ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΕΙΡΑΙΩΣ

ΤΜΗΜΑ ΝΑΥΤΙΛΙΑΚΩΝ ΣΠΟΥΔΩΝ

ΠΡΟΓΡΑΜΜΑ ΜΕΤΑΠΤΥΧΙΑΚΩΝ ΣΠΟΥΔΩΝ

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ΝΑΥΤΙΛΙΑ

FORMAL SAFETY ASSESSMENT OF PASSENGER SHIPS

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Διπλωματική Εργασία
που υποβλήθηκε στο τμήμα Ναυτιλιακών Σπουδών
του Πανεπιστημίου Πειραιώς ως μέρος των
απαιτήσεων για την απόκτηση του Μεταπτυχιακού
Διπλώματος Ειδίκευσης στη Ναυτιλία
Απρίλιος 2010

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ABSTRACT

The safety of vessels has been of concern to mariners for centuries. Concepts of vessel stability, the possibility of capsizing, and structural integrity have been recognized by shipbuilders and operators from the beginning of marine shipping industry. The concepts of metacenter and restoring arm as initial stability criteria for small heel angles and practical methodologies for their evaluation were introduced in 18th century.

The first safety regulations referred to sufficient height of the deck above waterline. The oldest traceable ship safety recommendations were found in the Venetian code of Maritime law (13th century) requesting marking and inspection of the load line mark. In more modern days, during the second part of 18th century, Lloyd's Register of Shipping issued recommendations for the magnitude of freeboard, 2 to 3 inches per foot of the depth of cargo hold. The development of safety recommendations by the international community was based solely on freeboard criteria and this approach continued until the Titanic disaster. Historically, progress in the development of stability criteria was driven by response to the most publicized marine disasters. After the Titanic tragedy the first International Conference on the Safety of Life at Sea (SOLAS) took place in 1913-1914, but its recommendations on subdivision and damage stability were not adopted until the next SOLAS meeting in 1929.

After the 1987 capsizing of the 'Herald of Free Enterprise' the need for more extensive shipping safety research was recognized. The 1992 report on the accident identified and recommended the need for replacement of prescriptive rules with performance based regulations. The UK Marine Safety Agency, in 1993, suggested to the IMO's Marine Safety Committee (MSC) the concept of formal safety assessment with respect to ship design and operations. The proposition was accepted and FSA became a high priority on the MSC agenda.

The Formal Safety Assessment process has been defined by the IMO as: structured and systematic methodology, aimed at enhancing maritime safety, including protection of life, health, the marine environment and property by using risk analysis and cost benefit assessment. The method is applicable to consider the safety of vessels in a global sense (all systems) or to take into account subsystems or individual aspects of safe operations. It could be applied in situations where risk needs to be reduced but required decisions are not clearly defined and need to be analyzed. It can be applied during ship design stages or to analyze single operational aspects of existing vessels. The process can be used to validate existing and/or new regulations developed applying prescriptive or risk based principles.

It should be kept in mind that shipping is a true international business and that the safety regime in principle shall be the same for developing and developed nations. It is well known that this is not the case and that the motivation and ability to enforce international standards is highly different. FSA will involve the risk basic risk analysis steps and benefit-cost assessment. The intention is that FSA may contribute to identification of risks not covered by the regulations and obtain a set of controls that are more effective.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Safety generally can be understood as a measure undertaken to either minimize or eliminate hazardous conditions, to prevent accidents from happening and make the consequences of any accident less serious for ship, cargo and environment. Historically accidents occur no matter how carefully safety procedures are planned and implemented. It should not, however, prevent engineers from designing and planning for the safest possible structures and their operations.

The safety of vessels has been of concern to mariners for centuries. Concepts of vessel stability, the possibility of capsizing and structural integrity have been recognized by shipbuilders and operators from the beginning of marine shipping industry. Archimedes first defined physical principles of stability for floating systems of simple geometry. The assessment of stability properties of a floating body of an arbitrary shape in its design stage became a general practice in 18th century due to work of Pierre Bouguer and Leonhard Euler. They independently proposed concepts of metacenter and restoring arm as initial stability criteria for small heel angles and developed practical methodologies for evaluating those criteria. Guillame Clairine-Deslauries conducted first known recorded inclining test on the newly built naval ship. The test established the ship's GM at 1.8m.

From the regulatory point of view, the first safety rules referred to sufficient height of the deck above the waterline. The oldest traceable ship safety recommendations were found in the Venetian code of maritime law (13th century) requesting the marking and inspection of the load line symbol. In more modern days, during the second part of 18th century, Lloyd's Register of Shipping issued recommendations for the magnitude of freeboard, 2 to 3 inches per foot of the depth of cargo hold. The development of safety recommendations based solely on freeboard criteria continued until the Titanic disaster.

Historically, international and national regulations are, for the most part, developed as a reaction to the most publicised publicly sensitive marine disasters as lessons learned. This approach tends to quickly fix a problem at hand to meet media/public-defined goals, but may not address the issue of safety in a global engineering sense.

Only after the capsizing of the naval ship Captain in 1870, and the loss of six fishing vessels in Germany 1894 it was realised that the metacentric height was not a sufficient measure of stability. Recommendations for the minimum value and range of the righting arm were developed and issued. The 1878 sinking of the excursion steamer Princess Alice after collision with the cargo ship Bywell Castle and the resulting loss of 640 passengers brought attention to need for watertight bulkheads.

After the Titanic tragedy (1912)[1] the first International Conference on the Safety of Life at Sea took place in 1913-4. It set standards for safe navigation, construction of ships, fitting of radio, lifesaving equipment and protection from fire. There have been four more SOLAS conventions expanding the safety rules in many areas. Recommendations on subdivision and damage stability were adopted at the next SOLAS meeting in 1929. The 1960 SOLAS recommended to the Intergovernmental Maritime Consulting Organisation (IMCO, IMO from 1982) development of intact stability standards for passenger, cargo ships ad fishing vessels. Until then the SOLAS Convention did not directly referred to the intact stability, except that they included the provision that the stability information must be provided to the master.

The response to disasters like that of the Morro Castle (1934) has been o built ships in which fire is less likely to break out and spread and to ensure that, if it does, it is detected early. Fireproof doors and bulkheads are part of ship structure, smoke alarms and heat detectors are placed at key locations and sprinkle systems have been installed since.

Pollution from Torrey Canyon tanker disaster (1964) inspired construction of double hull tankers hoping that double skin would prevent the cargo spill and devastation of the environment.

In 1992 Lord Carver's House of Lords committee published a report on the Safety Aspects of Ship Design and Technology in the wake of the British car ferry Herald of Free Enterprises accident (1987) where within 90 seconds the vessels had settled on her side on the bottom of the sea and a total of 193 lives were lost as a result of leaving the bow door to the car deck open after the ship left port. The report concluded that modern science and technology were not adequately used to improve safety within the shipping industry. The committee recommended, for all commercial vessels, the applications of goal-based safety founded on quantitatively assessed risks and cost benefit analysis. The final conclusions referenced safety practices implemented by other industries, especially the nuclear, chemical and offshore business.

The UK government followed up on those recommendations. They understood the international aspect of the notion and prepared a submission to 62nd session of IMO's Maritime Safety Committee (MSC 62) as a concept of Formal Safety Assessment (FSA) in 1993. The concept was presented as applicable for safety analysis of individual ships but also as a tool in decision making process, in formulating new and amended rules for shipping in general. The original Formal Safety Assessment concept was, at least partially, developed after the Piper Alpha catastrophe in 1988 in which and offshore platform exploded in the North Sea and 167 people lost their lives. In their proposal the UK delegation used the experience of the offshore industry.

In addition to the IMO, several other shipping industry stakeholders play an important role in maritime safety policy. For instance, flag states check if ships that fly their flags conform to regulations. Port states do the same for ships arriving at their ports. Classification societies are bodies that have the expertise and are assigned the task to check regulations on ship construction, maintenance and operation.

While it is generally accepted that the overall level of maritime safety has improved in recent years, further improvements are still desirable. However, it can be argued that much of maritime safety policy worldwide has been developed in the aftermath of serious accidents (such as 'Exxon Valdez', 'Estonia', 'Erika' and 'Prestige'). Industry circles have questioned the wisdom of such an approach. Why should the maritime industry and, in general, society, have to wait for an accident to occur in order to modify existing rules or propose new ones? The safety culture of anticipating hazards rather than waiting for accidents to reveal them has been widely used in other industries. The international shipping industry has begun to move from a reactive to a proactive[2] approach to safety through what is known as Formal Safety Assessment (FSA).

CHAPTER 2

RISK ASSESSMENT

2.1 Definition of Risk

2.1.1 Two–dimensional nature of risk

Risk has the following two dimensions:

- The severity or magnitude of the loss event
- The likelihood or probability of occurrence

The combination of both dimensions is what constitutes risk. However, risk perception by the public of high technology industrial activities tends to be associated with the severity dimension rather than the probability dimension.

It is essential for the technologist to appreciate the two-dimensional nature of risk. This also gives a two-pronged approach to managing risks; it minimizes the extent of loss or severity of the incident, and minimizes or eliminates the likelihood of the event.

2.1.2 Definition of risk

One obvious definition incorporates the concept of loss and the two-dimensional nature of risk:[3]

Risk is defined as the probability of occurrence of an event that could cause harm to people, property or the environment, over a specified period of time.

An alternative definition of risk is the following:

Risk is the adverse variation in the outcomes that could occur over a specified period in a given situation.

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 the risk does not mean ‘actual danger’ but the ‘possibility of danger’. 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 (actual events) the word frequency can be used.

Risk is subjective. No one knows what will happen in the future, not even statistically. And risk does not exist the way a thing or physical attribute such as energy does. In many situations there is either something significant that cannot be assumed constant or there is insufficient data, and it is then important not to believe that risk can be measured, estimated or calculated. Risk is always an assigned quantity.

The consequences of risk in a vessel are the following:

- Injuries
- Deaths
- Damage or total loss of vessel
- Economical expenses
- Environmental issues

Some areas could be improved in order to minimize the risk on vessels. The areas that if would be covered the risk would be lower are the following:

- Continuously education for seafarers
- Certification of seafarers
- Capability- Suitability for work
- Drug & alcohol use on board
- Exhaustion
- Working conditions on vessels
- Common language between crew members
- Vessel’s equipment
- Correspondence with other vessels and shore
- Systems for help in case of emergency
- Ship reporting systems

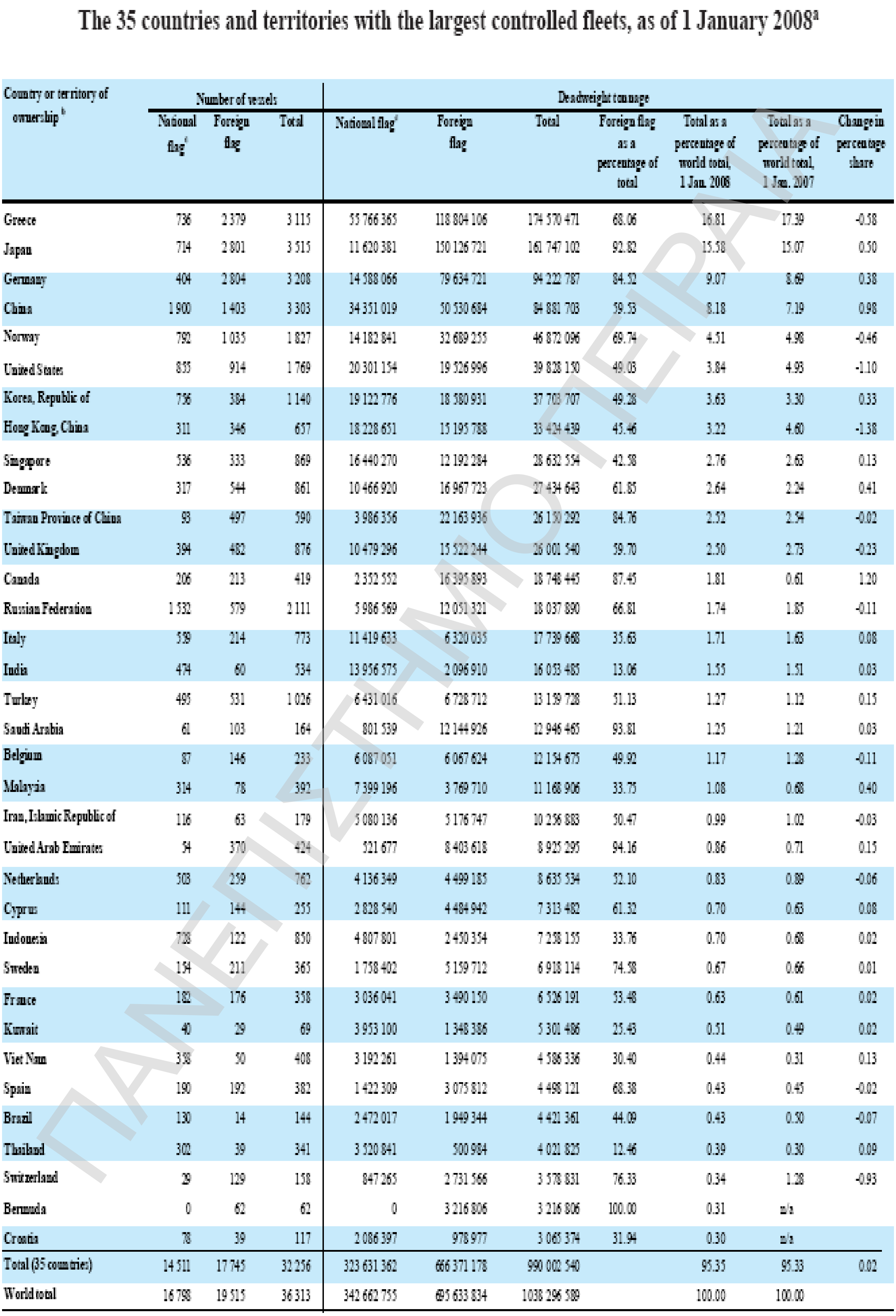
And the main organization that arranges for the maritime safety is IMO, and it is scientific approach is Formal Safety Assessment, which is a systematic process analytically explained in the following chapters.

2.2 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. 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).

For reasons of completeness the most important maritime countries and territories as of 1st January 2008 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 (UNCTAD 2008).



The 35 countries and territories with the largest controlled fleets, as of 1 January 2008[a]

Country or territory of ownership [b]	Number of vessels			Deadweight tonnage						
	National flag[c]	Foreign flag	Total	National flag[c]	Foreign flag	Total	Foreign flag as a percentage of total	Total as a percentage of world total, 1 Jan. 2008	Total as a percentage of world total, 1 Jan. 2007	Change in percentage share
Greece	736	2 379	3 115	55 766 365	118 804 106	174 570 471	68.06	16.81	17.39	-0.58
Japan	714	2 801	3 515	11 620 381	150 126 721	161 747 102	92.82	15.58	15.07	0.50
Germany	404	2 804	3 208	14 588 066	79 634 721	94 222 787	84.52	9.07	8.69	0.38
China	1 900	1 403	3 303	34 351 019	50 530 684	84 881 703	59.53	8.18	7.19	0.98
Norway	792	1 035	1 827	14 182 841	32 689 255	46 872 096	69.74	4.51	4.98	-0.46
United States	855	914	1 769	20 301 154	19 526 996	39 828 150	49.03	3.84	4.93	-1.10
Korea, Republic of	756	384	1 140	19 122 776	18 580 931	37 703 707	49.28	3.63	3.30	0.33
Hong Kong, China	311	346	657	18 228 651	15 195 788	33 424 439	45.46	3.22	4.60	-1.38
Singapore	536	333	869	16 440 270	12 192 284	28 632 554	42.58	2.76	2.63	0.13
Denmark	317	544	861	10 466 920	16 967 723	27 434 643	61.85	2.64	2.24	0.41
Taiwan Province of China	93	497	590	3 986 356	22 163 936	26 150 292	84.76	2.52	2.54	-0.02
United Kingdom	394	482	876	10 479 296	15 522 244	26 001 540	59.70	2.50	2.73	-0.23
Canada	206	213	419	2 352 552	16 395 893	18 748 445	87.45	1.81	0.61	1.20
Russian Federation	1 532	579	2 111	5 986 569	12 051 321	18 037 890	66.81	1.74	1.85	-0.11
Italy	559	214	773	11 419 633	6 320 035	17 739 668	35.63	1.71	1.63	0.08
India	474	60	534	13 956 575	2 096 910	16 053 485	13.06	1.55	1.51	0.03
Turkey	495	531	1 026	6 431 016	6 728 712	13 159 728	51.13	1.27	1.12	0.15
Saudi Arabia	61	103	164	801 539	12 144 926	12 946 465	93.81	1.25	1.21	0.03
Belgium	87	146	233	6 087 051	6 067 624	12 154 675	49.92	1.17	1.28	-0.11
Malaysia	314	78	392	7 399 196	3 769 710	11 168 906	33.75	1.08	0.68	0.40
Iran, Islamic Republic of	116	63	179	5 080 136	5 176 747	10 256 883	50.47	0.99	1.02	-0.03
United Arab Emirates	54	370	424	521 677	8 403 618	8 925 295	94.16	0.86	0.71	0.15
Netherlands	503	259	762	4 136 349	4 499 185	8 635 534	52.10	0.83	0.89	-0.06
Cyprus	111	144	255	2 828 540	4 484 942	7 313 482	61.32	0.70	0.63	0.08
Indonesia	728	122	850	4 807 801	2 450 354	7 258 155	33.76	0.70	0.68	0.02
Sweden	154	211	365	1 758 402	5 159 712	6 918 114	74.58	0.67	0.66	0.01
France	182	176	358	3 036 041	3 490 150	6 526 191	53.48	0.63	0.61	0.02
Kuwait	40	29	69	3 953 100	1 348 386	5 301 486	25.43	0.51	0.49	0.02
Viet Nam	358	50	408	3 192 261	1 394 075	4 586 336	30.40	0.44	0.31	0.13
Spain	190	192	382	1 422 309	3 075 812	4 498 121	68.38	0.43	0.45	-0.02
Brazil	130	14	144	2 472 017	1 949 344	4 421 361	44.09	0.43	0.50	-0.07
Thailand	302	39	341	3 520 841	500 984	4 021 825	12.46	0.39	0.30	0.09
Switzerland	29	129	158	847 265	2 731 566	3 578 831	76.33	0.34	1.28	-0.93
Bermuda	0	62	62	0	3 216 806	3 216 806	100.00	0.31	n/a	
Croatia	78	39	117	2 086 397	978 977	3 065 374	31.94	0.30	n/a	
Total (35 countries)	14 511	17 745	32 256	323 631 362	666 371 178	990 002 540		95.35	95.33	0.02
World total	16 798	19 515	36 313	342 662 755	695 633 834	1038 296 589		100.00	100.00	

The above table[4] shows the major players (state-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.

The Maritime Safety Committee as 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.

2.3 Risk Analysis

2.3.1 What is risk analysis?

Risk analysis, as used for the assessment of the hazards associated with ships, can be summarized by three questions:[5]

1) What can go wrong?
2) What are the effects and consequences?
3) How often will it happen?

The first question is purely qualitative and is often called a safety study. Such a study may reveal aspects of the ship and equipment, which require more consideration. It is then necessary to answer the next two questions in order to complete the risk analysis. The results of the analysis are used for judgment, about the acceptability of the risk and for decision making.

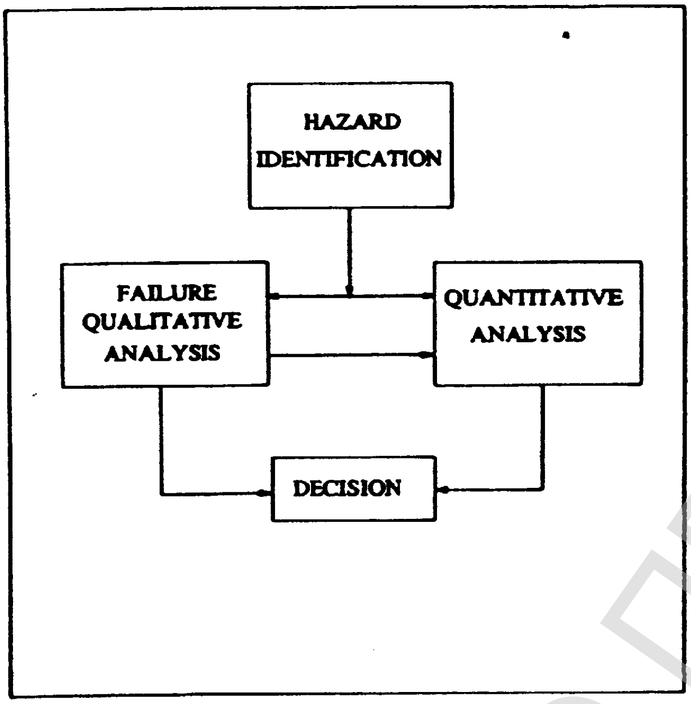


Fig1. Risk Analysis

Qualitative answers are often given to the second and third questions. However, recent developments have involved the application of quantitative techniques for obtaining answers to these two questions. This is usually referred to as quantitative risk analysis. The whole exercise may be called risk assessment. The process of risk assessment should cover all phases of the life of a ship-design, construction, commissioning and operation.

2.3.2 Provisions of risk analysis

This process of Risk Assessment would:

- ♦ Increase the understanding of ship safety through a systematic and logical development of accident sequences.
- ♦ Separate important accident sequences from unimportant ones.
- ♦ Provide a quantitative measure of risk.
- ♦ Determine the importance of ship operator actions in coping with accidents.
- ♦ Identify cost effective design or procedural changes for controlling risk.
- ♦ Improve the decision making (risk management process).

- Help clarify emergency planning needs.
- Provide assurance that state of the art methods have been responsibly used to access ship safety.

2.3.3 Examples of risk analysis

a) Port of Rafina

The port of Rafina is one of the biggest ports in Greece, and it is about 60 km from centre of Athens and used for the last 40 years. It is used mainly by Ro-Ro passenger ships, which go to the islands to the north Aegean Sea. Bigger ships that are traveling to other larger islands, due to its small size, (depth, capacity etc) cannot use it. Also only few, and small, cargo ships used this port because of its small size and the absence of appropriate equipment, resulting to their move to other bigger ports.

Hazards in the port

i) Collision of two ships under way into the port. This has never happened in this port, due to the fact that it is forbidden for two ships, since the early years of the port, to be under way into the port.

ii) Striking of a vessel moored by a passing vessel. This has happened a lot of times in the past due to the small size of the port, and the bad weather that the place, where the port is, usually has, with result the captains of the ships not to have the best view of the port. And one significant reason is the high waves and winds, due to the position of the port in the open sea.

iii)Impact of a ship into a dock. This has happened for the same reasons as the previous. Of course the human error is a major reason for whatever happens.

iv) Fire on a ship, or a port's area. Human error is also a major reason leading to this type of accident.

Consequences

The major problem of the port is the pollution. The major reason of this is referred above and is hazard v), as it happens continuously, without anyone doing anything to prevent this.

Pollution is caused, also, from fire on a ship as the area where the port is sited is densely populated.

For the three first hazards there is a big possibility for a ship to capsize. There are a lot of problems that would cause to the port. The first one is again the pollution of the sea. Then, due to the small depth of the port, up to the lifting up of the sunken ship the port should be closed, as no other ship would be able to enter. This will cause major problems to the area, as most of the citizens work in the port and they would lose their main income. And of course there is always a possibility, after an accident, for injuries and even death of people. Finally fire and impact of a ship into a dock would probably cause some problems that would need a lot of money and time in order to be repaired.

Frequency

As it has been referred above collision has never happened in this port. But generally in 26 accidents that happened in the 40 years that it is used, 2 people have died. Assuming that about 20 ships get into the port everyday, then the probability of occurrence is about 8.9 x 10^{-5} and from equation (1) the risk on lives is T_{si} = 1.78 x 10^{-4}.

There is no reason of estimating the frequency of hazard v) as it is done almost everyday and not by accident.

The most frequent hazard is the impact of a ship into a dock. It has happened 20 times, almost once every two years, and has caused a lot of injuries to passengers.

So in order to minimize the risks, a good solution is to extend the size of the port. This is not so difficult to happen as at the west part of the port there is a lot of space, which is unexploited, and could very easily be used for the improvement of the port. Such a change would differentiate the general view of the place, where the port is. More people would use this port, that means that more money would be spent in the area, and a lot of inhabitants, who are unemployed, may find a job in the port.

b) The monohull "Aiolos Express"

In April 2000 the first monohull passenger ship came in Greek seas and traveled in the route Piraeus-Mitilini and vice versa. That is "Aiolos Express" which makes the distance in 7 hours, while all the other ships need almost 12 hours for the same voyage, due to the high speed of his specific vessel.

Hazards

a) The major hazard comes from the fact that it is the first monohull in Greece. Everyone who works in the ship does not have big experience in such type of ship. So the possibility of human error is big.
b) Some ports of small Greek islands, where the ship passes in order to take new passengers, do not have the appropriate substructure for such a ship, and maybe some problems, as impact in a dock, would be occurred.
c) Problems in loading/unloading of cars/motorbikes and buses (especially in the summer when many people travel to the islands)
d) The extreme weather conditions of the north Aegean Sea may cause problems to the ship, which is not tested in such winds.
e) The ship is full of armchairs and has no cabins and beds.
f) The big speed of the ship may cause problems to passengers who are nauseated.
g) Problems with the stability of the ship due to the big speed.

Consequences

The nausea with the lack of a deck passenger cause terrible headaches to these passengers, together with the ship's big speed. This would possibly make some passengers to prefer the other ships for traveling in the same route, as their fare as well is almost half of the fare of "Aiolos Express". And because of the lack of beds, some passengers who want to sleep would possibly cause problems in order to find enough space to lie down. All these problems may lead to the lack of passengers, and the ship management of vessel may be led to sell the ship, as they would have no profit.

The Greek weather is a bit strange in the summer, especially in the north Aegean Sea. So, the ship will have some problems to travel there, as it is not used in such waves and winds. And the inexperience, in such ship type, of the crew member would be an important factor in a non-direct solution of the possible problems that may occur.

2.4. Quantitative Risk Analysis

In quantitative risk analysis, the risk is defined as the product of the probability of occurrence of unwanted event and the severity of associated consequence. According to this definition, the risk on lives generated by the accident scenario ‘Si’ caused by the event ‘S’ is expressed in the following formula:[5]

$$T_{si} = \alpha_{Si} \text{ x } E_{Si} \qquad (1)$$

Where:

$T_{Si:}$ risk on lives of the accident scenario ‘Si’

α_{Si} : probability of occurrence of the accident scenario ‘Si’

E_{Si} : number of lives lost caused by the accident scenario ‘Si’

During the period 1953-1987, 82 accidents of passenger Ro-Ro ship happened in near UK waters. In these accidents 338 people lost their lives. Assuming that 100 ships are doing their route every day the probability of occurrence is 6.6 x 10^{-5}.

So the risk on lives is:

$T_{si} = 6.6 \text{ x } 10^{-5} \text{ x } 338 = 2.23 \text{ x } 10^{-2}$

Only 26 accidents of them happened in port areas and 8 people died. The probability of occurrence is 2.1 x 10^{-5}.

The risk on lives is:

$T_{si} = 2.1 \text{ x } 10^{-5} \text{ x } 8 = 1.68 \text{ x } 10^{-4}$

On the other hand, every ship possesses its own risk on lives and it is defined as the risk generated by all the events which have possibility to affect the safety of persons on board. Hereafter, the risk on lives means ship’s own risk on lives. Therefore, the risk on lives is expressed by the following formula:

$$T = \sum_{s=1}^{n} \sum_{I=1}^{m} a_{Si} E_{Si} \qquad (2)$$

Where:

T: risk on lives generated by all over the events

S : index of a kind of event

i : index of a kind of accident scenario

m : number of accident scenarios caused by the event ‘S’

n : number of events

A simple definition of risk is the following: a weather forecast such as “30 percent of rain tomorrow” gives two outcomes together with their likelihoods: (30%, rain) and (70%, no rain). Risk is defined as a collection of such pairs of likelihoods and outcomes:

{(30%rain), (70%no rain)}

More generally, assume n potential outcomes in the doubtful future. Then risk is defined as a collection of n pairs.

Risk = $\{(L_1, O_1),\ldots..,(L_i,O_i),\ldots..,(L_n,O_n)\}$

Where O_i and L_i denote outcome i and its likelihood, respectively.

In making a risk assessment of any system, no matter how simple or how complex, there are four main stages, and an essential precursor of such an evaluation is that a detailed understanding of the design and construction of the plant involved is established and that all the processes carried out in the plant are identified. The four main stages are:

1) To establish the probability of the conditions occurring that could lead to a fault developing in the unit of interest.
2) To determine what is the probability of a fault developing and what will be the characteristics of the fault.
3) If the fault occurs, to determine what will be the hazard potential of the fault.
4) To determine the consequences in terms of loss of life, injury and damage to property of the fault developing.

The benefits from making an integrated assessment of risks are:

1) A comprehensive assessment requires that every aspect of the composition and operation of the whole system is examined in a systematic way that identifies the environment the system is exposed to, the interactions between the various components and between components and operators.

2) The process of quantifying risk acts as a check on the design in the sense that it shows if the system will operate in the way intended.
3) Putting numbers to the reliability of equipment highlights weak points in the system and indicates how reliable the whole system is likely to be.
4) Quantifying the risks associated with a plant gives the owner an indication of the extent of his potential financial liability for compensation for damage resulting from a fault with the plant.
5) The process of quantifying risks shows where the system can be modified to improve reliability and efficiency.
6) Quantification of risks gives the regulator a useful basis for assessing acceptability.

Generally, a risk assessment consists of the followings:

- Summary of risks to be assessed
- Hazards
- Persons at risk
- Nature of risk
- Preventative measures for risk control
- Maintenance
- Training
- Records
- What further action is required

2.4.1 Assumptions for quantitative risk analysis

Formulae (1) and (2) are the basis of the quantitative risk analysis, but it is not practical to quantify the risk based on the formulae directly. To be practical the three assumptions are introduced, and the new equations will be derived from the previous formulae. The assumptions are the following:

1) There is no life lost without ship's total loss. In case of fire, persons on board have possibility to be killed by smoke or heat, even the ship remains afloat. In such casualty, called as 'partial loss', we must substitute the loss of divided space for ship's total loss.

2) In case of ship's total loss, only the persons who evacuate from the ship by using the survival crafts remain alive.
3) The persons who evacuate from the ship with any survival crafts are alive. This assumption is not realistic, because it is known fact that the persons in a survival craft such as lifeboat have lost their lives in considerable cases.

2.4.2 Formulation for risk quantification

In case of the partial loss, it is considered that the same theory could be applied, by substituting the divided space's loss for ship's total loss. When the three assumptions are introduced, the basic formulae (1) and (2) become equations (3) and (4) respectively.

$$T_{Si} = (\xi_S \ \zeta_S \ n_{Si}) \left[\sum_{x=0}^{K} P_{Si}(x)\, x\right] \qquad (3)$$

$$T = \sum_{S=1}^{n} \ \sum_{Si=1}^{m} (\xi_S \ \zeta_S \ n_{Si}) \left[\sum_{x=0}^{k} P_{Si}(x)\, x\right] \qquad (4)$$

Where

S : index of a kind of event

i : index of a kind of accident scenario which leads the total loss of ship

Si : index of a kind of accident scenario which leads the total loss of ship, caused by the event 'S'

m : number of accident scenarios caused by the event 'S'

n : number of kind of events

ξ_S : probability of occurrence of the event 'S'

ζ_S : probability of ship's total loss caused by event 'S'

n_{Si} : probability of occurrence of the accident scenario 'Si'

x : number of lives lost

P_{Si} (x): probabilistic density function (PDF) of number of lives lost relating to the accident scenario 'Si'

K: permitted maximum number of persons on board

2.5 Qualitative Risk Analysis

Qualitative safety analysis is used to locate possible hazards and to identify proper precautions (administrative procedures, design changes, etc.) that will reduce the frequencies or consequences of such hazards.

Qualitative safety analysis should become an integral part of the design process of a product. It may be performed with one more of the following objectives:

1. To identify hazards in the design
2. To document and assess the relative importance of the identified hazards
3. To provide a systematic compilation of data as a preliminary step to facilitate quantitative analysis
4. To aid in the systematic assessment of the overall system safety

The general steps in a qualitative safety analysis are to:

§ Identify significant risks

§ Display the above information in a table, a chart, a fault tree or other format

Hazard consequence classification

	Description	Equipment	Personnel
I	***Catastrophic***	***System loss***	***Death***
II	Critical	Major system damage	Severe injury
III	Marginal	Minor system damage	Minor injury
IV	Negligible	Less than minor system damage	Less than minor injury

Hazard probability

Level	**Description**	**Frequency**
1	Frequent	Likely to happen
2	Probable	Several time during lifetime
3	Occasional	Likely to happen once
4	Remote	Unlikely but possible during lifetime

Risk assessment matrix

	Probability				
		Frequent	Probable	Occasional	Remote
	Catastrophic	I-1	I-2	I-3	I-4
Consequence	Critical	II-2	II-2	II-3	II-4
Severity	Marginal	III-3	III-2	III-3	III-4
	Negligible	IV-4	IV-2	IV-3	IV-4

Design action is required: I-1, I-2, I-3, II-1, II-2 and III-1.[6]

Hazards may need to be controlled: III-2, II-3 and I-4.

Hazard control is desirable: III-3 and II-4 if cost-effective.

No design action is required for others.

2.6 Top-down and Bottom-up safety assessment approaches

In the process of design for safety either a top-down or bottom-up safety assessment approach can be used to study various failure events and their scenarios. The decision as to which kind of analysis is more appropriate is dependent on the availability of failure data, the degree of complexity of the interrelationships of the design and the level of innovation in the design.[7]

2.6.1 Top-down safety assessment

A typical top-down process is shown in figure below. It starts with the identification of the top events which can be obtained from previous accident and incident report. The causes leading to the top events can be identified in an increasing detail until all the causes are identified at the required level of resolution. Either qualitative or quantitative analysis can be carried out to estimate and evaluate risk. For large marine systems with a comparatively lower level of innovation in the design, the top-down approach may prove convenient and efficient, because it deals with the failure paths leading to the top events.

2.6.2 Bottom-up safety assessment

A typical bottom-up safety assessment process is shown in figure 2 below. In order to identify all possible hazards all large marine or offshore system can be divided into subsystems which can be further broken down to the component level.

By using an inductive bottom-up safety assessment approach, it is almost sure that all of the failure events of a system and their respective causes are identified. In comparison to the top-down approach it has the following characteristics:

1. It may be more convenient to be incorporated into a computer package.
2. Omission of system failure events and their respective causes is less likely
3. It may be more suitable to be applied to the design of large offshore engineering systems with a high level of innovation.[7]

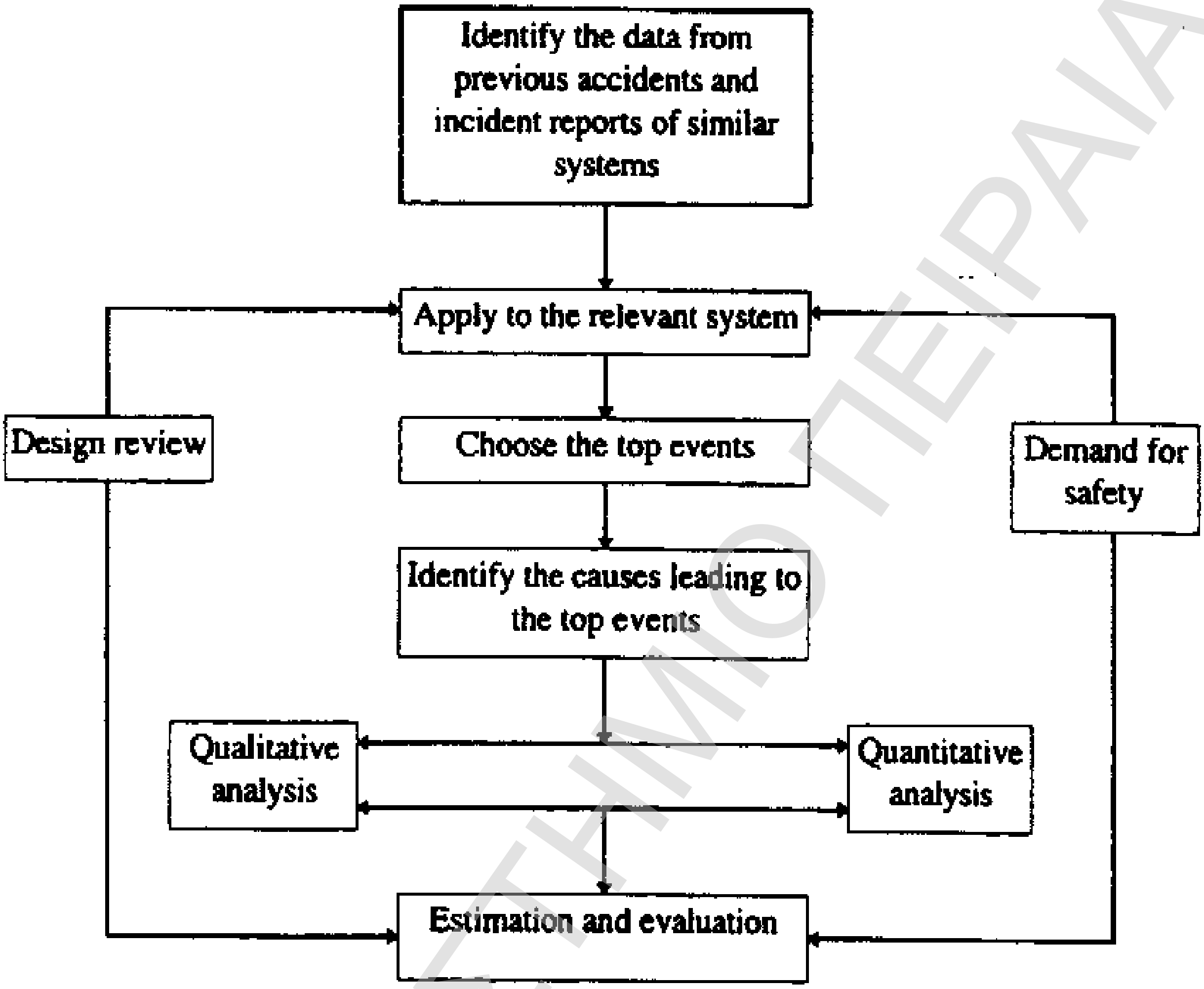

Identify the data from previous accidents and incident reports of similar systems
Apply to the relevant system
Choose the top events
Identify the causes leading to the top events
Design review
Demand for safety
Qualitative analysis
Quantitative analysis
Estimation and evaluation

Fig.2 A top-down safety assessment process

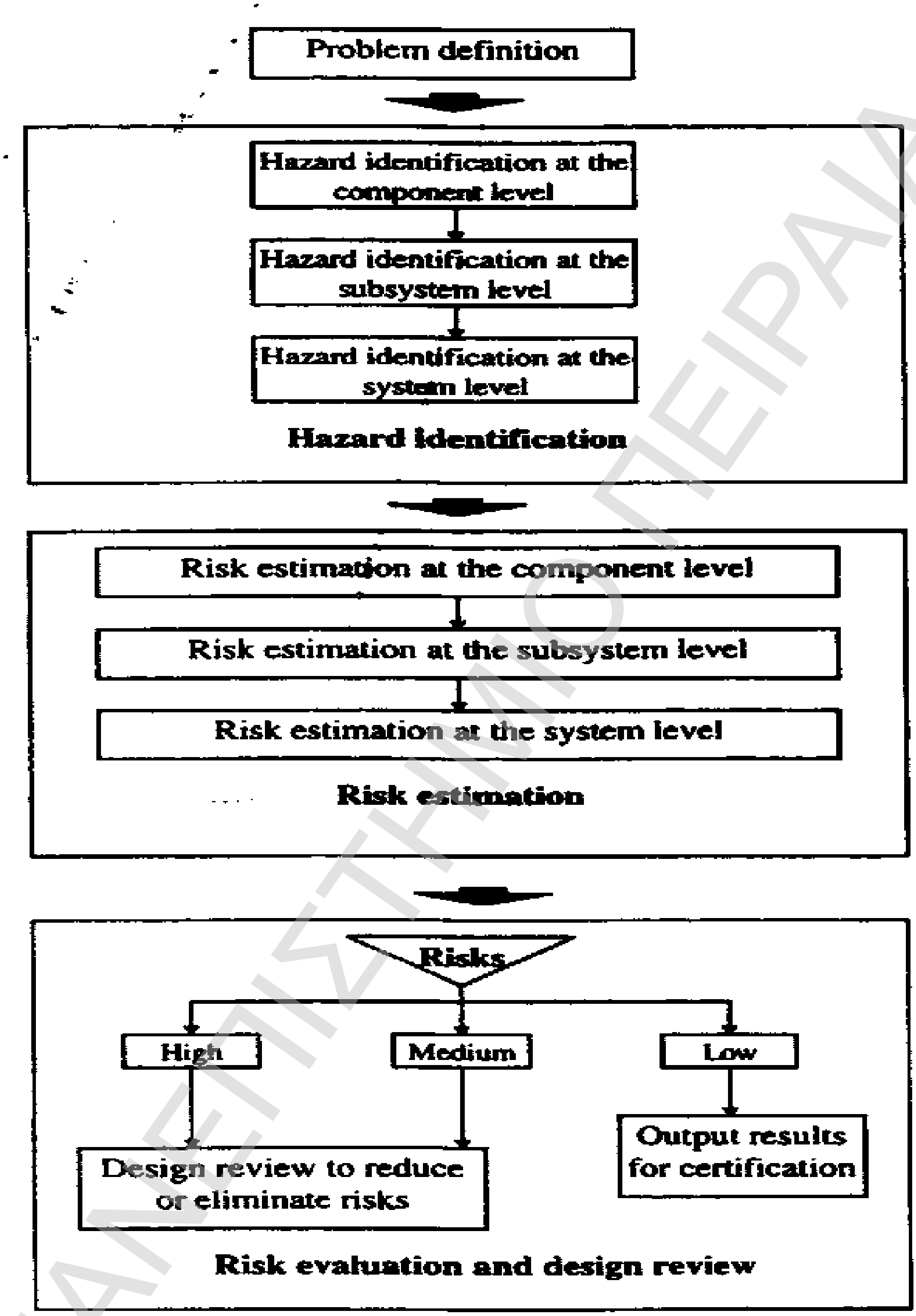

Problem definition
Hazard identification at the component level
Hazard identification at the subsystem level
Hazard identification at the system level
Hazard identification
Risk estimation at the component level
Risk estimation at the subsystem level
Risk estimation at the system level
Risk estimation
Risks
High
Medium
Low
Design review to reduce or eliminate risks
Output results for certification
Risk evaluation and design review

Fig.3 A bottom-up safety assessment process

2.7 Hazard and risk

The terms ‘hazard’ and ‘risk’ are often wrongly used interchangeably. It is essential to understand the difference between them.

It is difficult to have a single definition of ‘hazard’ that encompasses the entire risk management framework. A common definition of ‘hazard’ is given below: [6]

Hazard may be defined as a source of harm to people, property or the environment.

A slightly broader definition of hazard may therefore be given as follows:

A hazard may be defined as a situation that can potentially cause injury to people, damage to property, harm to the environment, or financial loss to the organization.

Following the previous definition of hazard, a broader definition of hazard can also be prepared:

A hazard is a potential adverse variation in the outcomes in a given situation.

The choice of definition is dictated by the situation being considered. For most purposes of engineering risks, the second definition is adequate.

In summary the concept of hazard and risk may be put in a few simple words:

- Consider a situation
- What can go wrong? (hazard)
- What are the consequences? (severity, one dimension of risk)
- What is the likelihood (of the hazard being realized)? (probability, second dimension of risk)
- Have sufficient measures been adopted to prevent an unwanted outcome and/or mitigate its adverse effects?

2.7.1 Types of engineering risk

The term ‘engineering risk’ itself is very broad, and encompasses several categories of risk. All categories are essential as they reflect various facets of an organization’s operations. Therefore, for any given situation, it is important to identify which of the categories of risk apply, before undertaking an analysis.

2.7.2 Risk categories

The main risk categories in engineering risks are:

- Occupational risks
- Property loss
- Environmental risks
- Liability risks
- Business interruption risks
- Project risks

Each category has its sub-categories. It should be noted that several of these risks are interlinked and overlapping, and cannot be treated in isolation

2.8 Analysis and Communication of information Activities

The main sources of information are the performance records of the ships, the incident reports as well as the information published by the classification societies, port state control reports etc. The information published by the port states is recorded in the port state register which has the following field:

1. port state
2. item inspected
3. description of deficiency
4. consequences

The structure of the system allows all the activities that are related to the various stages of the follow up of safety actions or measures to prevent recurrence of an incident, to be documented in an auditable manner.

2.9 Human error

Any system which involves human can be subject to human error. There is, therefore, a need to be able to introduce human reliability into a system and to be able to assess the reliability of a system and incorporate events that involve humans in some way. Humans are invariably integrated into complex systems of equipment, carrying out those tasks which cannot be carried out by a machine. Often these tasks imply some element of control. Human error involves some deviation from a presumed optimum action, sequence of actions or strategy. In many ways human error is an inevitable consequence of the greatest of man's strengths, namely, his adaptability·

It is difficult to change human nature. Therefore, instead of trying to persuade people not to make mistakes, it is better to remove opportunities for error by changing the work situation, i.e. the plant or equipment design or the method of operation. If this is not possible then it may be acceptable to negate the consequences of error, or provide opportunities to recover. The results of statistics related to causes of accidents are the following:[7]

a) 77% of the accidents are related to human error

b) 23% of the accidents are related to technical causes

In general, accidents which occur onboard merchant ships have been attributed to one or more of the following causes:

1. operational failure
2. technical failure
3. extreme weather conditions
4. inappropriate loading/unloading

This is comforting for ship managers as it implies that there is little or nothing that can be done to prevent most accidents. But this is wrong as better management can prevent most accidents i.e.:

- Better methods of operation
- Better training or instructions
- Better enforcement of the instructions
- Better working environment
- Better design

2.9.1 Improvement in Human Reliability

Human action is responsible for up to 20-90% of failures in many systems by:

a) Maintenance errors
b) Incorrect procedures
c) Accidental operations
d) Misreading of instruments

It is necessary to assess the quantitative effect of human reliability on system effectiveness. This would involve:

§ Human performance prediction
§ Performance analysis of man-machine systems
§ Reliability allocation to human performance
§ Human error overview

2.9.2 Human behavior

As it is shown in figure below there are three levels of human behavior in controlling or supervising tasks of design for safety. These are:

1) Skill-based
2) Rule based
3) Knowledge-based

Skill-based design for safety deals with safety problems at the lowest level. They require little conscious attention-nearly automatic. Rule-based behavior requires more mental effort, while knowledge-based design for safety involves higher level thinking, and knowledge to identify risks and determine what measures should be taken to control risks.[7]

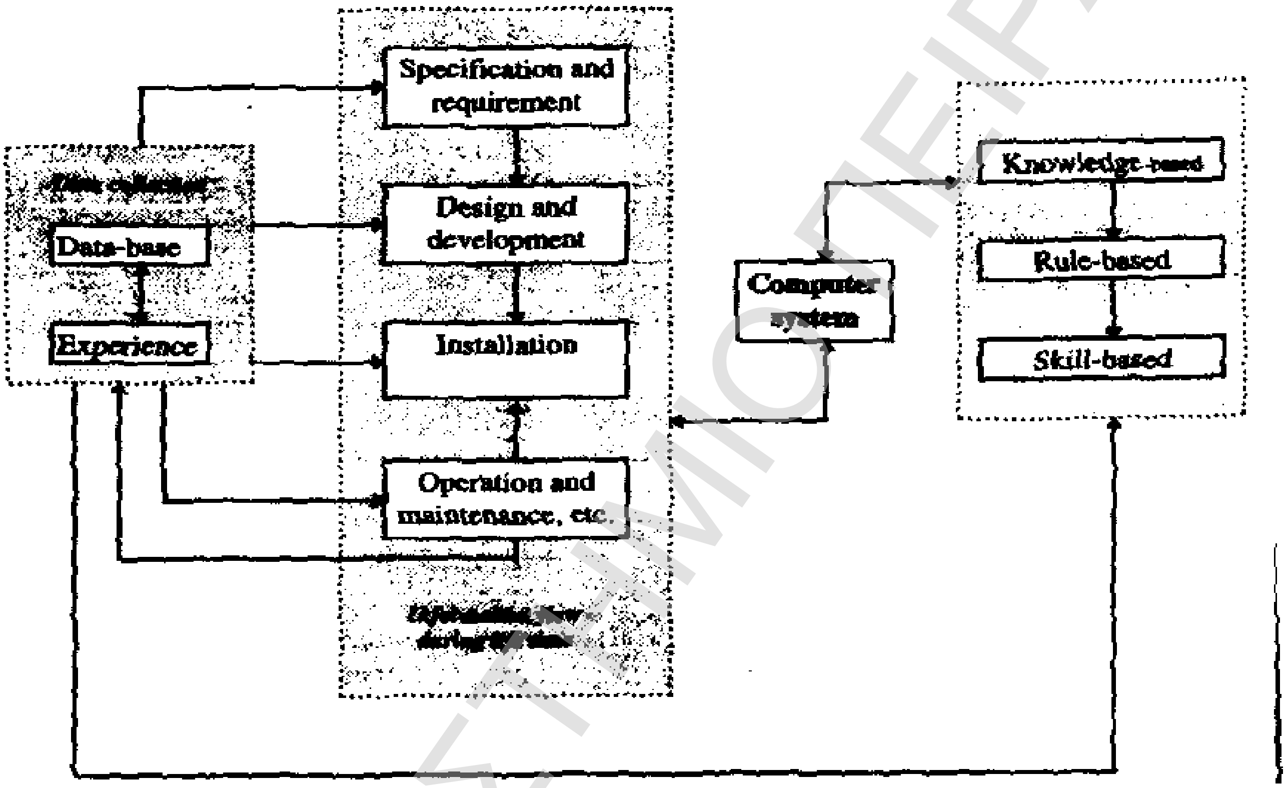


Fig.4 Three levels of human behavior

CHAPTER 3

PASSENGER SHIP

3.1 Passenger Ship

Passenger ships - usually defined as a ship carrying more than 12 passengers - on international voyages must comply with all relevant IMO regulations, including those in the SOLAS and Load Lines Conventions.[8]

Fig.5 A Passenger Ship

Passenger ships in operation today are subject to a vast array of regulations and standards covering every aspect of ship construction and operation. A number of incidents over the years have led to improvements in safety requirements, including those relating to fire safety measures - such as escape routes and fire protections systems for the large atrium typical of cruise ships - and life-saving appliances and arrangements.

Besides improvements in the technical regulations, the entry into force of the International Safety Management (ISM) Code for passenger ships in 1998 was an important step in focusing on the "human element" side of shipping, by providing an international standard for the safe management and operation of ships and for pollution prevention. Meanwhile, the entry into force on 1 February 1997 (with a phase-in period to 2002) of the 1995 amendments to the International Convention on Standards of Training, Certification and Watchkeeping for

Seafarers, 1978 has paved the way for greatly enhanced seafarer standards as well as giving IMO itself powers to check Parties' compliance with the Convention. The STCW Convention, as amended since 1995, includes specific training requirements for crew on passenger ships, such as training in crowd management, for use in emergency evacuation.

Large passenger ships can produce a tremendous amount of waste - regulations on garbage and sewage management are contained in MARPOL 73/78.

The Maritime Safety Committee (MSC) at its 82nd session in November-December 2006 adopted a package of amendments to SOLAS, the result of a comprehensive review of passenger ship safety initiated in 2000 with the aim of assessing whether the current regulations were adequate, in particular for the large passenger ships now being built.

The work in developing the new and amended regulations has based its guiding philosophy on the dual premise that the regulatory framework should place more emphasis on the prevention of a casualty from occurring in the first place and that future passenger ships should be designed for improved survivability so that, in the event of a casualty, persons can stay safely on board as the ship proceeds to port.

The amendments include new concepts such as the incorporation of criteria for the casualty threshold (the amount of damage a ship is able to withstand, according to the design basis, and still safely return to port) into SOLAS chapters II-1 and II-2. The amendments also provide regulatory flexibility so that ship designers can meet any safety challenges the future may bring. The amendments include:

- Alternative designs and arrangements
- Safe areas and the essential systems to be maintained while a ship proceeds to port after a casualty, which will require redundancy of propulsion and other essential systems
- On-board safety centres, from where safety systems can be controlled, operated and monitored
- Fixed fire detection and alarm systems, including requirements for fire detectors and manually operated call points to be capable of being remotely and individually identified
- Fire prevention, including amendments aimed at enhancing the fire safety of atriums, the means of escape in case of fire and ventilation systems

- Time for orderly evacuation and abandonment, including requirements for the essential systems that must remain operational in case any one main vertical zone is unserviceable due to fire.

The amendments are expected to enter into force on 1 July 2010.

The work on passenger ship safety has based its guiding philosophy on the premise that the regulatory framework should place more emphasis on the prevention of a casualty from occurring in the first place and that future passenger ships should be designed for improved survivability so that, in the event of a casualty, persons can stay safely on board as the ship proceeds to port.

With regard to the five pillars of the guiding philosophy for the Committee's passenger ship safety initiative, the following have been achieved since the work was initiated in 2000:

- Prevention**:** Amendments to SOLAS and the STCW Conventions and supporting guidelines that focuses on fire prevention, navigation safety, training and contingency planning.
- Improved survivability: Amendments to SOLAS chapters II-1 and II-2 and supporting guidelines that focuses on essential system redundancy, management of emergencies and casualty mitigation.
- Regulatory flexibility: Amendments to SOLAS chapters II-1 and III and supporting guidelines that focuses on promoting, through rigorous evaluation and approval procedures, the regulatory approval of new safety technologies and arrangements.

Operations in areas remote from SAR facilities: Action taken to develop amendments to SOLAS chapter III and supporting guidelines that will focus on reducing the time it takes to recover persons from survival craft and the water; supporting guidelines approved on external support from SAR Authorities, as well as guidance to assist seafarers taking part in SAR operations.

Health safety and medical care: Supporting guidelines that focus on establishing medical safety programmes and a revised Guide on Cold Water Survival.

The approved draft amendments to SOLAS chapters II-1, II-2 and III and the FSS Code relate to:

- alternative designs and arrangements;
- safe areas and the essential systems to be maintained while a ship proceeds to port after a casualty, which will require redundancy of propulsion and other essential systems;
- on-board safety centres, from where safety systems can be controlled, operated and monitored;
- fixed fire detection and alarm systems, including requirements for fire detectors and manually operated call points to be capable of being remotely and individually identified;
- fire prevention, including amendments aimed at enhancing the fire safety of atriums, the means of escape in case of fire and ventilation systems; and
- time for orderly evacuation and abandonment, including requirements for the essential systems that must remain operational in case any one main vertical zone is unserviceable due to fire.

The MSC agreed that the Sub-Committee on Ship Design and Equipment (DE) should develop performance standards for recovery systems for all types of ships, by 2008, with a view to preparing further draft amendments to SOLAS chapter III on recovery arrangements for the rescue of persons at sea. The Committee agreed that the new amendments and guidelines should be enforced by 2012. The MSC also agreed that the Sub-Committee on Standards of Training and Watchkeeping (STW) should develop relevant training standards after the performance standards have been finalized. The idea is that ships should be equipped to recover persons from the water and/or survival craft and rescue craft, and give functional requirements for achieving this.

The following circulars were approved:

- Guide to recovery techniques
- Guidelines on the provision of external support as an aid to incident containment for SAR Authorities and others concerned

- Enhanced contingency planning guidance for passenger ships operating in areas remote from SAR facilities, which includes Criteria for what constitutes an area remote from SAR facilities
- Guidelines on training of SAR service personnel working in major incidents
- Guide for cold water survival.

3.2 Major Accidents

The major accidents of passenger ships that happened during the last years, leading to the total loss of vessels are:[9]

1. Herald of Free Enterprise (1987)
2. Estonia (1994)
3. Express Samina (2000)
4. Al Salaam Bocaccio (2005)

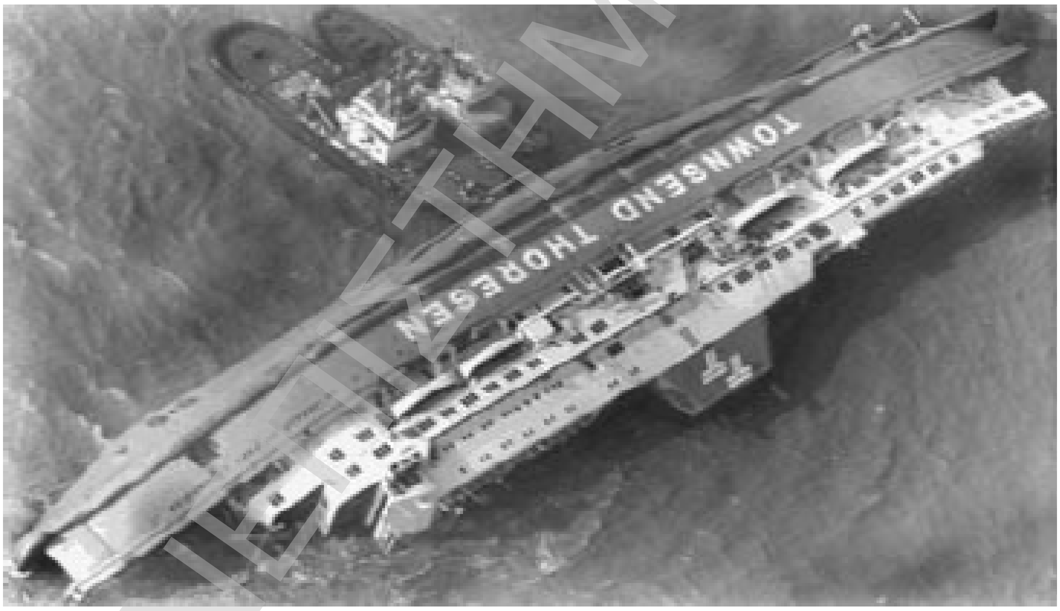


Fig.6 A Major Accident

In all these cases the human factor was the major cause of the accident that lead to the wreck of the vessel and the death of a lot of people. And one reaction from FSA is, after the accordance of Stockholm, the flotation with 50cm of ballast water in the garage of passenger vessels.

CHAPTER 4

FSA METHODOLOGY

4.1 Introduction

One way of ensuring that action is taken before a disaster occurs is the use a process known as formal safety assessment. This has been described as "a rational and systematic process for assessing the risks associated with shipping activity and for evaluating the costs and benefits of IMO's options for reducing these risks." It can be used as a tool to help evaluate new regulations or to compare proposed changes with existing standards. It enables a balance to be drawn between the various technical and operational issues, including the human element and between safety and costs.

FSA, which was originally developed partly at least as a response the Piper Alpha disaster of 1988, when an offshore platform exploded in the North Sea and 167 people lost their lives, is now being applied to the IMO rule making process. Guidelines for Formal Safety Assessment (FSA)_for use in the IMO rule-making process were approved in 2002. At its 80th session in May 2005, the MSC reviewed the report of the Joint MSC/MEPC Working Group on Formal Safety Assessment (FSA) which met during the session. The MSC approved, subject to MEPC concurrence, draft amendments to the *Guidelines for Formal Safety Assessment (FSA) for use in the IMO rule-making process* and a draft revised MSC/MEPCcircular.

The amendments include revisions to section 3 Methodology, including the addition of a paragraph outlining the need for data on incident reports, near misses and operational failures to be reviewed objectively and their reliability, uncertainty and validity to be assessed and reported. The assumptions made and limitations of these data must also be reported. The MSC agreed to establish a Correspondence Group to further consider unresolved issues in particular concerning inconsistent results of different FSAs on the same subject and clarifications of the technology used for particular FSAs. The MSC also agreed on the establishment, when necessary, of an FSA Group of Experts for the purpose of reviewing an FSA study if the Committee plans to use the study for making a decision on a particular issue. A flow-chart for the FSA review process was agreed. The MSC agreed in principle that the proposed expert group would undertake to review FSA studies on specific subjects submitted to the Organization, as directed by the Committee(s) and prepare relevant reports for submission to the Committee(s). The structure of the group of experts was left open for future discussion, though the Committee agreed, in principle, that members participating in the expert group should have risk assessment experience; a maritime background; and knowledge/training in the application of the FSA Guidelines.

Seen in a historical perspective the ship accident rate has been reduced considerably. The average loss rate has gone down from 3% of the fleet at risk per year compared to roughly 0.3% today. However, since last World War the pace of improvement has slowed down. A possible explanation to the present situation is that the maritime transport has exhausted the present approaches in safety work and that the new ones must be sought. It is further clear that safety in shipping is of major concern both to the public. It has been estimated that more than 1200 lives are lost annually due to ship accidents, that 400 fatalities are related to work onboard, and that 550 die from illness.

The risk level in shipping is dependent of two main factors: The probability of an accident and the conditional probability that the vessel will be lost. The consequences of a loss may be fatalities, environmental pollution and economic losses.

4.2 **What is FSA?**

FSA is a structured and systematic methodology, aimed at enhancing maritime safety, including protection of life, health, the marine environment and property, by using risk analysis and cost benefit assessment. FSA can be used as a tool to help in the evaluation of new regulations for maritime safety and protection of the marine environment or in making a comparison between existing and possibly improved regulations, with a view to achieving a balance between the various technical and operational issues, including the human element, and between maritime safety or protection of the marine environment and costs.

The purpose of FSA is to create a tool that could be used by IMO or other international and national regulatory authorities and class societies to create new or evaluate existing regulations based on hazard probabilities and consequences, risks and cost effectiveness, all with the aim of comparing alternatives. It aims at improving marine safety including protection of life, environment and property. The method is applicable to validate existing and/or new regulations developed applying prescriptive or risk based principles. It could be also applied in situations where risk needs to be reduced but required decisions are not clearly defined and needs to be analysed.

There are four challenges to which any approach to modern maritime safety regulations must respond. It has to be:[10]

- Proactive – Anticipating hazards rather than waiting for accidents to reveal them, which would in any case come at a cost in money and safety
- Systematic – Using a formal and structured process
- Transparent – Bing clear and justified on the safety level that is achieved
- Cost Effective – Finding the balance between safety (in terms of risk reduction) and the cost to the stakeholders of the proposed risk control options.

FSA consists of five steps:

1. Identification of hazards (a list of all relevant accident scenarios with potential causes and outcomes);
2. Assessment of risks (evaluation of risk factors);
3. Risk control options (devising regulatory measures to control and reduce the identified risks);
4. Cost benefit assessment (determining cost effectiveness of each risk control option);
5. Recommendations for decision-making (information about the hazards, their associated risks and the cost effectiveness of alternative risk control options is provided).

In simple terms, these steps can be reduced to:[10]

1. What might go wrong? = identification of hazards (a list of all relevant accident scenarios with potential causes and outcomes)
2. How bad and how likely? = assessment of risks (evaluation of risk factors);
3. Can matters be improved? = risk control options (devising regulatory measures to control and reduce the identified risks)
4. What would it cost and how much better would it be? = cost benefit assessment (determining cost effectiveness of each risk control option);

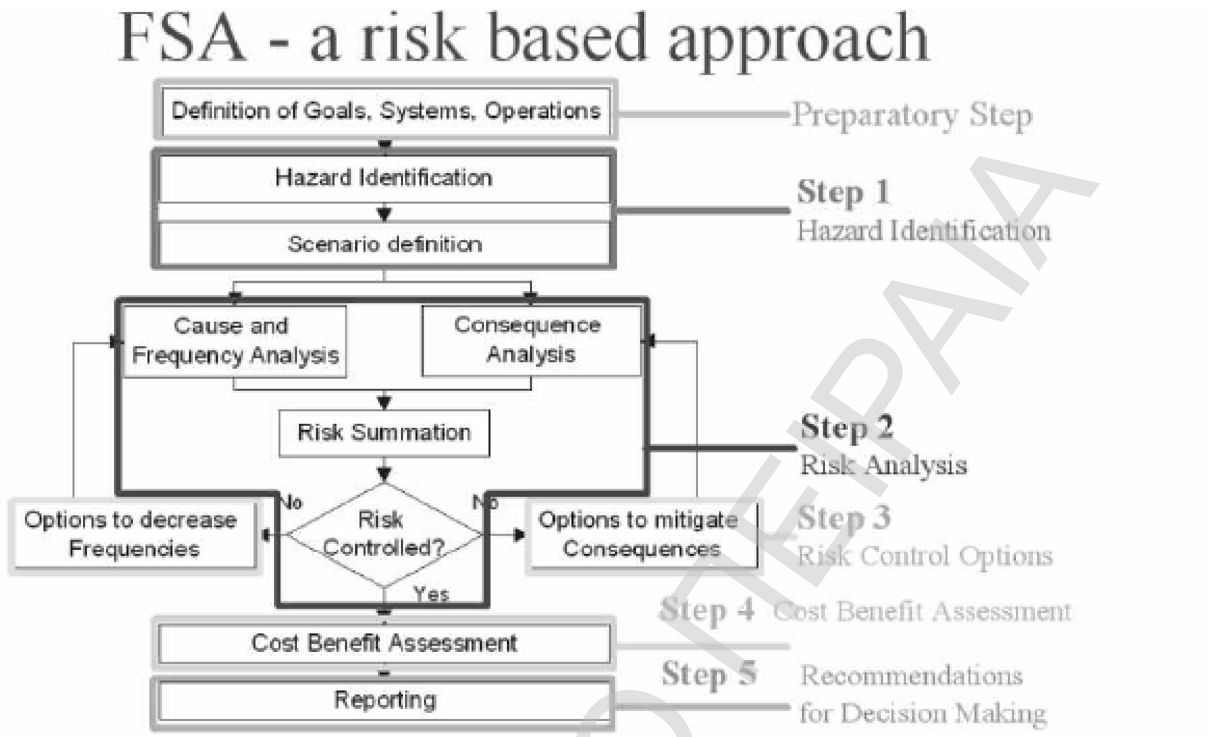


Fig. 7 FSA – A risk based approach

5. What actions should be taken? = recommendations for decision-making (information about the hazards, their associated risks and the cost effectiveness of alternative risk control options is provided).

Safety regulation of industries or activities perceived as being hazardous (e.g. nuclear power, petrochemical, offshore oil and gas production, air and rail transport) is increasingly being based on risk assessment techniques which may involve some or all of the above steps. In many cases the safety regulator requires a plant specific safety case to be developed which includes the identification of major hazards, the calculation of the associated risks and demonstration that the risks are being controlled to a level which is as low as reasonably practicable.

In the marine industry, due to its international nature, safety regulation is more diverse and complex. The Marine Safety Agency (MSA) has undertaken a major research program to develop a suitable FSA methodology and carry out a detailed trial application to demonstrate its practicability and utility.[1]

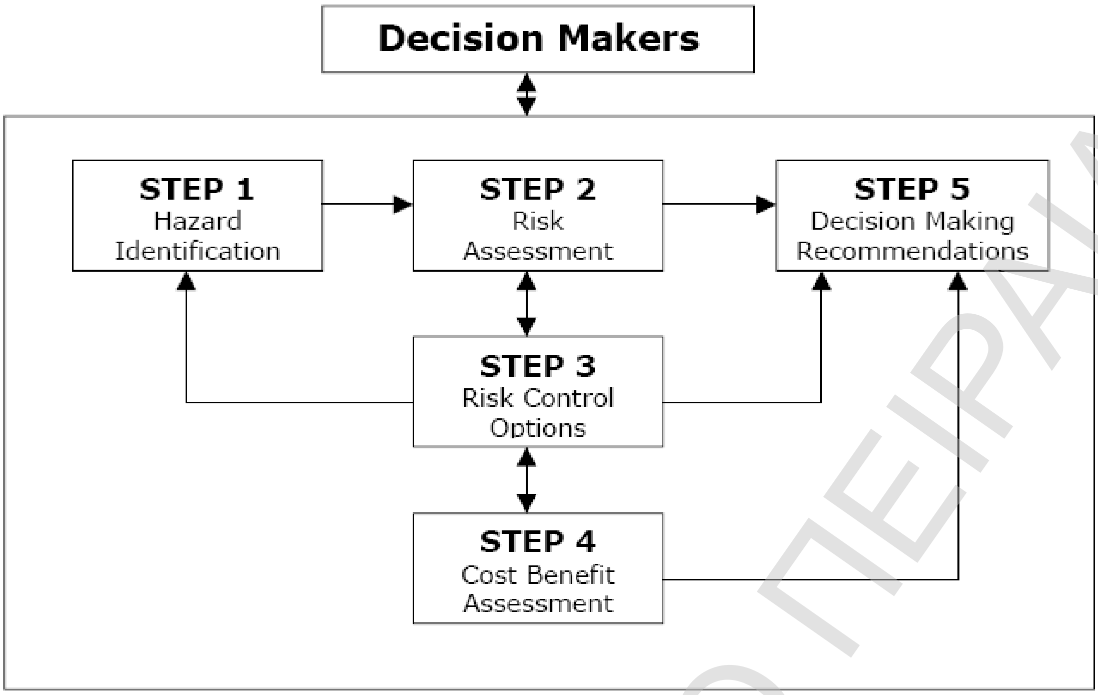


Fig. 8 Flow chart of the FSA process

FSA has been proposed, and the methodology developed, to be applicable at many levels within international shipping both within and beyond the direct interests of International Maritime Organisation (IMO), e.g.:

- To prioritise areas where regulations should be developed
- To consider a particular ship type
- To consider a particular failure mode (eg grounding or fire)
- To consider a particular failure cause (eg engine failure or navigational error)
- To consider a geographic area or region (eg straits or ports)

The methodology takes advantage of, and uses for risk quantification, historic data where relevant data are available but, where such data are not available, FSA mobilises expert judgment to look ahead to predict risk levels and the effect of risk control measures.

Application of FSA may be particularly relevant to proposals for regulatory measures that have far reaching implications in terms of costs to the maritime industry or the administrative or legislative burdens that may result.

This is achieved by providing a clear justification for proposed regulatory measures and allowing comparison of different options of such measures to be made. This is in line with the basic philosophy of FSA in that it can be used as a tool to facilitate a transparent decision-making process. In addition, it provides a means of being proactive, enabling potential hazards to be considered before a serious accident occurs.

FSA represents a fundamental change from what was previously a largely piecemeal and reactive regulatory approach to one which is proactive, integrated, and above all based on risk evaluation and management in a transparent and justifiable manner thereby encouraging greater compliance with the maritime regulatory framework, in turn leading to improved safety and environmental protection.

One area where FSA is already being applied is bulk carrier safety. In December 1998, the Maritime Safety Committee, IMO's senior technical body, agreed to a framework setting out project objectives, scope and application, namely:

- to inform IMO's future decision-making regarding measures to improve the safety of bulk carriers;
- to apply FSA methodology to the safety of dry bulk shipping; and
- to secure international collaboration and agreement.

FSA is highly technical and complex. But it does offer a way forward and a means of escaping from the dilemma of the past in which action was too often put off until something went wrong - with the result that the actions taken often owed more to public opinion and political considerations than they did to technical merit.

4.3 FSA Applications

Since IMO published its interim guidelines on FSA in 1997 many studies were conducted. Member governments, non-governmental observer organizations, International Association of Classification Societies (IACS) and individual class societies carried out variety of FSA studies. The purpose of those studies was to support international and national regulatory requirements for most concerned safety cases. The studies were carried out for various types of ships at holistic and generic level and for specific ship systems. These studies resulted in development of innovative risk control options and many of them were used to develop or amend new regulations.

Example of FSA studies and resulting RCOs influencing IMO regulations:
- RCOs regarding navigational safety of large passenger ships submitted by Norway:

- Improvement to bridge design
- Electronic Chart Display and Information System
- Automatic Identification System

4.4 Implementation

As a tool, FSA should enable decisions to be reached based on sound scientific analysis, allowing future conventions and regulations to be adopted by better informed regulators, who are aware of the full implications of their decisions. In using the currency of risk, the severity of legislation can be made proportional to the risk it is designed to ameliorate. A consistency of decision making can be achieved by recording and comparing the value of CURR associated with individual decisions. Additionally, FSA can enable the IMO to prioritise its own workload.

FSA is a powerful tool for use in the management of safety. The MSA believes that it can and should be adopted by the IMO as part of the regulatory process. Its use should be initially to support rather than replace the existing approach, to ensure that standards and requirements are risk based and comprehensive, whilst improving maritime safety in the most cost effective manner. It is not proposed that FSA should be introduced by the IMO for the assessment of individual ships.

4.5 The FSA Methodology

The methodology recognizes that there are relatively good historic data on marine accidents and their outcome but relatively poor information on their causes and the underlying influences, which affect the likelihood of an accident occurring or its escalation to a major loss. A generic set of accident types which is intended to cover all marine accidents has been derived as follows:

- ♦ Contact or collision
- ♦ Explosion
- ♦ External hazards
- ♦ Fire
- ♦ Flooding
- ♦ Grounding or standing
- ♦ Hazardous substances
- ♦ Loss of hull integrity
- ♦ Machinery failure
- ♦ Payload related

For the purpose of analysis the accident category or type is defined by the point at which the accident becomes a reportable incident having the potential to progress to loss or life, major environmental damage and/or loss of the vessel. The accident categories are used to record incident data as the starting point for hazard identification and structuring the resulting information as will be seen in the methodology overview below. Other information is required in order to define the problem under study as:

- § The various functions of the typical vessel
- § The people or entities with an interest in the shipping operation
- § The current regulations impacting on the operation
- § The various systems within the vessel
- § The tasks carried out by people and their organisation
- § Factors which affect performance of people

Once this information is assembled and there is a clear understanding and definition of the problem under study, the FSA five step process can proceed.

4.6 The Preparatory Step

The FSA process begins with a preparatory step, before step 1. This is the definition of the problem that will be assessed along with any relevant constraints (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. Doing so will also determine the depth and extent of the application.

Any FSA application starts with the preparatory step that is vital for the whole process. This is so because a less than precise definition of things such as definition of deficient ship operations, external influences or even ship category, may lead to deficient recommendations that may, among other deficiencies, exclude major risk categories from the assessment.

This is easier said than done. FSA studies with too large a scope present many difficulties. Most FSA studies fall into this category and thus, problems in coordination and project management may arise. As a result, most FSA studies take a long time to arrive at results. Furthermore, the consistency of input data, its detail, and the method used throughout the process cannot be guaranteed, which makes the review of the FSA not an easy proposition.

4.7 Step 1 - Identification of hazards

In a common formal safety assessment a hazard is defined as 'a physical situation with potential for human injury, damage to property, damage to environment or some combination'. With respect to ship formal safety assessment an accident can be defined as 'status of the vessel, at the stage where it become a reportable incident which has the potential to progress to loss of life, major environmental damage and/or loss if the vessel'. The goal of step 1 is to identify and prioritize, by risk level, causes of accidents and their associated scenarios relevant to the problem under review. The approach should assure that the process is proactive and not limited to past experience only. Information to achieve this goal can be obtained by analysis of historical accident data, near miss data and experts' consultation sessions. Experts in both FSA analysis and the relevant domain should carry out the task and qualitative and quantitative should be considered.

Hazard identification consists of determining what type of accidents could affect the shipping activities under consideration using "brainstorming" techniques involving trained and experienced personnel. An experienced facilitator but should bring together experts covering all relevant aspects of ship design, construction, operation and management would typically lead brainstorming. It should be structured to encourage unfettered thinking and participation but within a planned session (typically 1-2 days) covering all aspects which have a bearing on the ship type or regulations under consideration. The list of accident categories is used to structure the expert's thinking in defining the different possible accident scenarios and their direct causes and consequences.

Analysis of the combinations of failures which need to occur to cause the realisation of a shipping accident may be based on a fault tree type "top down" approach. For the hazard identification exercise, the fault tree analysis should be restricted to identifying the initiating events leading to the accidents. A hazard may be considered as a physical situation with a potential for human injury, damage to property or damage to the environment.

Tracing the outcomes of an accident, including escalation, the response of the ship's functions may be based on event tree analysis methods. The prediction of the frequency of occurrence of each possible outcome will be based on expert judgment, historical data or a combination of the two. The various accident categories and sub-categories are then screened and ranked in order to set priorities for more detailed risk evaluation. Risk is the combination of frequency of occurrence of an accident type with the severity of its consequence and may be expressed as:

Risk = Frequency of occurrence x Consequence of a given event

There are a lot of approaches to screening, and one of the most important is the risk matrix approach seen in table below. There, a risk level is assigned as the sum of the appropriate levels from the consequence and frequency bands.[10]

SAFETY CONSEQUENCE (S)		FREQUENCY						
		Low						High
		F0	F1	F2	F3	F4	F5	F6
Minor	S1	1	2	3	4	5	6	7
Significant	S2	2	3	4	5	6	7	8
Severe	S3	3	4	5	6	7	8	9
Catastrophic	S4	4	5	6	7	8	9	10

Note: Less frequency is equivalent to less than one incident in the lifetime of all ships of a particular type; high frequency incidents occur on average to each ship every year.

Frequency-Consequence Table

In cases where available data are inadequate, expert judgment is used to assign frequency and consequence ratings. It will be found important to devise scales, particularly for frequency, which have an easily grasped meaning within the experts' direct experience. It is also important to make an assessment of the uncertainties associated with both data and expert judgment. The former needs to give optimistic risk values due to incompleteness whereas the latter is often significantly pessimistic when calibrated against reliable known values.

Step 1 of the FSA is also known as the HAZID (for Hazard Identification) step. The objectives of this step are:

1. To identify all potential hazardous scenarios that could lead to significant consequences
2. To prioritize them by risk level.

The first objective can be satisfied with a combination of creative and analytical exercises 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. It has been noticed that most studies have extensively used historical data found in various casualty databases. It is understandable that if historical data are available, risk profiles can be drawn without the need to model scenarios. However, this usage has several disadvantages. The most important is that the whole philosophy of using historical data is not proactive and therefore cannot be used for new designs and cannot measure the effects of newly implemented risk control options (RCOs), as it needs to wait for accidents to happen to have sufficient data. Another problem of using historical data relates to the way casualty databases are structured and to the information that is contained in such databases.

The second objective of step1 is to rank the hazards and to discard scenarios judged to be of minor significance. Ranking is typically undertaken using available data and modeling supported by expert judgment. To that effect, a group of experts is used to rank risks associated with an accident scenario, where each expert develops a ranked list starting from the most severe.

4.8 Step 2 – Risk assessment

Step 2 continues directly from Step 1 and, as well as quantifying risks, attempts to identify and quantify the underlying causes and influences which affect the likelihood of initiation and progression of accident sequences. The process involves evaluating both the frequency and severity associated with each accident type (or category). Risk is a combination of frequency of occurrence and the severity of its consequence. Consequence may be measured in terms of loss of lives, pollution of the environment, damage to vessels or commercial loss. Frequency has a time-base and risk can therefore also be summarised as the estimate of loss in a given period of time. The frequency component is generated using database technology to analyse accident data, the output of which can be assisted by the use of expert judgment where appropriate or necessary.

Estimating the risk related to a hazard identified in Step 1 begins with the estimation of frequency. In most FSA studies, frequency is given as the following fraction:

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

Furthermore, most FSAs submitted to IMO quantify the consequences using the Potential Loss of Life (PLL). The definition of PLL according to FSA guidelines is :

$$PLL = \text{No of Fatalities} / \text{Shipyears}$$

Step 2 is completed by first constructing a Risk Contribution Tree, which displays risk contributors in a logical format, and then quantifying it in terms of frequency and consequence of outcome. The tree is constructed by starting at the accident category level and expanding downwards towards causation, as far as logic and data dictate. Construction then continues by working upwards, again from the accident category level to determine consequence of outcome.

With respect to human life, the risk must be considered in terms of individual risk and societal risk. When a large number of people are exposed to or affected by a possible accident, societal risk acceptance criteria should be considered. In the shipping industry this could be a passenger on a cruise ship, crewmember, port employees or society at large. Societal risks can be expressed in terms of frequency versus number of fatalities and usually presented in format of FN diagram or risk matrix.

Human error is generally recognised as being a significant factor in many accidents. Likewise, human intervention can prevent an incident occurring, or control or reduce the degree of escalation. Human factors therefore need to be fully taken into account during the risk assessment stage.

The quantified Risk Contribution Tree outputs the relationship between Frequency (F) and Consequence (N) in a graphical format, termed an FN curve. For each outcome, the FN curve is summated to determine the overall potential loss and this information is used to enhance the frequency distribution within the developed tree.

However, in the marine industry, the detailed data on human and hardware performance are not available to quantify the risk contributions down to detailed causes of accidents and their underlying influences. Another technique, termed an Influence Diagram, enables this to be achieved. The particular structure of the Influence Diagram approach adopted in the methodology distinguishes between regulatory influences, corporate policy influences, organisational implementation influences and direct influences and direct influences affecting the performance of humans and hardware in operation.

Qualitative risk assessment can be done using historical data (which reflects past experience), and judgment, or a combination of two. This qualitative evaluation can be improved upon by quantifying the result, using appropriate data and analysis or modeling methods. Quantification is not necessary, however, and meaningful judgments, particularly of risk ranking can be made based upon qualitative assessment of risk.

When an individual or a group of individuals are exposed to hazards imposed by the system, criteria based on individual risks could be more suitable. Individual risks could be related to occupational risk due to work related hazards and include risks of death, injury or ill health. This would comprise a crew member or passenger on board the ship or other parties affected by an accident. Individual risks can be presented in the form of probabilities per unit of time (year). The level of risk acceptable for an individual will depend on if the risk is taken voluntarily or involuntarily. Passengers on a ship have little control over risks and they are involuntarily exposed. A crew member has chosen his work place and has been trained and educated to have some control over the working environment.

In certain situations for a large number of people involved in public activities risk of an accident can be described in terms of societal risk, however, some individuals can in addition be exposed to other hazards best described by individual risks. In order to assess acceptable level of safety, all risks, societal and individual, must be considered.

Individual risk criteria are very often established based on acceptable risk levels adopted by other industries. The societal acceptable risk criteria can be developed based on various principles. Absolute probabilistic risk criteria do not consider costs associated with them and they are formulated as a maximum level or risk that cannot be exceeded. For example frequency of death, due to a hazardous situation, should not be higher than 10^{-6} per person-year. Another method for establishing (determining) acceptable criteria is the ALARP (as low as reasonably practical) approach. It assumes that risks should be as low as reasonably practicable and both risks and costs of risk mitigation are considered.

From the pragmatic point of view, three levels of risk are presently recognized:

- Intolerable (unacceptable risk that cannot be justified except for extraordinary circumstances)

- Tolerable (all risks should be in ALARP region)
- Negligible (broadly acceptable, so small that no action is necessary)

When determining intolerable, tolerable and negligible risk levels for specific circumstances, all individual and societal risks should be taken into account.[10]

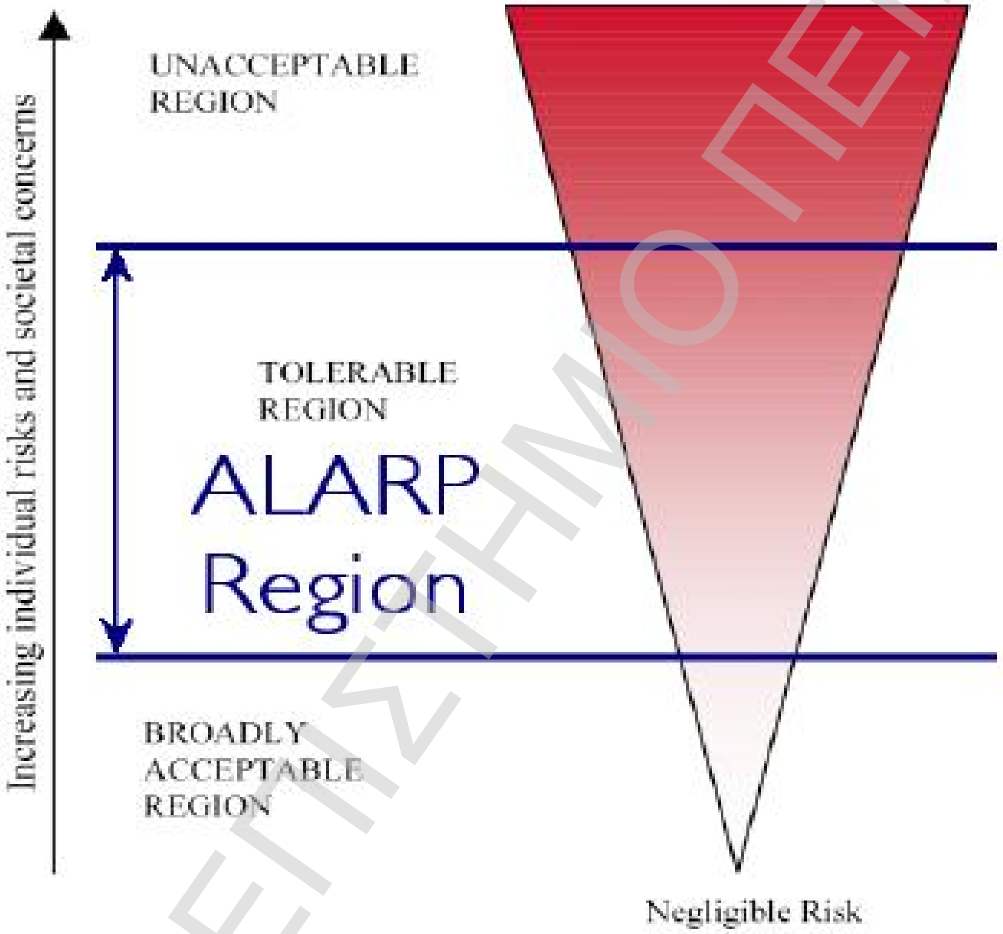

Increasing individual risks and societal concerns
UNACCEPTABLE REGION
TOLERABLE REGION
ALARP Region
BROADLY ACCEPTABLE REGION
Negligible Risk

Fig. 9 Tolerability of Risk Framework

Unacceptable region: Risk cannot be justified save in extraordinary circumstances.
Tolerable region: Control measures must be introduced for risk in this region to drive residual risk towards the broadly acceptable region. If residual risk remains in this region, and society desires the benefit of the activity, the residual risk is tolerable only if further risk reduction is

impracticable or requires action that is grossly disproportionate in time, trouble and effort to the reduction in risk achieved.

Broadly acceptable region: Level of residual tank regarded as insignificant and further effort to reduce risk not likely to be required as resources to reduce risks likely to be grossly disproportionate to the risk reduction achieved.

The following example individual risk criteria were proposed by Norway and submitted to IMO in 2000:

1. Boundary between broadly acceptable and tolerable risk, 10^{-6} per year
2. Maximum tolerable risk for workers (crew member), 10^{-3} per year
3. Maximum tolerable risk for public (passenger), 10^{-4} per year.

Development of societal risk criteria is more complicated than the individual risk criteria and must consider the frequency of accidents and the severity of their consequences. One of the methods adopted for that purpose is the use of criterion lines in conjunction with FN curves. FN curves represent the number of fatalities N and the probability of accident with N or more fatalities. Criterion lines (broken limit lines) are defined by anchor points and the slope. Based on studies conducted anchor points for different type of ships were proposed as follow:

	N	Frequency
Tankers:		
Boundary between negligible and tolerable (ALARP) risk	10	2×10^{-5}
Boundary between tolerable and intolerable risk	10	2×10^{-3}
Bulk and ore carriers:		
Boundary between negligible and tolerable (ALARP) risk	10	10^{-5}
Boundary between tolerable and intolerable risk	10	10^{-3}
Passenger ro-ro ships:		
Boundary between negligible and tolerable (ALARP) risk	10	10^{-4}
Boundary between tolerable and intolerable risk	10	2×10^{-2}

The slope of the FN criterion lines is usually between -1 and -2 on a log-log diagram. It tends to represent scenarios of more frequent accidents with fewer fatalities which potentially are as intolerable as fewer accidents with more fatalities.[1]

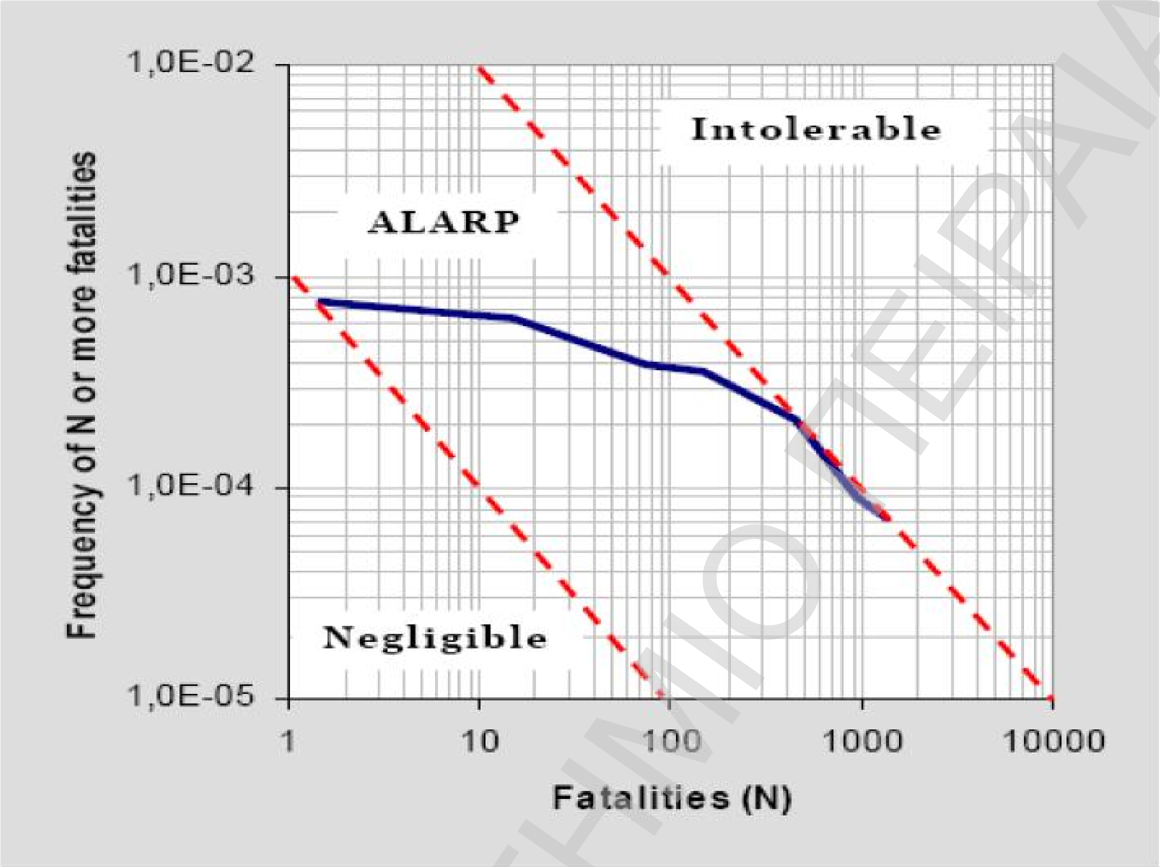


Fig. 10 Example of FN curve

Example of FN curve with two probabilistic values for negligible and intolerable and intolerable risks with ALARP area in between.

4.9 Step 3 – Risk management

The aim of step 3 is to identify the range of options to control risks. Risk control measure (RCMs) can control single element of risk, reduce the likelihood of an accident or mitigate the possible consequences. The risk control option is an appropriate combination of risk control measures. The selected risk control options (RCOs) should address historical risks and new risks recognized. New RCMs should be identified for risks that are not satisfactorily controlled by current measures. RCMs in general should aim at reducing frequency of failure and mitigate their consequences. They should be grouped into practical RCOs with goals to control the likelihood of initiation of an accident and/or escalation of accidents. The outcome of step 3 is a range of RCOs that are assessed for their effectiveness in reducing risk and a list of hazards affected by those RCOs.

Step 3 also aims to develop wide-ranging options to control risk. Measures are first generated by directly using the information provided by both FSA steps 1 and 2. Causal chains are constructed to identify areas where risk control measures could be inserted to best effect. Once a list of measures has been generated, attributes are attached to each measure to analyse effect, attributes could identify whether the measure is preventative (reducing the frequency of an event) or mitigating (reducing the consequence of occurrence), engineering or procedural, active (firefighting systems) or passive (fire resistant bulkheads).

Once a comprehensive understanding of each measure has been achieved, measures can be grouped into packages of options. The route of implementation of any option (operational management, flag state, port state or classification) should be considered, as should a review of any areas of continuing uncertainty in effectiveness or reliability. The effectiveness of each option is assessed by a repeat of step 2 to evaluate the change in risk level. It is not unreasonable to expect the overall risk benefit generated by a risk control option to be greater than the sum of each individual risk control measure, especially where the package addresses the underlying safety culture.

Different risk control options should be sought, by systematically considering prevention and mitigation, engineering and procedural, etc alternatives to provide a wide range of options. Then with an overview in mind from step 2 of all the risks to which shipping or a particular ship type is subjected, the effectiveness of these options needs to be established. Certain control measures may be effective against more than one risk. On the other hand, proposed risk reduction measures may of course introduce new hazards, and these need to be identified and evaluated, by iteration around steps 1 and 2.

The difference is that now the approach is made more robust by virtue of being virtue of being informed by the comprehensive hazard and risk analyses that precede it. What is not so well established is the consideration of such options in the context of a comprehensive assessment of all risks, rather than eg considering measures for reducing the risk associated with one particular accidental event. However, the nature of FSA, which considers hazards and their risks in an integrated way, allows options to be chosen and assessed for their effectiveness and implications across all risks associated with the operation of ships.

4.10 Step 4 – Cost benefit analysis

The purpose of step 4 is to estimate and compare benefits and costs associated with implementation of RCOs identified in step 3. Costs of risk reduction and willingness to pay such costs could become the criteria for defining the reasonable risk (ALARP) area.

The objective of safety management is to reduce risk to an acceptable level. It is not necessary to apply all possible risk reducing measures irrespective of their benefit or cost. The costs and benefits of the options identified in the previous step make an assessment in this step. The risk control effectiveness information from step 3 is combined with the cost of implementation of each risk control option to obtain a measure of cost effectiveness for alternative approaches. Costs will include:

- Capital costs and items requiring replacement
- Operating or recurrent costs
- Installation and commissioning costs
- Training
- Maintenance
- Inspection and certification
- Downtime or delay costs

Costs are estimated year by year during the life of the measure and reduced to net present value. Similarly, the benefits of implementation may be identified as follows:

- Reduction in search, rescue and salvage costs
- Increased availability of assets
- Reduced environmental damage including clean-up costs and impact on associated industries such as recreation
- Reduced vessel casualties including cargo and damage to infrastructure
- Reduced fatalities and injuries

$$NVP = \sum_{t=0}^{n} [(B_t - C_t) (1+ r)^{-t}]$$

where

C_t = the sum of costs in period

B_t = the sum of benefits in period t

r = the discount rate

t = measure of time horizon for the assessment,
starting in year 0 and finishing in year n

The resulting NVP is then used to calculate a Cost per Risk Reduction (CURR) by dividing NVP by the benefit of the estimated number of reduced equivalent fatalities. The CURR values may then be used to compare risk control measures for cost effectiveness in improving human safety.

Costs with regard to individual and societal risks could be expressed in terms of the cost of averting fatality, cost per-life-saved, value of life and should include initial, operating, training, inspection, certification, decommissioning and other elements. Benefits may include reduction in fatalities, injuries, environmental damage, liabilities, and increase in the average life of the ship. The IMO recommended indices for presentation of RCOs cost effectiveness in relation to safety of life are Gross Cost of Averting a Fatality (GCAF) and Net Cost of Averting a Fatality (NCAF). They are defined as:

$$GrossCAF = \Delta C / \Delta R$$

and

$$NetCAF = (\Delta C - \Delta B) / \Delta R$$

where

ΔC is the cost per RCO

ΔB is the economic benefit per ship from the implementation of RCO (this might include pollution prevention)

ΔR is the risk reduction per ship, in terms of fatalities averted, implied by RCO.

Both GCAF and NCAF criteria can be effectively used as the Cost Benefit Assessment tools. It is however recommended that GCAF be considered before NCAF. NCAF takes into consideration economic benefits of relevant RCOs. In some cases this approach could be biased due to overestimating of economic benefits of considered RCOs. NCAF could be applied when GCAF is within the accepted CAF range. In some studies, RCOs presented were associated with NCAF, which were very high and negative. This could mean that expected benefits were higher than the costs of RCO implementation (in monetary units) and/or that risk reduction potential ΔR was very low. Proposed RCOs with negative NCAF should always be considered from cost benefits and risk reduction potential point of views. The purpose of RCA estimate is to provide data for decision making about RCOs. The output included costs and benefits for each considered RCO. The value judgment is left for the decision-makers on RCO implementation.

4.11 Step 5 – Decision making

The overall aim of step 5 is to collate all the information generated by the steps 1 to 4, to assist in the choice of cost effective and equitable changes to regulations. For example, information about risk levels before and after implementation of risk control would be recorded alongside justification to iterate any part of the process. This step recognises FSA to be a tool, not a decision maker, and seeks to enhance the quality of information by first considering the cost effectiveness of a proposed option on an industry wide basis. A second stage examines whether the effect on all interests involved is equitable (i.e., one or more interests may be carrying a risk or cost at a level disproportionate to expected returns). Given this information, the normal decision making process can proceed, taking into account all the social, political and cultural influences that are necessary part of obtaining consensus on an international basis.

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 should i) reduce risk to the desired level and ii) be cost effective.

Also, to provide recommendations on relevant safety subjects to decision makers. The recommendations should be based on comparison and ranking of hazards identified in step 1, risk analysis conducted in step 2, comparison of RCOs selected in step 3, and cost benefit analysis conducted in step 4. The rationale for recommendation should be based on the assumption of risk reduction to ALARP levels and cost effectiveness. The output of step 5 should be an unbiased and transparent comparison of RCOs based on cost effectiveness and reduction of risks to improve safety.

4.12 Difference between FSA and the safety case

As both employ risk assessment techniques it is easy to confuse FSA with a safety case. But practically they are different. FSA is designed to be applied to shipping as a whole, or to safety issues common to a ship type, such as tankers, bulk carriers or high-speed passenger vessels. On the other hand, a safety case could be applied to a particular ship and the detail of its design and systems.

FSA takes a true top down approach to risk assessment, at the level of interest required by any marine organisation. Oppositely with the bottom up approach employed by the safety case, where each system is analysed from component level. FSA has also been designed to employ the type of information currently available to the marine industry. The marine accident information available is of a low frequency, high consequence type and the associated overall quality of detail is poor. Industries where the safety case is employed have built up detailed information on many high frequency, low consequence events, and comprehensive databases of equipment reliability have become available.

4.13 Difficulties in FSA

FSA is a new tool, so the adoption of FSA by the IMO is likely to occur over a period of time and constitutes a process of gradual change. But, use of the techniques by only a small proportion of the membership of IMO will lead to a general adoption of the approach. And as a new concept, there are relatively few practitioners around. And it is not sure that in the future there will be many individuals or firms that would learn the techniques and understand the concept. Some aspects of FSA, as the selection of risk control measures in an integrated way are less well developed. The methodology as a whole therefore still needs further development.

4.14 FSA Summary

The FSA process has a potential to become a very functional tool supporting the decision-making process at IMO and national regulatory levels as well it could be applied as a proactive tool at the design stages to optimize risk and safety for new ship designs. FSA can be employed for generic and holistic ship analysis and to study individual ship systems or operations. However, this useful tool could be rather complicated, particularly when applied at generic or holistic levels.

The FSA is facing a few challenges. Critics of the process are using the following arguments based on observed limitation of the process:

- Lack of IMO recommended acceptable risk criteria.
- FSA is time consuming and slows down decision process. Most studies conducted to date required at least one year to be completed. Assuming that most studies are still conducted as a response to an existing hazard or an accident, public pressure for fast solution could make it a very stressful process.
- FSA could be a manipulative tool. It should be an independent and transparent study and all risk and cost assumptions, including uncertainties, should be clearly stated.
- Cost effective data is sensitive to time and geographic location. Analysis should present current costs and conservative cost estimates based on a predicted long-term approach.
- Lack or incompleteness of historical accident records and information on near miss situations forces a need to rely on FSA experts' assessment to estimate acceptable risk levels, hazard probabilities and cost effectiveness. The obtained information could be unintentionally biased and relevant uncertainties must be estimated based on confidence in experts conducting the analysis.

- Costs of conducting FSA study are high. They, however, can be compensated by completeness and comprehensiveness of the approach.

CHAPTER 5

FORMAL SAFETY ASSESSMENT OF PASSENGER SHIPS

5.1 FSA of Passenger Ships

Over the last years, several serious accidents have attracted great attention to marine safety. The adoption of the safety case approach in the UK offshore industry encouraged marine safety analysis to look at the possibility to look at a similar approach in the marine industry. After that the formal ship safety assessment was adopted. Marine safety may be significantly improved by introducing a formal safety assessment approach so that the challenge of new technologies and their application to ship design and operation may be dealt with properly.

Generally, for the last several years the application of formal safety assessment has reached an advanced stage. The application of FSA in ship operation and design may offer great potential incentives as:

- Improve the performance of the current fleet, be able to measure the performance change and ensure that new ships are good designs.
- Ensure that experience from the field is used in the current fleet and that any lessons learned are incorporated in new ships.
- Provide a mechanism for predicting and controlling the most likely scenarios that could result in incidents.

5.2 First Application of FSA

According to FSA's Guidelines, the use of FSA is 'consistent with, and should provide support to, the IMO's 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.[11]

Since the first trial application IMO members realised that FSA is a pre-requisite to any significant change to maritime safety regulations. Furthermore, FSA adopts the latest techniques of risk assessment. As a result, FSA is currently the state of the art method to assess maritime risk and formulate safety policy.

The maritime community became aware of the enormous power of FSA in 1997, when the IMO reversed its prior positions to require Helicopter Landing Areas (HLAs) on all passenger ships even before the relevant regulation had come into effect. In fact, SOLAS regulations required all Ro-Ro passenger ships to be provided with an helicopter pick-up area and existing ships were required to comply with this regulation not later than the first periodical survey after 1st July 1997. However, a trial application was prepared by Norwegian classification society Det Norske Veritas (DNV) for Norway and the International Council of Cruise Lines (ICCL) showed that this could not be justified in terms of cost effectiveness. Specifically, it was shown that the costs of applying this measure were in great disproportion to it benefits for non Ro-Ro passenger ships. The so-called ‘cost of averting a fatality’ was about $37 million, much higher than the value of $3 million established by the IMO as the yardstick for the value of human life. A decision was therefore made to repeal the requirement. IMO is not known for reversing its positions and this was one of the rare times. Actually, this was the first time where FSA was involved.

5.2.1 Study on Cruise Ships

As in other FSA studies, collisions, contacts, groundings and fire/explosions are treated as primary causes of accidents. But these are consequences, not causes. A collision or grounding can be caused by other ‘higher-level’ events, such as black out, a steering gear failure, or other. Thus emphasis are placed on RCOs that try to mitigate the consequences of an accident, once that occurs, such as buoyancy enhancements, damage stability enhancements etc. Importantly, it is notable that the risk analysis used fatality data of ferries and RoPax vessels to formulate worst-case scenarios for cruise vessels. But some of the accident scenarios have been occurred on ferries, including water ingress via the bow door if left open (Herald of Free Enterprise) or is detached (Estonia), simply cannot occur on a cruise ship.[12] Much of the probability and consequence data that populates the various event trees used extensively in the analysis seems arbitrary or difficult to justify. Elaborate calculations, involving several assumptions, resulting in critical conclusions are not available for scrutiny. It is understood that many numbers are based on expert opinion, yet no estimate of experts’ degree of agreement is provided, as specified in FSA guidelines.

5.2.2 Study on RoPax Ships

A positive feature is that there is no apparent gap between step 1 and the rest of the FSA, however, as in other FSAs, consequential events are treated as causes which may skew the ensuing analysis including what may be appropriate RCOs. The RCOs that are proposed are very generic, e.g. ‘improved navigation safety’, ‘improved evacuation arrangements’, etc. It seems due to the high level nature of this FSA, the study does not calculate the specific risk associated with an RCO, but instead estimates the maximum risk reduction potential with a sensitivity analysis.

5.3 The safety of a high speed craft

The case deals with Stena Line’s catamaran with two hulls. The vessel has maximum loading capacities of 1,500 passenger and 375 cars, or 50 lorries and 100 cars. Its overall length is 126.40m and its displacement is 19,368tonnes. It is propelled by water jets generated by four gas turbines and has also two bow thrusters. An integrated bridge system is used for navigating and maneuvering. It satisfies the regulations of IMO’s International Code of Safety for High Speed Craft and is regarded as a Category B craft.

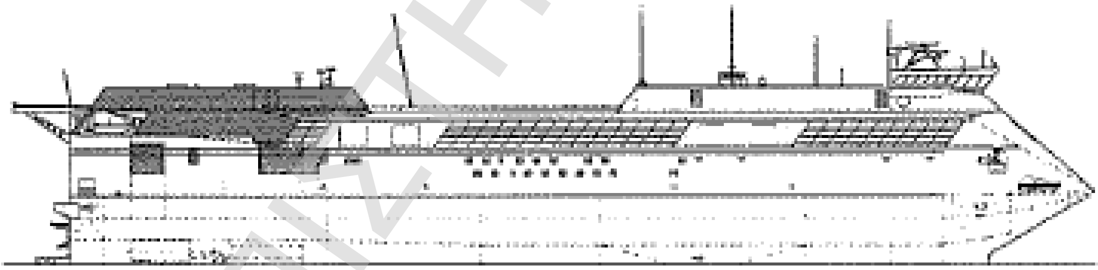


Fig11. Stena Catamaran

5.3.1 Hazard Identification

The more familiar hazards are:

- Collision with another ship in its path
- Grounding in shallow water
- Contact with a pier/fixed object during docking
- Fire in the engine room
- Equipment failure

And some less familiar hazards as: [13]

- Effects of wake at high speed on estuary shorelines and vessels at sea, as the vessel generates waves at high speed
- Bow thruster malfunction
- Mooring equipment failure
- Vehicle accident during loading/unloading
- Ballast system failure
- Blockage of water jet
- Passengers or crew suffering from food poisoning

5.3.2 Risk Assessment

A series of methods is used to perform risk assessment. Firstly, qualitative methods are used, based on the experience of the team members involved in the safety study. The results obtained assist the application of quantitative methods, such as considering statistical accident data, examining consequences and doing Fault Tree Analysis. The combined results are used in estimating the risk levels of the selected hazards as follows:

- Collision with another ship – Intolerable
- Grounding : Intolerable
- Contact with pier/fixed object: Tolerable
- Effects of wake at high speed: Tolerable
- Vessel falling into water: Negligible
- Food poisoning: Tolerable

The first hazard is selected for closer examination. A consequence value of 0.9 is obtained.[13] Using the fault tree analysis method and a selection of parameters it is possible to derive a numerical value for the probability of collision. The six parameters selected are:

a) computer failure (4 x 10^{-4})

b) radar malfunction (2 x 10^{-4})

c) tight schedule (500 x 10^{-4})

d) senior officer absence (400 x 10^{-4})

e) navigation error (20 x 10^{-4})

f) poor visibility (667 x 10^{-4})

The fault tree is shown in the figure below and the derived numerical value for the probability of a collision is 2.73 x 10^{-3} or 0.27 percent.

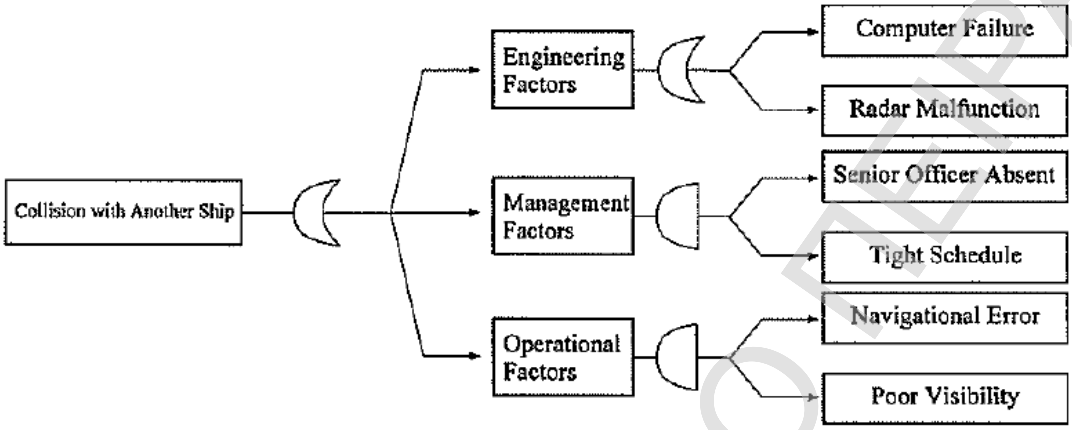


Fig12. Fault Tree prediction of collision with another ship

5.3.3 Risk Reduction

In this case the scope for reducing the risk level would involve reducing the probability of occurrence, by the following suggested means:

i) Computer failure: Select a computer with greater reliability; have a back up computer.

ii) Radar malfunction: Select a radar system with greater reliability; have a back-up system.

iii) Tight schedule: Make a decision to allow greater flexibility, revise the schedule, gain time from other components of the operation.

iv) Senior officer absence: Increase the presence of senior officers; identify likely collision scenarios; allocate resources for training.

v) Navigation error: Provide the crew with special training and use simulation for practicing navigation in difficult situations.

vi) Poor visibility: Improve the gathering of weather information; relate operation to visibility.

5.3.4 Emergency Preparedness

In addition to devising policies on emergency preparedness the actions that require attention are as follows:

- Investigate: Once an incident is reported, the Master should order an investigation, so that as much relevant data as possible can be speedily gathered.
- Decide: On the basis of the information acquired, the Master must decide what the next step should be.
- Prevent: Minimise the effects of the incident, e.g. use ballast to maintain the craft's position after collision.
- Escape: Move passengers to assembly points.
- Evacuation: If appropriate, order evacuation by marine escape systems.
- Rescue: Recover the passengers and crew from the sea.

5.3.5 Safety Management System

Regarding this category, emphasis has been given to the following actions:

- Policy: Ensure that rostering is such that the level of work fatigue is minimized for crew and shore staff.
- Organisation: Devise a communication mechanism so that safety-related information can be effectively transmitted and received.
- Implementation: Update safety related documentation on a regular basis.
- Measurement: Establish, operate and maintain active systems fo measuring performance objectively.
- Review: Establish benchmarks for comparison with other operators' standards.

CHAPTER 6

SAFETY METHODS

6.1 Maritime Safety Political View

A lot have been written about the method of Formal Safety Assessment (FSA) and how it is implemented in political subjects of maritime safety. The example of double hulls in tanker vessels is characteristic, where the method was used from opposite sides with opposite results. IMO was based in this method in order to decide not to demand obligatory double hulls, regardless that its former decision for mandatory double hulls was based in the same method.

However, we have to check if and how we have the attitude to lower the risk in maritime transports. The world has proved that have the willing to pay in order to have higher safety in maritime. The examples of double hulls in tankers and bulk carriers, as the new-building of Ro-ro ferries under the rules of Stockholm, that after studies decrease the risk of loss of lives if sea water enter into the ship, prove all the above, that when there is a safety issue and danger of human life, money are not taken into account.

The big question in the maritime safety is the amount; how we are willing to pay in order to increase the safety. And in action this has never been answered. One of the reasons is the difficulty to determine financial values as the value of human life, or even more of the animals that die every year due to i.e. fuel pollution. IMO has calculated the value of human life on/about 3 million dollars. Also, it is difficult to set and to make comprehensive the meaning of risk. IMO has developed specific instructions for the implementation of the methodology of FSA in the expression of the rules. Between them, risk is defined as the product of the possibility of an undesirable event to come about (i.e. accident) and the effect of this event, appropriately measured. For this reason two indexes are designated, the severity index and the frequency index in logarithmic levels as below:

Severity Index (SI)				
SI	Severity	Consequenses to human safety	Consequenses to vessel	S (Equivalent Deaths)
1	Minor	Minor injury	Local failure of equipment	0,01
2	Important	Multiple or heavy injury	Not severe failure on board	0,1
3	Severe	One death or major injuries	Severe failure	1
4	Catastrophic	Multiple Deaths	Total loss	10

Frequency Index (FI)			
FI	Frequency		F (per vessel and per year)
7	Frequent	Maybe to occur once per month in one vessel	10
5	Possible	Maybe to occur once per year in a fleet of 10 vessels, that is only a few times during vessel's life	0,1
3	Impossible	Maybe to occur once per year in a fleet of 1000 vessels, is possible to happen during life of several similar vessels	0,001
1	Extremely impossible	Possible to happen once in a fleet of 5,000 vessels (20 years)	0,00001

According to IMO, risk index is specified as the sum of the equivalent severity and frequency index, as:

Risk Index (RI)					
Frequency (FI)		Severity (SI)			
		1	2	3	4
		Minor	Important	Severe	Catastrophic
7	Frequent	8	9	10	11
6		7	8	9	10
5	Possible	6	7	8	9
4		5	6	7	8
3	Impossible	4	5	6	7
2		3	4	5	6
1	Very Impossible	2	3	4	5

The reader of the above tables thinks that the higher risk indexes correspond to scenarios that should be looked more carefully, at least regarding the proposed measures for avoidance or suppression of their consequences. However, except for being logical, the table has some problems. For example, though once per month (FI=7) there is one danger that leads to injury (SI=1). Let that there is another danger that once per year (FI=5) leads to one death (SI=3). In both cases the risk index is the same (RI=8). Of course, it is not sensible these two scenarios to be equivalent and the second case is surely more important.

A sensible explanation is that the risk is 2-dimensional (possibility, consequence) while oppositely the risk index is 1-dimensional. And obviously the compaction from two to one dimensions lead to the loss of some information. So, the risk index considers more severe events these with more frequency and not severe consequences from the opposite. It is obvious that the rules that have been adopted from such an analysis are more suitable for cases of accidents of high frequency and not severe consequences than opposite. Hence, another way should be adopted in order all cases to be covered, as i.e. the use of probability instead of frequency.

There is no doubt that this approach from IMO is up to nowadays the best way for the order of different danger in shipping. However, the weaknesses of this factor are obvious and clear. Therefore, special care is needed during its implementation, especially if it targets to the expression of rules that concern safety at seas. In the general frame, safety policies that are based in problematic scientific setting could be the same problematic with policies that are adopted without previously being scientifically analyzed and mainly under political pressure.

6.2 Comparison of Modeling Methodologies

The following safety analysis methods are the typical ones which can be applied to the design for safety process of engineering products. Each of the safety analysis methods may be used in different ways or in different formats, and offer considerable benefits to engineering products, by improving the safety aspects. They are, also, being developed in various possible application areas. However, further developments are still required to make safety analysis methods more flexible and effective to satisfy the requirements of engineering products. Finally, some of these methods may be more beneficially used in a combined manner for effective and efficient safety analysis.

6.2.1 FMECA

A FMECA provides a basis for recognizing component failure modes identified in component and system prototype tests, and failure modes developed from historical ‘lessons learned’ in design requirements. It is used to assess the safety of system components, and to identify design modifications and corrective actions needed to mitigate the effects of a failure on the system. Also, it is used in planning system maintenance activities, subsystem design, and as a framework for system failure detection and isolation. A FMECA can be done at any level of design from the overall system vessel to the lowest component or piece part level depending on the information available and the needs of the program. The lower the level of the counterfoil at which the analysis is done, the more detail required in the analysis and the more failure modes that must be considered.

FMECA is a step by step design evaluation procedure. It is an important and widely used method for the identification of failure modes and is essentially aimed at equipment and systems. Its objective is to identify reliability critical areas or potential system weaknesses in a design and to make recommendations for modifications which will reduce the probability of failure. The key steps are:

1. Consider each mode of failure for every component of a system.
2. Ascertain the effects on system operation of each failure mode in turn:

(a) Overall system level

(b) Subsystem level

3. Ascertain potential causes of failure.
4. Classify failure modes in relation to the severity (S) of their effect, and the probability that the failure will take place.(O)
5. Find the detectability (D): the probability that the fault will go undetected before the failure takes place (D_1) added to the probability that the fault will go undetected before having an effect (D_2), and all this over 2.
6. Find the risk priority number of the product (RPN) based on the occurrence, severity and detectability ratings. Each of these is rated on a scale of 1-10.

   Risk Priority Number = O x S x D
7. Recommend the corrective actions and counter measures which have been put in place.

A simple example of FMECA is shown below in the table.

Potential Failure Mode	Potential effects of failure	Potential causes of Failure	Current Controls	Occurrence (O)	Severity (S)	Detectability (D1+D2)/2	RPN = O x S x D
Propeller does not Work	The ship cannot move	The machine Has broken down	Inspection by the engineers	1	9	1	9
		The power is not transmitted to the propeller due to technical problem		3	7	3	63
		The generator has broken down		3	6	2	24

6.2.2 Fault Tree Analysis

Fault trees are amongst the most useful models for the description of system failure. They make possible the reliability analysis of large and complex systems by means of analytical or statistical methods. It has become a most useful method and, with supporting, computer software, an extremely effective tool. A fault tree is a model which graphically and logically represents how the various combinations of basic events, both failures and normal operations of components, lead to the top-event (failure of the system- root of the tree). A fault tree is a finite directed graph without directed circuits. There is only one top-event in the tree. A fault tree describes the dynamic change of system states when components fail. The undesired event (top-event), the probability of which is to be evaluated, represents system failure.

The advantages are that they can help the analyst to see failure combinations that would otherwise have gone unnoticed, provide a graphic aid to system managers. They also highlight the important aspects of the system (according to the particular top event) and

precipitate either qualitative or quantitative analysis. Also, fault trees allow the analyst to concentrate on one failure mode at time and give him a good insight into system behavior.
On the other hand, fault trees can be tedious and expensive to construct for complex systems, chosen to represent situations so complicated. Also, a major disadvantage is the inability of standard fault tree models to capture sequence dependencies in the system and still allow an analytical solution. Fault tree is broadly used in FSA as an efficient tool in risk engineering used to analyze the frequency of system failure either qualitative by the logical, structured hierarchy of failure events or quantitative by the estimation of occurrence rate of top-event.

Equipment faults and failures that occur in a fault tree are of three types:

1) Primary faults and failures
2) Secondary faults and failures
3) Command faults and failures

Primary faults and failures are equipment malfunctions that occur in the environment for which the equipment was intended. They are the responsibility of the equipment that failed and cannot be attributed to some external force or condition. Secondary faults and failures are equipment malfunctions that occur in an environment for which the equipment was not intended. Command faults and failures are equipment malfunctions in which the component operates properly but at the wrong time or place. They are not the responsibility of the equipment but are due to the source of an incorrect command.

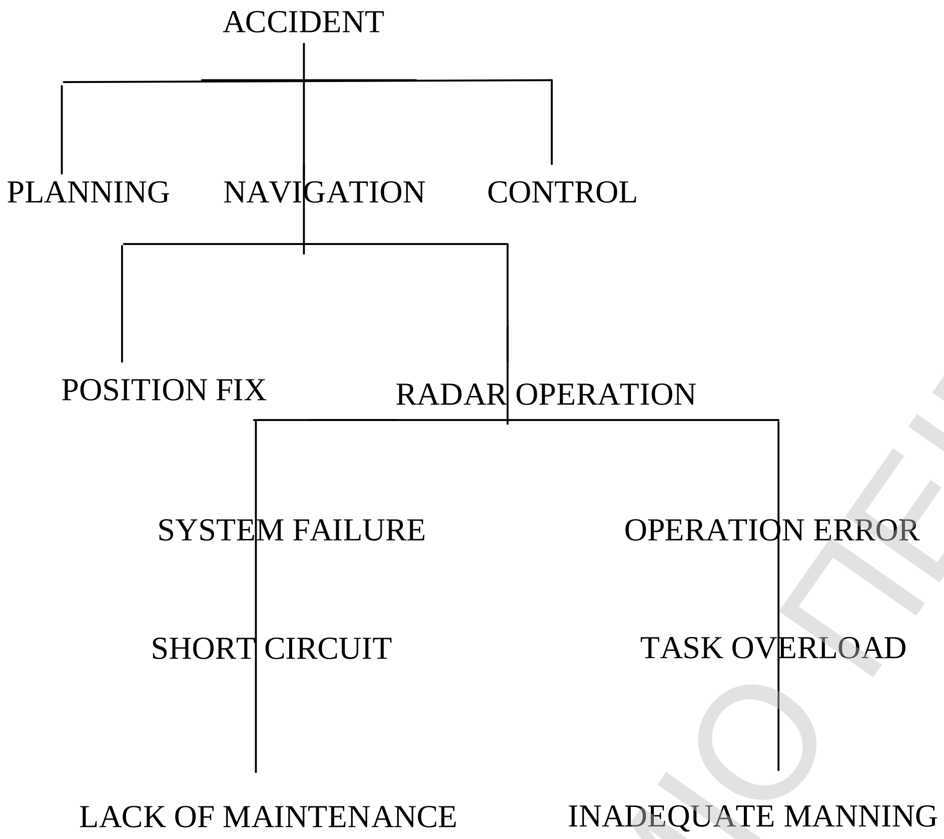


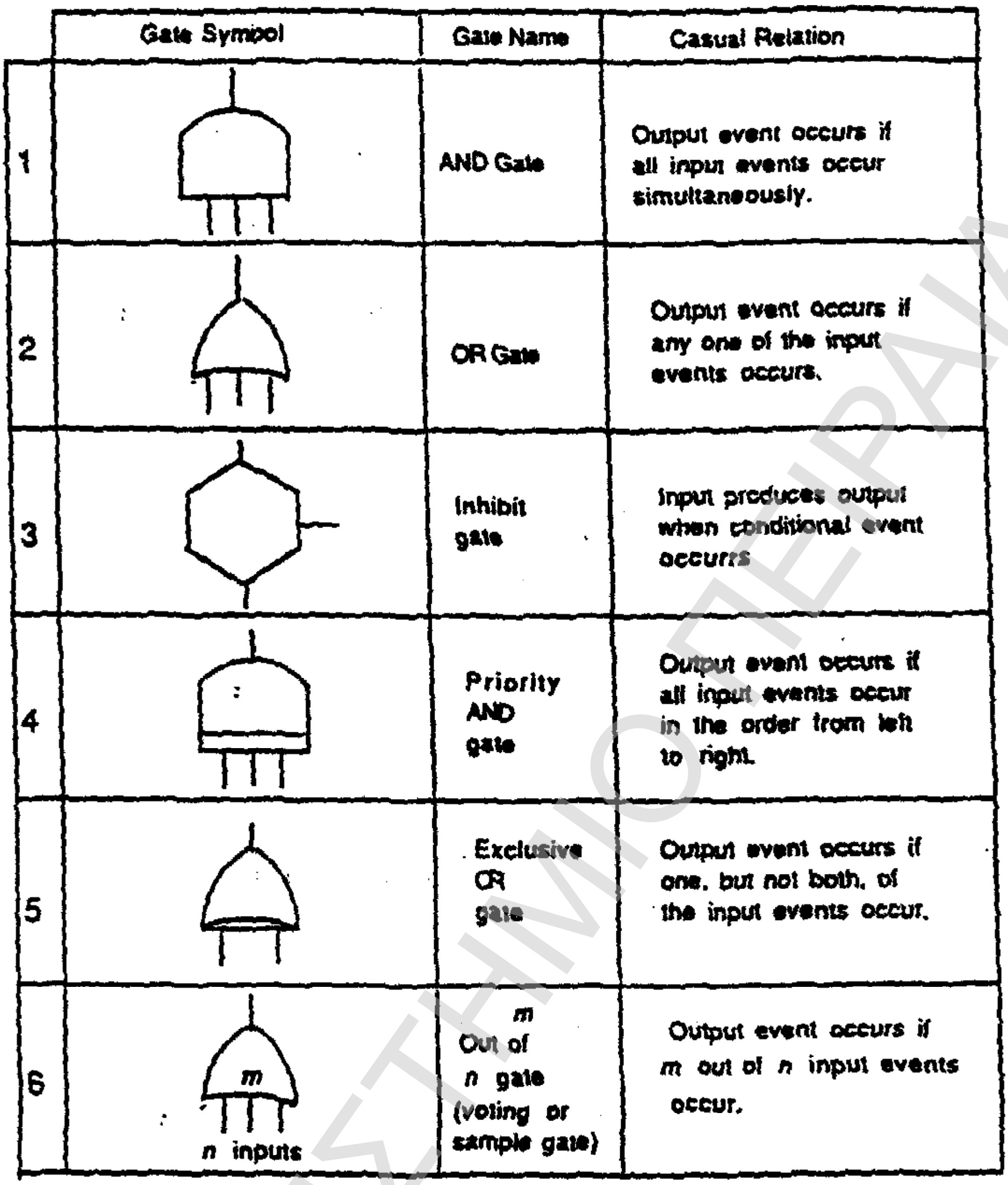
Fig13. Traditional decomposition in FTA

Gate symbols connect events according to their causal relations.[14] The symbols for the gates are listed in the figure below.

The steps in FTA are the followings:

1. Identification of top events
2. Representation of each top event by means of a fault tree
3. Evaluation of the probability of occurrence of each top event
4. Determination of critical failure modes

FTA is used in the risk identification and risk estimation phases of the design for safety process to identify the minimal cut sets associated with serious system top events.



	Gate Symbol	Gate Name	Casual Relation
1		AND Gate	Output event occurs if all input events occur simultaneously.
2		OR Gate	Output event occurs if any one of the input events occurs.
3		Inhibit gate	Input produces output when conditional event occurrs
4		Priority AND gate	Output event occurs if all input events occur in the order from left to right.
5		Exclusive OR gate	Output event occurs if one, but not both, of the input events occur.
6	*m* *n* inputs	*m* Out of *n* gate (voting or sample gate)	Output event occurs if *m* out of *n* input events occur.

Fig 14. FTA Gates

6.2.3 Event Tree Analysis

Event Tree Analysis is applied when a single hazardous event can result in a variety of consequences. The analysis identifies and evaluates potential accident outcomes that might result following a failure, called an initiating event. Demand frequencies and component failure probabilities are applied to calculate the frequency of outcome events. Event trees are presented in the form of an event tree logic diagram, which is inductive bottom-up logic. This analysis can be integrated into the risk identification and risk estimation phases of the design for safety process.

An event tree is a graphical representation of the logic model that identifies and quantifies the possible outcomes following an initiating event. Event tree analysis provides an inductive approach to reliability assessment as they are constructed using forward logic. Fault trees use a deductive approach as they are constructed by defining top events and then use backward logic to define causes. Event tree analysis and fault tree analysis are, however, closely linked. Fault trees are often used to quantify system events that are part of event tree sequences. The logical processes employed to evaluate event tree sequences and quantify the consequences are the same as those used in fault tree analyses. Generally, Event tree analysis is based on binary logic, in which an event either has or has not happened or a component has or has not failed. It is valuable in analyzing the consequences arising from a failure or undesired event. It is generally applicable for almost any type of risk assessment application, but used most effectively to model accidents where multiple safeguards are in place as protective features. Also, it is highly effective in determining how various initiating events can result in accidents of interest. An event tree begins with an initiating event, such as a component failure, increase in temperature/pressure or a release of a hazardous substance. The consequences of the event are followed through a series of possible paths. Each path is assigned a probability of occurrence and the probability of the various possible outcomes can be calculated.

Characteristics of Event Tree Analysis:

- Models the range of possible accidents resulting from an initiating event or category of initiating events
- A risk assessment technique that effectively accounts for timing, dependence, and domino effects among various accident contributors that are cumbersome to model in fault trees.
- Performed primarily by an individual working with subject matter experts through interviews and field inspections.
- An analysis technique that generates the following:
    - Qualitative descriptions of potential problems as combinations of events producing various types of problems (range of outcomes) from initiating events.

- Quantitative estimates of event frequencies or likelihoods and relative importance of various failure sequences and contributing events.
- Lists of recommendations for reducing risks
- Quantitative evaluations of recommendation effectiveness

The process of Event Tree Analysis is:

- Define the system or area of interest. Specify and clearly define the boundaries of the system or area for which event tree analyses will be performed
- Identify the initiating events of interest. Conduct a screening-level risk assessment to identify the events of interest or categories of events that the analysis will address. Categories include such things as groundings, collisions, fires, explosions, and toxic releases.
- Identify lines of assurance and physical phenomena. Identify the various safeguards (lines of assurance) that will help mitigate the consequences of the initiating event. These lines of assurance include both engineered systems and human actions. Also, identify physical phenomena, such as ignition or meteorological conditions that will affect the outcome of the initiating event.
- Define accident scenarios. For each initiating event, define the various accident scenarios that can occur.
- Analyze accident sequence outcomes. For each outcome of the event tree, determine the appropriate frequency and consequence that characterize the specific outcome.
- Summarize results. Event tree analysis can generate numerous accident sequences that must be evaluated in the overall analysis. Summarizing the results in a separate table or chart will help organize the data for evaluation.
- Use the results in decision-making. Evaluate the recommendations from the analysis and the benefits they are intended to achieve. Benefits can include improved safety and environmental performance, cost savings, or additional output. Determine implementation criteria and plans. The results of the event tree may also provide the basis for decisions about whether to perform additional analysis on a selected subset of accident scenarios.

6.2.4 Hazard and Operability studies (HAZOP)

The HAZOP method is a technique in which process and engineering equipment and operating procedures can be systematically examined to identify potential hazards. It is an inductive technique, which is an extended FMECA, however it is a flexible approach, and can be applied to a variety of installations, procedures and situations. It can be applied at any time during the life cycle of a plant, but is most effective during the detailed design stage.

Its distinctive features are:

i) A focus on state variables rather than mechanical components.
ii) An emphasis on an expert team approach.
iii) An explicit consideration of operator effects.
iv) A good foundation for subsequent quantitative risk analysis.

The HAZOP study investigates the proposed scheme systematically for every conceivable deviation, and looks backwards for possible causes and forward for the possible consequences.

It may involve the following eight basic steps:

1) Define the scope of the study.
2) Select the correct analysis team.
3) Gather the information necessary to conduct a thorough and detailed study.
4) Review the normal functioning of the process.
5) Subdivide the process into logical sub-units for efficient study and confirm that the scope of the study has been correctly set.
6) Conduct a systematic review according to the established rules for the procedure being used and ensure that the study is within the special scope.
7) Document the review proceedings.
8) Follow up to ensure that all recommendations from the study are adequately addressed.

The HAZOP methodology may stand a better chance of being a comprehensive detector of failure modes than other alternative methods used in risk identification.

6.2.5 Cause-Consequence Analysis (CCA)

CCA is a diagrammatic approach, which is a marriage of event tree analysis and fault tree analysis. It is extremely flexible as it can work forward using event trees and backward using fault trees. Its construction starts with a choice of a critical event. The consequence part of a CCA involves taking the initial event and following the resulting chains of events through the system. Its cause identification part involves drawing the fault tree and identifying the minimal cut sets leading to the identified critical event.

6.2.6 Decision Table Method [Boolean Representation Method (BRM)]

Decision table method is an inductive bottom-up method and can be integrated into the risk identification and risk estimation phases of the design for safety process. It contains all the possible system top events and the associated cut sets. This method is extremely useful for analyzing systems with a comparatively high degree of innovation, since their associated top events are difficult to obtain by experience or by other means. An engineering system can be described in terms of components and their interactions. A component can be described by a set of input events and a set of output events. Each output event specifies the state of the output and a set of input events specifies the states of inputs. Each event may have several states.

6.2.7 Digraph-based Analysis (DA)

DA is a bottom-up event-based qualitative technique. From the constructed digraph, the causes of a state change and the manner of the associated propagation can be easily found out. Digraph representation provides explicit causal relationships among variables and events of systems with feedback loops. In this analysis the nodes correspond to the state variables, alarm conditions or failure origins, and the edges represent the causal influences between the nodes.

Digraph-based Analysis is becoming increasingly attractive, because relatively little information is needed to set up digraphs and perform safety analysis.

6.2.8 Selection of Safety Analysis Methods

The use of safety analysis methods in an integrated manner may make safety analysis comparatively efficient and convenient since safety information and the advantages of each method may be more efficiently explored by doing so. In such an integration, one method may be used to process the information produced using another method. The safety methods, classified as top-down or bottom-up event-based as described before, may be applied to study the system states, operational and environmental conditions and other design considerations.

The selection of safety analysis methods is dependent on the following considerations:

- The level of the product breakdown at which the risk identification is carried out.
- The degree of innovation associated with the product design.
- The degree of complexity of the inter-relationships of the items at the investigated indenture level of the product breakdown.

When there is a lack of knowledge or experience inductive bottom-up methods, although more time consuming, should yield a higher level of confidence that all hazardous system states and respective failure modes are identified. Otherwise, top-down methods may prove more convenient and efficient. Both methods could be used in an integrated manner.

CHAPTER 7

CONCLUSION

7.1 Conclusion

The FSA process has a potential to become a very functional tool supporting the decision making process at IMO and national regulatory levels as well it could be applied as a proactive tool at the design stages to optimize risk and safety for new ship designs. FSA can be employed for generic and holistic ship analysis and to study individual ship systems or operations. However, this tool could be rather complicated, particularly when applied at generic levels. FSA is facing new challenges. Critics of the process are using the following arguments based on observed limitations of the process:

- Lack of IMO recommended acceptable risk criteria.
- It is time consuming and slows down decision process
- Most studies required more than one year to be completed
- Cost effective data is sensitive to time and geographic location.
- Lack or incompleteness of historical accident records and information on near-miss situations forces a need to rely on FSA experts' assessment to estimate acceptable risk levels, hazard probabilities and cost effectiveness.
- Cost of conducting FSA study is high. They can be compensated by completeness and comprehensiveness of the approach.

As it has been mentioned, FSA is considered as a tool to:

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

Despite the assistance that FSA has provided so far, none of the above seems to be working very well under the current regime. Until now, most FSA studies have not been as transparent as they should be, and, in any case, they could not justify proposed measures. FSA studies in the past tried to influence the IMO bodies and persuade member-states that the results of these studies were correct and beyond 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 its results had to be modified in order to take into account the findings of the new study. Strengthening the FSA process would mean that an FSA study would not have to be modified each time a new FSA study on the same subject appears.

It can be easily understood that the FSA process is not designed to produce final answers. It will take some time to realize that FSA has limitations, but when they will be realized and measures to improve the process are taken, the full benefits will be reaped. In particular, the extension of FSA to environmental protection issues has to be performed with a view of these limitations, and a view to find ways to alleviate them, particularly if the results will be used for policy formulation.

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