Assessment (FSA). FSA was introduced as a process to assess risks and to evaluate costs and benefits of the IMO's options for reducing these risks and, thus, to provide support to the Organization's decision-making process.

FSA was proposed by the United Kingdom and was based on the risk assessment approach of the country's offshore industry. The IMO, initially, studied FSA at the 62nd meeting of its Marine and Safety Committee (MSC) in 1993 following a proposal by the UK's Marine Coastguard Agency (MCA). Two years later, in 1995, MSC 65 agreed that FSA should be a high priority on its agenda.
In 1997, the Maritime Safety Committee (MSC) at its 68th session and the Marine Environment Protection Committee (MEPC) at its 40th session approved the "Interim Guidelines for the application of Formal Safety Assessment to the IMO rule-making process".

Experience gained from the trial applications since 1997 finalized the Guidelines (MSC Circ. 1023) that were, finally, adopted at MSC 74 and MEPC 47 and superseded the Interim Guidelines. The Guidelines are the following document: "Guidelines for Formal Safety Assessment for use in the IMO Rule-Making Process" (MSC Circ. 1023 and MEPC Circ. 392, 5 April 2002).

1.2 Objective and Scope of the Work

The overall objective of the following thesis is to review the process of Formal Safety Assessment. FSA studies that were submitted to the IMO and trial applications that are published in scientific journals were studied by the author. Weaknesses were identified. The author proposes some measures to eliminate or to mitigate them, furthermore, the author discusses and analysed methods that were found in various documents submitted to IMO or in the current practice of other industries.

This thesis consists of nine chapters. Chapter 2 deals with the historical background of safety assessments and, particularly, of risk assessments ranging from the Piper Alpha Disaster in 1988 to the approval of the Interim FSA Guidelines (MSC Circ. 829) in 1997.

Chapter 3 describes the process of Formal Safety Assessment based on the Guidelines that were adopted by the MSC in 2001 (Circ. 1023). This chapter describes the overall process and the experience gained by the submitted work.

Chapters 4 through 8 describe the process mentioned above step by step. Each chapter deals with each single Step describing its scope according to the Guidelines, reviewing the methods used in FSA studies, noticing the weak points and commenting on possible procedures that can strengthen it. These procedures are either mentioned in documents submitted to the IMO or borrowed from other industries.

Chapter 8, is of particular interest because it describes the last that deals with the recommendations for decision-making. Risk Acceptance and Cost Effectiveness Criteria are being assessed in detail. Ways to manipulate the results of the FSA based on these criteria are mentioned and proved using mathematical formulas. In addition, recent statistics are being used to provide up-to-date criteria.

Finally, Chapter 9 contains an overall conclusion of the study presenting a compilation of the findings and proposals of previous chapters as well as recommendations for further work.

Chapter 2

Theory and Background

CHAPTER 2.

THEORY AND BACKGROUND

2.1 Probability and Risk

Risk can be defined in many ways. The term "risk" is frequently used in everyday life, but the exact meaning is hard to be captured.

According to the Merriam-Webster's Dictionary risk is being defined as :
" risk \"risk\ *noun*
[1655–65; < F risque < It risc(hi)o, earlier risico, prob. < MGk rizikón, rouzikón fate, fortune] "

1 : possibility of loss or injury : PERIL
2 : someone or something that creates or suggests a hazard
3 a : the chance of loss or the perils to the subject matter of an insurance contract; *also* : the degree of probability of such loss
b : a person or thing that is a specified hazard to an insurer c : an insurance hazard from a specified cause or source <war *risk*> "

The word risk is derived etymologically from the Greek word rizikon (**ριζικόν**) which means fate or fortune. The etymological root of this word is riza (**ρίζα**) which means root, kernel, basis, primary causal etc. This meaning contains the idea of a probable danger.

According to the FSA Guidelines (MSC Circ. 1023) risk "is the combination of the frequency and the severity of the consequence".

The last definition is the one used in modern Risk Management. Consequences are, simply, the unwanted events that can negatively affect subjects of interest such as people, property, environment etc. On the other hand, frequency has not a very clear meaning in this context. Frequency is the number of occurrences of an undesirable event expressed as events per unit of time.
It has to be noticed that in most FSA studies frequency was defined as the number of casualties divided by the number of ship years. However, this approach does not include the element of future (which is included in the greek root of the word risk).

Defining risk as "the possibility of loss or injury" or "exposure to the chance of injury or loss; a hazard or dangerous chance" shows that risk doesn't mean "actual danger" but the "possibility of danger" (HSE, 2001). The word risk must contain the concept of probability (rather than possibility or frequency) and consequence, usually, negative, of that unwanted event that can probably happen. Possibility is a more wide term than probability. In cases of dealing with past events (not probable nor possible but actual events) the word frequency can be used.
In this thesis the word frequency will be used containing the concept of probability.

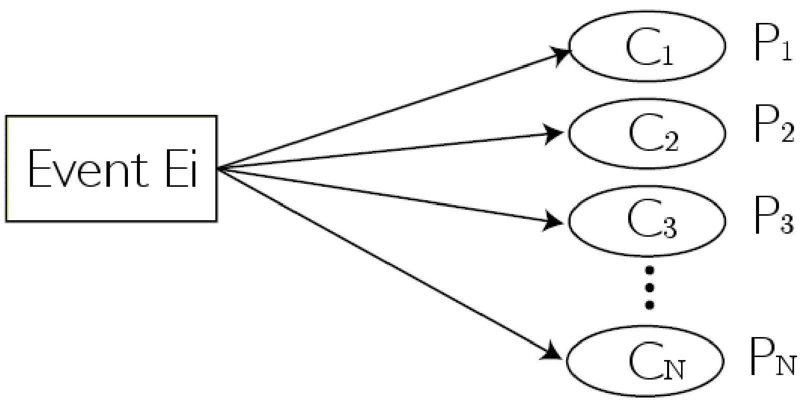
Some more definitions of the word risk should be given in order to clarify its meaning.
Given that an accidental event (E_i) has occurred the consequences (C_i) are uncertain, and thus described by a marginal probability density function π (C_i | E_i). The risk associated with an accidental event is a combination of the probability of the event and the magnitude of its consequences.
The entire risk on an activity given the probability of i accidental events (in a specific period of time) is the sum of the risk associated with each accidental event.

$$R_i = Prob(E_i) \otimes [\pi_1(C_1 | E_i), \pi_2(C_2 | E_i), ...]$$

where $\otimes$ is a multiplicative factor.

It has to be noticed that the word event is used for the focused event, which can be any event in a chain of the course of events after the initiating event (which is, btw, one of the meanings of the greek word riza **(ρίζα)**).

For each one of these events the following "consequence spectrum" can be illustrated.



A **consequence spectrum** of an event is a listing of its potential consequences and the associated probabilities, usually, considering only unwanted consequences.
Risk is, then, defined as

$$\text{Risk}=C_1 \cdot P_1 + C_2 \cdot P_2 + \ldots + C_N \cdot P_N = \sum_{i=1}^{N} C_i \cdot P_i$$

This requires that all consequences have to be measured using a common measure (e.g. monetary unit). This is an important issue and will be discussed in the following chapters.

To sum up, **Probability** is something (as a situation, condition or event) that is probable; the chance that a given event will happen. Probable is something that is likely to become true or real. **Possibility** is something being within the limits of ability or realization, thus, may or may not be true or actual. **Frequent** is the fact or condition of occurring frequently, thus, that "something" has happened at least one time.

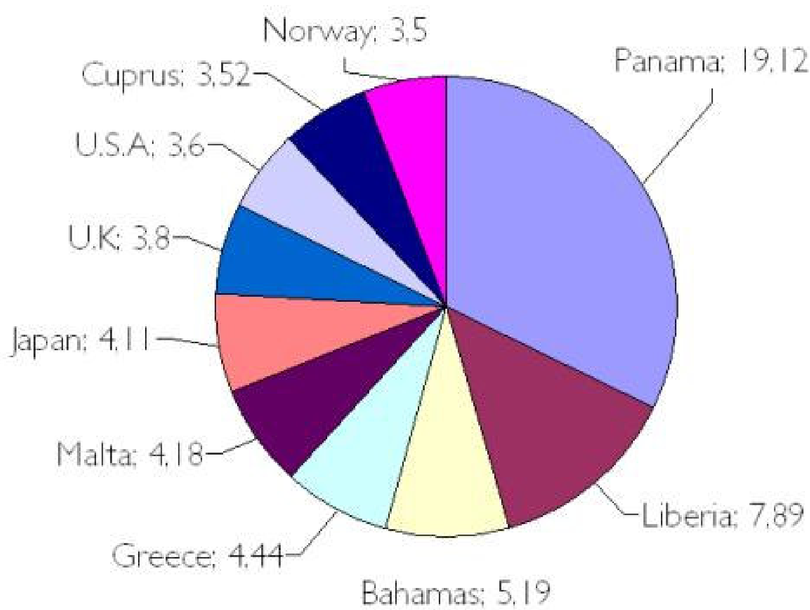
Finally, it should not be omitted that according to the glossary of terms in use by IACS members , risk is "a measure of the **likelihood** that an undesirable event will occur together with a measure of the resulting consequence within a specified time i.e. the combination of the frequency and the severity of the consequence. " [MSC 76/Inf. 3]

To sum up, the word risk in each FSA study has its corresponding meaning according to the context. FSAs that study events that have happened can be approached using frequencies -which are widely used. However, the use of possibilities rather than frequencies leads to the direction of having a proactive approach which is the goal of the introduction of FSA in the maritime industry.

2.2 International Maritime Organization (IMO)

IMO is the United Nations' specialized agency responsible for the improving of maritime safety and is directly connected with the promotion of quality and safety in the industry. One of the high-priority objectives of the IMO is "the promotion of the implementation of the international standards and regulations for the improvement of maritime safety and for the prevention and control of marine pollution from ships," [Res. A.500(XII)]

IMO is the only international regulatory body of all kind of affairs in the maritime industry and is being recognized by most key-players of the shipping industry as the organization with the authority to set safety and quality standards to be achieved and to be applicable to all Member-Countries.
IMO was formally established in 1948 and the IMO Convention entered into force ten years later, in 1958. IMO has its headquarters in London, United Kingdom.
The governing body is the Assembly, which consists of more than 140 Member States. Most of the IMO's work is carried out in a number of committees and sub-committees such as the Maritime Safety Committee (MSC) and the Marine Environment Protection Committee (MEPC).



Contributions to the IMO budget come from each member - state depending primarily on the tonnage of its merchant fleet.
In 2003 the percentage of contribution of the top ten countries (in total 59,39 % of the budget) were as shown in Fig. 2-1.

Fig 2-1 IMO Budget Contribution (2003)

For reasons of completeness the most important maritime countries and territories as of 1 Jan. 2003 are given in the following table. Statistics are compiled by the United Nations Conference on Trade and Development (UNCTAD) and are on the basis of data supplied by Lloyd's Register – Fairplay. (UNCTAD, 2003)

Country of domicile	Number of vessels			Deadweight tonnage				
	National flag	Foreign flag	Total	National flag	Foreign flag	Total	Foreign flag as % of total	Total as % of world total
Greece	758	2 345	3 103	44 849 923	105 010 880	149 860 803	70.07	19.52
Japan	747	2 163	2 910	13 472 332	90 924 107	104 396 439	87.10	13.60
Norway	872	819	1 691	27 138 155	30 959 452	58 097 607	53.29	7.57
China	1 617	704	2 321	22 680 169	21 623 434	44 303 603	48.81	5.77
United States	583	870	1 453	11 001 954	31 536 497	42 538 451	74.14	5.54
Germany	377	1 925	2 302	7 231 590	33 517 881	40 749 471	82.25	5.31
Hong Kong (China)	235	334	569	13 206 714	24 527 094	37 733 808	65.00	4.92
Republic of Korea	491	364	855	9 135 854	16 633 763	25 769 617	64.55	3.36
Taiwan Province of China	133	395	528	6 313 645	16 014 886	22 328 531	71.72	2.91
Singapore	457	257	714	12 627 368	6 764 542	19 391 910	34.88	2.53
United Kingdom	396	383	779	7 867 951	10 225 805	18 093 756	56.52	2.36
Denmark	349	333	682	8 540 665	7 971 422	16 512 087	48.28	2.15
Russian Federation	2 176	380	2 556	8 429 692	7 816 315	16 246 007	48.11	2.12
Italy	519	119	638	8 315 551	3 886 635	12 202 186	31.85	1.59
Saudi Arabia	52	69	121	923 734	10 086 880	11 010 614	91.61	1.43
World total	15 649	14 579	30 228	281 241 565	486 350 815	767 592 380	63.36	100.00

Table 2-1 The 15 most important maritime countries (UNCTAD, 2003)

Fig. 2-1 and Table 2-1 show the major players (states-members) in the shipping industry. It is not a coincidence that these players have the highest briskness in IMO's committees and try to influence most the IMO's decision-making process. IMO is like any other political organization and this has its own disadvantages.

Formal Safety Assessment (FSA) can be another manipulative tool in the hands of these countries. This thesis will comment on the issue of the bias of the results since the author will try to throw some light to the unclear points of the process. Some decisions of the IMO based on FSA or antithesis between results can be justified taking into account the conflict of interests between these countries.

2.3 Safety and Risk Assessments

Citizens of modern societies are aware of and sensitive to the discomforting reality that the benefits of technology come at no cost in safety and money. More and more people demand the control over the risk to which they are exposed. The complexity of most activities in engineering requires a cooperative effort made by specialists to model the uncertainties of risk and to seek reductions measures. This urgent need to deal with the problems of risk led to the development of risk-related disciplines like Risk Analysis, Risk Assessment and Risk Management. (see Fig 2-2)

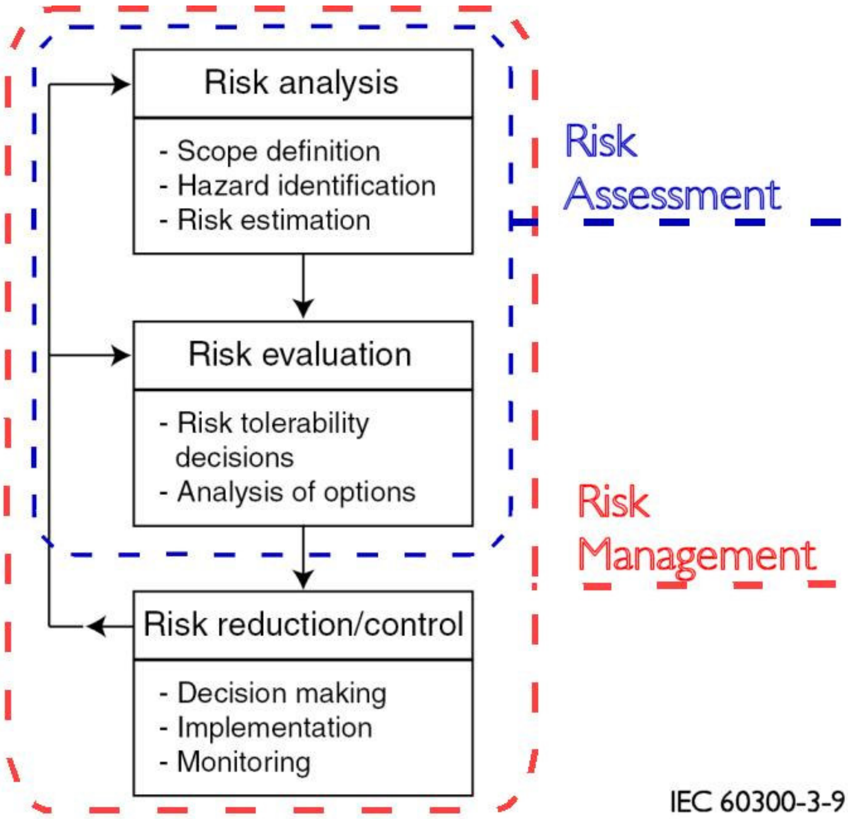


Fig 2-2 Risk Assessment and Management Flowchart (IEC, 1994)

Risk Analysis is "the "systematic use of available information to identify hazards and to estimate the risk to individuals or populations, property or the environment" (IEC).
Risk Assessment is to review the acceptability of risk that has been analyzed and evaluated based on the comparison with standards or criteria that define the risk tolerability.
Risk Management is the application of risk assessment with the intention to inform the decision making process with the appropriate risk reduction measures and their possible implementation.

The intention of the application of such disciplines is to make the public feel safe. Safe doesn't necessarily mean "free of harm or risk". This is the ultimate goal but society and decision-makers know that this, most of the time, requires a huge amount of money, an amount that society cannot pay in order to achieve the state of "no risk". Feel safe means feeling **secure** from danger and its consequences. The amount of risk that society is willing to accept and to tolerate will be discussed in the last Step of the FSA process. It has to be mentioned that one of the slogans that IMO widely used in last decades was "*Safer Shipping and Cleaner Oceans".*

2.4 Historical Background

The way that industries and, particularly the maritime one have approached the goal of safety will be discussed. Safety issues depend on the industry. Industries that involve high risks such as the nuclear and the aviation, are less tolerate to risk and, thus, harder measures are being taken in comparison to other industries that do not suffer from high risks. Two of these high-tech industries will be now discussed.

The study of risk assessment in the **nuclear power industry** started in the early 1970s, when a comprehensive assessment of core melt accidents in two representative nuclear power plants was undertaken by the United States Atomic Energy Commission. The landmark WASH-1400 study was the first ever application of probabilistic risk assessment. However, till the Tree Mile Island accident in 1979 they were not widely accepted by the regulatory authorities or the power plant operators.

Today, each power plant is examined through an Individual Plant Examination (IPE) process by the US Nuclear Regulatory Commission (NCR) which consists of the performance of a plant-specific probabilistic safety assessment for both internal and external initiators.

Another high-tech industry is the aerospace one. The roots of risk assessment within the National Aeronautics and Space Administration (NASA) go back to the initiation of the Apollo program in the early 1960s where quantitative goals for mission success and crew safety were established. Whatever the reasons, the lack of quantitative results led NASA to rely on a qualitative process for accessing the reliability. After the Challenger accident in 1986 NASA moved towards to a quantitative risk assessment and two pilot studies were initiated in 1987. NASA was one of the first to create a Quantitative Risk Analysis Software (QRAS) computer code. NASA's studies focus on systems such as the Auxiliary Propulsion Unit and the Main Propulsion Pressurization System or on the vessel and crew, for example, the Loss of Vehicle and Crew (LOV/C) assessment.
For more information on the current Risk Management practices can by found in the review carried out by ERI Consulting & Co. (ERI/ESA, 2000).

2.5 Offshore Industry and the Piper Alpha Disaster

The offshore industry has always been viewed as a major risk industry, which always looked towards nuclear industry's attempts to study and establish risk assessments.
Between 1980 and 2001, there were a total of 1377 serious injuries and fatalities and 376 deaths, not to mention the 104 fatalities in helicopter incidents. Unlike the nuclear industry, offshore has a large amount of historical data of incidents and accidents. The offshore industry moved to a new era in risk assessment soon after the tragical accident of the Piper Alpha.

The Piper Alpha Disaster

Piper Alpha was an oil and gas platform 110 miles from the Coast of Aberdeen in the North Sea that was built in 1976. In June 1998 it produced 10% of the total British North Sea oil. On July 6, 1988 a gas processor had exploded and set of a chain reaction which led to massive explosions that completely destroyed the platform in 3 hours. The disaster caused 167 deaths out of the 228 working on board at that time. The Cullen Inquiry (in 1990) to investigate the causes of the disaster led to the largest safety reform in the offshore industry. The Offshore Installation Regulations issued by the UK Health and Safety Executive (HSE) came into force in 1993. The regulations required operational Safety Cases to be prepared for all existing offshore installations (fixed and mobile) till November 1993 and both operational and design Safety Cases for new installations.

A Safety Case is a written submission prepared by the owner or operator of an offshore installation and contains all the particulars to demonstrate that hazards with the potential to cause major accidents have been identified, risks have been evaluated and measures have been taken to reduce them to As Low As Reasonably Practicable (ALARP) (see 8-1). A Safety Case must, also, include a comprehensive description of the installation and of its safety management systems including plans and procedures for emergency cases. No installation can be legally used without an accepted -by the HSE Offshore Safety Division – Safety Case.
It has to be noticed that a Safety Case is applied to a particular installation and it is the responsibility of the owner to prepare it. This is very similar to the plant-specific probabilistic assessment that is used in the nuclear industry.

2.6 Lord Carver's Report and MSC62 Proposal

In the shipping industry quite a few serious accidents including the capsize of the Herald of Free Enterprise attracted great attention to ship safety. The adoption of the Safety Case in the UK offshore industry encouraged the safety analysts to look at the possibility of employing a similar regime. In 1992 Lord Carver's report into ship safety (actually, this report was on the investigation of the capsize of the Herald of Free Enterprise) raised the issue of "a more scientific approach to the subject" and recommended the use of a "performance-based regulatory approach" (House of Lords, 1992).

The UK Marine Coastguard Agency in 1993 (MSC 62) proposed to the IMO the use of Formal Safety Assessment (FSA) to ensure safety and pollution prevention. The MCA proposed that IMO should explore, also, the possibility of introducing FSA in relation to ship design and operation. It should be noticed that FSA in not a Safety Case since it does not apply to a specific ship nor is it prepared by the ship owner or operator.

FSA represented a fundamental cultural change, from a largely reactive approach to proactive one. This fact was probably why IMO reacted that favourably to the UK's proposal. This proposal led to the establishment of an FSA Working Group at MSC 66 and since then many administrators undertook trial applications of the FSA methodology. The working group met again at MSC 67 and 68 and finalized the proposal of the FSA Guidelines.

2.7 IMO's Interim Guidelines

The Maritime Safety Committee at its 68th session (28 May to 6 June, 1997) and the Marine Environment Protection Committee at its 40th session (18 to 23 and 25 September, 1997) approved the **Interim Guidelines** for the application of Formal Safety Assessment to the IMO rule-making process. The Guidelines were published in **November 1997** and **MSC/Circ. 829** became an official IMO Circular.

MSC invited member governments and non-governmental organizations to carry out trial applications of the FSA process in order to gain the necessary experience.

FSA was officially the new IMO's tool aiming at enhancing maritime safety, including protection of life, health and marine environment and property by using risk and cost/benefit assessments". Since the publication of the Interim Guidelines a number of applications have been carried out. In 1999 the International Society of Classification Societies (IACS) submitted a paper to the IMO providing a guidance on how to incorporate the human element into the FSA process through a tool named HRA. This proposal was accepted in May 2000 at MSC 72 and **Human Reliability Analysis (HRA)** was decided to be an annex of the Guidelines. Although HRA is a crucial tool, this thesis will comment very little on it.

Chapter 3

Introduction to
Formal Safety Assessment

CHAPTER 3.

INTRODUCTION TO FORMAL SAFETY ASSESSMENT

3.1 FSA Guidelines MSC/Circ. 1023

Experience gained from the trial applications since 1997 finalized the Guidelines. Throughout this thesis, the word Guidelines refers to the document named "Guidelines for Formal Safety Assessment for use in the IMO Rule-Making Process". (MSC Circ. 1023 and MEPC Circ. 392, 5 April 2002). These Guidelines were adopted at MSC 74 and MEPC 47 and superseded MSC/Circ. 829. This document is the official Guidelines of FSA and contains in Appendix 1 the Guidance of Human Reliability Analysis. *HRA is an issue that will not be widely discussed in this thesis.*

Furthermore, many papers were submitted to the IMO providing clarifications and more concrete tools such as Risk Acceptance Criteria. Many FSA studies were, also, submitted to the IMO showing the ways that FSA could be applied. All these documents provide the knowledge that we have on FSA and this framework is the one that will be discussed and criticized in this thesis.

According to the Guidelines "FSA is a rational and systematic process for assessing the risk related to maritime safety and the protection of the marine environment and for evaluating the costs and benefits of IMO's options for reducing there risks. The use of FSA is consistent with, and should provide support to, the IMO decision-making process". FSA's basic philosophy is that it "can be used as a tool to facilitate transparent decision-making process that provides a clear justification for proposed regulatory measures and allowing comparison of different option of such measures to be made".

This means that Formal Safety Assessment is a tool to

- Provide transparent decision-making process
- Clearly justify proposed measures
- Allow comparison of different options

It will be noticed from the beginning of this thesis that FSA is a process to allow comparison of different options and not to justify, or not, the use of a single measure. FSA is a tool to help the decision-making when proposing or assessing proposed regulations. FSA is not a tool to produce regulations !

3.2 Overview

According to the Guidelines (§1.3.1) "the FSA methodology can be applied by:

- a **Member Government or an organization in consultative status** within IMO, when proposing amendments to maritime safety, pollution prevention and response-related IMO instruments in order to analyse the implications of such proposals; or
- a **Committee**, or an instructed subsidiary body, to provide a balanced view of a framework of regulations, so as to identify priorities and areas of concern and to analyse the benefits and implications of proposed changes."

FSA trial applications were, also, carried out by scientists -and were published in scientific magazines- and by classification societies and individual operators (e.g. P&O Cruises) that used FSA as a risk assessment tool.

An FSA study compromises of the following steps:

Step 1	Identification of Hazards
Step 2	Risk Analysis
Step 3	Risk Control Options
Step 4	Cost Benefit Assessment; and
Step 5	Recommendations for Decision-Making

Figure 3-1 is a flowchart of the FSA methodology taken from the Guidelines. A more illustrative approach is Figure 3-2 which was presented by IACS in MSC 75.

<u>Preparatory Step</u>

The process begins with the definition by the decision-makers of the problem that will be assessed along with any relevant constrains (goals, systems and operations).
The purpose of problem definition is to carefully define the problem under analysis in relation to the regulations under review or to be developed which will, also, determine the depth and extend of the application.

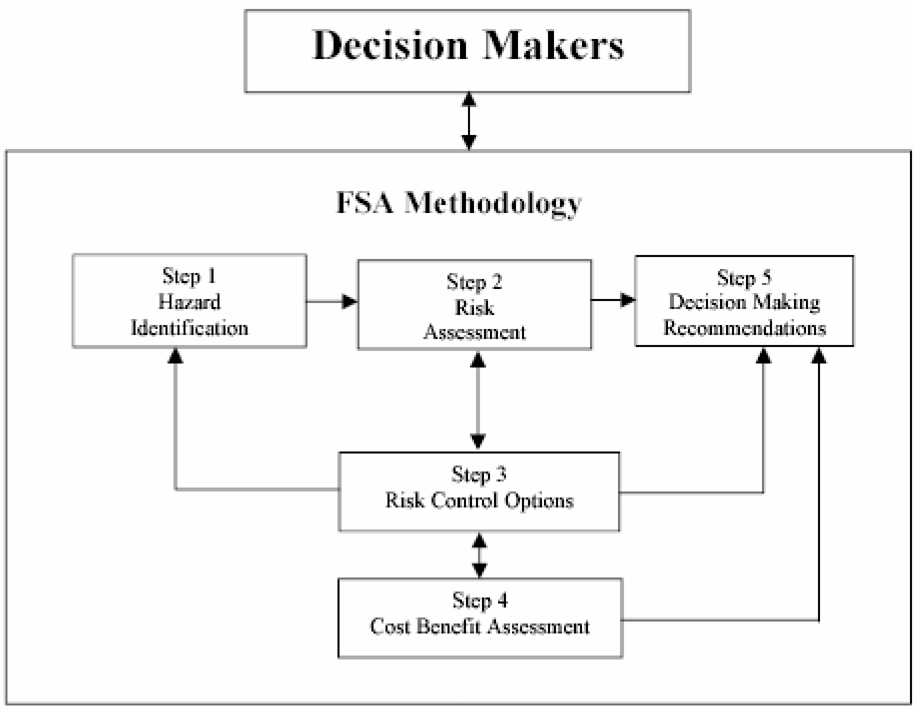


Fig. 3-1 FSA Flowchart [MSC Circ. 1023]

Relevant aspects when addressing ships and, thus, areas for which FSA studies may be applied are according to the Guidelines (§4.1) the following

1. ship category (e.g. type, new or existing, type of cargo);
2. ship systems or functions (e.g. layout, subdivision, type of propulsion);
3. ship operations (e.g. operations in port and/or during navigation);
4. external influences on the ship (e.g. Vessel Traffic System)
5. accident category (e.g. collision, explosion, fire); and
6. risks associated with consequences such as injuries and/or fatalities to passengers and crew, environmental impact, damage to the ship or port facilities, or commercial impact.

<u>Step 1 Identification of Hazards</u>

The purpose of this Step is to identify a list of hazards and associated scenarios and to rank them by risk level. The approaches used are a combination of creative and analytical techniques. The creative element is to ensure that the process is proactive while the analytical element ensures that experience from the past is taken into account. The step makes extensive use of experts. Databases providing data from past accidents and expert's experience as well as modeling, are some of the approaches used.

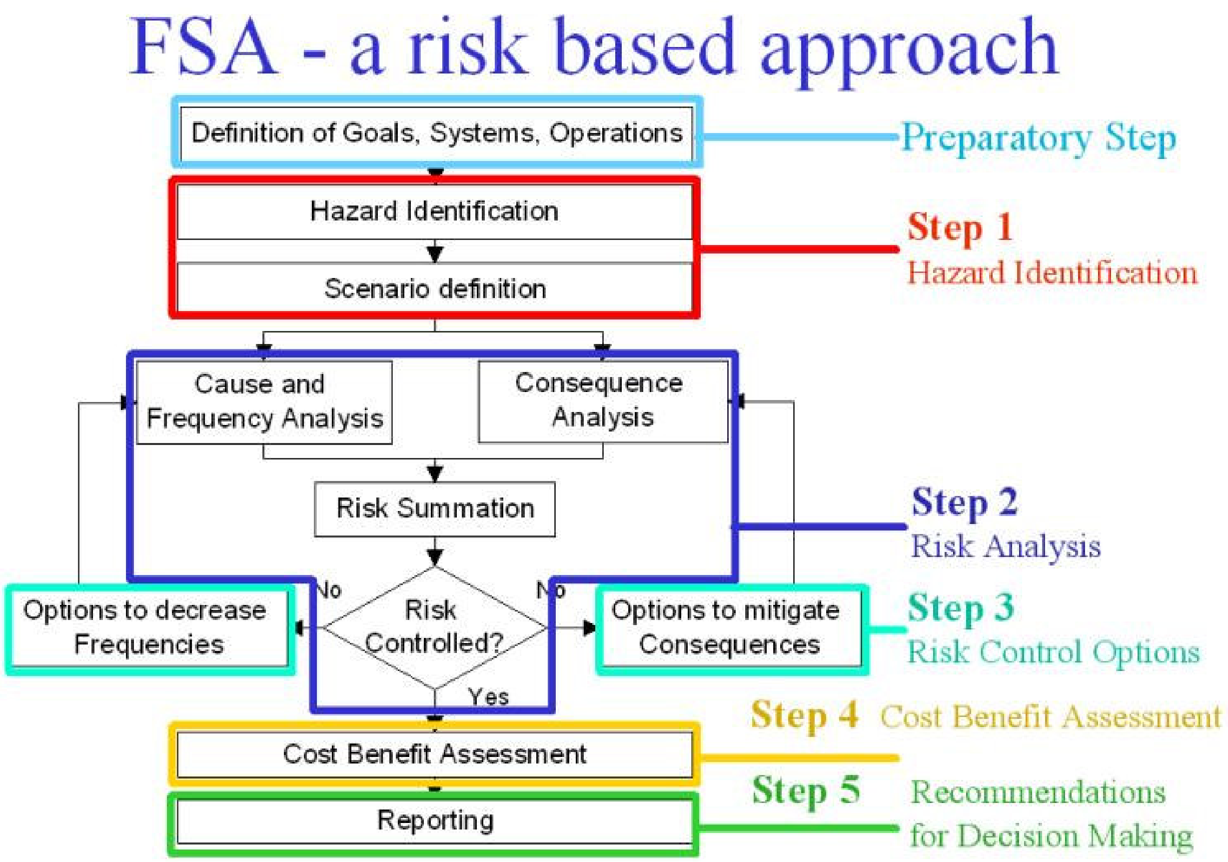


Fig. 3-2 FSA Flowchart [IACS – MSC 75, 2002]

<u>Step 2 Risk Analysis</u>

The probabilities and consequences of the most important scenarios identified in the previous Step are being investigated. Once again, the use of the word probability needs to be emphasized. The Guidelines refer to "Causes" whereas IACS' figure mentions "Causes and Frequencies". When approaching scenarios with no historical data then a probabilistic approach has to be used. In any case, these two quantities form the risk of each scenario. Most of the time, this Step has to be focused only on high risk areas. Finally, it has to be mentioned that the most widely used methods in this Step are the Fault Trees and the Event Trees.

<u>Step 3 Risk Control Options</u>

Focusing on areas that need to be controlled, potential measures that reduce the risk (either reducing the probability of occurrence or the frequency and by mitigating consequences) have to be identified. By re-evaluating Step 2, measures that seem to be effective are grouped into Risk Control Options (RCOs).

Step 4 Cost Benefit Analysis

The cost and the benefit for the implementation of each of the RCOs of the previous Step have to be estimated. Then, these options have to be compared and ranked using some kind of cost effectiveness index such as the Cost of Averting a Fatality (CAF) which is the one used in relation to safety of human life.

Step 5 Recommendations for Decision-Making

This Step should provide a comparison of all Risk Reduction Options, based on the potential reduction of risks and their cost effectiveness. The use of Risk Acceptance Criteria or common practices such as the As Low As Reasonably Practicable (ALARP) -that will be deeply analyzed in Chapter 8- result on the recommendations that will be given to the decision-makers. All FSA results should be given in an auditable and traceable manner using a specific reporting format.

"Timely and open access to the supporting documents" should, then be given to the interested parties. Final results are the basis for discussions during meetings of the corresponding groups of the IMO and relevant proposals may be made according to these findings. It has to be stressed once again that Formal Safety Assessment is a process to aid decision-making; it is not a system for making decisions.

Furthermore, Formal Safety Assessment has its limitations. It is not the "magic wand" that will solve all safety problems in the maritime industry or the tool that will provide the most reliable or correct recommendations. In any case, the outputs are always restricted by the precision of the input data and the assumptions and methods that were used throughout the process. On the other hand, FSA seems to be a very promising tool and with a proper use FSA can be very valuable to IMO's decision-making process.

3.3 Experience and Submitted Work

IMO initially decided to require Helicopter Landing Area (HLA) on all passenger ships. Regulation 28.1 of SOLAS Chapter III required all Ro-Ro passenger ships to be provided with a helicopter pick-up area and existing ships were required to comply

with this regulation not later than the first periodical survey after 1 July 1997. However, a trial application prepared by DNV for Norway and ICCL (International Council of Cruise Lines) showed that this could not be justified in terms of cost effectiveness.
IMO reversing its position on HLAs before the regulation had even come into effect was a remarkable event in the history of the Organization and clearly showed that FSA was meant to be one of the most powerful tools.

At MSC 74 the Guidelines were approved. Following MSC 74's decision, since the development of FSA Guidelines had been finalized, the working group on FSA was not retained on a permanent basis. However, the subject of FSA was retained on the agenda so that a Working Group could be established at future sessions. During MSC 76 the item of FSA was not included and at MSC 78, due to lack of time, there was no discussion for this item. Since MSC 74 only few interesting submission to the item of FSA were made.

However, in the history of FSA, the most concerted applications were the ones on improving the safety of **Bulk Carriers** (BC) and it is the issue of **Double Side Skins** (DSS) of Bulk Carriers that brought FSA in a new era. Bulk Carrier Safety is a separate item on the agenda of MSC but is the only item where FSA studies were that widely used.
Many studies on how to improve the safety of BC were submitted to the IMO. The most important were the International Collaborative FSA study, managed by the United Kingdom, the FSA carried out by Japan and the study on fore-end watertight integrity carried out by IACS.
The FSA study by the United Kingdom that recommended the mandatory construction of DSS for Bulk Carriers was the beginning of an unpredictable series of reactions. IMO proposed the construction of DSS following UK's study. Japan noticed in September 2002 (MSC 76) the fact that studies on the same matter using the same statistics provided different recommendations.
Greece, responded quickly by submitting to MSC 78 (Feb. 2004) the documents MSC 78/5/1 and MSC 78/Inf.6. These presented the findings of a comparative study of the FSA applications of Japan, IACS and the UK and focused on the study of single

and double side skin Bulk Carriers concluding that the mandatory introduction of DSS is not cost-effective.
The United Kingdom commented on these findings and used ruthless phrases such as that "the authors of the work reported in MSC 78/5/1 have, as a result of **not seeking consultation or clarification**, misinterpreted and been unreasonably selective with information and casualty data provided in the IC FSA study". The UK, even, mentioned a study undertaken by the National Technical University of Athens, Greece that had come to the conclusion that the introduction of DSS represents a cost-effective measure for new buildings.
Finally, in the voting session of MSC 78, 32 delegations preferred not to make DSS construction mandatory but to offer it as an alternative, 22 voted in favour of DSS and 15 abstained.
It has to be noticed at this point that the world's largest bulk carriers fleet is possessed by Greek owners. This, however, does not necessarily means that Greeks did only care about their fleet -that is rather old and DSS means that huge amounts of money have to be paid- and not for BC safety when submitted the above-mentioned documents. On the other hand, some movements like this one was rather expected.

In any case, at MSC 78, there was criticism on the action to reverse the earlier decision by the IMO of the introduction of DSS and review of the FSA process was proposed. IACS submitted three papers containing the experience that IACS gained, some risk evaluation criteria and a concordance coefficient to measure the degree of agreement between experts. Subsequently, the Committee, at its 79th session, agreed to establish the Working Group on FSA at MSC 80.

In February 4th, 2005, the Secretariat submitted a document (MSC 80/7) for the establishment of a group of expert to review the Formal Safety Assessment process.
The aim is to consider when and how to apply the FSA process and how to develop an international approach to ensure that "the Organization could base its decision on a single, internationally recognized, set of findings and recommendation".
This document acknowledges the advantages of FSA but, also, notices that there are some weaknesses that have to be identified by experts that will review the past experience. The author believes that we are very close to a set of relevant

amendments that will enable FSA to be a more quantitative assessment; IACS' risk acceptance criteria are moving FSA towards this point.

This thesis studies the concurrent developments, reviews past experience (FSA applications) and relevant submissions to the IMO, proposes possible ways to improve the process and, finally, hopes that the future Guidelines will form a stronger tool, of which the IMO would be very proud.

Finally, the following is a short list of FSA studies:

Reported to the IMO

- FSA study on disabled oil tankers, Germany, MSC 70/20/2
- Helicopter Landing Area . Norway/ICCL COMSAR 3/2, DE 41/INF.2;
- Helicopter Landing Area . Italy, MSC 69/14/7, MSC 69/INF.31;
- BC FSA . International Study (United Kingdom), MSC 76/5/4;
- BC FSA . IACS, MSC 74/5/4;
- BC FSA/Life-saving Appliances . Norway/ICFTU MSC 74/5/5
- BC FSA . Japan Study, MSC 75/5/2;
- BC International Collaborative, United Kingdom, MSC 75/5/5
- BC FSA less than 150 m . Cyprus, MSC 77/5/2.
- BC Comparative Sudy of Single and Double Side Skin, Greece, MSC 78/5/1
- Trial Application to High-Speed Passenger Catamaran Vessels . United Kingdom, MSC 68/INF.6, DE 41/INF.7, MSC 69/14/4, MSC 69/INF.14;
- FSA Study on Navigational Safety of Passenger Ships, Norway, MSC 78/4/2

Individual Class Societies studies

- Concerted action on FSEA by BV, DNV and GL
- Loading and Unloading BCs by Lloyds Register

Papers

(these applications do not follow the standard format, are rather simple, but are quite interesting for various reasons)

- Wang, J., Foinikis, P. (2001). "Formal Safety Assessment of containerships". Marine Policy, 21, p143– 157.
- Loughran C., Pillay A., Wang J., Wall A. & Ruxton T. (2002), "Formal fishing vessel safety assessment", Journal of Risk Research, Vol.5, No.1, pp.3-21.
- Jae-Ohk Leea, In-Cheol Yeob, Young-Soon Yanga (2001), "A trial application of FSA methodology to the hatchway watertight integrity of bulk carriers", Marine Structures, Vol. 14, pp 651-667
- P.Lois, J.Wang, A.Wall, T.Ruxton (2004) , "Formal safety assessment of cruise ships", Tourism Management, Vol.25, p. 93–109

Chapter 4

FSA Step 1
Identification of Hazards

CHAPTER 4.

FSA STEP 1 - IDENTIFICATION OF HAZARDS

FSA Step 1 – Identification of Hazards

Definition of the word "Hazard"

According to the Merriam-Webster Dictionary the word Hazard has the following meanings:

1	a: an adverse chance (as of being lost, injured, or defeated) b: a thing or condition that might operate against success or safety
2	a possible source of peril, danger, duress, or difficulty b: a condition that tends to create or increase the possibility of loss
3	a: the effect of unpredictable, unplanned, and unanalyzable forces in determining events b: an event occurring without design, forethought, or direction

IMO's Circ 1023 gives the following definition:

"Hazard : A potential to threaten human life, health, property or the environment."

Objectives

The objectives of this Step are:

a. to identify all potential hazardous scenarios which could lead to significant consequences and
b. to prioritize them by risk level.

The first can be done with a combination of creative and analytical techniques (which will be discussed in paragraphs 4.1 – 4.3) that aim to identify all relevant hazards. The creative part (mainly brainstorming) is to ensure that the process is proactive and not confined only to hazards that have materialized in the past.

The second objective is to rank the hazards and to discard scenarios judged to be of minor significance. Ranking is undertaken using available data supported by expert judgement.

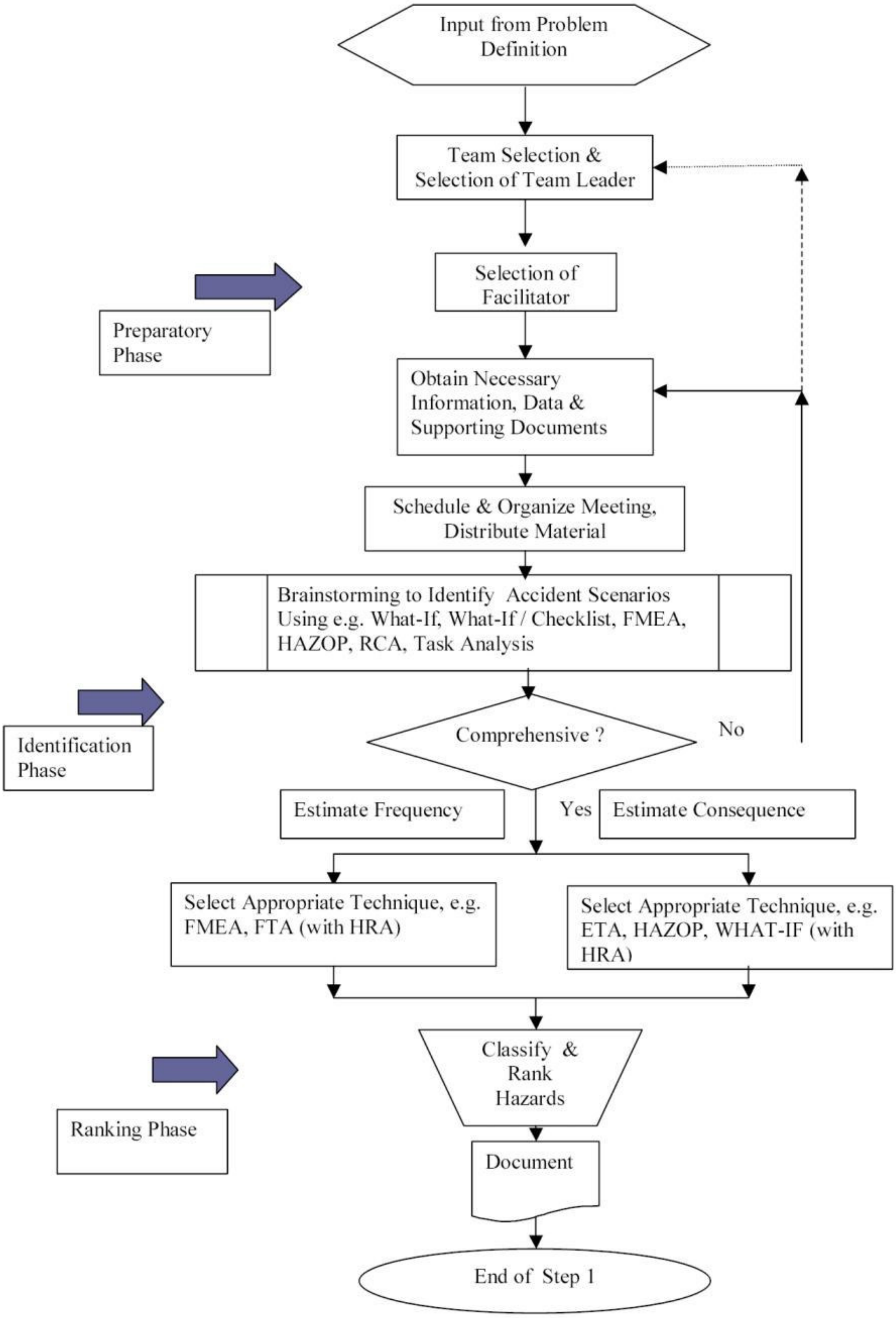


Fig 4-1 Typical Process Flow Chart – STEP 1 [Dasgupta,2003]

4.1 Overview of Hazard Identification Techniques

Hazard Identification

Hazard Identification (HAZID) is the process of systematically identifying hazards and associated events that have the potential to result in a significant consequence (to personnel, environment or any other third part). This is the essential first step of a Risk Assessment.

HAZID is, most of the time, a qualitative exercise strongly based on expert judgement. Many different methods are available for hazard identification and some of them have become standard for particular applications. Experience proved that there is no need to specify which technique should be used in particular cases. Typically, the system being evaluated is divided into parts and the team leader chooses the methodology which can be a standard technique, a modification of one of these or, usually, a combination of several.

In other words, the technique used is not that important since each group can follow a methodology of combined techniques. The most important thing is that the HAZID has to be creative in order to obtain comprehensive coverage of hazards skipping as less areas as it could practicably be.

Also, it is very important that the conclusions of HAZIDs will be discussed and documented during a final session, so that they represent the views of the group rather than of an individual.

Techniques that are used in industry are, now, going to be discussed.

HAzard Operability (HAZOP)

A Hazard and Operability (HAZOP) study is a method of identifying hazards that might affect safety and operability based on the use of guidewords. A team of experts in different aspects of the system (ship, offshore installation etc.), under the guidance of an independent leader, systematically considers each sub-system of the process in turn.

A standard list of guidewords is being used to prompt the experts to identify deviations from design intent. For each credible deviation, experts consider possible causes and consequences, and whether additional safeguards should be recommended. The conclusions are reported in a standard format during the sessions.

Guidance on HAZOP is given in CCPS (1992) and Ambion (1997).
Although these refer to onshore process industries, HAZOP of offshore process equipment is essentially the same. *HAZOP is one of the most commonly used HAZID techniques in the offshore industry* (Ambion, 1997). However, its classic form is intended for continuous chemical processes and is not efficient for marine hazards. Typical example of HAZOP is illustrated in Table 4-1.

Hazard and Operability Analysis of the Vessel's Compressed Air System						
Item	*Deviation*	*Causes*	*Consequences*	*Safeguards*	*Risk Ranking (Consequence, Likelihood)*	*Recommendations*
1. Intel Line for the Compressor						
1.1	High flow		No mishaps of interest			
1.2	Low/no flow	Plugging of filter or piping (especially at air intake) Rainwater accumulation in the line and potential for freeze-up	Inefficient compressor operation, leading to excessive energy use and possible compressor damage Low/no air flow to equipment and tools, leading to production inefficiencies and possibly outages	Pressure/vacuum gauge between the compressor and the intake filter Periodic replacement of the filter Rain cap and screen at the air intake	Medium Risk (Consequence: Medium, Likelihood: Medium)	Make checking the pressure gauge reading part of someone's daily rounds OR Replace the local gauge with a low pressure switch that alarms in a manned area

Table 4-1 Example of HAZOP Analysis [ABS,2003]

HAZOP's strengths and weaknesses are given in DNV/HSE (2001).

The strengths of HAZOP are:

- It is widely-used and its advantages and disadvantages are well-understood
- It uses the experience of operating personnel as part of the team
- It is systematic and comprehensive, and should identify all hazardous process deviations.
- It is effective for both technical faults and human errors.
- It recognises existing safeguards and develops recommendations for additional ones.
- The team approach is particularly appropriate to marine hazards in offshore operations requiring the interaction of several disciplines or organisations.

Its **weaknesses** are:

- Its success depends on the facilitation of the leader and the knowledge of the team.
- It is optimised for process hazards, and needs modification to cover other types of hazards.
- It requires development of procedural descriptions which are often not available in appropriate detail. However, the existence of these documents may benefit the operation.
- Documentation is lengthy (for complete recording).

Other Techniques

What-If Analysis

What-if analysis is a brainstorming approach that uses structured questioning which generates qualitative descriptions of potential problems (=responses to the questions) as well as lists of recommendations for preventing problems. It is widely used alone, especially for simple failure scenarios, but most often is used to supplement other techniques like Checklist Analysis or SWIFT (Structured What-IF checklist Technique).

Checklist Analysis

Checklist Analysis uses hazard checklists which are lists of questions intended to prompt consideration of a range of issues regarding a specific structure, system or scenario. Checklists are widely used in offshore activities, mainly addressing process, safety and environmental risks. The nearest equivalent to checklists used in HAZID sections can be the checklists that are used by surveyors in classification surveys.

Checklists can be prepared very easy, however, are limited to previous experience and they do not encourage brainstorming thinking.

SWIFT (Structured What-IF checklist Technique)

SWIFT is based on brainstorming and is a more structured form of the "What-If Analysis". SWIFT is considered to be a quicker alternative to HAZOP.

Unlike HAZOP, SWIFT uses a team familiar with the system (e.g. operating personnel of an offshore installation) so that its outcome strongly depends on the experience and knowledge of the team and especially its leader. It needs adequate preparation of the checklists in order not to omit critical hazards. An example is illustrated in Fig 4-2 and in Table 4-2 an overview of the above techniques is given.

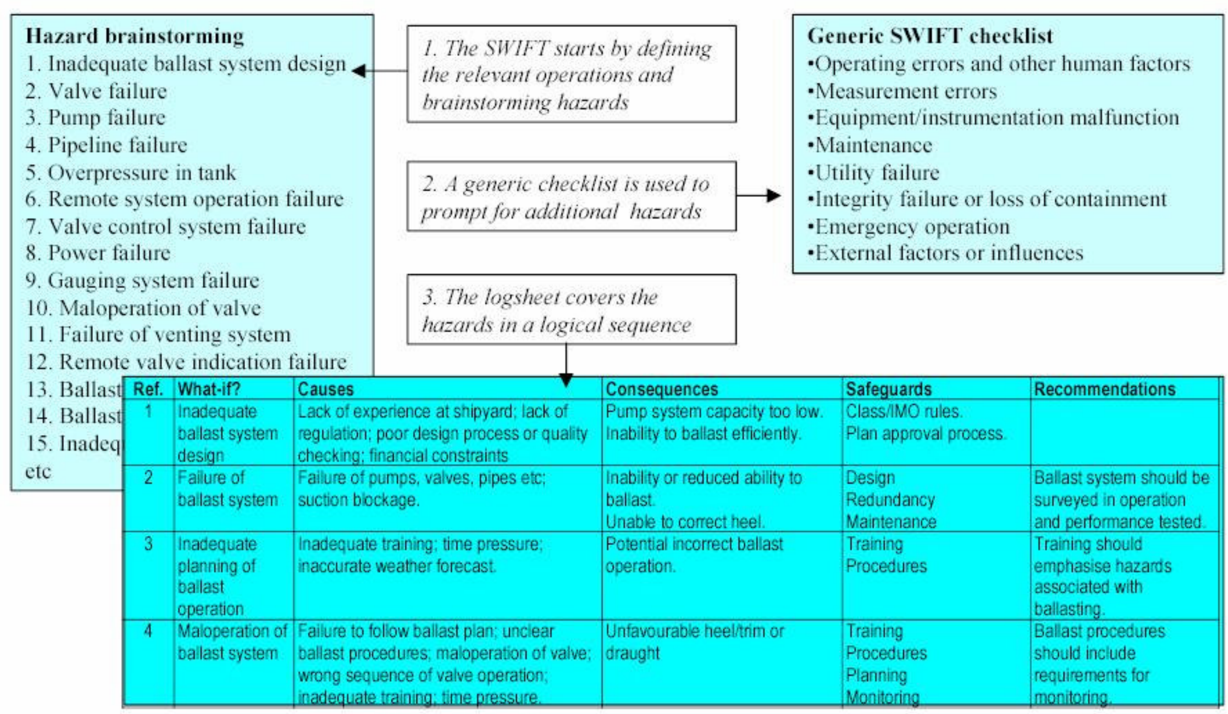


Fig. 4-2 Example SWIFT of Ballast System [DNV/HSE, 2001]

Hazard Risk Analysis Methods	*Summary of Method*	*More Common Uses*
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 preestablished 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 know 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.
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.

Table 4-2 Overview of Widely Recognized Techniques [DNV/HSE, 2001]

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.
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

Table 4-2 (cont.) [DNV/HSE, 2001]

4.2 Use of Casualty Data and Databases

Many FSA studies have extensively used historical data, in many instances the use was exclusive (FSA studies on bulk carriers). There are several Databases available at international and national level and most of them are widely available. Most FSA studies use Lloyd's Maritime Services (LMIS) database, only a few use IMO's database ("Reports on Marine Casualties and Incidents") and, at least one study, MAIB's (Marine Accident Investigation Branch) database..

A study of the current state of the art of databases relevant to FSA was performed and the findings are reported in the Concerned Action on Formal Safety Assessment of Ship Operations (FSEA), a project funded by the European Commission.
A list of the available databases is given in the table below.

Database	Availability	Type of Data	Level of Detail 1: low 5: high	Accident (a) or Incident (i) Data	Event Chain Description	Human Factors included	Usefulness for Risk Analysis 1: low 5: high
DAMA	Public	narrative, partial statistical	2	accident	no	no	2
IMO database	Public	statistical	1	accident	no	no	1
LR database	Public	statistical	1	accident	no	no	1
MAIB	Public	narrative, partial statistical	increases with severity of casualty 2-5	accident	depends on severity of casualty	partial	depends on provided level of detail: 3-5
MARS	Public	narrative	increases with severity of casualty 2-5	accident, incident	depends on severity of casualty	partial	depends on provided level of detail: 3-5
MIIU	Public	narrative	increases with severity of casualty 2-5	accident, incident	depends on severity of casualty	partial	depends on provided level of detail: 3-5
MINMOD	not public	narrative, statistical	3	accident, incident	yes	limited	3
SAFIR	Private	statistical, narrative (?)	5	accident, incident	partial	yes	4
SYNERGI	Private	statistical, narrative	5	accident, incident	yes	yes	4

Table 4-3 Comparison of Databases [FSEA, 1999]

Lloyd's Maritime Information Services (LMIS) database
IMO's database -Marine Accident Reporting Scheme (MARS)
National databases are: Marine Accident Investigation Branch (MAIB) of UK,
Marine Incident Investigation Unit (MIIU) - Australia, MINMOD - USA and DAMA - Scandinavia.
Company level databases: Safety and Improvement Reporting System (SAFIR) and SYNERGI.

Casualty data and information given by databases can be used for various reasons including hazard identification. If historical data are available, risk profiles can be drawn without need to model scenarios and this approach was made in all FSA studies relevant to bulk carriers.

However this usage has several disadvantages. The most important is that this whole philosophy of using historical data is not proactive and therefore it can not be used

for new designs and cannot, even, measure effects of newly implemented risk control options as it needs to wait for accident to happen to have sufficient data.
In some cases, especially simple FSAs, historical data can be used, but in general analytical modelling is strongly recommended.

If the limitations and disadvantages of the use of this kind of data are clearly understood, this information can be a very useful supplement to the above mentioned techniques.

4.3 Risk Matrices

In Step 1 of FSA through a specific technique (like the ones described above) hazards are being identified. Scenarios are, typically, the sequence of events from the initiating event, up to the consequence, through the intermediate stages of the scenario development. Hazards have to be prioritised and scenarios to be ranked.

Risk matrices provide a traceable framework for explicit consideration of the frequency and consequences of hazards. This may be used to rank them in order of significance. A risk matrix uses a matrix dividing the dimensions of frequency (also known as likelihood or probability) and consequence (or severity) into categories.
Each hazard is allocated to a frequency and consequence category and the risk matrix then gives a form of evaluation or ranking of the risk that is associated with that hazard.
Therefore, the Risk Matrix is the most important tool that is provided to the group of experts and is being used to accomplish the previously mentioned task. A literature review of their use in various industries as well as in the maritime industry is necessary for a better understanding and a potential improvement.

4.3.1 Survey of the Use of Matrices in various Industries

Defence Standard Matrix

A risk matrix that has been applied to marine activities (see 4.3.2) derives from the US Defence Standard 00-56 "Safety Management Requirements For Defence Systems Part1: Requirements" (1996). This sets out a 6 x 4 risk matrix based on frequency and consequence definitions as follows.

The severity categories are defined as :

CATEGORY	DEFINITION
Catastrophic	Multiple deaths
Critical	A single death; and/or multiple severe injuries or severe occupational illnesses
Marginal	A single severe injury or occupational illness; and/or multiple minor injuries or minor occupational illness
Negligible	At most a single minor injury or minor occupational illness

Table 4-4 Defence Standard Matrix - Severity categories [DNV/HSE,2001]

The frequency categories are defined as :

ACCIDENT FREQUENCY	OCCURRENCE (During operational life considering all instances of the system)
Frequent	Likely to be continually experienced
Probable	Likely to occur often
Occasional	Likely to occur several times
Remote	Likely to occur some time
Improbable	Unlikely, but may exceptionally occur
Incredible	Extremely unlikely that the event will occur at all, given the assumptions recorded about the domain and the system

Table 4-5 Defence Standard Matrix - Frequency categories [DNV/HSE,2001]

in four risk classes as shown below.

RISK CLASS	INTERPRETATION
A	Intolerable
B	Undesirable and shall only be accepted when risk reduction is impracticable
C	Tolerable with the endorsement of the Project Safety Review Committee
D	Tolerable with the endorsement of the normal project reviews

Table 4-6 Defence Standard Matrix – Risk Classes [DNV/HSE,2001]

The actual Risk Matrix (taking into account tables 4-4,4-5 and 4-6) is as follows:

	Catastrophic	Critical	Marginal	Negligible
Frequent	A	A	A	B
Probable	A	A	B	C
Occasional	A	B	C	C
Remote	B	C	C	D
Improbable	C	C	D	D
Incredible	C	D	D	D

Table 4-7 Defence Standard Matrix – Risk Matrix [DNV/HSE,2001]

National Aeronautics and Space Administration (NASA)

Historically, NASA was distrustful of absolute reliability numbers for various reasons. It was publicised that reliability numbers tend to be optimistic, or taken as facts which they are not. (DNV/HSE, 2001)

At the present, NASA is aggressively pursuing safety studies using probabilistic risk analysis of its various space missions. This change in NASA's practices can be attributed to the extensive investigations following the 1986 shuttle disaster.

NASA has used risk assessment matrices to avoid the problem of managers treating the values of probability and risk as absolute judgements.

Qualitatively, the likelihood of occurrence and consequences of adverse scenarios may be described as shown in Tables 4-8 and 4-9, respectively.

Likelihood of Occurrence (Wiggins 1985)

Level	Description	Detailed Description
A	Frequent	Likely to occur frequently
B	Probable	Will occur several times in life of a system
C	Occasional	Likely to occur at sometime in life of a system
D	Remote	Unlikely but possible to occur in life of a system
E	Improbable	So unlikely that it can be assumed its occurrence may not be experienced

Table 4-8 Likelihood of Occurrence matrix [DNV/HSE,2001]

Levels of occurrence may be based on expert-opinion elicitation or actual probability data. The consequences described in Table 4-9 may be best determined using expert-opinion elicitation.

Consequence (Wiggins 1985)

Level	Description	Mishap Definition
I	Catastrophic	Death or system loss
II	Critical	Severe injury, severe occupational illness, or major system damage
III	Marginal	Minor injury, minor occupational illness, or minor system damage
V	Negligible	Less than minor injury, occupational illness, or system damage

Table 4-9 Consequence Matrix [DNV/HSE,2001]

Tables 4-8 and 4-9 can be combined to from the risk matrix. Risk assessment is based on the pairing of the likelihood of occurrence and consequences.
Table 4-10 shows this pairing and is called a risk assessment matrix.

Risk Assessment Matrix (Wiggins 1985)

Likelihood level	Consequence level			
	I Catastrophic	II Critical	III Marginal	IV Negligible
A: Frequent	1	3	7	13
B: Probable	2	5	9	16
C: Occasional	4	6	11	18
D: Remote	8	10	14	19
E: Improbable	12	15	17	20

Risk Index	Suggested Criteria
1-5	Unacceptable
6-9	Undesirable (project management decision required)
10-17	Acceptable with review by project management
18-20	Acceptable without review

Table 4-10 Risk Assessment Matrix [DNV/HSE,2001]

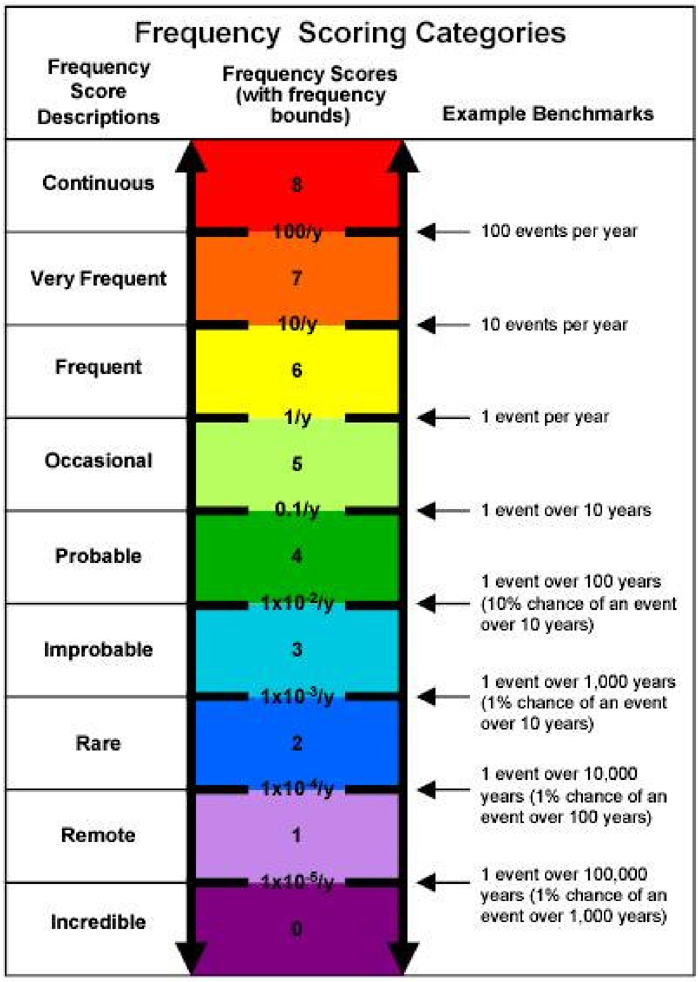
US Coast Guard

In 1992, the United States Coast Guard's Research and Development Center (RDC) launched a multiyear project to develop methodologies and tools to improve the effectiveness of risk management within the Coast Guard. This overall project is called Loss Exposure and Risk Analysis Methodology (LERAM). USCG has developed frequency scoring categories, consequence severity categories and risk screening criteria, which define the level of risk (frequency of occurrence of losses) .

Level of Effect	Types of Effects*			
	Safety/Health	Equipment/Property	Mission Interruption	Environmental
A	An injury or illness results in a fatality or pemanent total disability	The cost of reportable property damage is $1,000,000 or more	Vessel/base is unable to respond to accomplish critical missions	Substantial offsite impact (ocean life effects or offsite health effects) extending beyond the local area
B	Any injury and/or illness results in partial disability Five or more people are inpatient hospitalized	The cost of property damage is $200,000 or more, but less than $1,000,000	Major impact on ability of vessel/base to rapidly accomplish critical missions Significant command attention	Major local area/ offsite impact (ocean life effects or offsite health effects)
C	A nonfatal injury or illness results in loss of time from work for four or more work/ duty days	The cost of property damage is $10,000 or more, but less than $200,000	Moderate impact on ability of vessel/base to rapidly accomplish critical missions Limited capabilities, but able to respond if needed	Significant local area/ offsite impact (enough for an international treaty violation, community alert, or awareness)
D	A nonfatal injury or illness occurs that does not meet the criteria above A person is overboard, an accidental firearms discharge occurs, or an electric shock occurs, none of which meets the criteria of a higher classification	The cost of property damage is less than $10,000	Minor impact on ability of vessel/base to rapidly accomplish critical missions Operational nuisance	Vessel/onsite release of a substance with minor/no offsite effects Possible personnel exposure

Losses in these categories result from both immediate as well as long-term effects associated with a loss sequence (e.g., considering both acute and chronic effects when evaluating safety/health).

Table 4-11 USCG Consequences Categories [DNV/HSE,2001]



Certainty Category	Description
High	Very confident that the actual frequency is at or below the assigned frequency category and data exist to support the frequency category
Medium	Confident that the actual frequency is at or below the assigned frequency category and expect data could be obtained to support the frequency category
Low	Little confidence that the actual frequency is at or below the assigned frequency category and unsure whether data exist or no data exist to support the frequency category

Location Contribution	Description
H	High contributor to the deviation risk; most all of the deviation risk is due to this location
M	Moderate contributor to the deviation risk; a moderate (significant) portion of the deviation risk is due to this location
L	Low contributor to the deviation risk; a minimal portion of the deviation risk is due to this location
N	No or little significant contribution to the deviation risk; little or no portion of the deviation risk is due to this location

Screening Criteria (equal to or less than)	A	B	C	D
	1*	1	3	4

* Actual frequency estimate is at least an order of magnitude less than the bounds of this category

Fig. 4-3 USCG Frequencies Categories – Screening Criteria

US Department of Defense (DOD)

MIL-STD-882D, Standard Practice for System Safety, February 2000, presents an approach to evaluate environmental, safety, and health mishap risks encountered in the development, test, use, and disposal of U.S. Department of Defense (DoD) systems, subsystems, equipment, and facilities.

MIL-STD-882D was developed by the U.S. Airforce Materiel Command for the DoD. Table 4-12 shows the MIL-STD-882D risk matrix.

Mishap severity categories are defined to provide a qualitative measure of the most credible mishap. The dollar values shown in the risk matrix may be modified based on the size of the system being analyzed. In fact, the standard recommends categories are explicitly adapted for the system under analysis before being used.

The mishap probability is the probability that a mishap will occur during the planned life expectancy of the system.

Mishap Severity ↑ / Mishap Probability →	E Improbable	D Remote	C Occasional	B Probable	A Frequent
	P = 10^{-6}	P = 10^{-3}	P = 10^{-2}	P = 10^{-1}	
I Catastrophic (S = 10^6 \$)	[12] ind.* < R < ind.*	[8] 1.0 < R < ind.*	[4] 10^3 < R < ind.*	[2] 10^4 < R < ind.*	[1] 10^5 < R < ind.*
II Critical (S = 2 x 10^5 \$)	[15] ind.* < R < 1.0	[10] 0.2 < R < 10^3	[6] 200 < R < 10^4	[5] 2 x 10^3 < R < 10^5	[3] 2 x 10^4 < R < ind.*
III Marginal (S = 10^4 \$)	[17] ind.* < R < 0.2	[14] 0.01 < R < 200	[11] 10 < R < 2 x 10^3	[9] 100 < R < 2 x 10^4	[7] 10^3 < R < ind.*
IV Negligible (S = 2 x 10^3 \$)	[20] ind.* < R < 0.01	[19] 0.002 < R < 10	[18] 2.0 < R < 100	[16] 20 < R < 10^3	[13] 200 < R < ind.*

Key: Mishap Risk Assessment Value from Table A-III of Ref. 1 → N; $R_{(isk)}$ (\$/T) → R_{min} < R < R_{max}

Mishap Risk Category

18-20	10-17	6-9	1-5
Low	Medium	Serious	High

Mishap Risk Acceptance Level **

High	Component Acquisition Executive
Serious	Program Executive Officer
Medium	Program Manager
Low	As directed

*ind. = indeterminate ** From Table A-IV of Ref. 1

Table 4-12 **MIL-STD-882D**

4.3.2 Risk Matrix According to IMO

In the maritime industry a very simple matrix compared to the ones above has been adopted. As it has been said it is very similar to the Defence Standard Matrix. Analytically, IMO has introduced a 7 x 4 Risk Matrix, reflecting the greater potential variation for frequencies than for consequences.

To facilitate the ranking and validation of ranking, it is generally recommended to define consequence and probability indices on a logarithmic scale. A risk index may therefore be established by adding the probability/frequency and consequence indices. By deciding to use a logarithmic scale, the Risk Index for ranking purposes of an event rated remote (FI=3) with severity Significant (SI=2) would be RI=5.

$$\text{Risk} = \text{Probability} \times \text{Consequence}$$
$$\text{Log(Risk)} = \text{Log(Probability)} \times \text{Log(Consequence)}$$

Frequency Index			
FI	FREQUENCY	DEFINITION	F (per ship year)
7	Frequent	Likely to occur once per month on one ship	10
5	Reasonably probable	Likely to occur once per year in a fleet of 10 ships, i.e. likely to occur a few times during the ship's life	0.1
3	Remote	Likely to occur once per year in a fleet of 1000 ships, i.e. likely to occur in the total life of several similar ships	10^{-3}
1	Extremely remote	Likely to occur once in the lifetime (20 years) of a world fleet of 5000 ships.	10^{-5}

Table 4-13 Frequency Index [MSC Circ. 1023]

Severity Index				
SI	SEVERITY	EFFECTS ON HUMAN SAFETY	EFFECTS ON SHIP	S (Equivalent fatalities)
1	Minor	Single or minor injuries	Local equipment damage	0.01
2	Significant	Multiple or severe injuries	Non-severe ship damage	0.1
3	Severe	Single fatality or multiple severe injuries	Severe damage	1
4	Catastrophic	Multiple fatalities	Total loss	10

Table 4-14 Severity Index [MSC Circ. 1023]

Note that according to Table 4-14 1 fatality equals to 10 severe injuries.

Taking into consideration the following equation

Risk Index = Frequency Index + Severity Index

the Risk Matrix can be constructed.

Risk Index (RI)					
		SEVERITY (SI)			
		1	2	3	4
FI	FREQUENCY	Minor	Significant	Severe	Catastrophic
7	Frequent	**8**	**9**	**10**	**11**
6		**7**	**8**	**9**	**10**
5	Reasonably probable	**6**	**7**	**8**	**9**
4		**5**	**6**	**7**	**8**
3	Remote	**4**	**5**	**6**	**7**
2		**3**	**4**	**5**	**6**
1	Extremely remote	**2**	**3**	**4**	**5**

Table 4-15 Risk Index [MSC Circ. 1023]

The risk index (RI) may be used to rank hazards in order of priority for risk reduction effort. In general, risk reduction options affecting hazards with higher RI are considered most desirable.

It can be seen that this form of risk matrix is easy to apply and requires few specialist skills, and for this reason it is attractive to many project teams.
On the other hand there are a few weaknesses that have to be mentioned.

4.3.2 Weaknesses of Risk Matrices

Risk matrices strongly rely on expert's opinion. Expert Judgment is a long story and it will be discussed later (see 4.4). Weaknesses not related to this subject are going to be discussed in here.

Several problems to the Risk Matrix approach according to DNV/HSE (2001) are:

- Many judgements are required on likelihood and consequence and, unless properly recorded, the basis for risk decisions will be lost.
- The judgements must be consistent among different team members, which is difficult to achieve whether qualitative or quantitative definitions are used. Statistical methods can be used to aggregate expert's judgements.

- Where multiple outcomes are possible (e.g. a fall on a slippery deck – consequence can range from nothing to a broken neck), it can be difficult to select the "correct" consequence for the risk categorisation. Many practitioners suggest using the more pessimistic outcome (in this case: broken leg) and not a very rare worst case nor the most likely trivial outcome.
- A risk matrix looks at hazards "one at a time" rather than in accumulation, whereas risk decisions should really be based on the total risk of an activity. Potentially many smaller risks can accumulate into an undesirably high total risk, but each smaller one on its own might not warrant risk reduction. As a consequence, risk matrix has the potential to underestimate total risk by ignoring accumulation.

FREQUENCY				
Frequent				HIGH RISK
Reasonably probable				
Remote				
Extremely remote	LOW RISK			
	Minor	Significant	Severe	Catastrophic
				CONSEQUENCE

Table 4-16 Risk Matrix [MSC Circ. 1023]

Moreover, there are many weaknesses that are obvious. For example the Severity Index, as it is adopted, gives no discrimination between scenarios or hazards that have more than 10 fatalities.

It has to be noticed that public may be not informed of the following disasters

- Capsize of overloaded Senegalese Ferry resulted in more than 950 deaths (Sept. 26th, 2002)
- Capsize of overcrowded Ferry in Port-au-Prince resulted in more than 900 deaths (Feb. 17th,1993)

but it is informed of the sunk of the Japanese trawler "Ehime Maru" by surfacing US submarine "Greeneville" where only 9 people died. This was happened near Hawaii in the Pacific Ocean (Feb. 9th, 2001).

Is the fact that it is quite unique to have a "crash" between a submarine and a trawler the reason? Probably the reason is the difference of GDP between the above countries. Or we just don't expect that accidents with more than -let's say 500 fatalities- can happen in the developed world?

Another weakness can be seen considering the following imaginary cases.

Case 1
Let's suppose that once per month (FI=7) there is a hazard that leads to one single injury (SI=1). The Risk Index is the sum of these two, which means RI=8
In another situation, one fatality (SI=3) that happens once per year (FI=5) gives a SI of 8 which is the same as the above. Which situation is worse?
In this case it can be said that a hazard causing one injury per month is going to attract public attention.

Case 2
Let's consider another example. United States has a fleet of about 1.453 ships. (UNCTAD, 2003) An incident that is likely to occur once per year in a fleet of 1000 ships has FI=3. Imagine that once per year a hazard leads to a catastrophic disaster of more than 10 fatalities (SI=4) has a RI of 7. There is no reasonable explanation why this case is considered to be less important than the previous ones that have RI=8.
Concluding, the use of the Risk Matrix as it has been adopted by the IMO is probably the best way to rank hazards. Its limitations can be eliminated with a careful categorization of risk and consequences as well as by means of combination of rankings. The last one is going to be discussed in the next paragraph.

4.4 Expert Judgment in Initial Ranking of Scenarios

As it has been, previously, discussed most HAZID techniques are based on teams formed by experts. Experts are used to rank risks associated with accident scenarios or to rank frequency or severity of hazards. One example is the ranking that takes place at the end of FSA Step 1 where each expert develops a ranked list starting from the most severe.

In this paragraph it will be discussed in details how a group is formed, what the weaknesses of expert opinion are, how to "judge" expert judgment and how to enhance the transparency of the results.
It has to be emphasized from the beginning that the role of experts in this step and in the overall procedure of safety assessment is one of the most important.
Whatever will be discussed in this chapter, can be applied to any step of FSA that uses expert judgment.

4.4.1 Establishment of a Group of Experts on FSA

One of the latest IMO's documents (Feb. 4th,2005) is MSC 80/7 titled "Consideration of the establishment of a group of experts on FSA" which contains a proposal for the establishment of a group of experts to review the FSA process.
It includes procedures for selection of experts and funding options, therefore, can be a good basis for the discussion on the establishment of expert groups.

As it is proposed, Member Governments nominate authoritative and independent FSA specialists of unchallenged scientific credibility for inclusion in a permanent pool of FSA experts, maintained by the IMO Secretariat and the MSC or other Committees formally establishes a group of experts on FSA for a certain project.
A multinational group of experts is not rare in HAZID sections of past FSA studies. This idea can contribute to the development of an international approach with a view to ensure that, in the future, the Organization could base its decisions on a single, internationally recognized, set of finding and recommendations. Especially after the Bulk Carrier –related studies this is a must.

Funding of the team is no need to be taken into consideration as it is outside of the scope of this thesis. What is important is the proposal on the number of experts that are going to form the group.
A review of FSA studies that were submitted to the IMO in the past years proved that there is no standard number of participants. Experts can vary from 5 (Genoa brainstorming session - BC FSA. IACS, MSC 74/5/4) to 18 (Comparative Study of Single and Double Side Skin Bulk Carriers, Greece, MSC 78/5/1).
However, MSC 80/7 proposes the selection of ten (10) experts, which is a reasonable number and can be taken as a good basis for future establishments.

It is the author's opinion that this proposal on forming multinational group can not be easily followed by the Member Governments in FSA applications but, hopefully, it may lead on the establishment of more groups having "a geographic, gender and cross-disciplinary balance" in order to, somehow, prove that the to-be-submitted FSA is not just representing the views of its respective government.

The above-mentioned paper is not a guide for the establishment of groups in FSA applications but only for the establishment of a group that will review the FSA process. However, this paper contains useful information and can be a basis for the establishment of groups of experts in "multinational" FSAs.

4.4.2 Comments on Expert Opinion

In order to fully understand the advantages and disadvantages of expert opinion a closer look at it with both mathematical and behavioural approaches is necessary. In the last years, behavioural approaches were used more than mathematical ones. The usual Expert Judgement process has three steps. The first is the selection of experts which is followed by elicitation and aggregation of the judgments.
Elicitation is the process of obtaining expert judgement through special methods. One of them is based on the formalism of the question. The most important issue is, simply, whether the question asked is appropriate. Formalism, in sum, is asking the right questions. Furthermore, judgement is affected by how the question is posed which means that different forming of the question usually elicits inconsistent answers. The final step in process, **aggregation**, is the combination of the judgment of

multiple experts. Mathematical approaches uses models or processes that combine the individual values (or probability distributions) into one singe value or distribution. On the other hand, behavioural approaches like the Delphi method and the Nominal Group Technique use structured interaction among experts to conclude to a common opinion.
Extensive literature exists on expert judgment and interesting issues concerning the engineering expert judgment were found, however it is out of the scope of this thesis to analyze this issue.

Extensive details of the processes that were followed in HAZID meeting of FSAz are not known to the author. The most used method was the following one :
Experts gave their opinion of risk (matrices like the risk one were, often, used) providing a numerical value for each hazard. Then the average for each hazard was calculated (using opinion of all experts) and hazards were ranked according to these values.
The author suggests that experts should provide their rankings for each hazards (risk matrices are strongly suggested). Then a statistical test has to be used -the Concordance Coefficient that will be presented in the following paragraph, for example- in order to prove the transparency of the rankings. Methods, like the Delphi one, could be very useful, however, they demand time-consuming preparation and a modification to suit the needs of the shipping industry before these methods can be adopted. A simple mathematical formula can, somehow, indicate whether an acceptable result has been achieved. The final ranking is the ranking of the average values.

4.4.3 Concordance Coefficient

To enhance the transparency in the result -when a group of experts is asked to rank objects according to one attribute using the natural numbers 1 to J (e.g ranking list of hazards)- the resulting ranking should be accompanied by a concordance coefficient, indicating the level of agreement between the experts,. The following one is proposed by IACS (MSC 78/19/3, Feb. 5th, 2004).

Concordance Coefficient

Assume that a number of experts (J experts in total) have been tasked to rank a number of accident scenarios (I scenarios), using the natural numbers (1, 2, 3, .. ,I). Expert j has, thereby, assigned rank X_{ijx} to scenario i.

The concordance coefficient W may, then, be calculated by the following formula:

$$W=\frac{12\sum_{i=1}^{i=I}\left[\sum_{j=1}^{j=J}x_{ij}-\frac{1}{2}J(I+1)\right]^2}{J^2(I^3-I)}$$

The coefficient W varies from 0 to 1. W=0 indicates that there is no agreement between the experts. On the other hand, W=1 means that all experts rank scenarios equally by the given attribute.

The level of agreement is characterized in the following table:

0 <W<0.5	Not acceptable
0.5<W<0.7	Minimum Acceptable
0.7<W<1	Acceptable, Good Agreement

Some examples of calculating this coefficient are given in MSC 78/19/3. In each example there are 6 experts (J=6) that rank 10 scenarios (I=10). It is the opinion of the author that this number is acceptable but is not the average number of experts that take part in typical sessions.

Table 1: Group of experts with high degree of agreement										
Experts \ Hazards	1*	2	3	4	5	6	7	8	9	10
1	1	3	4	2	5	6	8	10	7	9
2	2	3	1	5	4	6	7	8	9	10
3	1	2	3	4	5	6	7	8	9	10
4	2	1	4	3	6	5	7	8	10	9
5	2	3	1	4	5	6	8	10	9	7
6	1	2	4	3	5	7	6	8	9	10
$\sum x_{ij}$	9	14	17	21	30	36	43	52	53	55
* Numbers correspond to the initial list of hazards.										

Calculations based on the ranking in Table 1 result in W = 0,909; χ^2 =47,5 ; α = 0 999 ,
where α is the confidence level of probability.

Table 4-17 Concordance Matrix – Example [MSC 78/19/3]

Better examination of the W coefficient can show that it can be an acceptable measure. Moreover, the following properties can be identified :

- It measures the "distance" between opinions

Lets suppose there are 6 experts (J=6) that are called to rank 10 hazards (I=10).

1. In the case that all experts give the same rank then W=1 as expected.

2. If the first expert ranks as the most severe (10) hazard what everybody else has rank as the most insignificant (1) (and ranks as most insignificant what others rank as most severe) then W=0,727 which is very close to the minimum acceptable area. This will be later defined as "Extreme Swap".

3. If the same expert (or just one of the experts) ranks as 9th in the rank what other experts have rank as the most insignificant (1) then W=0,785. If the expert does the swap between the first two places then W will be equal to 0,997 which is insignificant.

The above cases are illustrated in the following tables.

Haz / Exp	1	2	3	4	5	6	7	8	9	10
1	10	2	3	4	5	6	7	8	9	1
2	1	2	3	4	5	6	7	8	9	10
3	[illegible]	[illegible]	[illegible]	4	5	6	7	8	[illegible]	10
4	[illegible]	[illegible]	[illegible]	4	5	6	7	[illegible]	[illegible]	[illegible]
5	1	[illegible]	[illegible]	4	5	6	[illegible]	[illegible]	[illegible]	10
6	1	[illegible]	[illegible]	[illegible]	5	6	[illegible]	[illegible]	[illegible]	10
$\sum_{j=1}^{j=J} x_{ij}$	**15**	**12**	**18**	**24**	**30**	**36**	**42**	**48**	**54**	**51**

W=0,727

Haz / Exp	1	2	3	4	5	6	7	8	9	10
1	9	2	3	4	5	6	7	8	1	10
2	1	2	3	4	5	6	7	8	9	10
3	1	2	3	4	5	6	7	8	9	10
4	1	2	3	4	5	6	7	8	9	10
5	1	2	3	4	5	6	7	8	9	10
6	1	2	3	4	5	6	7	8	9	10
$\sum_{j=1}^{j=J} x_{ij}$	**14**	**12**	**18**	**24**	**30**	**36**	**42**	**48**	**46**	**60**

W=0,785

Haz / Exp	1	2	3	4	5	6	7	8	9	10
1	2	1	3	4	5	6	7	8	9	10
2	1	2	3	4	5	6	7	8	9	10
3	1	2	3	4	5	6	7	8	9	10
4	1	2	3	4	5	6	7	8	9	10
5	1	2	3	4	5	6	7	8	9	10
6	1	2	3	4	5	6	7	8	9	10
$\sum_{j=1}^{j=J} x_{ij}$	**7**	**11**	**18**	**24**	**30**	**36**	**42**	**48**	**54**	**60**

W=0,997

Table 4-18 Concordance Matrices – Swaps

"Extreme Swap" is defined as the swap of the values of the two extreme hazards that is made by one expert.

The following Figure shows the sensitivity of the Concordance Coefficient in one single "Extreme Swap" when the number of hazards that are going to be ranked varies from 3 to 10 and the number of experts is 6,7 and 10. It shows that the more hazards have to be ranked the less experts have to be used. Furthermore, a group of 10 experts provides a good stability.

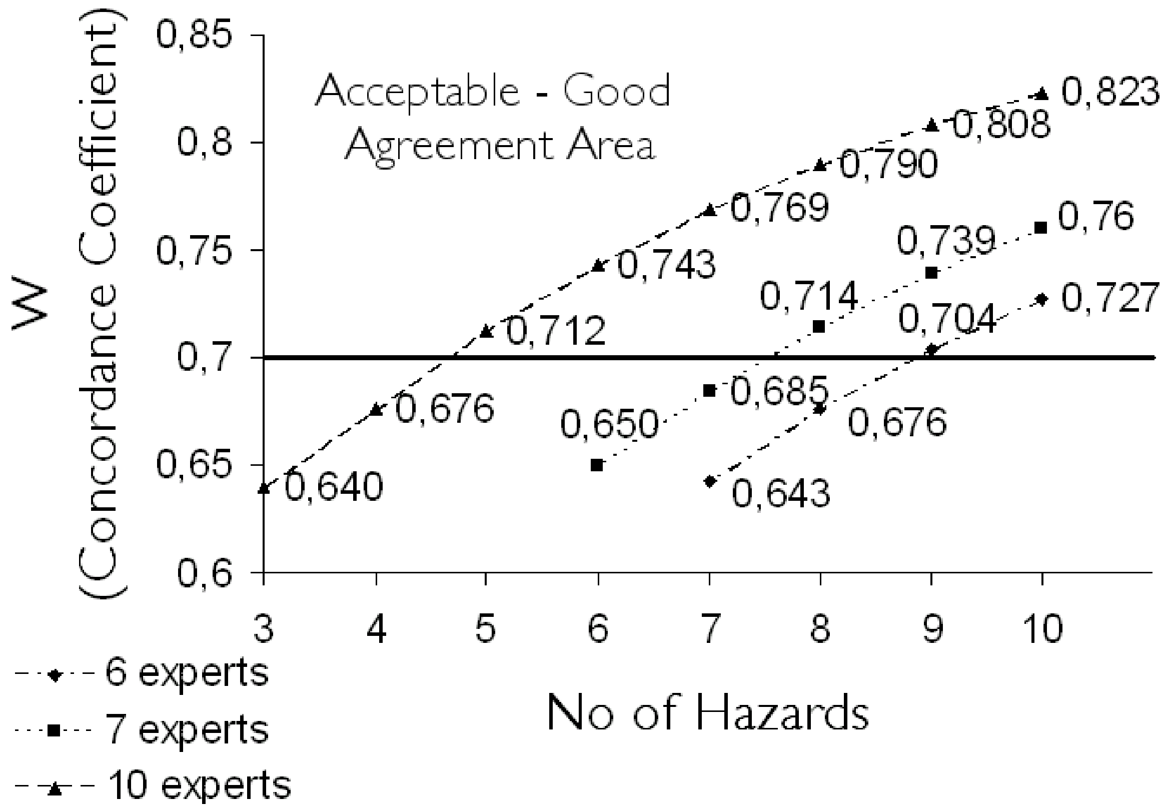


Fig 4-4 Concordance Coefficient in one "extreme swap"

NOTE on Concordance Coefficient

The given formula is actually a formula to calculate the Kendall's Coefficient W , which is one of the most known sample tests used in non-parametric statistics.

The following is an excerpt from SPSS®'s help file. "Kendall's W is a normalization of the Friedman statistic. Kendall's W is interpretable as the coefficient of concordance which is a measure of agreement among raters. Each case is a judge or rater and each variable is an item or person being judged. For each variable, the sum of ranks is computed. Kendall's W ranges between 0 (no agreement) and 1 (complete agreement). "

SPSS® is a statistical analysis software package. SPSS® for Windows , v. 12.0 was used to perform sample tests on the data given in Table 4-17 (which is a example matrix given in MSC 78/19/3).

The output of the program is the following:

NPar Tests

Kendall's W Test

Ranks

	Mean Rank
VAR00001	1,50
VAR00002	2,33
VAR00003	2,83
VAR00004	3,50
VAR00005	5,00
VAR00006	6,00
VAR00007	7,17
VAR00008	8,67
VAR00009	8,83
VAR00010	9,17

Test Statistics

N	6
Kendall's W[a]	,909
Chi-Square	49,091
df	9
Asymp. Sig.	,000

a. Kendall's Coefficient of Concordance

How to calculate Kendall's W using SPSS

Enter data, click on "Non-parametric tests" ("Analyze" menu) and then "K Related Samples". Mark all variables(columns =rank of hazard) and press the button with the arrow to use them as test variables. Tick the appropriate test type and press "OK".

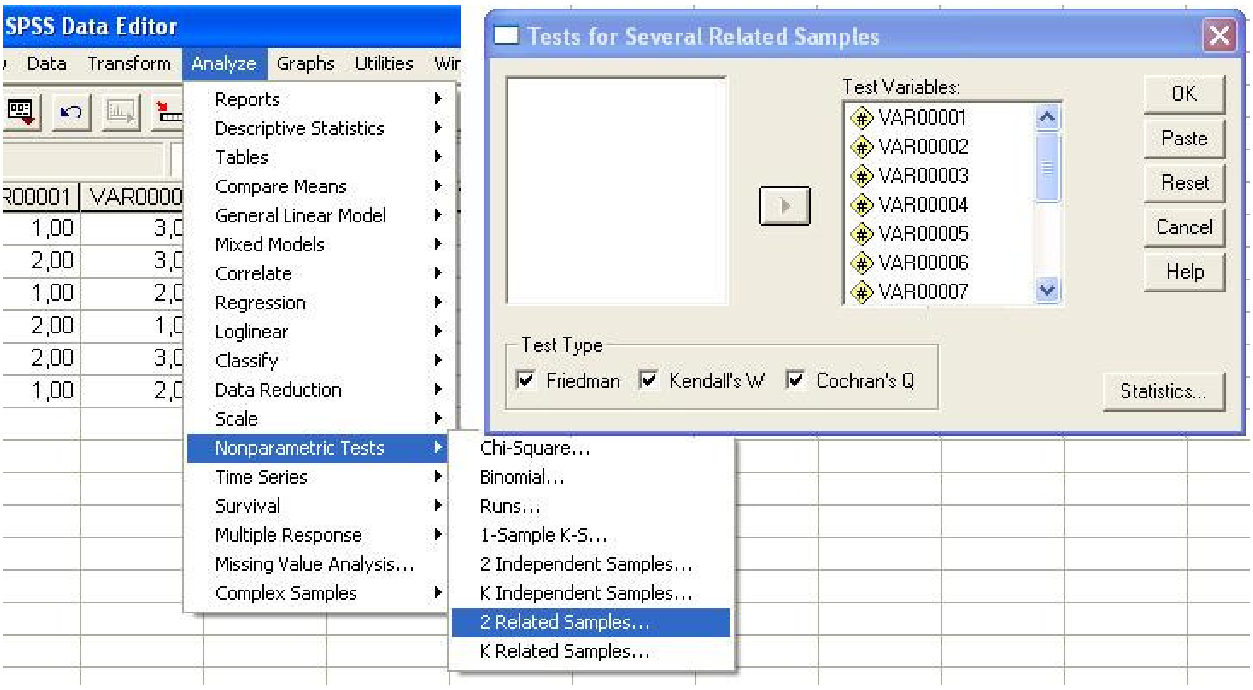


Fig 4-5 Calculating W using SPSS®

The calculation of W for all cases of Table 4-18 was made using Microsoft® Excel, which means that the use of a statistical software package is optional. However, statistical analysis can give us valuable outputs like the following table which shows a descriptive statistical analysis of the same data. The 25^{th}, 50^{th} and 75^{th} percentiles are still the simplest way to have a view of the concordance of expert's opinion. Kendall's coefficient is very specialized test, however, it is extremely easy to be calculated.

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum	Percentiles		
						25th	50th (Median)	75th
VAR00001	6	1,5000	,54772	1,00	2,00	1,0000	1,5000	2,0000
VAR00002	6	2,3333	,81650	1,00	3,00	1,7500	2,5000	3,0000
VAR00003	6	2,8333	1,47196	1,00	4,00	1,0000	3,5000	4,0000
VAR00004	6	3,5000	1,04881	2,00	5,00	2,7500	3,5000	4,2500
VAR00005	6	5,0000	,63246	4,00	6,00	4,7500	5,0000	5,2500
VAR00006	6	6,0000	,63246	5,00	7,00	5,7500	6,0000	6,2500
VAR00007	6	7,1667	,75277	6,00	8,00	6,7500	7,0000	8,0000
VAR00008	6	8,6667	1,03280	8,00	10,00	8,0000	8,0000	10,0000
VAR00009	6	8,8333	,98319	7,00	10,00	8,5000	9,0000	9,2500
VAR00010	6	9,1667	1,16905	7,00	10,00	8,5000	9,5000	10,0000

Further information will not be given on Kendall's W. This coefficient is without doubt a must to enhance the transparency in the results of HAZIDs.

The author strongly suggests the above method to be used in the FSA process but proposes a stricter limit of the minimum acceptable region and, thus, only rankings with w>0,7 to be acceptable. Furthermore, the number of experts to form the group should be in accordance to those discussed above and illustrated in Fig 4-4.

Chapter 5

FSA Step 2
Risk Analysis

CHAPTER 5.

FSA STEP 2 – RISK ANALYSIS

FSA Step 2 – Risk Analysis

5.1 Overview

Scope

"The purpose of the risk analysis in step 2 is a detailed investigation of the causes and consequences of the more important scenarios identified in step 1. This can be achieved by the use of suitable techniques that model the risk. This allows attention to be focused upon high risk areas and to identify and evaluate the factors which influence the level of risk/" [MSC Circ. 1023]

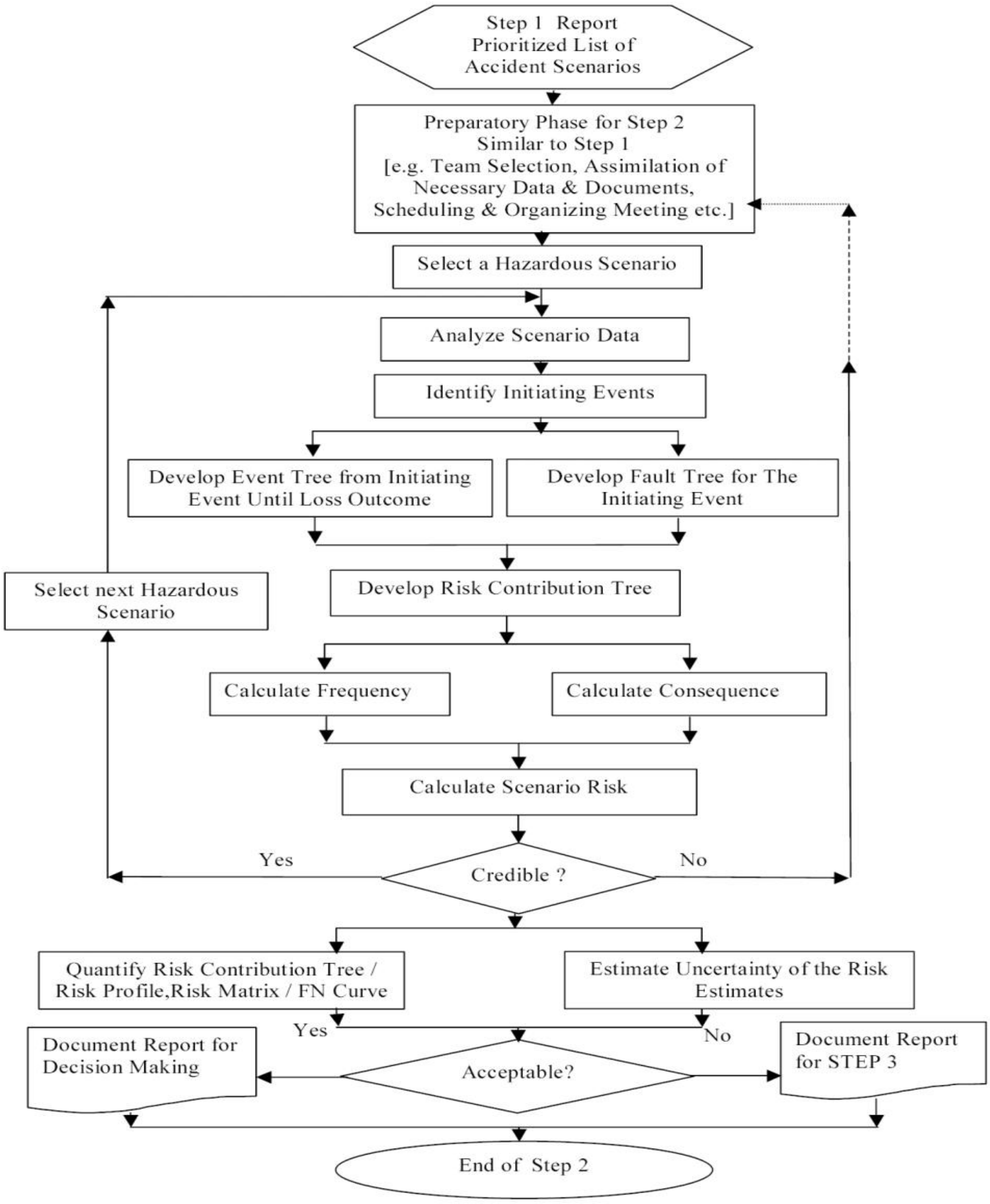


Fig 5-1 Typical Process Flow Chart – STEP 2 [Dasgupta,2003]

Risk Analysis

The output of this step comprises the identification of high risk areas. This can be done by obtaining :

1. a quantitative measure of the probability of occurrence of risk contributors
2. an evaluation of the potential consequences associated with the accident scenarios identified in the previous step

The evaluation of probability and consequences will be discussed later in this Chapter.

5.2 Regulatory Influence Diagrams (RIDs)

Influence Diagrams are used to model the network of influences on an event. These influences link failures at the operational level with their direct causes and with the underlying organisational and regulatory influences as will be explained later.

5.2.1 General Idea and Background

The RID approach is derived from Decision Analysis and as a technique is a variation of the influence diagram methodology applied in Risk Management by other industrial sectors (for example, the nuclear and offshore industry).

As the Influence Diagram recognises that the risk profile is influenced, for example by human, organisational and regulatory aspects, it allows a holistic understanding of the problem area to be displayed in a hierarchical way.

The RID approach is strongly based on expert judgement; therefore, it can be particularly useful in situations for which there may be little, or no empirical data available. This means that RID offers a **proactive** approach to identify the potential influencing factors that could cause the occurrence of an accident.

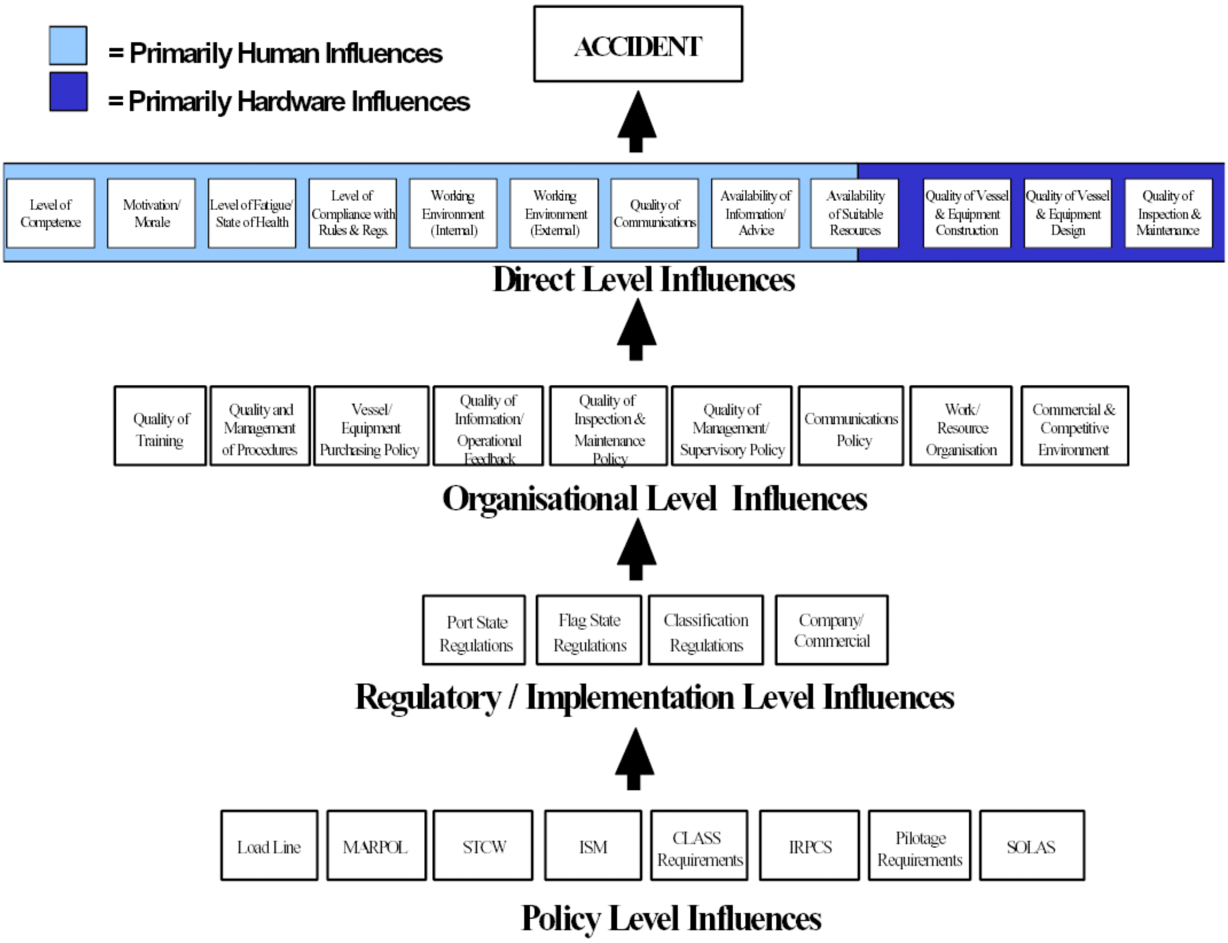


Fig 5-2 Example of RID [MSC 72/16/1]

5.2.2 Clarification of its Use and Thoughts for Removal

Since the adoption of FSA's Interim Guidelines (MSC Circ . 829) by IMO, only the trial application on high-speed crafts by the United Kingdom and Sweden (MSC 69/14/4) made extensive use of the Regulatory Impact Diagram. It was viewed by many that the use of RIDs within the FSA process was of questionable significance.
As a result, there was a proposal by Italy [MSC 71/14, Feb. 1999] to "remove the reference to the Regulatory Impact Diagram in paragraph 5.3 of the FSA Interim Guidelines or fully clarify its use in step 2 and step 4."

Following this proposal, the U.K. submitted a paper [MSC 72/16/1, March 2000] that provided a summary on the use of the RIDs. The discussion on RIDs was, then, ended and the reference to RIDs was, finally, in Circ. 1023. However, since then it is not extensively used within the FSA process.

The paper submitted by the U.K. provides a clarification of RIDs. According to this paper, "the construction of a RID involves defining the target event - the accident - and describing the general setting and conditions, the associated influences, for example the quality of inspection and maintenance procedures, which lead up to the event."
An example of a RID is illustrated in Fig 5-2. In this case the influences on the event are modelled applying a hierarchy of 4 levels:

- a Direct Level - the direct causes of accidents, e.g. grounding, loss of hull integrity, etc.;
- an Organisational Level - the factors that influence the direct level;
- a Regulatory Level - the regulations and requirements that influence the shipping organisation;
- a Policy Level - the Codes and Conventions and political structure that influences national regulators."

Finally, no more information will be given in this thesis as RIDs were, only, used extensively by MCA (Marine and Coastguard Agency, UK) in two FSA applications (Bulk Carrier Safety and High Speed Crafts) but is, nowadays, out of favour.

Further information on RIDs can be found on the following papers:

1. MCA, (2002), FSA of Bulk Carriers Development and Quantification of Influence Networks Summary Report, C999\06\118R, Rev A, UK.
2. THEMES – Thematic Network for Safety Assessment of Waterborne Transport, Report - DELIVERABLE: D 5.4 Version 3, 2003

Particularly, THEMES's report provide an analytical approach of how RIDs can be quantified by assigning a numerical weighting value to each link between factors.

5.3 Risk Contribution Diagrams

The risk associated with an accident data is assessed by constructing and quantifying a diagram called 'the risk contribution tree', based on accident data and expert judgement to display the distribution of risk. The following figure is an example of RCT.

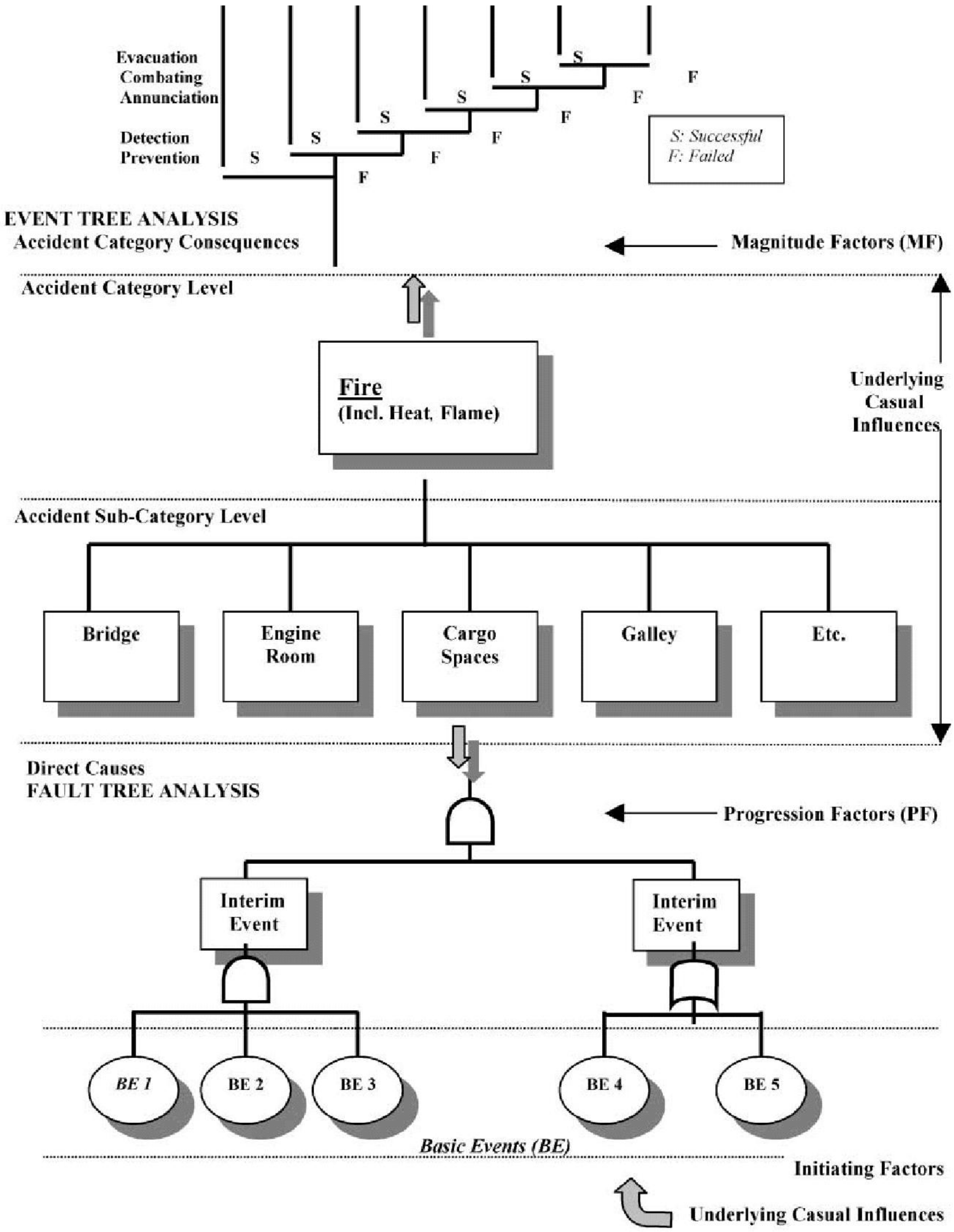


Fig 5-3 Risk Contribution Diagram for Fire [Wang J., 2001]

The Fault Trees (FT) and Event Trees (ET) which will be discussed in this section are quantified in developing the Risk Contribution Tree (also called risk contribution diagram).

Fault and Event Trees are not the only way to develop an RCT. Other techniques like the ones described in 4.1 can be used. FTs and ETs are extensively used in the FSA process and quite all FSA applications that were submitted in the last years use them.
These trees can, also, be used in identifying hazards (which is the previous step in the FSA process) but are being discussed in this step since its full potential can only been seen in Step 2.

Only the qualitative part of FTs and ETs will be discussed in this section. Quantification of frequencies and consequences will be discussed in 5.4 and 5.5 respectively.

5.3.1 Fault Tree Diagram

"A Fault Tree is a logic diagram showing the causal relationship between events which singly or in combination occur to cause the occurrence of a higher level event. It is used in Fault Tree Analysis to determine the probability of a top event, which may be a type of accident or unintended hazardous outcome. Fault Tree Analysis can take account of common cause failures in systems with redundant or standby elements. Fault Trees can include failure events or causes related to human factors.
The development of a Fault Tree is by a top-down approach, systematically considering the causes or events at levels below the top level. If two or more lower events need to occur to cause the next higher event, this is shown by a logic .and. gate. If any one of two or more lower events can cause the next higher event, this is shown by a logic .or. gate. The logic gates determine the addition or multiplication of probabilities (assuming independence) to obtain the values for the top event. "
[IMO Circ. 1023]

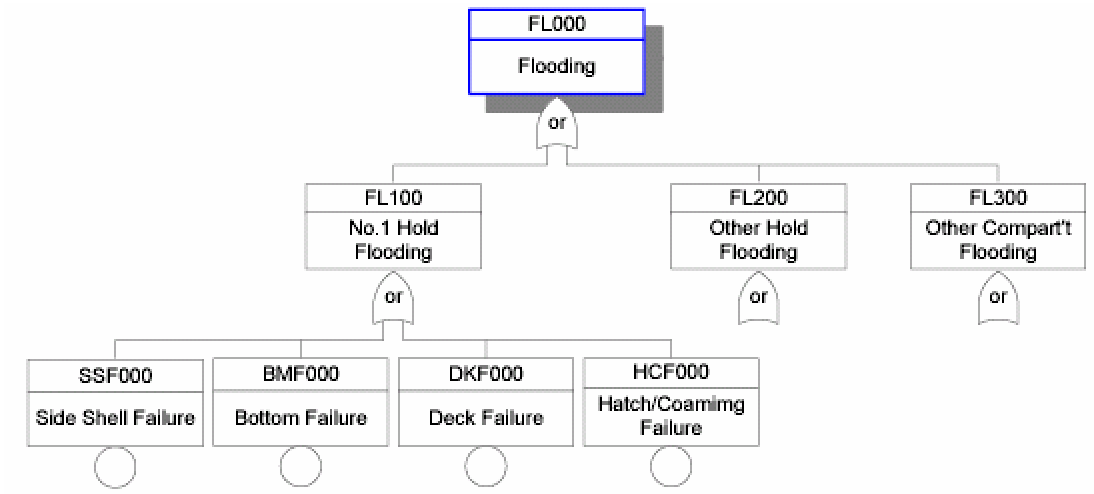


Fig 5-4 Fault Tree [BC FSA, Japan]

Fault Tree Analysis uses "logic gates" (mainly AND or OR gates) to show how "basic events" may combine to cause the critical 'top event'. The top event would normally be the major hazard such as ship loss but it can, also, be any event on which we want to focus.

Construction, usually, starts with the top event, and works down towards the basic events. For each event, it considers what conditions are necessary to produce the event, and represents these as events at the next level down. If any one of several events may cause the higher event, they are joined with an OR gate. If two or more events must occur in combination, they are joined with an AND gate. There are special symbols used in FTA and these can be seen in Fig 5-4.

5.3.2 Event Tree Diagram

"An Event Tree is a logic diagram used to analyse the effects of an accident, a failure or an unintended event. The diagram shows the probability or frequency of the accident linked to those safeguard actions required to be taken after occurrence of the event to mitigate or prevent escalation.
The probabilities of success or failure of these actions are analysed. The success and failure paths lead to various consequences of differing severity or magnitude. Multiplying the likelihood of the accident by the probabilities of failure or success in each path gives the likelihood of each consequence. "
IMO Circ. 1023

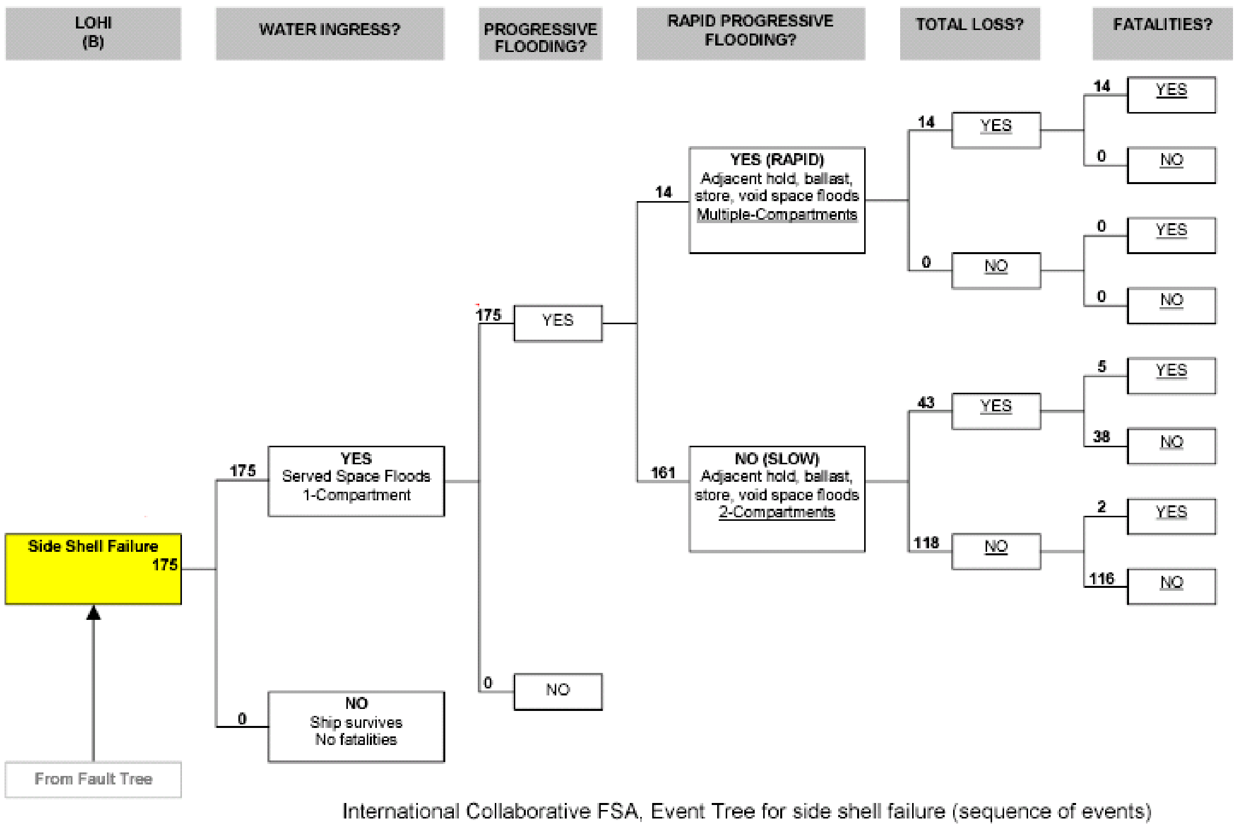


Fig 5-5 Event Tree [BC Collaborative FSA, Greece]

Event tree analysis (ETA) is a logical representation of the various events that may follow an initiating event (e.g. in the above figure, Side Shell Failure). It uses branches to show the various possibilities that may arise at each step. It may also be used to quantify failure probabilities, where several contributory causes can only arise sequentially in time.

Construction starts with the initiating event (e.g. failure) and works through each branch in turn. A branch is defined in terms of a question (e.g. 'Water Ingress?'). The answers are, usually, binary ('yes' or 'no'), and each branch is conditional on the appropriate answers to the previous ones in the tree.
Usually, an Event Tree is presented with the initiating event on the left and the outcomes on the right. The questions defining the branches are placed across the top of the tree, with upward branches signifying 'yes' and downward ones for 'no'.

5.4 Estimation of Frequency of Occurrence

The first part in the estimation of the risk related to a hazard identified in Step I is the estimation of frequency. In general, there are two ways to quantify the frequency, through statistics and through models. These two ways have been used in FSA applications submitted to the IMO. The first one, which is the most used, is the numerical estimation using historical data (e.g. databases) and the other is done by using Frequency Indexes –like the ones described in previous chapters.. Both methods strongly rely on expert judgment. The first one, that is supposed to be widely accepted, strongly depends on the statistical sample that is being used. This is the reason why using the same database there are many FSAs that led to different results.

Take for example Figures 5-6, 5-7 [MSC 78/5/1].

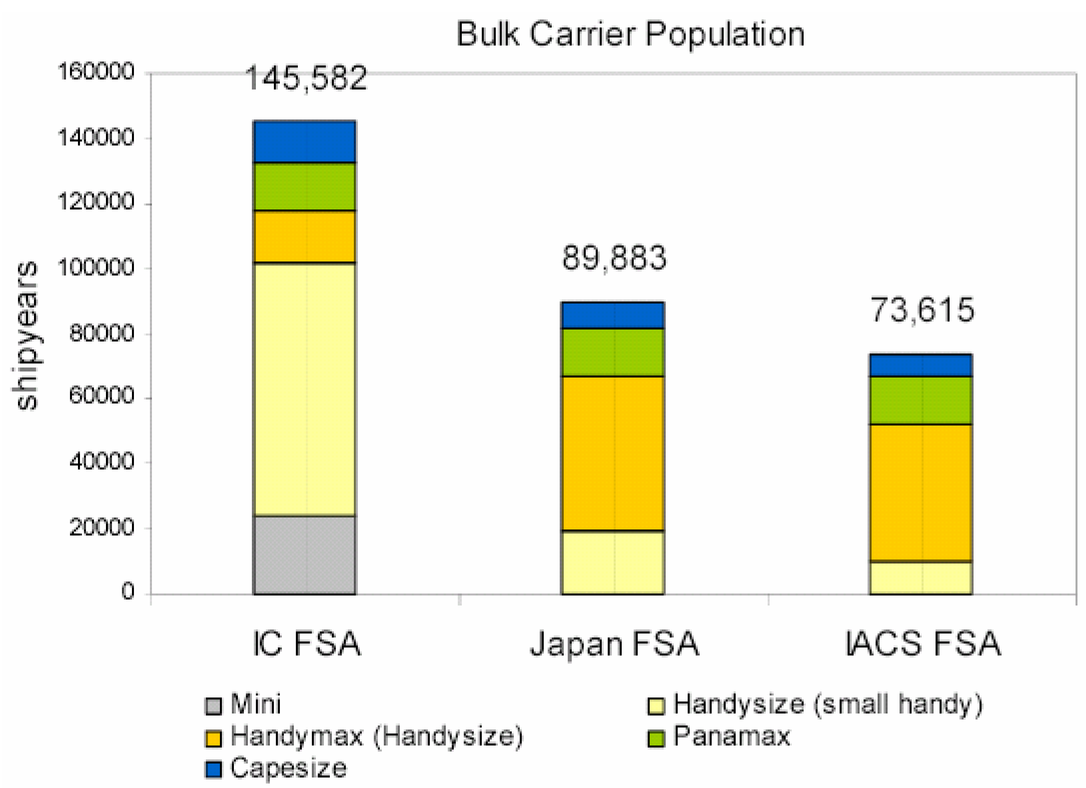


Fig 5-6 Bulk Carrier Population [MSC 78/Inf.6]

The differences in the statistical sample selected in each FSA application can be seen in the above figure.

These result on the following frequencies (F):

Parameter	IC FSA	Japan FSA	IACS FSA
Basis bulk carrier population (ship years)	145,582	89,883	76,615
Number of structural failure (all causes[15]) / associated fatalities		237 / 1031	187 / 850
Number of structural failure (side shell) / associated fatalities	174 / 361[16]	208 / 785[17]	160 / 572[18]
F structural failure [all causes] (casualties per ship year)		2.64 E-3	2.54 E-3
F structural failure [side shell] (casualties per ship year)	1.20 E-3	2.31 E-3	2.09 E-3

Table 5-1 Frequency of side shell failure [MSC 78/Inf.6]

In this FSA, as well as in most FSAs that use casualty analysis, frequency is given as the following fraction :

$$F = \frac{\text{No of Casualties}}{\text{Shipyears}}$$

for example (see Table 5-1)

$$F = \frac{174}{145.582} = 1{,}2 10^{-3}$$

The disadvantage of the first method is that statistics will only represent the past and not take into account recent or potential developments. However, it has been seen that this method is being preferred since it is supposed to be more "scientific".

5.5 Quantification of Consequences - PPL

The two basic ways of quantification of consequences are the same as for frequency quantification. What are considered as "Consequences" in an FSA application depends on the application itself, so it can be f.e. ship loss or fatalities. Most FSAs submitted to IMO quantify the consequences using the Potential Loss of Life (PLL),

Parameter	IC FSA	Japan FSA	IACS FSA
Basis bulk carrier population (ship years)	145,582	89,883	76,615
Number of structural failure (all causes[15]) / associated fatalities		237 / 1031	187 / 850
Number of structural failure (side shell) / associated fatalities	174 / 361[16]	208 / 785[17]	160 / 572[18]
F structural failure [all causes] (casualties per ship year)		2.64 E-3	2.54 E-3
F structural failure [side shell] (casualties per ship year)	1.20 E-3	2.31 E-3	2.09 E-3
PLL structural failure [all causes] (fatalities per ship year)		1.15 E-2	1.15 E-2
PLL structural failure [side shell] (fatalities per ship year)	2.48 E-3	8.73 E-3	7.77 E-3

Table 5-2 PPL of failure [MSC 78/Inf.6]

Potential Loss of Life (PLL)

The unit depends on the type of the FSA, and as it has been said in most FSAs the consequences are measured using the Potential Loss of Life (PPL).

The definition of PLL according to most FSAs submitted is

$$PLL=\frac{\text{No of fatalities}}{\text{Shipyears}}$$

According to this definition, the above table (Table 5-2) was constructed.

Furthermore, two more definitions of PPL where found in literature.

One is the **average fatality rate per unit economic production**:

for crew / workers

$$PLL=q\cdot EV \quad \text{where} \quad q=\frac{\text{No of occupational fatalities}}{\text{GNP}}$$

for passengers

$$PLL=r\cdot EV \quad \text{where} \quad r=\frac{\text{No of fatalities due to transport}}{\text{Contribution to GNP from Trasportation}}$$

where EV is the economic value of the activity and GNP the Gross National Product.

Another definition, which is the most interesting of all, is the following one. This one **connects PLL with F-N curves** (Frequency of N or more fatalities F versus fatalities N) which is a very useful tool for estimating Societal Risk and its Acceptance Criteria. FN Curves will be discussed later in this thesis. According to this, PLL is defined using the following equation.

$$PLL=\sum_{N=1}^{N_u} N \cdot f_N = F_1\left(1+\sum_{N=1}^{N_u-1}\frac{1}{N+1}\right)=F_1 \cdot \sum_{N=1}^{N_u-1}\frac{1}{N}$$

where

Nu is the upper limit of the number of fatalities that may occur in one accident

f_N is the frequency of occurrence of an accident involving *N* fatalities, and

F_1 is the frequency of accidents involving one or more fatalities.

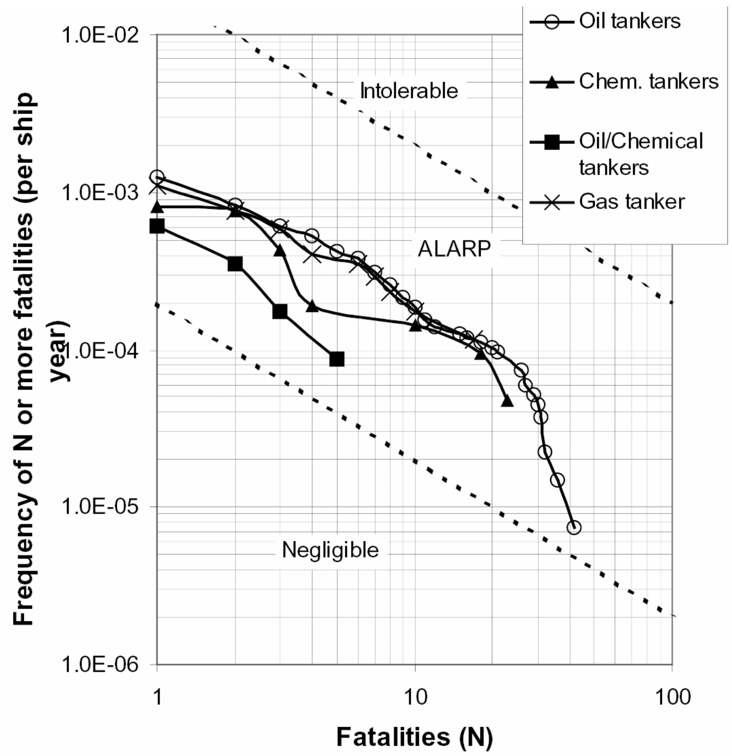


Fig 5-7 Typical F-N Curves

Monetary Value of Consequences

Using a monetary unit can be the best way of summing consequences. Let's consider a hazard that leads to the loss of humans and to the loss of the ship. We can't add human lives and ship loss without having a common unit of measuring them. That's why converting both of them to their monetary equivalents we can have a result expressed on the same unit which in this case can be a monetary unit (e.g. euro or dollar). Here comes the ethical question of what the value of a human life is. In any case, "monetary value" is the only common ground for this task.

5.6 Expert Judgment in Risk Analysis

It is obvious that this Step strongly relies on the use of experts. Their involvement is either on the selection of the sample that will be used in the statistical analysis or, in general, in any other way of estimation of frequencies and consequences (e.g. using indices or matrixes).

The theory on expert judgment that was discussed on the previous chapter applies only when experts are invited to estimate without the use of data. This is something that has not been used in Risk Analysis –or at least, the author is not aware of any FSA that used this method. As it has been said the analysis of data is seen as the most scientific way of estimation in this Step.

However, it is obvious that the use of the same data depending on the selection of the sample data can lead to different estimations which can bias a result. Sample selection has to be extensively justified when done.

5.7 Ways to improve this Step

It is the opinion of the author that in this Step no "numerical" estimation in the form of PPL has to be done. This Step according to the FSA Guidelines is "to focus on high risk areas and to identify and evaluate the factors which influence the level of risk" in order to identify the Risk Control Options which is the next step in the FSA process. Detailed, in that extend, estimation of causes and consequences is not needed in order to identify high risk areas.

Expert judgement using Frequency and Consequence Indices- as they were defined in the previous Chapter- can be proved a very good tool. This, actually, means modelling the scenarios according to the objectives of the FSA.

On the other hand, if casualty analysis is preferred, then expert judgment has to be used in order to have more realistic estimations since historic data can be, by its nature, proactive. Databases can't be accurate in cases where recent accident data don't exist like soon after the implementation of a new regulation. However, experts can be used to estimate the change, reduction in most of the cases, of the frequency and consequences. Actually, this is what is being used in the estimation of risk reduction (ΔR) in the next Step of the process. The same methodology can be applied in this step.

Summing up, the use of modelling has to be extended -taking into account the advantages of the use of expert judgement, and the construction of FT and ET has to be based more on modelling than on the not-so-proactive use of accident data.

A detailed and more "numerical" estimation of risk in terms of frequency and consequence will be done, only for the high risk areas, in the next Step where the Risk Reduction of a Risk Control Option, that will reduce the risk in one of these areas identified in this Step, has to be calculated. Numerical estimations in this Step, especially with the used of PPL can only lead to focus specific areas and bias the results of the FSA.

Chapter 6

FSA Step 3
Risk Control Options

CHAPTER 6.

FSA STEP 3 – RISK CONTROL OPTIONS

FSA Step 3 – Risk Control Options

Risk control measure (RCM): A means of controlling a single element of risk.
Risk control option (RCO): A combination of risk control measures.

Scope of Step 3

"The purpose of step 3 is to propose effective and practical RCOs comprising 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; and
4 grouping RCMs into practical regulatory options. " [MSC Circ. 1023]

6.1 Identification of RCOs

The basic task of this Step is to group Risk Reduction Measures (RCMs) into possible Risk Control Options. Firstly, existing measures must be investigated. It has been noticed that existing measures can control the risk but, possibly, they are not being implemented. Secondly, Risk Control Measures have to be generated referring back to Step 2, or even Step 1, of the FSA process.

The way that the RCMs will be identified strongly depends on the group of experts. To aid this task, IMO has proposed Risk Contribution Trees (see Step 2) and Causal Chains, which will be presented now. Both of them are diagrams and this helps to identify very easily the areas that need to be focused.

Identification Using Causal Chains

According to FSA's Guidelines a useful tool in the identification of possible risk reduction measures is the development of the causal chain.
Causal Chains can be expressed as follows :

Causal Factors —(1)→ Failure —(2)→ Circumstance —(3)→ Accident —(4)→ Consequences

Any RCM should be aimed at, at least, one the following:

(1). Reducing the frequency of failures
(2). Mitigating the effect of failure
(3). Alleviating the circumstances in which failure must occur
(4). Mitigating the Consequences of accidents

Causal Chains are not used, lately, in FSA applications. However, their use was extensive in many FSA-related papers that were published soon after the adoption of the Interim Guidelines.

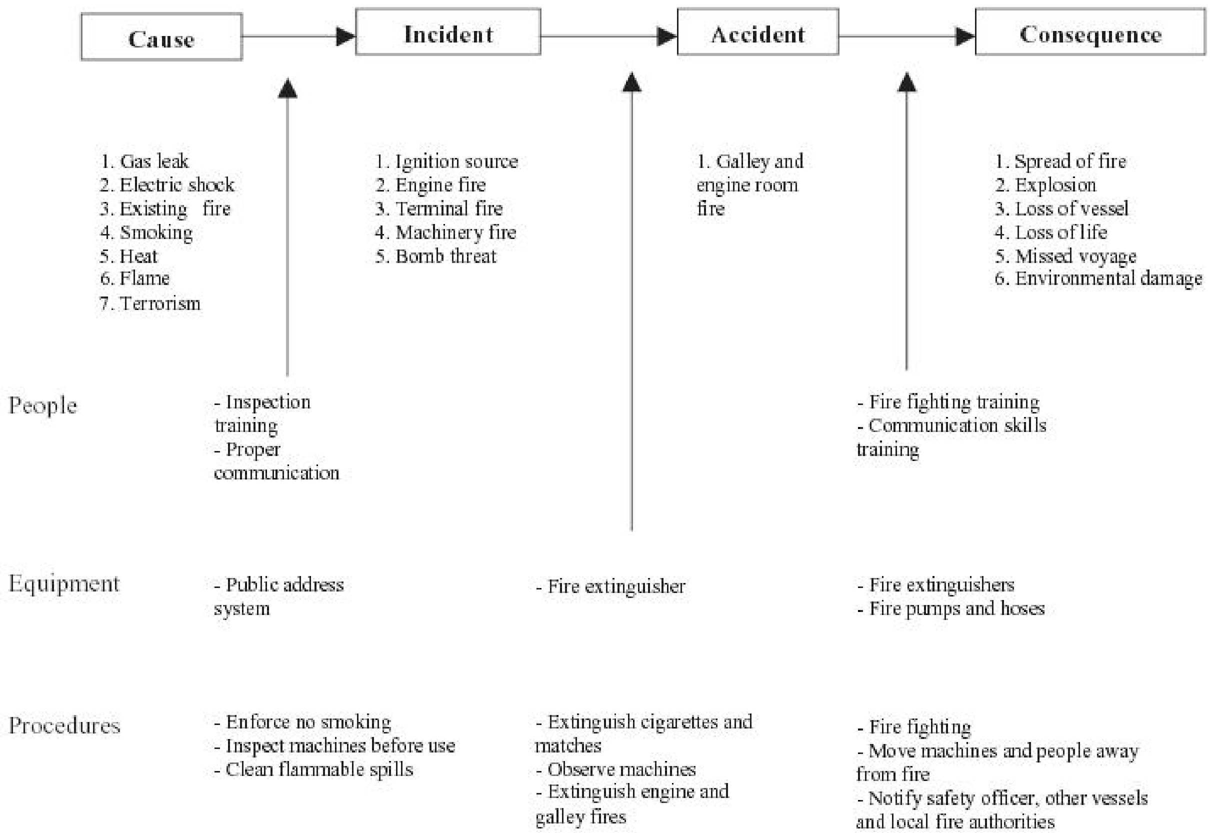


Fig. 6-1 Causal Chain (Fire in galley and engine room) [Lois P. ,2004]

Identification Using Risk Contribution Diagram

The most valuable tool for this Step is the Risk Contribution Diagram of the previous Step. In easy cases, just Fault Trees or Event Trees may be enough. It has been noticed that, in most expert meetings, the identification of measures was done by a close study of the FT and ET only.

Probably, the best way to identify RCM is the above method. These trees (FT and EV) show, in a very simple way to understand, the frequencies and the consequences that need to be reduced.

It has to be noticed that Causal Chains are not so popular as Risk Contribution diagrams in the RCM identification. However, any RCM, without reference to the way of its identification has to aim at one of the above mentioned targets.

Areas that have to be focused, in general, are those related to high frequencies or high consequences. The definition of "high" needs a comparison measure or a mathematical definition. These criteria are called Risk Acceptance Criteria and will be discussed in the next chapters. Risk Matrices and the ALARP (As Low As Reasonable Practicable) risk areas on F-N Curves (see Fig. 5-10) play, for example, a very important role in the selection of the areas that have to focused.

6.2 Grouping of RCOs

Risk Control Measures, through expert meetings, are combined into potential Risk Control Options. The criteria of grouping can vary. It can be just the decision of the experts or can be the fact that RCMs prevent the system from the same failure or type of accident. The grouping of RCMs is very important and more important is the grouping of the RCOs.
The outcome of this FSA step is a list of RCOs that will be analysed in the next Step for their cost and benefit effectiveness.

It is, clearly, noticed that, in most cases, the decision making step of the FSA process is based, only, on the implementation of a single RCO. In cases where two or more elemental RCOs are introduced simultaneously, the calculation of Risk Reduction and of the Cost-Benefit Effectiveness is not that simple.
These quantities (risk reduction, cost and benefit) of a combined RCO depend on the relation among those of the elemental RCOs.
Generally speaking, the introduction of elemental RCOs can be recommended but their simultaneously introduction might not be recommended (see 7.4). The author

suggests that the list of RCOs is useful to include any reasonable combination of these RCOs in the form of a "single" RCO. The introduction of more than one RCO in the same time can, sometimes, be proven to be better in terms of risk reduction, cost and benefit effectiveness than the introduction of a single one.

It must be noticed that recently (Feb. 2004) IACS submitted a document [MSC 78/19/1] which comments on the interaction of RCOs and suggests performing as a minimum a qualitative evaluation of RCO dependencies. This evaluation, as proposed in this document, could take the form of the following matrix. Three different matrices (for cost, benefits and risk reduction) could be given.

Dependency table for Cost/Benefit/Δ Risk				
RCO	1	2	3	4
1		Strong	No	Weak
2	Strong		Weak	No
3	No	Weak		No
4	Weak	No	No	

Table 6-1 Dependency Table

For example in this case the table states that if RCO1 is implemented then RCO3 can be implemented without the need of re-evaluation (since there is no dependency).

6.3 Risk Reduction

This is one of the most important tasks in this Step. Risk Reduction (ΔR) is a very important quantity since it measures the effectiveness of the implementation of the Risk Control Option. Risk Control Options that will be analyzed in the next step are either those that will reduce the risk to the acceptable level or the ones that provide a high reduction rate.

To measure this quantity, a couple of methods can be used. One is through modeling which means that models of Step 2 (for example Fault Trees or Event Trees) have to be re-constructed taking into consideration the implementation of the RCO. Another method, which is very popular lately, is to evaluate the risk reduction using a risk reduction rate, which is based on expert judgment. Unless the RCO has been implemented there is no historical data on the reduction which means that, in this Step, databases cannot be of any use. Reduction Rates are calculated using expert judgment like in the following example (Table 6-2).

	IC FSA		Japan FSA		IACS FSA	
RCO Identification/ Description	RCO-B5 Double Side Skin in all cargo holds for new ships		RCO-15 Double Side Skin in all cargo holds for new ships		RCO-5 Double Side Skin in all cargo holds for new ships	
Assumption	In addition to SOLAS Chapter XII		As an alternative to SOLAS Chapter XII		As an alternative to SOLAS Chapter XII	
Risk reduction rate (r_{RCO})			Small handy	75.8%	Small handy	75%
	Handy	40%	Handy	46.4%	Handy	57%
	Panamax	40%	Panamax	84.4%	Panamax	86%
	Capesize	40%	Capesize	73.3%	Capesize	82%
	Total	40%	Total	64.9%	Total	69%
Basis PLL	Historical risk (1978-2000) Effect of ESP → 0% Effect of SOLAS XII → 0% Scenario: Structural failure (side shell failure only)		Historical risk (1978-2000) Effect of ESP ≈ 20% Effect of SOLAS XII → from 57% to 80% Scenarios: Structural failure (side shell, deck fittings and hatch cover failures)		Historical risk (1978-2000) Effect of ESP ≈ 20% Effect of SOLAS XII → 0% Scenarios: Structural failure (side shell, deck fittings and hatch cover failures)	
ΔPLL (r × PLL)			Small handy	3.95×10^{-3}	Small handy	7.71×10^{-3}
	Handy	4.44×10^{-4}	Handy	1.34×10^{-3}	Handy	4.93×10^{-3}
	Panamax	3.83×10^{-3}	Panamax	1.32×10^{-3}	Panamax	4.25×10^{-3}
	Capesize	3.29×10^{-3}	Capesize	2.57×10^{-3}	Capesize	1.72×10^{-2}
			Total	2.01×10^{-3}	Total	6.40×10^{-3}
Expected lifetime (T_e)	Handy	22.2 years	25 years		25 years	
	Panamax	22.5 years				
	Capesize	21.2 years				
ΔR			Small handy	0.099	Small handy	0.193
	Handy	0.010	Handy	0.034	Handy	0.123
	Panamax	0.086	Panamax	0.033	Panamax	0.106
	Capesize	0.069	Capesize	0.064	Capesize	0.430
	Total		Total	0.050	Total	0.160

Table 6-2: Results of risk reduction implied by the DSS [MSC 78/Inf.6]

For example (Bulk Carrier Safety – IC, Japan, IACS) the risk reduction (ΔR) is calculated using the following formula

$$\Delta R = [r_{RCO} \times PLL_{basis} \cdot (1 - r_{ESP}) \cdot (1 - r_{SOLAS\_XII})] \cdot T_e$$

where

r_{RCO} is the reduction rate of the implementation of the RCO

r_{ESP} and r_{SOLAS_XII} are the reduction rates of the implementation of ESP and of SOLAS's Chapter XII respectively and

T_E is the remaining time life of the ship.

The values given to these variables are shown in the above table [Table 6-2].

Differences on the expert opinion in these FSAs are very high and this is something that will be analyzed now.

6.4 Expert Judgment in FSA Step 3

Expert opinion is used, in this Step, in two major tasks. The first has to do with the identification of RCO and the second with the estimation of the risk reduction.

In the first task, experts have to collect data from previous Steps and to identify the potential measures. The group has to be creative and use the knowledge and imagination of its members to decide which preventive or curative measures are suitable to produce a number of possible and practical RCOs. A good way to produce them is not to aggregate the opinions of all experts -using a mathematical approach- but through discussions, or using a suitable technique (such as the Delphi technique), to let experts conclude on common measures (behavioural approach).

Re-construction of diagrams, such as Fault Trees or Event Trees, has to be done by the experts jointly. Group interaction process can suffer from, for example, group polarization or the influence of dominant personalities, however, for this task no other procedure is recommended.

On the other hand, more "mathematical" approaches have to be used in the risk reduction estimations. Modelling using, for example, the -proposed by the

Guidelines- Indices (Risk Indices/Matrices) can be done and each expert can give his estimation but, then, a statistical method has to be used to aggregate a common value. The Concordance Coefficient that was introduced (see Step 1) can be, also, used in ranking of RCOs according to their risk reduction effect. Similar methods should be used for the risk reduction rates, for example. In the late case, and, in general, when numerical quantities are used any acceptable statistical method should be used. There is no experience in use of statistical methods in the FSAs or their reports that are available to the public.

6.5 Notes

It has been commented before that, in most FSAs submitted to the IMO, the use of mathematical expressions is being, extensively, used. It is the author's opinion that, most of the time, this in not done to provide more justification but in order to present the results more justified than those of other studies that do not use a numerical approach . This is something relative to what psychologists call "Structural Bias". Structural Bias is the situation where, an individual or a group, is unduly influenced by the manner of the presentation of data or problem. The same bias applies to the way of the presentation of the report.

The author reviewed a great number of assessments and noticed that most studies done soon after the introduction of the Interim Guidelines (1997) and before the FSA Guidelines (2002) extensively used modelling and quantification through Indices (which is being used, even, nowadays in other industries such as the nuclear one). Lately, especially FSA studies that were done on the Bulk Carrier safety issue avoided the use of numerical risk ranking through indices.

Chapter 7

FSA Step 4
Cost Benefit Analysis

CHAPTER 7.

FSA STEP 4 – COST BENEFIT ANALYSIS

FSA Step 4 – Cost Benefit Analysis (CBA)

Scope of Step 4

"The purpose of step 4 is to identify and compare benefits and costs associated with the implementation of each RCO identified and defined in step 3. A cost benefit assessment may consist of the following stages:

1 consider the risks assessed in step 2, both in terms of frequency and consequence, in order to define the base case in terms of risk levels of the situation under consideration;
2 arrange the RCOs, defined in step 3, in a way to facilitate understanding of the costs and benefits resulting from the adoption of an RCO;
3 estimate the pertinent costs and benefits for all RCOs
4 estimate and compare the cost effectiveness of each option, in terms of the cost per unit risk reduction by dividing the net cost by the risk reduction achieved as a result of implementing the option; and
5 rank the RCOs from a cost-benefit perspective in order to facilitate the decision-making recommendations in step 5 (e.g. to screen those which are not cost effective or impractical). " [MSC Circ. 1023]

7.1 Estimating Cost and Benefit

Each RCO, which has been forwarded from the previous Step, needs to be evaluated in accordance with the cost for its implementation and maintenance through the lifetime of the vessel, as well as the benefits received for the same period. These calculations are the basis for the decision-making on the RCOs identified in Step 3.

Costs and Benefits should be as comprehensive as possible. It has been mentioned before that, even, for the same RCO several different estimations can be given (see Table 7-1).

FSA study	IC		Japan		IACS	
Assumption	In addition to SOLAS XII		As an alternative to SOLAS XII		As an alternative to SOLAS XII	
Description	Initial Cost US$	Running Cost US$ / year	Initial Cost US$	Running Cost US$ / year	Initial Cost US$	Running Cost US$ / year
Additional building cost, steel	293,148-684,012 195 ton, $1,500-$3,500/ton		219,240 244 ton, $900/ton		149,924 188 ton $800/ton	
Additional building cost, coatings	71,626 - 119,377 4,775 m^2 $15-$25/m^2		71,078 7,797 m^2 $9.12/$m^2$		0	
Loss in earnings due to reduced deadweight [19]		5,962-6,132 350-360 day/year $0.19/ton/day (46% shipments)				0
Loss in earnings due to reduced cargo capacity		17,743 - 18,250 635 m^3 186-191 day/year $0.15/$m^3$/day		27,712 833 m^3		0
Additional repair & maintenance costs		1,554		0		0
Total	364,774-803,389	25,259-25,936	290,318	27,712	149,924	0
Total in NPV	364,774-803,389	334,161-343,118 (r_d=5%,Te=22.2y)	290,318	251,441	149,924	0
ΔC (NPV)	**922,721** (50%min+50% max)		**542,119**		**149,924**	
Breakdown of ΔC	63.3%	36.7%	53.6%	43.3%	100%	0%

Table 7-1 Cost Analysis for DSS [MSC 78/Inf.2]

In general, the **cost** component consists of the one-time (initial) and running costs cumulating over the lifetime of the system. The **benefit** part is much more intricate as benefits may not, only, be valued in terms of risk reduction.
Cost is, usually, expressed using monetary units but benefit can be, for example, reduce in fatalities or benefit to the environment or economical benefit from preventing a total ship loss. A monetary value has to be given to the last two ones for reasons of comparison.

Some equivalents for estimating benefits will, now, be given.

Value of human life

ICAF (Implied Cost of Averting a Fatality) $3m or £2m

800 billion Joules of energy (Norwegian Offshore Sector, NORSOK)

Value of injury or ill health (MSC 72/16 – Mar. 2000)

Quality Adjusted Life year (QALY) $42.000 per life year

Economical Value of a total loss of Ship (MSC 75/5/2 – Feb. 2002)

Average Bulk Carrier $24.808.000

Cape Size Bulk Carrier $43.900.000

Value of oil pollution (OPA 90 – Lloyds List May 2001)

$10.000 per barrel of oil pollution averted

It has to be mentioned, once again, that the value of human life is a controversial matter. This issue will be discussed in the next chapter.

In any case, literature provides no common way of estimating cost and benefit. FSA analysts use their own way to do these estimations. This part of the assessment has to be very detailed and enough evidence on the estimations has to be given.

7.2 Indices of Effectiveness

7.2.1 Cost of Averting a Fatality (CAF)

After the estimations on Cost and Benefit, these values have to be combined with the Risk Reduction. There are several indices that express the effectiveness of a RCO but only one is being extensively used. This is the Cost of Averting a Fatality (CAF) and can be expressed in two forms: the Gross and the Net.
According to Appendix 7 of the Guidelines their definitions are:

Gross Cost of Averting a Fatality (GCAF)

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

Net Cost of Averting a Fatality (NCAF)

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

where
ΔC is the cost per ship of the risk control option
ΔB is the economic benefit per ship resulting from the implementation of the RCO
ΔR is the risk reduction per ship, in terms of the number of fatalities averted, implied by the risk control option

7.2.2 Notes on the Use of CAFs and Bias in Results

CAFs are the most common criteria. There are many approaches in estimating Risk, Cost and Benefit but the use of CAFs seems to be the most standard.

Standard Reporting of final results							
RCO	Description	PLL (lifetime)	Δ Benefit (lifetime)	Δ Cost (lifetime)	Δ PLL (lifetime)	GCAF	NCAF
1							
2							
3							

Table 7-2 Standard Reporting of Results [MSC 78/19/1]

Table 7-2 shows a reporting table as it was proposed by IACS. In this table CAFs are the only indices that are used, proving its domination as cost-effectiveness index.

On the other hand, there is criticism on the use of the CAFs. These indices are being expressed through very simple mathematical formulas but this is not an advantage. In order to be able to understand how the indices can be misused or manipulated some basic introduction to the criteria used for decision-making has to be given.

Cost Effectiveness Criteria

One example of how this can be done will be given using one of the criteria that are proposed by the IMO [MSC 78/19/2]. According to the following table [Table 7-3] in order to recommend a Risk Control Option for implementation this must give a CAF less than $ 3 million.

	NCAF [US $]	GCAF [US $]
criterion covering risk of fatality, injuries and ill health	3 million	3 million
criterion covering only risk of fatality *)	1.5 million	1.5 million
criterion covering only risk of injuries and ill health *) **)	1.5 million	1.5 million

Table 7-3 Cost Effectiveness Criteria

The proposed values for NCAF and GCAF in Table 7-3 have been derived by considering societal indicators (refer to MSC 72/16, UNDP 1990, Lind 1996). These criteria should be updated every year according to the average risk free rate of return or using (approx. 5%) or by use of the formula based on LQI which will be discussed on the next chapter.

Priority of CAFs

It has been proposed by many FSA reviewers that first priority should be given to GCAF. Having a constant risk reduction (ΔR) GCAF depends, only, on cost so the only way to manipulate GCAF is by using cost estimation. On the other hand NCAF depends on two variables and can, even, give negative estimations (see 7.2.3).

NCAF that takes into account economic benefits from the RCOs under consideration may be misused in some cases for pushing certain RCOs, by considering more economic benefits on preferred RCOs than on other RCOs.

Bias of CAFs

CAFs can be manipulated to give estimations that satisfy or not the criteria (for example the $3m criterion).

Consider the following example.

Given the same RCO and risk reduction the NCAF formula gives

$$NCAF=\frac{\Delta C-\Delta B}{\Delta R}<\$3m \Rightarrow \Delta C-\Delta B<\$3m\cdot\Delta R$$

This means that cost and benefit can be manipulated –even separately- to satisfy the following inequalities

$$\Delta C<\$3m\cdot\Delta R+\Delta B$$
$$\Delta B>\$3m\cdot\Delta R-\Delta C$$

and, thus, the criterion of $3m which will result in the recommendation of the RCO to be introduced. On the other hand, suitable estimations of cost and benefit can direct to dissatisfaction of the inequalities and, thus, the RCO will be not recommended anymore.

In the same way, CGAF can be manipulated. Since Risk Reduction is always positive a the Cost could be calculated that way that it can give the desired GCAF value (= the one below $3m)

7.2.3 Quality Adjusted Life Years (QALY)

In separate studies of risk of injuries and ill health, which means no fatalities, the CAFs cannot be used. In MSC68/Inf.6 there is a definition of serious injuries as 1/10 equivalent fatalities and minor injuries as 1/100 equivalent fatality.

The Quality Adjusted Life Year (QALY) has been created to combine quality and quantity of life. It takes one year of perfect health-life expectancy to be worth 1 and locates a specific health state on a continuum between this and 0 (=death).

QALY can be an indicator of the benefits gained from a variety of RCOs in terms of quality and survival. Figure 7-1 shows an example of QALY gained by one person by implementing an RCO.

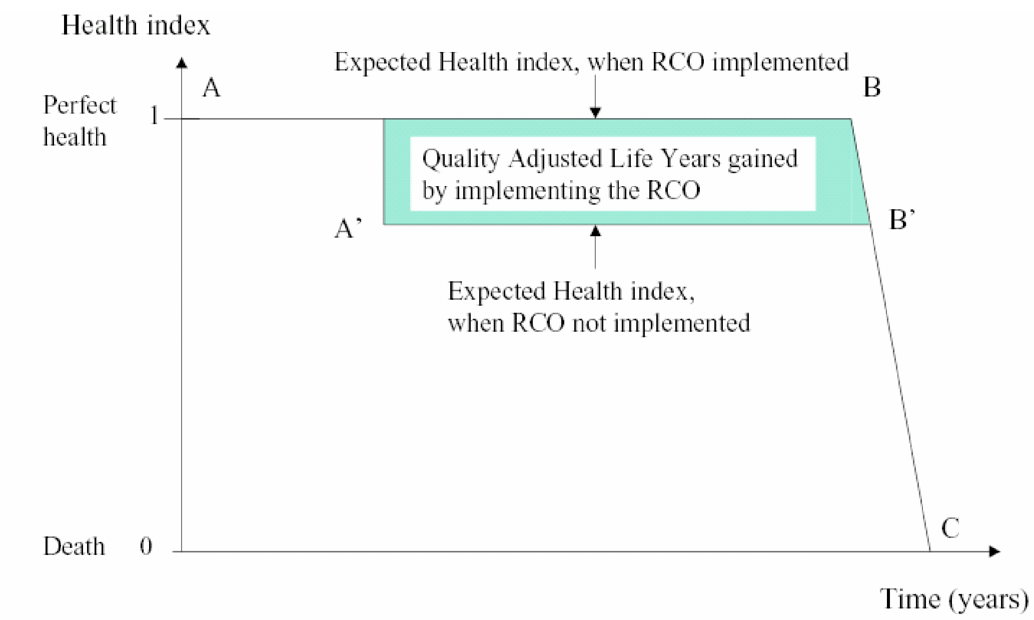


Fig. 7-1 Example of QALY

It was assumed that, on average, one prevented fatality implies 35 Quality Adjusted Life Years gained. The following quantity is the monetary value per QALY gained.

$$QALY = \frac{ICAF/2}{De} = \frac{\$3m/2}{35} = \$42.000$$

7.3 Comparing and Ranking of RCOs

The last task in this Step is to rank the RCOs using a cost-benefit perspective in order to facilitate the decision-making recommendations. Most often, the CAFs are being used in a way that the ranking is very easy; the lower the CAF of a Risk Control Option is the more priority has to been given in its implementation. While figures of GCAF and NCAF are positive, their meanings are understandable, however, when a figure of NCAF becomes negative, the figure or absolute value of NCAF becomes meaningless. Recent FSA studies have come up with some Risk Control Options (RCO) where the associated NCAF was negative.

$$NCAF=\frac{\Delta C-\Delta B}{\Delta R} < 0 \Rightarrow \Delta C-\Delta B<0 \Rightarrow \Delta C<\Delta B$$

A negative NCAF means that the benefits in monetary units are higher than the costs associated with the RCO. As it was proposed in MSC 76/5/12, when comparing RCOs whose figures of NCAF are negative, the absolute values of $\Delta C-\Delta B$ should be used. The same paper gives the following example.

	ΔR	ΔC (US$)	ΔB (US$)	ΔC - ΔB (US$)	NCAF (Million US$)
Case 1	0.002	1,000,000	1,100,000	-100,000	-50.0
Case 2	0.01	1,000,000	1,200,000	-200,000	-20.0
Case 3	0.02	1,000,000	1,200,000	-200,000	-10.0
Case 4	0.20	1,000,000	2,000,000	-1,000,000	-5.0
Case 5	0.20	1,000,000	1,200,000	-200,000	-1.0

Table 7-4 An example of imaginary results of cost effectiveness assessment with negative NCAF [MSC 76/5/12]

The document states : "In this example, Case 4 would be recommended because of the largest ΔR and the smallest Net Cost while its NCAF value is neither smallest one nor largest one among five cases."

The author agrees that Case 4 is the best of all other but even in this case the RCO should not be recommended because of its high GCAF ($5m).

	ΔR	ΔC ($)	ΔB($)	GCAF ($m)	NCAF ($m)
Case 1	0,002	1.000.000,00	1.100.000,00	500	-50
Case 2	0,010	1.000.000,00	1.200.000,00	100	-20
Case 3	0,020	1.000.000,00	1.200.000,00	50	-10
Case 4	0,200	1.000.000,00	2.000.000,00	5	-5
Case 5	0,200	1.000.000,00	1.200.000,00	5	-1

Another topic that has to be highlighted is the interaction of RCOs. It was mentioned in the previous chapter that when a RCO is implemented, the CAF for the implementation of another RCO changes. CAFs have to be re-calculated in these cases, expect if, in the list of the RCOs, an option of another RCO, which is a combination of them, exists.

	ΔR	ΔC ($)	ΔB($)	GCAF ($m)	NCAF ($m)
RCO A	0,500	1.000.000,00	500.000,00	2,0	1,0
RCO B	0,500	1.500.000,00	500.000,00	3,0	2,0
RCO A+B (1)	0,600	2.500.000,00	600.000,00	4,2	3,2
RCO A+B (2)	0,700	2.000.000,00	600.000,00	2,9	2,0
RCO A+B (3)	0,600	2.500.000,00	800.000,00	4,2	2,8

Table 7-5 Imaginary results of CAFs – Interaction of RCOs

The above table shows two RCOs: A and B. The given values of CAFs are below the $3m criterion, therefore, they are recommended. Let's suppose three imaginary cases for the interaction of them. The combined RCO, the RCO A+B, in the first case will not be recommended, in the second case it will be recommended and in the third case the GCAF criterion is not satisfied and, having a high NCAF, the RCO A+B in this case should not be recommended, at least, by the author.

This is a clear-cut example why in cases where two or more elemental RCOs are introduced simultaneously the Cost-Benefit Effectiveness is not so clear.

Finally, for comparing and ranking of RCOs the author recommends the following:

1. GCAF should be prioritized rather than NCAF.
2. In cases where negative NCAFs are estimated, GCAF has to be calculated and if the GCAF has an acceptable value then the NCAF should be considered.
3. Interaction of RCOs needs, in general, re-calculation of CAFs. In general recommendation of two elemental RCO does not necessarily suggest the recommendation of implementing both of them simultaneously.

Chapter 8

FSA Step 5
Recommendations on
Decision-Making

CHAPTER 8.

FSA STEP 5 – RECOMMENDATIONS ON DECISION-MAKING

FSA Step 5 – Recommendations for Decision-Making

Scope

"9.1.1 The purpose of step 5 is to define recommendations which should be presented to the relevant decision makers in an auditable and traceable manner. The recommendations would be based upon the comparison and ranking of all hazards and their underlying causes; the comparison and ranking of risk control options as a function of associated costs and benefits; and the identification of those risk control options which keep risks as low as reasonably practicable.

9.1.2 The basis on which these comparisons are made should take into account that, in ideal terms, all those entities that are significantly influenced in the area of concern should be equitably affected by the introduction of the proposed new regulation. However, taking into consideration the difficulties of this type of assessment, the approach should be, at least in the earliest stages, as simple and practical as possible. "[MSC Circ. 1023]

The final Step of FSA aims at giving recommendations to the relevant decision makers for safety improvement taking into consideration the findings during all four previous steps.

The RCOs that are being recommended

- ✓ Are Cost Effective
- ✓ Reduce Risk to the "desired level".

The IMO Guidelines suggests that, both, the Individual and Societal Types of risk should be considered for crew members, passengers and third parties. Individual Risk can be regarded as the risk to an individual in isolation while Societal Risk as the risk to the society of a major accident – an accident that involves more than one person. In order to be able to analyse further these categories of risk and their acceptance criteria, we must have a look at the levels of risk. As it has been said, a RCO is being suggested for recommendation when it reduces risk to a "desired level".

The next paragraph will present the levels of risk and the definition of the "desired", or better, of the acceptable risk level will be given.

8.1 ALARP and other principles

ALARP

According to Health and Safety Executive's (HSE, United Kingdom) Framework for the tolerability of risk, there are three regions in which risk can fall in. (HSE, 2001) Unacceptable Risk (for example resulting from high accident frequency and high number of fatalities) should either be forbidden or reduced at any cost.
Between this region and the Acceptable Risk region (where no action to be taken is needed) the ALARP (As Low As Reasonable Practicable) region is found. Risk that is falling in this region should be reduced until it is no longer reasonable (i.e. economically feasible) to reduce the risk. Acceptance of an activity whose risk falls in the ALARP region depends on the cost-benefit analysis.

These regions are illustrated in the following figure.

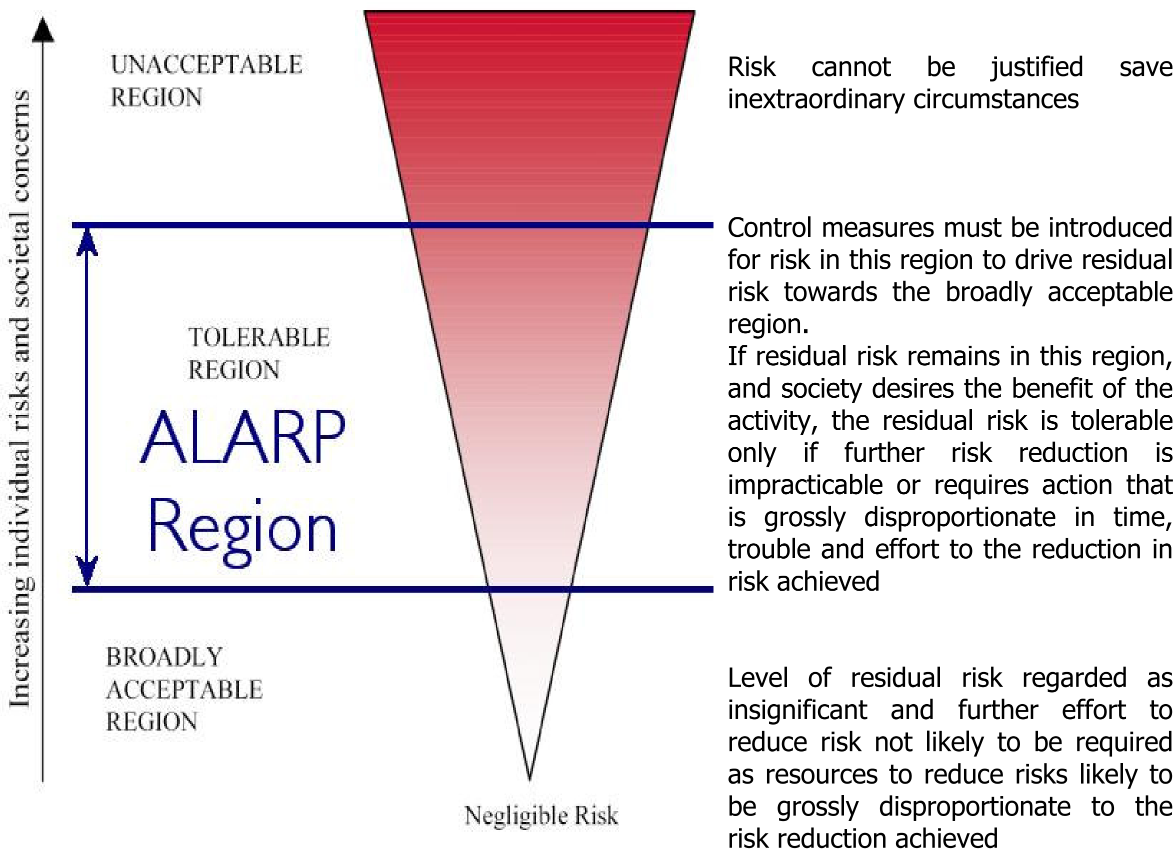


Fig 8-1 Tolerability of Risk Framework [HSE, 2001]

The ALARP principle originated as part of the philosophy of the UK Health and Safety at Work Act 1974, which requires "every employer to ensure, so far as is reasonably practicable, the health, safety and welfare of all his employees." This remains the basis of the approach by the HSE for risk management in the UK.
The term "reasonably practicable" has a particular meaning drawn from legal precedent. The key case is Edwards vs. The National Coal Board, where the Court of Appeal considered whether or not it was reasonably practicable to make the rood and sides of a road in a mine secure. The Court held that

"… in every case, it is the risk that has to be weighted against the measures necessary to eliminate the risk. The greater the risk, no doubt, the less will be the weight to be given to the factor of cost." and

"Reasonably practicable" is a narrower term than "physically possible" and implies that a computation must be made in which the quantum of risk is placed in the one scale and the sacrifice involved in the measures necessary for averting the risk (whether in money, time or trouble) is placed in the other, and that, if it be shown that there is a gross disproportion between them - the risk being insignificant in relation to the sacrifice - the defendants discharge the onus on them [of proving that compliance was not reasonably practicable]. "

Thus, determining that risks have been reduced ALARP involves an assessment of the risk to be avoided,, of the sacrifice (in money, time and trouble) involved in taking measures to avoid that risk, and a comparison of these two. This approach has been adopted widely. In order to apply it, the duty holder must, first, ensure that the risks are not unacceptable, and must, then, show that the risks are either ALARP or broadly acceptable.

It should be noted that the application of numerical values for the limits of the regions may not be, always, appropriate. Numerical values for the boundaries of the ALARP region will be given for Individual and Societal Risks. When risks are expressed in qualitative form, the criteria to help evaluate their significance are, usually, expressed on a risk matrix.

Other Principles

France - GAMAB (Globalement Au Moins Aussi Bon): The risk of any new system is compared with an existing system already accepted. The new system must offer a level of risk globally, at least, as good as the one offered by any existing system. By following this principle the decision-maker does not have to specify a specific level of risk acceptance.

Germany - MEM (Minimum Endogenous Mortality): In an extended form, this principle says that hazards due to a new development or activity should not significantly augment the total (present) level of Individual Risk. It could, for instance, be argued that the new activity should not increase the risk by more than say 1%.. By following this principle, the decision- maker still have to decide the risk acceptance target. However, the principle provides good support to that decision.

ALARP was, firstly, used in the United Kingdom and has been adopted in many countries. Principles like GAMAB and MEM can not be widely used and, therefore, the ALARP principle is the only that can be used in the FSA process. However, the GAMAB Principle is based on the so called "comparison-methods". The main methods that belong to this wide category according to Skjong (2002a) are :

Comparison with other hazards : A comparison is made with other industries that are felt to represent a reasonable target, and where documentation is good. Some of these industries are the chemical, the nuclear, and the ones that are close to shipping (offshore and aviation).

"Shipping should be as safe as road transport"

Comparison with natural hazards : The main idea of this principle is to compare things we do to ourself (and, thus, risk we take) with things done to us by Nature (God). It is not clear what can be justified as an "Act of God", however, this is used in maritime law meaning "an extraordinary interruption by a natural cause (as a severe flood or earthquake) of the usual course of events that experience, prescience, or care cannot reasonably foresee or prevent". Courts of Justice and P&I Clubs may accept it as a cause.

"Risks posed by human activity should be smaller than those posed by nature"

Comparison with risk we normally take. : A comparison is made with activities of our everyday life. People don't consider activities like crossing a street, driving cars or sports as a hazardous, but, in reality, they are more risky than many other activities. Actually, the statement that "most dangerous place to be is at home" is verified by statistics, for example see Table 8-1.

"Risks that are smaller than staying at home may be accepted"

Type of accident	Risk	Basis of risk and source
Fairground accidents	1 in 2 326 000 rides	UK 1996/7-1999/00
Road accidents	1 in 1 432 000 Km travelled	GB 1995/99
Rail travel accidents	1 in 1 533 000 journeys	GB 1996/97-1999/00
Burn or scald in the home	1 in 610	UK 1995-99

Table 8-1 Average Annual Risk as a consequence of an activity [HSE,2001]

8.2 Individual Risk

According to MSC 78/19/2, Individual Risk is taken to be the risk of death and is determined for the maximally exposed individual. IR is person and location specific and is determined by the following equation :

$$IR_{\text{for person Y}} = F_{\text{of undesired Event}} \cdot P_{\text{for person Y}} \cdot E_{\text{for person Y}}$$

where

F=frequency

P=resulting casualty probability

E=fractional exposure to that risk

The risk to an individual according to the above definition takes into consideration

- ✓ The location of the individual (aboard, onshore etc.)
- ✓ The level of participation (passenger, crew, third party)

Besides the individual risk, as mentioned above, many other expressions of it can be found in literature. For example

- the loss of life expectancy shows the decrease of life expectancy due to various causes.
- The activity specific hourly mortality rate reflects the probability per time unit while engaged in a specified activity. An example is the Fatal Accident failure Rate (FAR) which gives the number of fatalities per 10^8 hrs of exposure to a certain risk.
- the death per unit activity (a variant of the above), which replaces the time unit by a unit measuring the amount of activity. For example, the risks of travel by car, train or aeroplane are, often, expressed as the number of deaths per kilometre travelled.

Annual Individual Risk ($x10^{-5}$)		Annual Individual Risk ($x10^{-5}$)	
Industry		**Mechanical engineering**	1.9
Oil and gas production	100.0	**Electrical engineering**	0.8
Agriculture	7.9	**Construction**	10.0
Forestry	15.0	**Railways**	9.6
Deep sea fishing	84.0	**All manufacturing**	1.9
Energy production	2.5	**All services**	0.7
Metal manufacturing	5.5	**All industries**	1.8
Chemical industry	2.1	**Bulk carriers**	13.0

Table 8-2 Annual Individual Risk [Mathiessen, 1997]

A different definition of the Individual Risk which can provide an alternative Risk Acceptance model will now be introduced.

This definition that will be given is very similar to the ones used by the Dutch Technical Advisory Committee on Water Defences (TAW,1985) and by Bohnenblust (Bohnenblust,1998) who studied the safety of the railway system in Germany.

Individual Risk, which can be regarded as the risk to an individual in isolation, can be defined as the probability that an average unprotected person, permanently present (voluntarily or not) at a certain location, is killed due to an accident resulting from a hazardous activity.

$$IR=\beta \cdot P_f \cdot P_{k|f}$$

where

P_f the probability of failure

$P_{k|f}$ the probability of an individual being killed in the case of failure and

β the value of a policy factor that varies according to the degree to which participation in the activity is voluntary (similar to Bohnenblust's beta).

8.2.1 Individual Risk and Acceptance Criteria

The term "Risk Acceptance Criteria" is used for criteria that define the limits of the risk regions, however, IMO uses the term "Risk Evaluation Criteria" to indicate that criteria can not, only, be used as the decision criteria but other considerations may be appropriate.

There is no single universal level of acceptable individual risk. IMO's guidelines provide no Risk Acceptance Criteria; currently decisions are based on those published by the UK Health & Safety Executive (HSE,1999).

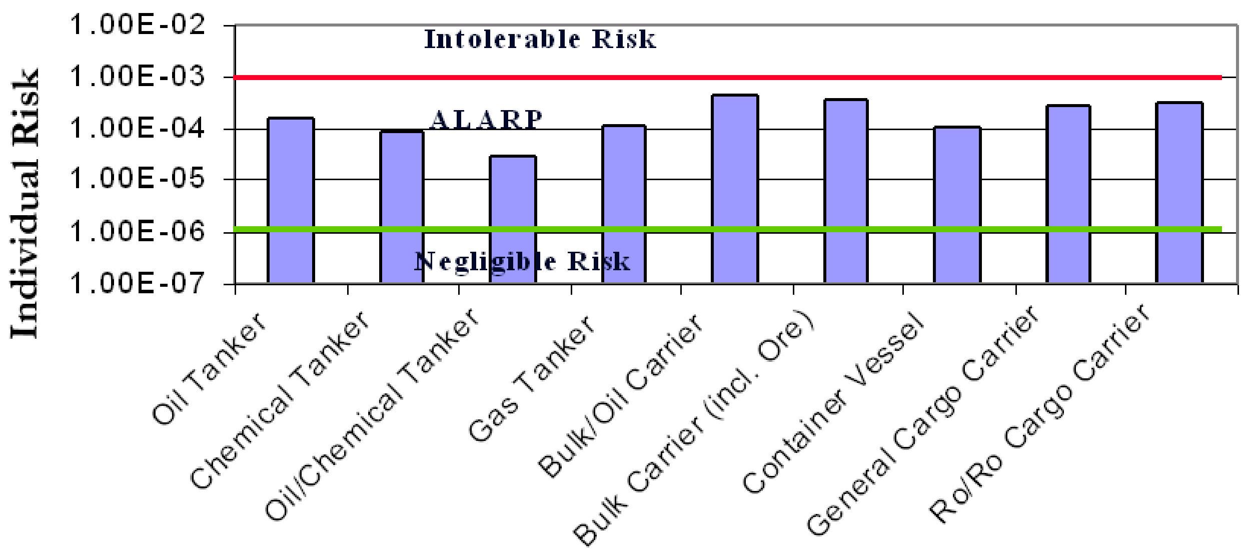


Fig 8-2 Annually Individual Risk [Skjong,2002a]

Classical Risk Assessment uses a risk criterion - like the ones used by Bohnenblust and TAW - that defines the minimum value of unacceptable risk. TAW, for example, has the following standard: $IR<10^{-6}$ (per year).

Any risk lower than this value should, always, be reduced to a level which is ALARP.

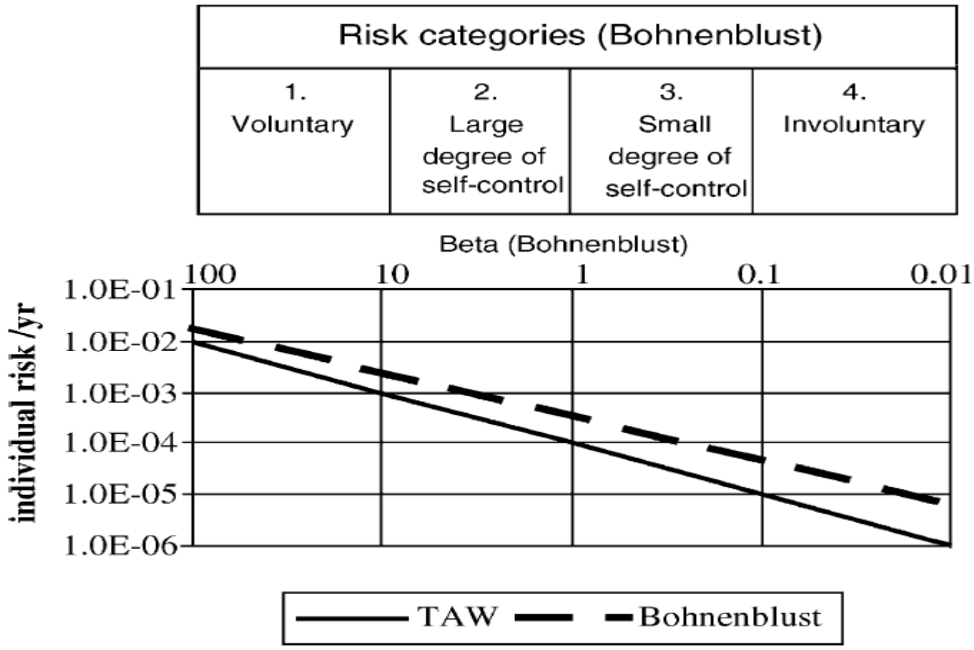


Fig 8-3 Annually Individual Risk according to TAW and Bohnenblust

On the other hand, IMO has adopted HSE's criteria that follow the Modern Risk Assessment practice which use of criteria that define the intolerable and the negligible risk.

Maximum tolerable risk for crew members	10^{-3} annually
Maximum tolerable risk for passengers	10^{-4} annually
Maximum tolerable risk for public ashore	10^{-4} annually
Negligible risk	10^{-6} annually

Risks below the tolerable level but above the negligible risk (for crew members, passengers and third parties) should be made ALARP by adopting cost-effective Risk Control Options.

It has to be noticed that 10^{-3} was the annual fatality rate for all reasons in the period of life when this is at its lowest (4-15 of age) in OECD member countries when HSE introduced the above criteria. Today, according to Skjong, this figure in some countries is down to $2\ 10^{-4}$. Furthermore, the difference in the criteria is based on the fact that for passengers a stricter criterion has to be used, because they are less informed about the risk and are less in control (similar to Bohnenblust's beta).

Individual Risk Criteria in Use		
Authority	**Description**	**Criterion (per yr)**
HSE (HSE, 1999)	Maximum tolerable risk to workers	10^{-3}
	Maximum tolerable risk to the public	10^{-4}
	Negligible risk	10^{-6}
Netherlands (Bottelberghs, 1995)	Maximum tolerable for existing situations	10^{-5}
	Maximum tolerable risk for new situations	10^{-6}
New South Wales, Australia (DUAP, 1997)	Sensitive developments (hospitals, schools etc.)	$5 \cdot 10^{-7}$
	Residential, hotels, motels, tourist resorts etc.	$1 \cdot 10^{-6}$
	Commercial, retail, offices etc	$1 \cdot 10^{-5}$
	Sporting complexes, active open space	$1 \cdot 10^{-5}$
	Industrial	$5 \cdot 10^{-5}$
Western Australia (EPA, 1998)	Sensitive developments (hospitals, schools etc.)	$5 \cdot 10^{-7}$
	Residential zones	$1 \cdot 10^{-6}$
	Non-industrial (commercial, sporting etc.)	$1 \cdot 10^{-5}$
	Industrial	$5 \cdot 10^{-5}$

Table 8 -3 Individual Risk Acceptance Criteria in Use [MSC 72/16]

Table 8-3 shows some IR Acceptance criteria used in various countries. It is obvious that there exist more strict criteria than the ones proposed by HSE. The author believes that these criteria are capable of ensuring the safety levels of shipping since according to Fig. 8-3 the fatality risk for crew for all ship types is below the level of 10^{-3}. Crew members are the most exposed individuals so this figure is enough to prove safety for all individuals. This means that Individual Risk, in any type of individual, falls in the ALARP region and only cost-effectiveness criteria have to be applied.

Fig. 8-3 shows individual fatality risk (annual) for crew of different ship types, shown together with the proposed individual risk evaluation criterion (data from 1978 to 1998, data source: LMIS/Ship accidents). According to this figure, the fatality risk for crew for all ship types is below the level of 10^{-3}.

However, the above data are based on past data, thus, it provides no evidence that future statistics will show that all risks in shipping fall into the ALARP region. Risk Criteria is absolutely sure that will employ future FSA reviewers and researchers.

8.3 Societal Risk

In the HSE's publication 'Reducing risks, protecting people,' 'societal risk' is described as follows:
"...the risks or threats from hazards which impact on society and which, if realised, could have adverse repercussions for the institutions responsible for putting in place the provisions and arrangements for protecting people, e.g. Parliament or the Government of the day. This type of concern is often associated with hazards that give rise to risks which, were they to materialise, could provoke a socio-political response, e.g. risk of events causing widespread or large scale detriment or the occurrence of multiple fatalities in a single event. Societal concerns due to the occurrence of multiple fatalities in a single event is known as 'societal risk.' Societal risk is therefore a subset of societal concerns." (HSE, 2001)

Another definition is the following : "Societal Risk is the average risk, in terms of fatalities, experienced by a whole group of people (e.g. crew, port employees, or society at large) exposed to an accident scenario. "

The purpose of societal risk acceptance criteria is to limit the risks from ships to society as a whole, and to local communities (such as ports) which may be affected by ship activities. In particular, societal risk acceptance criteria are used to limit the risks of catastrophes affecting many people at the same time, since society is concerned about such events (high consequence index) .
Usually, Societal Risk is taken to be the risk of death and is, typically, expressed as FN-diagram or Potential Loss of Life (PLL). Societal Risk is not person and location specific.

Potential Loss of Life is defined in 5-5 and has been used in many FSAs to quantify risks. Societal Risk expressed as FN-diagram will be, now, discussed. One way of defining them is using Potential Loss of Life.

8.3.1 F-N Curves

F-N diagram shows the relationship between the annual frequency F of accidents with B or more fatalities. An F-N diagram is used to quantify societal risk as it ccounts for large accidents as well as for small ones which enable us to express risk aversion. Risk aversion in F-N curves is used to express that, in general, society is less willing to accept one large accident with many fatalities than many accidents each with a small number of fatalities.

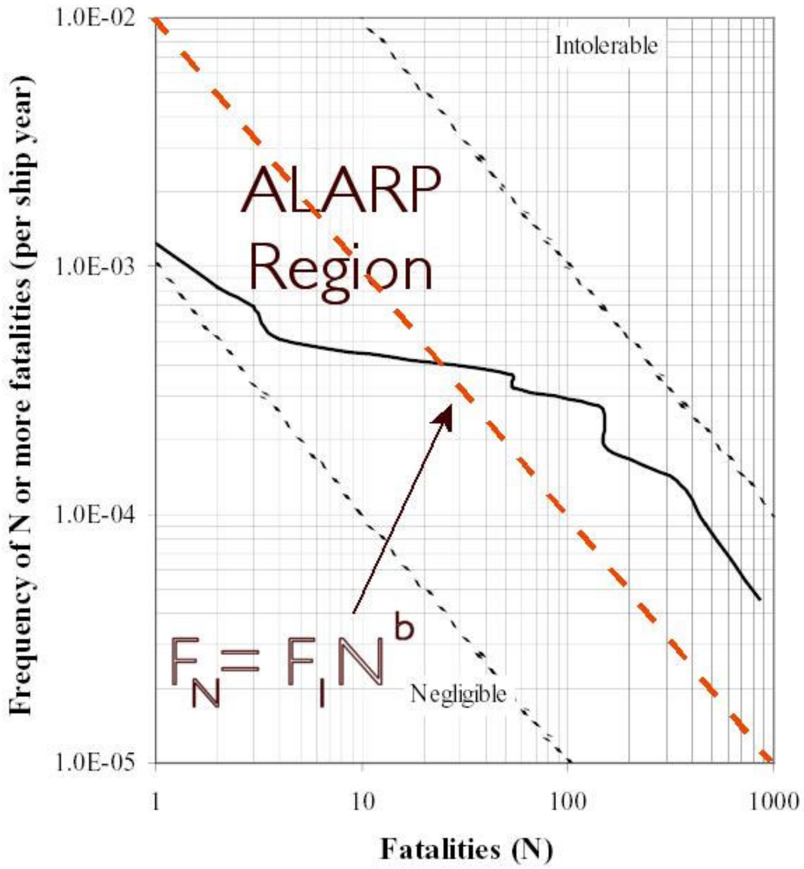


Fig 8-4 Typical F-N Diagram

Mathematical Definition

The straight line in a log-log plot as in Fig. 8-4 has the expression

$$F_N = F_1 \cdot N^b \qquad Eq. 8-1$$

where

F_N is the frequency of *N or more fatalities*

F_1 is the frequency of accidents involving one or more fatalities

b is the slope (-1 in the case of IMO)

The *frequency of exactly N fatalities* is

$$f_N = F_N - F_{N+1} = F_1\left(N^b - (N+1)^b\right) \overset{b=-1}{\Leftrightarrow} f_N = F_1\left(\frac{1}{N(N+1)}\right)$$

It is easy to prove that this can be regarded as a probability function.

The *expected number of fatalities E(N)* is

$$E(N)=F_1 \cdot \sum_{N=1}^{N_u} \frac{1}{N+1}$$

Nu is the upper limit of the number of fatalities that may occur in one accident

Fitting an F-N curve to a resulting PPL

An FN curve with inclination b may be fitted to the resulting PPL by

$$PLL=\sum_{N=1}^{N_u} N \cdot f_N = F_1\left(\frac{1}{N_u^{\,b-1}} + \sum_{N=1}^{N_u-1} \frac{(N+1)^b - N^b}{(N+1)^b}\right)$$

where

Nu is the upper limit of the number of fatalities that may occur in one accident

f_N is the frequency of occurrence of an accident involving *N* fatalities, and

F_1 is the frequency of accidents involving one or more fatalities.

IMO followed the recommendation by Health & Safety Committee(1991), Statoil(1995) and b=1 is chosen. There is a huge discussion on whether b=1 is risk averse and what b should be. For example, The Netherlands, for example, has chosen b=2.

It has to be noticed that this b is not the same as in the $F_N = F_1 \cdot N^b$ *formula.*

Thus,

$$PLL=\sum_{N=1}^{N_u} N \cdot f_N = F_1\left(1+\sum_{N=1}^{N_u-1} \frac{1}{N+1}\right) = F_1 \cdot \sum_{N=1}^{N_u-1} \frac{1}{N} \quad \text{or} \quad F_1 = \frac{PLL}{F_1 \cdot \sum_{N=1}^{N_u-1} \frac{1}{N}} \qquad (Eq.8-2)$$

Another way to establish the F-N curve has to be mentioned.
Fatality statistics can provide the upper limit Nmax (= the number of fatalities from one accident). The expected number of fatalities E(N) can be estimated from the observed fatality statistics. The value of F_1, which is the frequency of accidents involving one or more fatalities, is given by the following equation:

$$F_1 = \frac{E(N)}{\sum_{N=1}^{N_u} \frac{1}{N+1}}$$

The equation defines a point on the curve. This point is $(1, F_1)$. Since the slope is known (b=-1 as advocated by IMO), the FN curve corresponding to the given data is defined using $F_N = F_1 \cdot N^b$.

In this formula slope due to a different definition of the F-N Curve b=-1. b= -1 in this formula and b=1 in MSC 76/12 express the same slope. It is just a matter of different definition in literature.

8.3.2 Societal Risk Acceptance Criteria

Most of the time F-N curves are shown in log-log plot. The curve -that is defined using eq. 8-1, the given slope and the value F_1 (derived using eq. 8-2) -- separates the plane into three regions : the acceptable, the unacceptable and the ALARP region. (see Fig 8-4)

The ALARP region is introduced by assuming that the risk is intolerable if more than one order of magnitude above the average acceptable and negligible if more than one order of magnitude below the average acceptable. This implies that the region where risks should be reduced to As Low As Reasonably Practicable (ALARP) ranges over two orders of magnitude, in agreement with most published FN acceptance criteria. In the ALARP area, cost-effectiveness considerations would be applied. Figure 1 therefore illustrates the general format of societal risk acceptance criterion.
Summing up, the ALARP region comprises one order of magnitude on either side of this curve.

The F-N curves are a very complicated but, also, interesting tool in societal risk assessment, however these curves will not be discussed further. Finally, some F-N curves that are being widely used in FSAs will now be given.

The figures also contain historic risk data. These are extracted from LMIS, representing the period 1988-1998. All figures are published in Eknes, M and R. Skjong "Economic activity and risk acceptance"(Skjong and Eknes,2001)

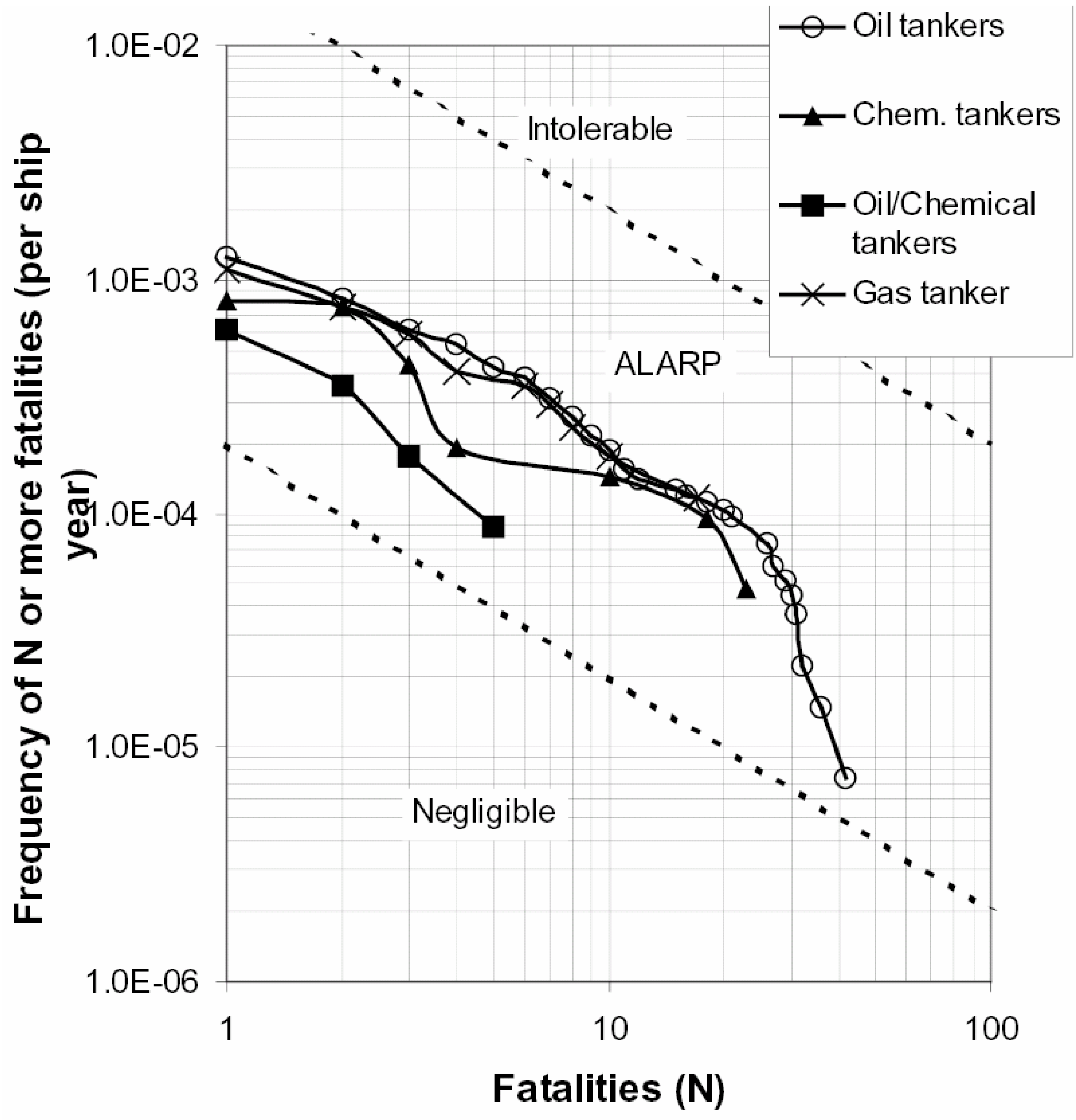


Fig 8-5 F-N Diagram (crew) – Tankers

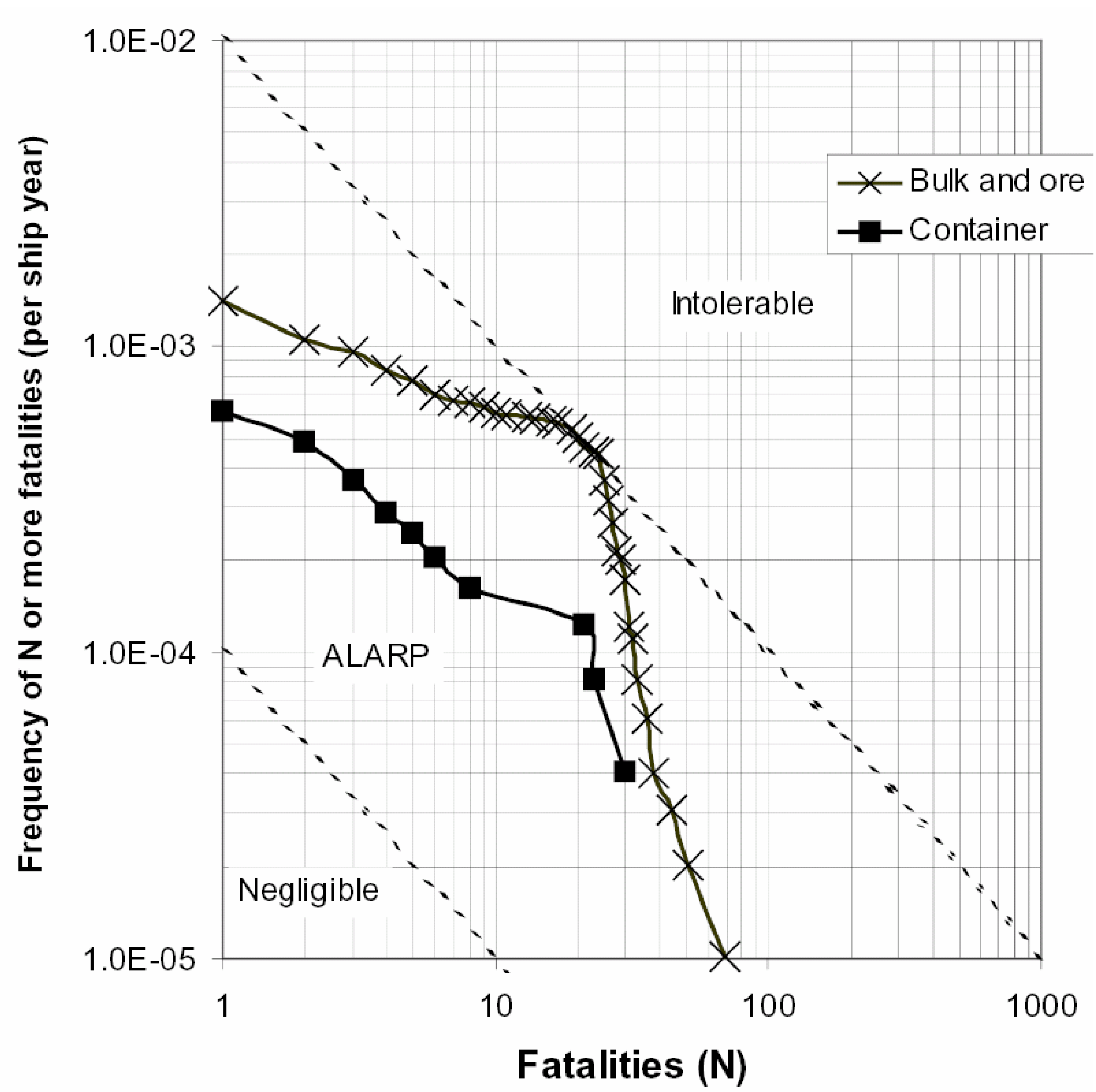


Fig 8-6 F-N Diagram (crew) –Bulk-Ore & Container ships

The resulting curves suggest that all ship types are within the ALARP area. This is expected since it shows that intolerable risks were removed by the existing regulations. However, bulk carriers are very close to the unacceptable risk region which is probably the reason for the huge attention given to the bulk carriers' safety by the MSC and the big amount of FSA studies.

It has to be emphasized again, when an activity falls into the ALARP region only cost effectiveness criteria have to be considered.

8.4 Other types of risk

Most FSA studies deal on the loss of human life. Even injuries or ill health are being neglected. However, about this subject the DALY criteria has been discussed in the previous chapter and in any case the following equalities can be used

- 1 fatality equals to 10 severe injuries
- 1 severe injury equals to 10 minor injuries

Complete absence of other type of risks and acceptance criteria such as for the environment has been noticed. To the authors' knowledge no FSA study till now has used any acceptance criterion or even extensively studied the risk to the environment. However, some paper introduce risk measures for these kind of risks and will, now, be mentioned.

Jonkman mentions a measure for environmental risk applied by NORSOK.
NORSOK (the competitive standing of the Norwegian offshore sector) has proposed the ***probability of the excess of the time needed by the ecosystem to recover from the damage*** as a measure for environmental risk. (NORSOK,1998)

$$1-F_T(x)=P(T>x)=\int_x^\infty f_T(x)dx$$

where F_T is probability distribution function of the recovery time and
f_T is the probability density function of the recovery time of the ecosystem.

This is similar to one of the definitions of F-N curves which is "the probability as a function of the number of fatalities" (on double logarithmic scale)

$$1-F_N(x)=P(N>x)=\int_x^\infty f_N(x)dx$$

This means that a curve similar to the F-N ; something like a F-T curve can be defined. NORSOK uses the following limit to determine the acceptable risk for oil platforms.

$$1-F_T(x)<\frac{0,05}{x}$$

Another measure mentioned in Barlettani (1997) is the **energetic impact index** which is a measure for the amount of energy lost per year, expressed in Joules. This method regards man as a part of the ecosystem. The energy loss caused by injured and dead humans and animals can be expressed in Joules, just like any other damage to nature. According to this method human life is equivalent to a certain amount of energy, about 800 billion Joules which results in the following formula:

$$GPPlost = EPP + GPP' \; T$$

where GPPlost is the effect on the ecosystem and humans in Joules;

EPP the energy loss of the system and

GPP the amount of energy needed during period *T* for recovery of harmed organisms.

According to Jonkman et al. (2003) no use of risk acceptance criteria that use this index can be found in literature.

Finally, another useful measure can be found in Ventikos and Psaraftis (2004). This is the **Polution Potential** (P.P) and is given under the following form which is the expected value revealing the risk of structured flows.

$$P.P=\left\{P_{MC|fa}\times\sum_i P_{DC_i}\times\sum_i SV_k\times\sum_i P_{AT_i}\times\sum_n\left(P_{OT}\times \text{outcome}\begin{cases}AT, & AT>1\\ 1, & AT\geq 1\end{cases}\right)_n\right\}x$$

where P is the probability, MC is the main cause, fa is the field of actions, DC is the direct causes, SV is joint study of EDN stages 7 and 8, AT is assessed targets, and OT is outcome.

Even-Decision Networks (EDN) is a strategic framework of oil cleanup operations.

Considering the risk for these cases (= non-human loss) and defining risk acceptance criteria for them is one of the things that have to be done. Risk acceptance criteria are an open issue in the FSA process.

8.5 Cost effectiveness criteria

In 7.2 an introduction to Cost-Effectiveness Criteria was made. The general idea of these Criteria is that, in order a Risk Control Option to be proposed for recommendation, the estimated CAF must be less that a given value.

Many CAF values are published and are being used in Safety Assessments. Some of these values are given in the table below; however, it has to be noticed that the Maritime Sector must not adopt or use CAFs that are published for other industries.

Published CAFs in use as acceptance criteria

ORGANISATION	SUBJECT	CAF	SOURCE
US Federal Highway	Road Transport	\$2.5m (£1.6m)	FHWA (1994)
UK Dep. of Transport	Road transport	£1.0 m (1998)	DETR (1998)
UK Health & Safety Exec.	Industrial safety	As above or higher	HSE (1999)
UK Railtrack	Overground	As above to £2.65m	Railtrack (1998)
London Underground Ltd	Underground	£2m	Rose (1994)
EU	Road Transport	ECU 1 million (£0.667m)	Evans (1998)
Norway	All hazards	NOK 10m (£0.8m)	Norway (1996)

CAF values that have been used in FSA applications and were proposed by IMO are given in the following table [MSC 78/19/2]

	NCAF [US \$]	GCAF [US \$]
criterion covering risk of fatality, injuries and ill health	3 million	3 million
criterion covering only risk of fatality *)	1.5 million	1.5 million
criterion covering only risk of injuries and ill health *) **)	1.5 million	1.5 million

*) NCAF and GCAF criteria are normally used covering not only fatalities from accidents, but implicitly also injuries and/or ill health from them. This is an adequate approach, because, as was mentioned above, many accidents involve both consequence categories: fatalities and injuries/ill health.

However, if accidents are analysed that involve only one of the two categories, the criteria should be adjusted to cover explicitly only the category relevant to the accident under consideration. In MSC 72/16 a proposal was made, that the NCAF and GCAF criteria are split equally for the two consequence categories.

**) refer also to QALY approach

Table 8-4 Cost-Effectiveness Criteria [MSC78/19/2]

The above criteria seem to be the ones that are used most in FSAs. However, the proposed values have been derived by considering societal indicators that were

introduced in literature (MSC 72/16, UNDP 1990, Lind 1996) during the last decade. It is obvious that these criteria should be updated as frequent as it can be. For this reason MSC 78 proposed the use of the formula based on LQI and the average risk free rate return (approx. 5%).
The first proposal, the one of the LQI which stands for Life Quality Index will be, now, extensively discussed.

8.5.1 Implied Cost of Averting Fatality (ICAF)

Life Quality Index (LQI) is intended as a social indicator that reflects the expected length of "Good Life", in particular the enhancement of the quality of life by good health and wealth. The original LQI definition is given by Nathwani, Lind and Pandey (1997).
There are many ways to express LQI but it is out of the scope of this thesis even to mention them. A way of expressing it is somehow like this : $LQI=g^{w}\cdot e^{1-w}$
The determination of ICAF (Implied Cost of Averting a Fatality) as it was proposed by Skjong & Ronold will be given. ICAF is a very interesting value in the FSA process and it is derived from LQI.

The ICAF value is determined by assuming that an option is accepted as long as the change in LQI owing to the implementation of the option (=RCO) is positive.
This

$$ICAF=\frac{g\cdot e}{4}\cdot\frac{1-w}{w} \qquad (8\text{-}1)$$

where
g is the Gross Domestic Product per capita
e is life expectancy at birth
w is the proportion of life spent in economic activity.

Many assumptions were made to derive this definition but the one that has to be noticed is that the above formula was derived under the assumption that the remaining life of an individual at any given point of time equals to half of the life expectancy e at birth.

Assumptions for formula 7-1

- Life Quality depends only on GDP and life expectancy e
- Options are being implemented only if the change in LQI is positive
- Remaining life of an individual at any given point of time is e/2

Sources of Values used in ICAF estimation (2003)

"The Word Fact Book" published by the Central Intelligence Office (CIA,2004) which provides the 2003 estimations will be used.

Notice on GDP

According to the Fact Book "This entry gives the gross domestic product (GDP) or value of all final goods and services produced within a nation in a given year. GDP dollar estimates in the Factbook are derived from purchasing power parity (PPP) calculations."

The calculated ICAF and the data that where used are shown in the Table 8-5 and Fig 8-7

Country	2003 est CIA GDP ($/capita)	Life Exp. at Birth (years)	2003 CIA ICAF ($ million)
Greece	19.900	78,94	2,749
Japan	28.000	81,04	3,971
Norway	37.700	79,25	5,229
China	5.000	71,96	0,630
USA	37.800	77,43	5,122
Germany	27.600	78,54	3,793
U.K	27.700	78,27	3,794
Luxenburg	55.100	78,58	7,577
Tanzania	600	44,39	0,047
World	8.200	64,05	0,919

Table 8-5 GDP, Life Expectancy and ICAF (2003 est.)

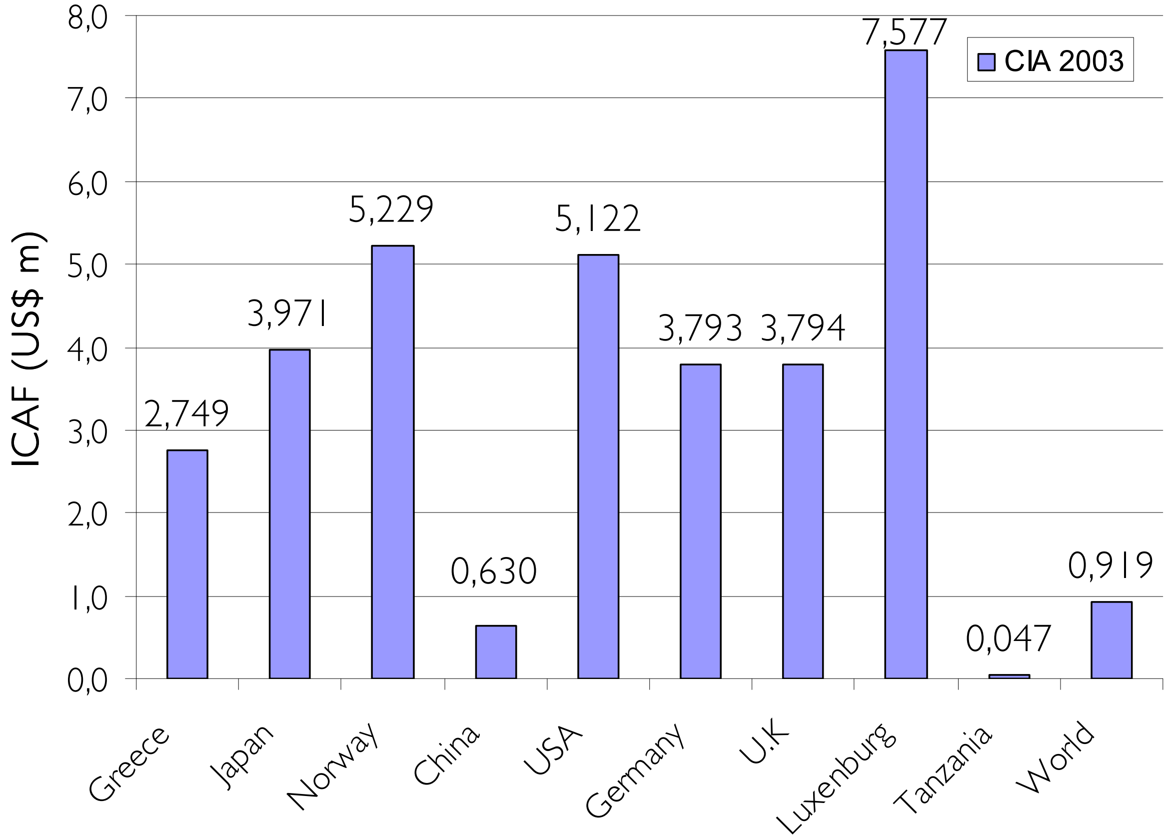


Fig 8-7 Calculated ICAF (using CIA Factbook – 2003 Estimations)

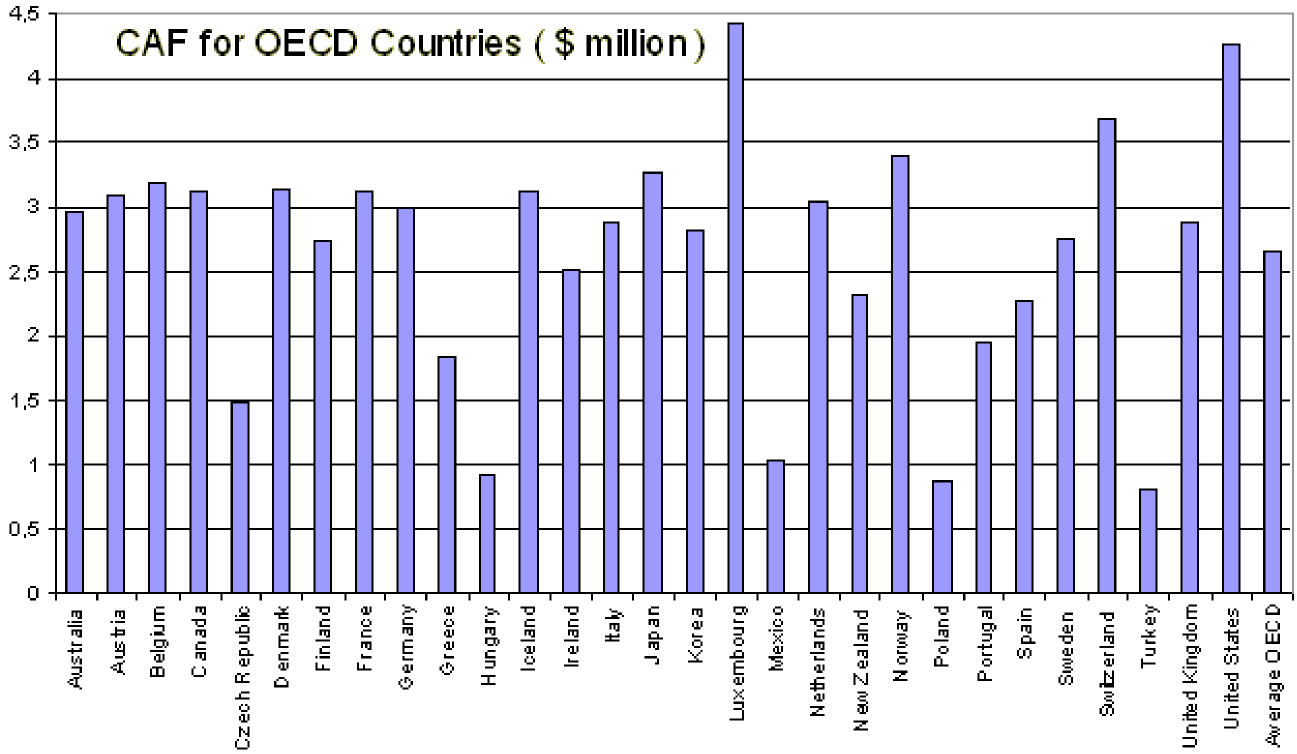


Fig 8-8 ICAF [Skjong and Ronold, 2002]

It has to be noticed that the calculated ICAFs (2003) in Fig 8-7 have no similarity to the ones provided by Skjong and Ronold (2002) (Fig. 8-8). This is probably because of the fact that in their study they used averages between years 1984 and 1994. However the above calculations is based on the same formula and uses the same the proportion of life spent in economic activity (w=0,125)

This divergence of ICAF forced the author to do a more deep research. The OECD data that where used by Skjong and Ronold were, then, used. OECD 2005 Statistics provide data for both GDP and Life Expectancy only till 2002. The results are in accordance with those provided by Skjong and Ronold. OECD data use the PPP approach which is being used in CIA's Fact Book.

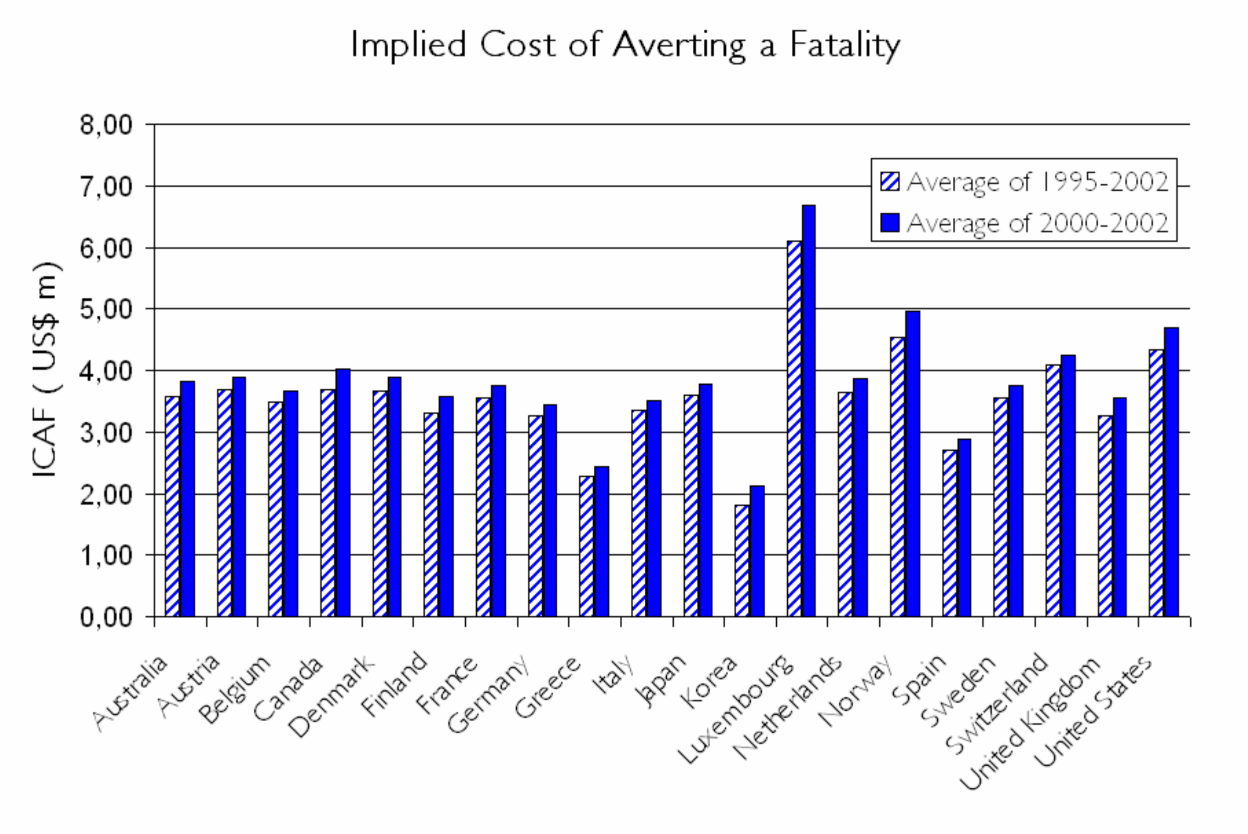


Fig 8-9 Average ICAFs for periods 1995-2002 and 2000-2002

Given the OECD Data (2004,Version 1) the ICAF values for the years 1980,1990,1995,2000,2001,2002 and the average for periods 1980-1995, 1990-2002,1995-2002 and 2000-2002 were calculated. The results are shown in Table and are being illustrated in Fig. 8-9

Implied Cost of Averting a Fatality (in million $) – OECD Countries

	1980	1990	1995	2000	2001	2002	Average 00-02	Average 95-02
Australia	1,282	2,260	2,874	3,684	3,830	3,943	3,819	3,583
Austria	1,269	2,499	3,059	3,791	3,912	3,975	3,892	3,684
Belgium	1,250	2,397	2,914	3,534	3,701	3,779	3,671	3,482
Canada	1,425	2,586	3,047	3,954	4,075		4,014	3,692
Czech Republic		1,387	1,538	1,795	1,955	1,992	1,914	1,820
Denmark	1,344	2,395	2,958	3,787	3,935	3,946	3,890	3,657
Finland	1,175	2,363	2,548	3,449	3,603	3,642	3,565	3,310
France	1,278	2,443	2,900	3,584	3,797	3,896	3,759	3,544
Germany	1,405	2,679	2,866	3,405	3,492		3,448	3,254
Greece	0,917	1,526	1,791	2,281	2,416	2,601	2,433	2,272
Hungary			1,104	1,489	1,649	1,764	1,634	1,501
Iceland	1,511	2,733	3,001	3,900	4,078	3,989	3,989	3,742
Ireland	0,777	1,692	2,355	3,734	4,013	4,431	4,060	3,633
Italy	1,199	2,344	2,823	3,429	3,539	3,573	3,514	3,341
Japan	1,146	2,571	3,122	3,676	3,792	3,843	3,770	3,608
Korea			1,473		2,128		2,128	1,800
Luxembourg	1,360	3,303	4,320	6,621	6,719	6,737	6,692	6,099
Mexico	0,410	0,748	0,855	1,150	1,165	1,178	1,165	1,087
Netherlands	1,323	2,397	2,946	3,668	3,938	3,974	3,860	3,632
New Zealand	1,062	1,874	2,308	2,811	2,942		2,876	2,687
Norway	1,254	2,400	3,250	4,934	5,044	4,909	4,963	4,534
Poland		0,757	0,952	1,315	1,361	1,409	1,362	1,259
Portugal	0,637	1,383	1,738	2,294	2,396	2,481	2,390	2,227
Slovak Republic			1,027	1,370	1,466	1,584	1,473	1,362
Spain	0,886	1,743	2,143	2,771	2,893	3,000	2,888	2,702
Sweden	1,351	2,534	2,936	3,706	3,759	3,811	3,759	3,553
Switzerland	1,877	3,337	3,613	4,164	4,229	4,323	4,239	4,082
Turkey	0,230	0,527	0,643	0,803	0,723	0,774	0,766	0,736
United Kingdom	1,071	2,150	2,681	3,443	3,650		3,546	3,258
United States	1,570	3,036	3,651	4,649	4,738		4,694	4,346
All OECD	1,160	2,150	2,448	3,214	3,298	3,315	3,272	3,069

Table 8-6 ICAF – OECD Countries (2002 data)

** Countries in bold are member-countries before 1994*

It has to be noticed that the CAF Acceptance criterion of $3m was proposed according to Figure 8-8 which is based on the average value for years 1984-1994.
In Fig. 8-8 the average ICAF (for all OECD countries) for the above mentioned period is at about $2,7m; nevertheless no explanation was given for the $3m recommendation as an acceptance criterion.

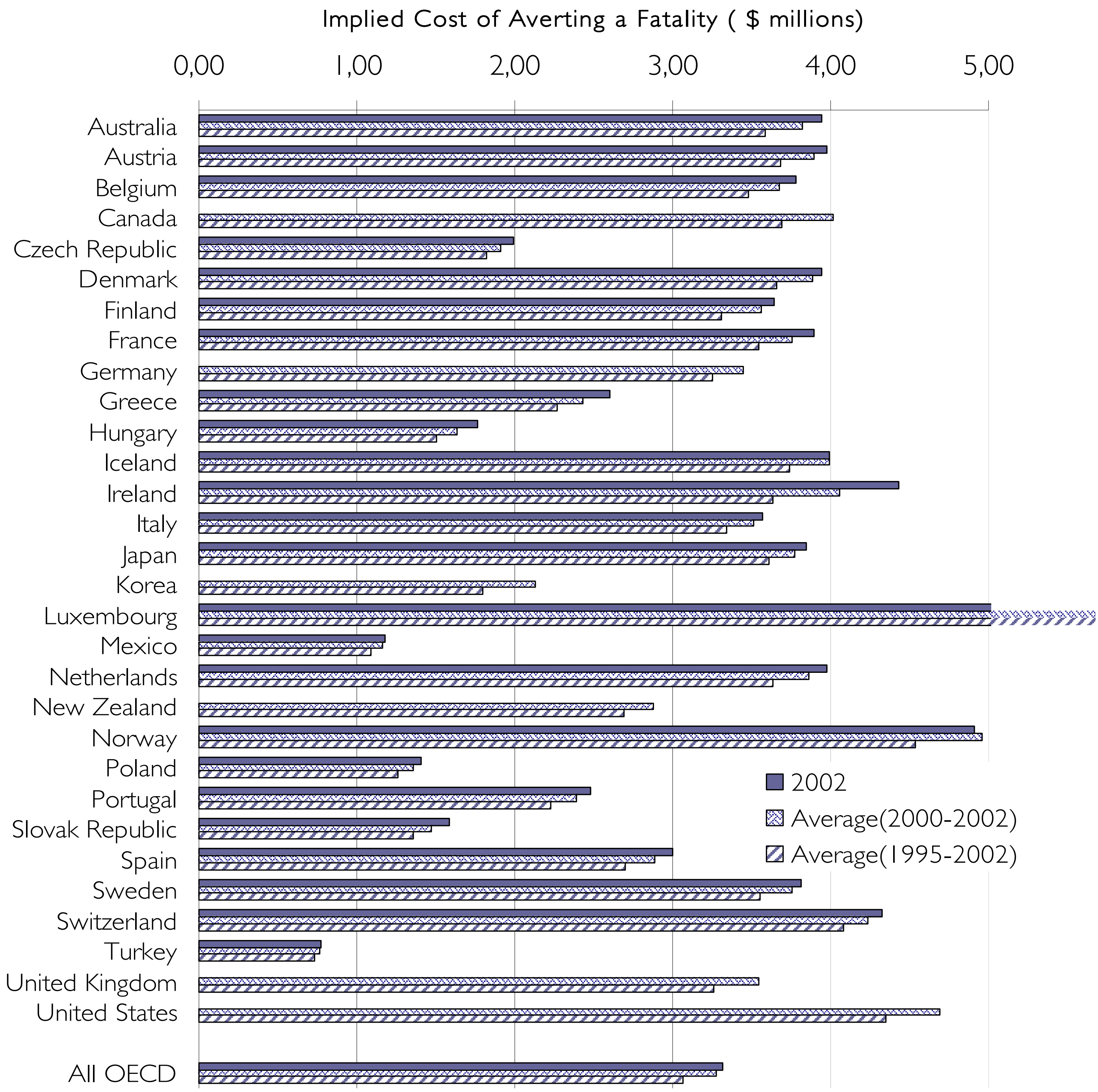


Fig 8-10 ICAF – OECD Countries (2002 data)

The average ICAF value for all OECD countries for the period of 2000-2002 is \$3,272 whereas for the period of 1995-2002 is \$ 3,069. In the study of Skjong and Ronold data was given only for 25 countries. It has to be noticed that after 1994 and till today five more countries entered the OECD.

Proportion of life spent in economic activity

According to Formula 8-1 ICAF depends on w which is the proportion of life spent in economic activity. The following figure shows the relationship between the work time fraction and the resulted ICAF. GDP and life expectancy are the ones provided by CIA's Factbook 2005 and are estimations for 2003.

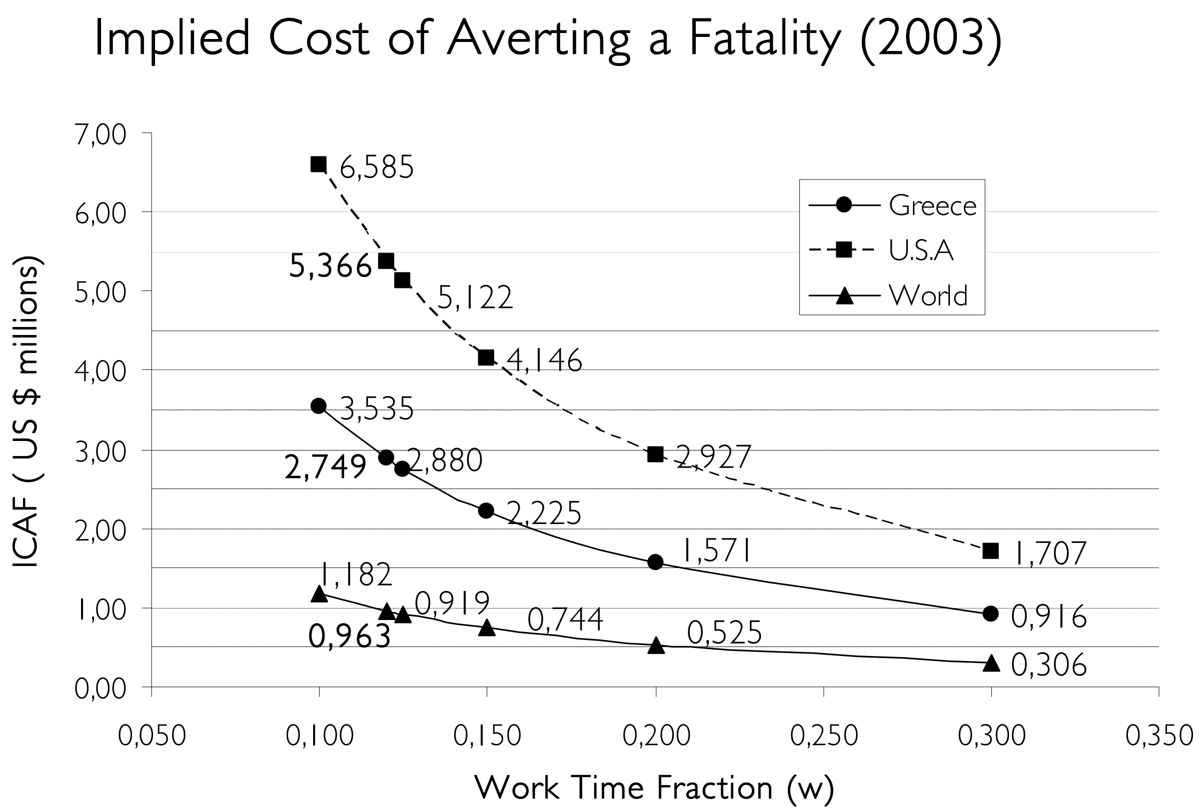


Fig 8-11 Work Time Fraction and the resulting ICAF

ICAFs of figures Fig 8-8 and 8-9 were estimated using the value $w=\frac{1}{7}=0{,}125$.

W depends on the country and on occupation. About the last, the maximum hours of work is 72 in any seven-day period for seafarers (International Labor Organization, Convention C180) while in the assessment below the working time is 40 hrs per week.

Assuming the expected life at birth to be 80 years; the first 18 years are assessed to be work free (last years of them occupied with education) , the next 50 years of life are the working years (8 hours per day in 5 days per week in 45 weeks per year) and the last 12 are years of retirement.

This assessment gives

$$w=\frac{50yrs\cdot 8\frac{hrs}{day}\cdot 5\frac{days}{week}\cdot 45\frac{week}{yr}}{80yrs\cdot 24\frac{hrs}{day}\cdot 7\frac{days}{week}\cdot 52\frac{week}{yr}}=\frac{90.000hrs}{698.880hrs}\Rightarrow w=0,129$$

This model has a very close value to the one given in Skjong and Ronold.

The value of w is very questionable. In literature there in no general consensus on w. OECD gives the value of w for a wide range of countries and it varies from 0,1 for Australia to 0,15 for USA, for example. However, Ditvlevsen (2004) gives a value of w=0,38 and comments that "a value of order of size of 0,15 or even smaller puts unreasonably small weight on the money side".

Dependence of ICAF

ICAF depends on

- Time (year or period) [GDP, Life expectancy, w]
- Country [GDP, Life expectancy, w]
- Occupation of the person whose fatality will be averted [w]

8.5.2 CAF Acceptance Criteria

The above discussion was done in order to have a better view of the CAF acceptance criteria. According to these criteria in order to recommend a Risk Control Option for implementation this must give a CAF (NCAF or GCAF) less than ICAF which is the amount of money that society is willing to pay in order to avert a statistical fatality.

It has to be noticed that the ICAF value depends on location (country) and time (year or period). The proposed ICAF of $3m is very close to the average ICAF for the period 1995-2002 which is $ 3,069 m.

However, OECD has only 30 members and an average ICAF depends on the data (the selection of countries that will be included). Fig. 8-8 shows that the selected countries have an average ICAF of about $4 million.
Furthermore, an ICAF based, only, on data from developed countries has no meaning when applied to other countries.

The author's opinion on the acceptance criterion is that it should depend on the FSA and its objectives. If the FSA studies a system that will be applied in a specific region then the ICAF should be calculated using the data of the region's countries.
On the other hand, OECD member-countries are countries with low tolerance to accidents involving fatalities. A high value of ICAF is needed in order to have a high safety level. If all humans have the same value which is the most ethical –although not applied in modern societies- then the same high level of safety that is being used for developed countries has to be used for all countries of the world.

In conclusion, the use of the CAF criterion is irreplaceable. The $3m value is good for general use; however more attention has to be given in very demanding cases. Special attention has to be given in cases of negative CAFs. This was discussed in the previous chapter. Furthermore, in separate studies of risk of injuries and ill health where the value of ICAF has no meaning (except if the equivalent of serious injuries as 1/10 of a fatality and minor injuries as 1/100 of a fatality will be used) then see 7.2.3 which gives the definition of Quality Adjusted Life Years QALY.

8.6 Results &Presentation of FSA Step 5

Finally, after all these Steps, the FSA process has reached its ending. . The outputs of the process should be according to the Guidelines :

"1. an objective comparison of alternative options, based on the potential reduction of risks and cost effectiveness, in areas where legislation or rules should be reviewed or developed; and

2. feedback information to review the results generated in the previous steps. "

Step 4 is the most important step in the FSA process. Based on the assessment of the risk and the purpose of the FSA study, decision-makers should provide recommendations to the IMO. Decisions should help on recommending

- If the activity that is being assessed should be permitted
- Whether risk control options are necessary to reduce its risk
- Which of the various options should be selected

Hence it is desirable for FSA to produce clear view on the above issues, which can be understood by other parties not having the same experience as the one that has carried out the study. A "good" presentation of the results of an FSA is essential to produce this "clear view".

PRESENTATION OF FINAL RESULTS

Another important issue is the presentation of results. Usually, the only paper that is submitted for a study is its report. All information on the FSA is combined in a single paper of maximum 20 pages (excluding figures and appendices). The report should provide a clear statement of the final recommendations, justified in an auditable and traceable manner by explaining all assumptions, limitations, models and inferences used or relied upon in the study.

To people that have experience on FSA studies the limit of 20 pages is, probably, known, however, the author found no comment on the fact that most of the studies submitted to IMO do not respect this limit. Appendix 8 of the Guidelines proposes that the report "should not exceed 20 pages". The author understands that the word "should" gives the possibility of submission of reports with more than 20 pages; however large reports do not facilitate the understanding and use of results.

Contrariwise, there is a false belief that large FSAs are the ones that provide factual results. Therefore, the author deems it policy to cite the Standart Reporting Format according to FSA's Guidelines

STANDARD REPORTING FORMAT

(According to MSC/Circ. 1023 – MEPC/Circ.392 – IMO FSA Guidelines)

"1 TITLE OF THE TRIAL APPLICATION

2 SUMMARY (maximum 1/2 page)

2.1 Executive summary: scope of the application and reference to the paragraph defining the problem assessed and its boundaries.

2.2 Actions to be taken: type of action requested (e.g. for information or review) and summary of the final recommendations listed in section 7.

2.3 Related documents: reference to any supporting documentation.

3 DEFINITION OF THE PROBLEM (maximum 1 page)

3.1 Definition of the problem to be assessed in relation to the proposal under consideration by the decision-makers.

3.2 Reference to the regulation(s) affected by the proposal to be reviewed or developed (in an annex).

3.3 Definition of the generic model (e.g. functions, features, characteristics or attributes which are relevant to the problem under consideration, common to all ships of the type affected by the proposal).

4 BACKGROUND INFORMATION (maximum 3 pages)

4.1 Lessons learned from recently introduced measures to address similar problems.

4.2 Casualty statistics concerning the problem under consideration (e.g. ship types or accident category).

4.3 Any other sources of data and relevant limitations.

5 METHOD OF WORK (maximum 3 pages)

5.1 Composition and level of expertise of those having carried out the application (name and expertise in an annex).

5.2 Description on how the assessment has been conducted in terms of number of meetings, organization of working groups, etc

5.3 Start and finish date of the assessment.

6 DESCRIPTION OF THE RESULTS ACHIEVED IN EACH STEP (max 10 pages)

For each step, describe:

1 method and techniques used to carry out the assessment;
2 assumptions or limitations, if any, and the basis for them; and
3 outcomes of each step of the FSA methodology, including:

STEP 1 - HAZARD IDENTIFICATION:

- prioritised list of hazards
- identified significant accident scenarios

STEP 2 - RISK ANALYSIS:

- types of risk (e.g. individual, societal, environmental, business)
- presentation of the distribution of risks depending on the problem under consideration
- identified significant risks
- principal influences that affect the risks
- sources of accident and reliability statistics

STEP 3 - RISK CONTROL OPTIONS:

- what hazards are covered by current regulations
- identified risk control options
- assessment of the control options as a function of their effectiveness against risk reduction

STEP 4 - COST BENEFIT ASSESSMENT:

- identified types of cost and benefits involved for each risk control option
- cost-benefit assessment for the entities which are influenced by each option
- identification of the cost effectiveness expressed in terms of cost per unit risk reduction

STEP 5 - RECOMMENDATIONS FOR DECISION-MAKING

- objective comparison of alternative options
- discussion on how recommendations could be implemented by decision-makers

7 FINAL RECOMMENDATIONS FOR DECISION MAKING (max 2 1/2 pages)
List of final recommendations, ranked and justified in an auditable and traceable manner.

ANNEXES (as necessary)
.1 name and expertise of the experts involved in the application
.2 list of references
.3 sources of data
.4 accident statistics
.5 technical support material
.6 any further information "

The FSA study has come to its ending. The report is submitted to IMO or given to public through some other mean (e.g scientific paper published in a journal). "Timely and open access to relevant supporting documents and a reasonable opportunity for, and a mechanism to, incorporate comments" should be given. Those submitting an FSA are not the decision-makers. They, just, provide recommendations to the decision-maker which is the IMO.

Formal Safety Assessment is the best tool that IMO, ever, had in decision making. It has limitations; it is a very new process and experience is, now, being established. The overview of the Steps, the clarification and the critical review of them were essential in order to understand more deeply the way that the process was done and some things that may help the process to become more reliable, more clear and more "safe". Issues concerning the objectivity that has been noticed in many FSA studies has been discussed in the corresponding Steps and will be recapitulated in the next chapter.

Chapter 9

Conclusions and Recommendations for further Work

CHAPTER 9.

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER WORK

9.1 Critical Review of the Overall Procedure

The experience gained by the submitted studies proved that FSA strayed from its original scope. As it has been mentioned before Formal Safety Aseessment is a tool to:

- Provide transparent decision-making process
- Clearly justify proposed measures
- Allow comparison of different options

First of all, taking into account FSAs concearning the introduction of DSS, it is more than clear that, even, the same input data (databases and casualties data) can lead to different results. Till now, most FSA studies are not as transparent as they should be and, in any case, they cannot clearly justify proposed measures. Expert judgement in HAZID, when calculating risk reduction and in cost-benefit analysis is one of the main reasons for this inconsistency of results.

Besides, FSA studies, especially in the BC case, were made to justify, or not, the use of a single measure –in that case of the Double Side Skin. However, the scope of FSA is not that. FSA studies in the past tried to influence IMO's Committees, especially BC and MSC, and to persuade Member-States that the results of these studies were correct and beyond of any doubt. It was supposed that the results of each study had to lead to the formation of a set of rules. A new FSA automatically meant that an existing FSA and, thus, the resulting regulations had to be modified in order to take into account the findings of the new study.
For example, the FSA study on Helicopter Landing Area that reached to the conclusion that HLAs on all passenger ships must be a necessity led to the introduction of Regulation 28.1 of SOLAS Chapt. III. In the first place, it is not clear to the author why the results of a study should "push" IMO into the introduction of a new regulation or the modification of an existing one. Furthermore, a new study coming to the opposite conclusion, immediately, forced IMO to reverse its position. It is quite sure that if there was a new FSA study "proving" that HLA could be justified in terms of cost-effectiveness then IMO would, again, change its position.

Finally, FSA is a tool to allow comparison of different options. Actually, of the options (RCO) that are proposed in the same study. However, in general, NO comparison can be done to RCOs recommended in different studies and, only, one RCO should be proposed for implementation each time, since, as it has been discussed, implementation of one RCO alters the cost effectiveness of the implementation of another RCO. Note particuraly that these apply in general but there are some cases where the grouping of RCOs is such that it allows simultaneously implementation to be considered without the need of re-evaluating the common cost-effectiveness.

In order to be more specific, a recapitulation of the weaknesses of each step and the ways to bolster them up, as they have been noticed in previous chapters, will be made.

STEP 1 – Identification of Hazards

Since the whole study will deal with the hazards and their associated scenarios that are identidied in this Step, an exact identification is very crucial to the next Steps. Casualty Databases should be very carefully processed –even if past data makes the whole process not to be so proactive- but it is also a necessity that modelling, mainly using potential Fault or Event Trees, should be used more. Furthermore, aggregiation of expert opinion using a concordance coefficient can strengthen the way of ranking hazards.

STEP 2 – Risk Analysis

The purpose of this Step is to investigate causes and consequencies od the more important scenarios. It has been seen in all submitted studies only numerical estimations were given in this Step. Actually, there is no need that detailed estimations to be given. Even qualitative estimations are still enough. The qualitative approach help this Step to be more proactive since it can be compined very well with modelling and its associated Fault and Event Trees. Frequency and Consequency Indices can be used and expert judgement can be justified using the before-mentioned concordance coefficient. Besides, numerical estimations compise the danger of extreme error, that extreme that can mislead the results of the study.

Step 3 – Risk Control Options

The most important issue in this Step is the grouping of RCOs. Risk Control Measures sould be very carefully compined into potential RCOs. It is very important that future studies should include combined RCOs so that the introduction of elemental as well as of compined RCOs could be assessed in the next Step. Expert judgement is being used in this task, however, its use is more crusial during the estimations of risk reduction. Once again, modelling throught Trees could help the process to move to a more proactive era.

Step 4 - Cost Benefit Analysis

This Step contains no actual weakness in the way that calculations are done. The only thing that has to be noticed is the fact that a common basis for both cost and benefit must exist and this should also be common among all RCOs. Thus, giving a monetary equivalent to both cost and benefit even in the case of human life loss or environmental harm is the only way to have comparable. However, Cost Effectiveness Criteria in its use – but not in their calculation method- are very valnurable.

The CAF criteria which are the most dominant criteria can be very easily manipulated and this will be discussed in next paragraph. Finally, negative NCAFs can appear in CBA and RCOs that have such a value should be considered very carefully. (see 7.3)

Step 5 – Recommendations for Decision-Making

It has been noticed, that the Guidelines contain no Risk Acceptance Criteria and no Cost Effectiveness Criteria that are capable to ensure a transparent study. Commonly accepted criteria, as well as criteria that include harm to the environment are the future of FSA. In any case, most ship types fall into the ALARP risk region which means that in these cases, only, cost effectiveness criteria have to be considered.

These criteria could be very easily manipulated and since this is a very important fact in the process it will be discussed in next paragraph.

Furthermore, presentation of the results is a very important issue and FSA authors should keep in mind that its size should follow the recommendations of the Guidelines.

Finally, as proposed by the Guidelines "timely and open access" should be given so that these studies can be extensively reviewed and, thus, to become more reliable and more acceptable.

9.2 Bias of Results

After reviewing the whole FSA process the author has identified the tasks that can be biased in favor of certain results.

Concisely, the set of recommendations depend, primarily, on the Cost-Effectiveness Criteria. A Risk Control Option should be proposed for implementation only if its estimated CAF is less than a specific value. The ICAF value of \$3m is that limit.. There will be no arguing on this value, since the manipulation of the results does no depend on that value.

Most of the time, Risk Acceptance Criteria are fulfilled in both individual and societal risk. As soon as risk lies within the ALARP region, the GAFs are the dominant criteria.

In the case where benefit is greater than cost the NCAF value is negative and, then, GCAF value can be very easily manipulated to satisfy the criteria.

It has to be noticed that in order to recommend a RCO there must be a reduction in risk which implies that the value of ΔR is, always, positive.

The mathematical expression of both NCAF and GCAF are very simple. It is very easy to reach the following formulas.

Gross Cost of Averting a Fatality

$$\text{GCAF}=\frac{\Delta C}{\Delta R}<\$3m \Leftrightarrow \Delta C<\$3m \cdot \Delta R$$

Net Cost of Averting a Fatality

$$\text{NCAF}=\frac{\Delta C\text{-}\Delta B}{\Delta R}<\$3m \Leftrightarrow \Delta C\text{-}\Delta B<<\$3m \cdot \Delta R \Leftrightarrow \begin{cases} \Delta C<\$3m \cdot \Delta R+\Delta B \quad \text{or} \\ \Delta B>\$3m \cdot \Delta R\text{-}\Delta C \end{cases}$$

At this point the only thing that remains is to estimate the suitable values of ΔC,ΔB and ΔR that will satisfy the above inequalities. One could possibly express the obvious mystification of how simple this task is. It is of no question that suitable selection of data could lead to the appropriate "values".

The author believes that the key-point in the FSA process is the Cost Benefit Analysis. To enhance the transparency of results, any FSA study should provide clear justification on the above estimations.

In any case, most of the time, risk reduction or benefit has to be estimated through modelling or expert judgement. Costs are, usually, more "clear". However, the other two, strongly depend on past experience. When no historic data is available or modelling is used -in order to ensure a proactive study- then, benefit may have any possible, but realistic, value. Especially, when estimating environmental benefits things are more complicated.
To sum up, the only way to ensure clear justification is through mandatory review that will check all the assumptions and estimations made in association to these values.

Finally, it is, still, a necessity to forget the fact that most risk areas accessed are within the ALARP region. Besides, in most cases only human or ship losses are assessed. In cases of environmental harm there is still no proposed criterion. In all FSA studies Risk Acceptance Criteria have to be applied before the Cost Effectiveness Analysis, whose use, however, in submitted FSA is very limited.

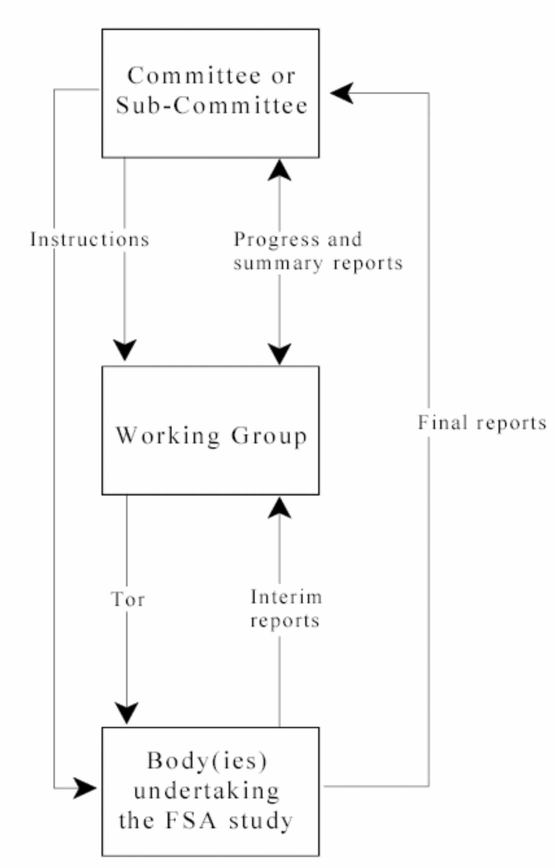
9.3 Collaboration of International Players & Review

The author truly believes in the power of Formal Safety Assessment. FSA is, beyond any doubt, a very advanced tool that can really help IMO's Rule-making process.
New regulations are introduced and existing are modified when, and only when, it is supported by the majority of the Member-States. IMO, as any other organization, strongly relies in the democratic process of voting. Especially in the past years, the formulation of powerful lobbies among its members was a way to manipulate the results of a voting session. It is, beyond dispute, that each country tries to protect its own interests and this is, abolutelly, normal. Especially for countries that control large fleets new regulations may cost a lot in terms of money and prestige. There are changes in the current regulations that could bring economical disaster to these major players. That's why it is not rare that, even, single countries want to influence the voting sessions and, thus, to stop the implementation of such measures.

In the past years this could, only, be done by influencing the votes of other countries. The formulation of lobbies was, and still is, very common among countries that have common interests. However, nowadays, FSA can manipulate the opinion of other countries and, thus, their voting. If the results of an FSA study are considered to be beyond any doubt -as it is done till now, until a new study is done to reverse the previous findings- any FSA could be used to persuade Member-States on the implementation of the suggested RCOs.

Once again, it should be noticed that the author does not imply that these countries do not care on the safety of their fleet or of the shipping industry, in general. However, for example, the action to reverse an earlier decision (see DSS issue) resulted to severe criticism. FSA should be that clear that no margin, even, for the slightest doubt would be left.
Harmonious collaboration of international maritime key-player is absolutely necessary. Studies submitted by IACS are moving towards this direction. Furthermore, following IACS' proposal [MSC 78/19/1] FSA studies should include a multidisciplinary team in the analysis. Multinational groups of experts can ensure that IMO could base its decision on a single, internationally recognized, set of recommendations.

Furthermore, IACS recommendation to make an internal review mandatory can be seen as a very good step to assure a quality level and transparency of the results.



The adjacent figure (Fig 9-1) shows a possible flowchart of the internal review. This is taken from Circ. 1022 which is the Guidance on the use of Human Element Analysing Process (HEAP).

According to this figure the review should be carried out within the Organisation by an intersessional correspondence group and/or working group.

Fig 9-1 Internal Review [Circ. 1022]

The review process should, also, be carried out along the lines suggested in Fig 9-2 (taken from IACS FSA training course). The process suggested is the one followed in the case of Helicopter Landing Areas, in which IMO reversed its position for the first time in the history of FSA.

As implied by this figure, any review should:

- Verify its results
- Ensure the correct application of the FSA methodology
- Check the appropriateness of the applied scenarios and the assumptions that were made
- Ensure the proper evaluation of RCO

and, finally,

- Study the transparency and comprehensive of the study.

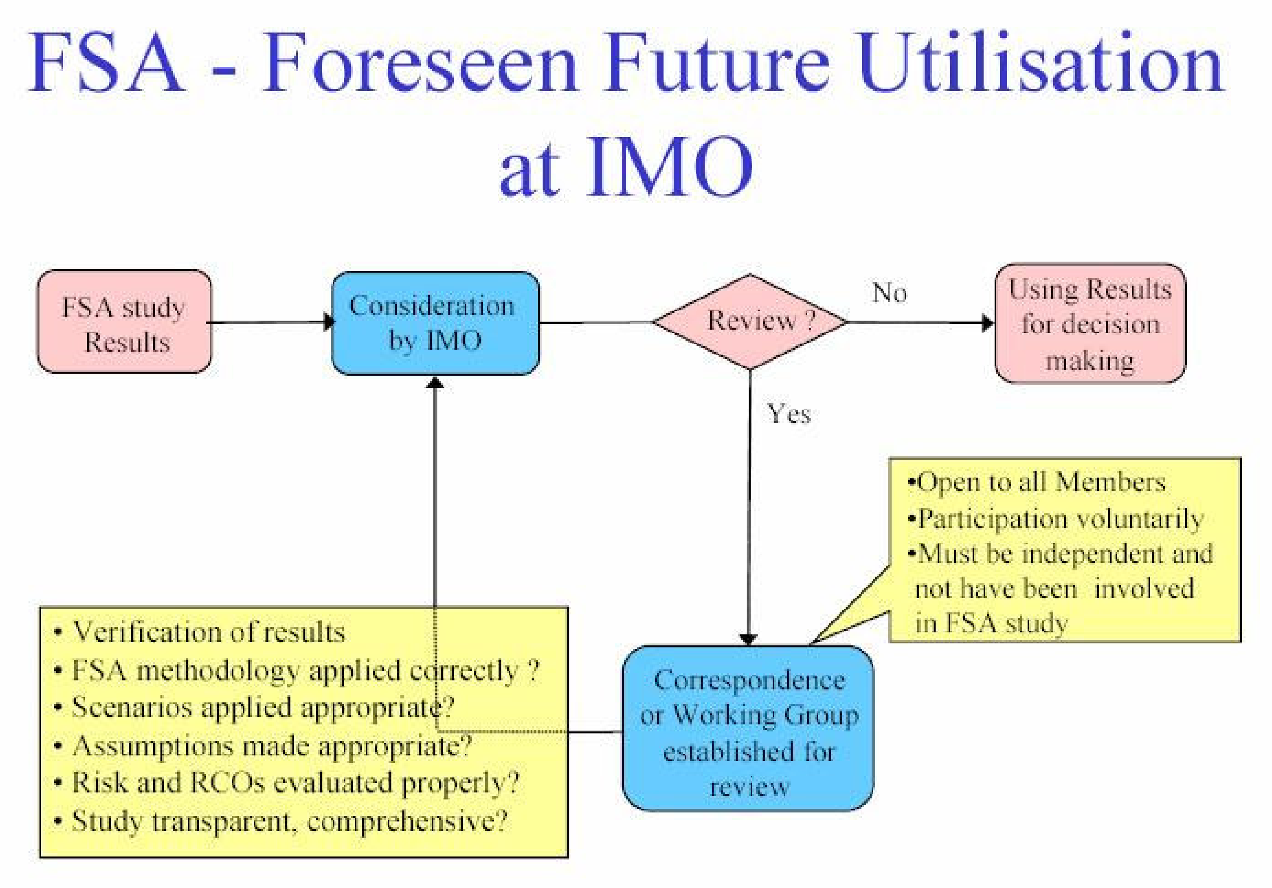


Fig 9-2 Internal Review [MSC 78/19/1]

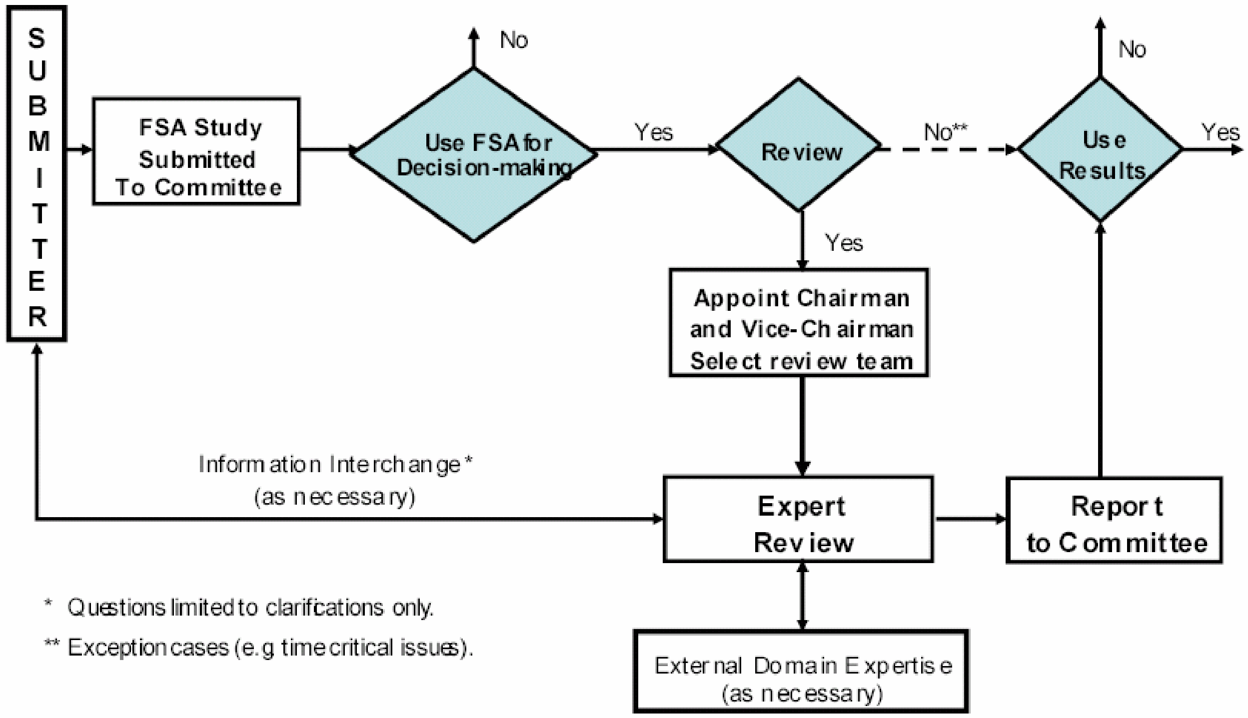


Fig 9-3 Review Flowchart [MSC 80/Wp.9]

9.3 Summary of Latest Developments & Further Work

The time that this thesis was in the process of typing the report of MSC80 was expected by the author. The Working Group on FSA met from 12 to 17 May 2005. The report confirmed things that were commented in this thesis and some of the expected amendments were discussed.

MSC80 confirmed the will of IMO to integrate a **review process** in FSA. The Committee agreed that when IMO plans to use a study for making decisions then the FSA group of experts will be instructed to review the study in the way that is shown in Fig 9-3.

The second important issue that was discussed is the link between FSA and **goal-based standards** (GBS). These standards are one of the latest developments in MSC. As it was noticed, in the DSS issue, the Committee was advised by those who had made the selection that it should adopt all of the measures because researchers considered them to be the best choice. The criticism that followed lead to the consideration of goal-based standards that should state what has to be achieved, rather than how it should be achieved, leaving the method of reaching particular goal open to different approaches and to innovation.

Furthermore, **cost effectiveness criteria** and **risk acceptance criteria**, as proposed in MSC 78/19/2, were, also, discussed noting the fact that GCAF and NCAF indices have to be considered. Another issue discussed was the one concerning the combination and interdependencies of RCOs in a particular study and from separate studies on the same subject.

Finally, the need of **probabilistic modeling** of failures and development of accident scenarios in order to achieve a proactive approach was discussed.

All the above were discussed during MSC 80 and are, currently, under development. In the next sessions more amendments to the Guidelines are expected to be made and the proposals submitted after April 2002 is very possible that will be annexed and incorporated in Circ. 1023. Besides, risk indices relevant to the protection of the marine environment are expected to be proposed during the next MEPC session.

9.5 Final Conclusions

The Bahamas during MSC 79 submitted a document (MSC 79/6/19) that contained the following very apt comparison. "When radar was first installed on board merchant ships, many people expected an end to the collisions in fog. It was compared to be the equivalent of being able to appreciate visually what was happening around the ship." The same was done with the introduction of FSA. FSA was believed to be the magic tool. The researchers undertaking a study come to some recommendations. To them they are the best choice. What was bad is that the Marine Safety Committee was not making the final decisions. The researchers were doing them.
It can be, easily, understood that the FSA process is not designed to produce final answers. Criticism of the recent decisions on double side skin bulk carriers was benefactory. It will take some time to realize that FSA has limitations, but when the limitations will be realized, the full benefits of the process will be reaped.

After all this research this thesis comes to its ending. The author realized through this process that FSA is a very powerful tool. Experience is gained everyday. Every new study makes the process better. Along with all this experience, goal-based standards are, definitely, going to help FSA to move to a new era.
Despite the introduction of FSA most rules within the shipping industry were still prescriptive and the level of safety inherent to them is, still, unknown. The risk based approach that was used in other industries and in particular in the offshore and aviation industry was introduced to shipping with the FSA method. FSA provides a clear and transparent basis for decision making and, in this sense, the first 3 Steps of the process are ideal for the development of high level goals. As a next step, the last three (RCOs, CBA and Recommendations for Decision-Making) can feed goal based standards and help to select between alternative technical or regulatory solutions.

This last one will help so that all affected stakeholders will be "happy" with the decisions, no reverse in IMO's decision will be needed and shipping will be safer and oceans cleaner .

REFERENCES

ABS (2003) "Risk Evaluations for the Classification of Marine-Related Facilities", Guide, American Bureau of Shipping, 2002

Ambion (1997) "Approaches to Hazard Identification", Ambion Consultants, Offshore Technology Report OTO 97 068, Health & Safety Executive, HSE Books.

Barlettani M., Fruttuoso G., Lombardi P.,(1997) "An ecological approach for risk and impact ranking,", Proceedings New Risk Frontiers, Society of Risk Analysis, Stockholm

Bohnenblust H. (1998) "Risk-based decision making in the transportation sector", Quantified Societal Risk and Policy Making, Kluwer Academic Publishers, Dordrecht

CCPS (1992) "Guidelines for Hazard Evaluation Procedure", 2nd edition, Center for Chemical Process Safety, American Institute of Chemical Engineers, New York

CIA (2004) ,"The Word Fact Book", Central Intelligence Office, 2004

Dasgupta J., "Quality Management of Formal Safety Assessment (FSA) Process"

Ditlevsen O. (2004) Closure of discussion to: Ditlevsen,O., "Life quality index revisited", Structural Safety, 26, p.443-451, 2004

DNV/HSE (2001) "Marine Risk Assessment", Offshore Technology Report, Prepared by Det Norske Veritas (DNV), Health and Safety Executive, 2001

ERI/ESA (2000) "Review of Risk Management practices in various organizations and industries", ERI Consulting &Co, Prepared for European Space Agency, 2000

FSEA (1999) "Concearned Action on FSEA", Final Report, WA-96-CA-1555, Germanischer Lloyd

House of the Lords (1992) "Safety aspects of ship design and technology", Committee on Science and Technology, HMSO,1992

HSE(1991) ‘Quantified Risk Assessment: Its Input to decision Making’, Health & Safety Commission, 1991

HSE (1999) “Reducing Risks, Protecting People”, Discussion document, Health & Safety Commission, 1999

HSE (2001) “Reducing Risk, Protecting People :HSE’s decision-making process”, Health & Safety Commission, 2001

IEC (1994), “IEC 60300-3-9 : Risk analysis of technological systems”, International Electrotechnical Commission, Geneva, 1994

Jonkman S.N.,van Gelder P.H.A.J.M , Vrijling J.K. (2003) “An overview of quantitative risk measures for loss of life and economic damage”, Journal of Hazardous Materials, Elsevier, I-30, 2003

Lind, N.C (1996) Safety Principles and Safety Culture, Proceedings; 3rd International Summit on Safety ate Sea, Conference organised by the Norwegian Petroleum Society; Oslo, Norway, 1996

Lois P., Wang J., Wall A., Ruxton T. (2004) “Formal safety assessment of cruise ships”, Tourism Management, Vol.25, p. 93–109

Mathiensen T.C (1997) “Cost Benefit Analysis of Existing Bulk Carriers”, DNV Paper Series No 97-P008.

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

NORSOK (1998) Risk and emergency preparedness, (Z-013 rev.1), “Annex C: Methodology for establishment and use of environmental risk acceptance criteria”, 1998

Skjong R. and Eknes M.L. (2001) “Economic Activity and Societal Risk Acceptance”, ESREL 2001, 16-20 September, 2001, Turin, Italy

Skjong R. (2002a) “Risk Acceptance Criteria: current proposals and IMO position”, Surface transport technologies for sustainable development, Valencia, Spain 4-6 June,

Skjong, R. and Ronold, K. (2002) "So Much for Safety", Presentation at OMAE 2002, Oslo, June 24th - June 28th, 2002

Statoil (1995) “Risk Acceptance Criteria in the Statoil Group”. Doc. no. K/KR-44, Rev. No. 0, 01.05.95, Statoil, Norway

TAW (1985), Technical Advisory Committee on Water Defences, “Some considerations of an acceptable level of risk in The Netherlands”, TAW, 1985

UNCTAD (2003) “Review of Maritime Transport 2003”, Report by the UNCTAD Secretariat, United Nations, 2003

UNDP (1990) United Nations Development Programme; Human Development Report; Oxford University Press, 1990

Ventikos N., Psaraftis H. (2004) “Spill accident modeling: a critical survey of the event-decision network in the context of IMO’s formal safety assessment”, Journal of Hazardous Materials, Elsevier, p. 59-66, 2003

Wang J., Foinikis P. (2001) “Formal safety assessment of containerships”, Journal of Marine Policy,25, p. 143-157

BIBLIOGRAPHY

(extensive bibliography has been avoided)

Apostolakis G.. Expert Judgment in Probabilistic Safety Assessment. In C.A. Clarotti and D.V. Lindley, editors, Accelerated Life Testing and Experts' Opinions in Reliability. North–Holland, 1988

Apostolakis G.. The concept of probability in safety assessment of technological systems. Science,250:1359–64, 1990

Clemen, R.T. "Calibration and the Aggregation of Probabilities," Management Science, Volume 32, Issue 3, pp.312-314, 1986

Clemen, R.T., Winkler, R.L. 1999. Combining Probability Distributions from Experts in Risk Analysis, Risk Analysis, 19(2), 187–203

Cooke, R.M., Experts in Uncertainty, Oxford: Oxford University Press, 1991.

Ditlevsen O. and P. Friis-Hansen. Life Quality Allocation Index-an equilibrium economy consistent version of the current Life Quality Index. Structural Safety, in press, 2004

Fischhoff B., S. Lichtenstein, P. Slovic, S.L. Derby, and R.L. Keeney. Acceptable Risk. Cambridge University Press, New York, 1981

Holmberg J. Holmberg, U. Pulkkinen, K. Porn, and K. Shen. Risk Decision Making in Operational Safety Management – Experience from the Nordic Benchmark Study. Risk Analysis, 14(6):983–991, 1994

Jae-Ohk Leea, In-Cheol Yeob, Young-Soon Yanga "A trial application of FSA methodology to the hatchway watertight integrity of bulk carriers", Marine Structures, Vol. 14, p 651-667, 2001

Kaplan S.. Risk Assessment and Risk Management - Basic Concepts and Terminology. Hemisphere Publ. Corp., Boston, Massachusetts, USA, 1991. In Risk Management: Expanding Horizons in Nuclear Power and Other industries, pp. 11–28

Kendall M. Rank correlation methods. Griffin and Co, London, 1970

Litai, D. (1980) “A Risk Comparison methodology for the Assessment of Acceptable Risk” PhD Thesis, Massachusetts Institute of Technology, Cambridge, Massachusetts

Loughran C., Pillay A., Wang J., Wall A. & Ruxton T. (2002), "Formal fishing vessel safety assessment", Journal of Risk Research, Vol.5, No.1, pp.3-21

Lois P., J.Wang, A.Wall, T.Ruxton (2004) , “Formal safety assessment of cruise ships”, Tourism Management, Vol.25, p. 93–109

Pulkkinen U., Holmberg J. 1997. A method for using expert judgement in PSA. (Radiation and Nuclear Safety Authority of Finland STUK), Technical report STUK-YTO-TR 129, Helsinki, Finland

Pulkkinen, U. 1993. Methods for combination of expert judgements. Reliability Engineering and Systems Safety, 40, 111–118

Rackwitz R.. Optimization and risk acceptability based on the life quality index. Structural Safety, 24(2-4):297–332, 2002

Rosqvist, T., Tuominen, R., Jalonen, J., Salmikuukka, J., Reunanen, M. 1998. Formal Safety Assessment: Trial application of FSA to the transportation of dangerous goods on passenger/ro-ro cargo vessels. Report VAL B353. VTT Automation, Tampere, Finland

Skjong, R. and Ronold, K. (1998) "Social Indicators and Risk Acceptance", Offshore Mechanics and Arctic Engineering Conference, OMAE, Lisbon 1998

Skjong, R. and Wentworth, B. H. (2001) "Expert Judgement and Risk Perception", Offshore and Polar Engineering Conference, ISOPE, Volume IV, pp 537-544, Stavanger 17-22 June, 2001

Skjong, R. and Eknes, M. L. (2001) "Economic activity and societal risk acceptance", ESREL 2001, 16-20 September, 2001, Turin, Italy

Skjong, R. (2002a) "Risk Acceptance Criteria: current proposals and IMO position", Surface transport technologies for sustaninable development, Spain 4-6 June, 2002

Skjong, R. (2002) "Setting Target Reliabilities by Marginal Safety Returns", Joint Committee on structural Safety (JCSS), Workshop on Reliability Based Code Calibration, Zurich, Switzerland, March 21st - 22nd, 2002

Wang J, Pillay A,Wall A,Ruxton T. The latest development in ship safety assessment. Proceeding of the Fourth International Conference on Reliability, Maintainability and Safety, (ICRMS'99),Shanghai, China, May 18-21,1999. p. 711-719

IMO Documents

MSC x/y/z x: Session, y : Agenda Item, z : Document number of Agenda Item
For a list of IMO Documents see Appendix 1.

FSA STUDIES

FSA study on disabled oil tankers, Germany, MSC 70/20/2
Helicopter Landing Area. Norway/ICCL COMSAR 3/2, DE 41/INF.2;
Helicopter Landing Area. Italy, MSC 69/14/7, MSC 69/INF.31;
BC FSA . International Study (United Kingdom), MSC 76/5/4;
BC FSA . IACS, MSC 74/5/4;
BC FSA/Life-saving Appliances. Norway/ICFTU MSC 74/5/5
BC FSA. Japan Study, MSC 75/5/2;
BC International Collaborative, United Kingdom, MSC 75/5/5
BC FSA less than 150 m . Cyprus, MSC 77/5/2.
BC Comparative Study of Single and Double Side Skin, Greece, MSC 78/5/1
Trial Application to High-Speed Passenger Catamaran Vessels. United Kingdom, MSC 68/INF.6, DE 41/INF.7, MSC 69/14/4, MSC 69/INF.14;
FSA Study on Navigational Safety of Passenger Ships, Norway, MSC 78/4/2