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Abstract	This report summarizes the most important issues in risk determination and risk management. After a historical overview the main methods in use in risk analysis are summarized. There is some emphasis on the use of precursors which are recently introduced. Cost 301 as a European project in the eighties explored new alleys for the numerical determination of risk. The origin is discussed which lay the foundation of modern marine risk analysis.
Key Findings / Conclusions	The most important recommendation is that member States and other authorities making use of maritime risk analysis start using a dynamic risk model. These applications will be enhanced when accurate numerical data regarding vessels, routes become available. The use of AIS and MOS centers is a very important step to collect this information for future risk management work.
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1. Objectives of the Study

This report is the first in a series of reports on maritime risk analysis. This report summarizes the most important issues in risk determination and risk management. After a historical overview the main methods in use in risk analysis are summarized. There is some emphasis on the use of precursors which are recently introduced. Cost 301 as a European project in the eighties explored new alleys for the numerical determination of risk. The origin is discussed which lay the foundation of modern marine risk analysis.

2. Target Stakeholders

- Maritime administrations
- Ship owners
- Port authorities
- Policy makers
- Maritime Operational Centers/Coast Guards/OPRC/SAR/VTM

3. Glossary terms

Abbreviations

AIS	Automatic Identification System
ALARP	As Low As Reasonable Possible
ASPM	Accident Sequence Precursor Method
BF	Beaufort
CPA	Closest Point of Approach
CURR	Costs per Unit Risk Reduction
EMSA	European Maritime Safety Agency
ENC	Electronic Navigation Chart
FAR	Fatal Accident Rate
FMECA	Failure Mode, Effect and Criticality Analysis
FSA	Formal Safety Assessment
FTA	Fault Tree Analysis
GDC	General Dry Cargo
GT	Gross Tonnage
HAZID	Hazard Identification
HAZOP	Hazard and Operational Analysis
HM	Hull and Machinery
HRS/HRV	High Risk Ship/Vessel
HSE	Health and Safety Agency (UK)
ICAF	Implied Costs of Averting a Fatality
IMO	International Maritime Organization
LMIS	Lloyds' Maritime Information Services
LNG	Liquid Natural Gas
MCA	Maritime and Coastguard Agency
MCR	Mean Collision Rate
MOS	Maritime Operational Services
MoU	Paris Memorandum of Understanding on Port State Control
MRCC	Maritime Rescue Coordination Centre

NPV	Net Present Value
PSC	Port State Control
PPU	Personal Pilot Unit
RCO	Risk Control Option
SSN	Safe Sea Net
TSS	Traffic Separation Scheme
VSL	Value of Statistical Life
WTP	Willingness To Pay
VONOVI	Verkeers Onderzoek Noordzee met Visuele Identificatie, Traffic Surveys North Sea
VTM	Vessel Traffic Management
VTS	Vessel Traffic Services

4. Analysis

4.1. Literature survey

4.1.1. Overview of the development of safety

A tremendous reduction of accidents took place in shipping accidents since 1880. Lancaster [1] compiled the graph presented in Figure 1.This loss diagram contained the losses of vessels as a percentage of the world fleet. In somewhat more than a century the loss percentage fell with a factor 10. It illustrates the improvements in design and improvements in operations during that time period. It became also clear that absolute improvements of the loss ratio are nowadays difficult to achieve.

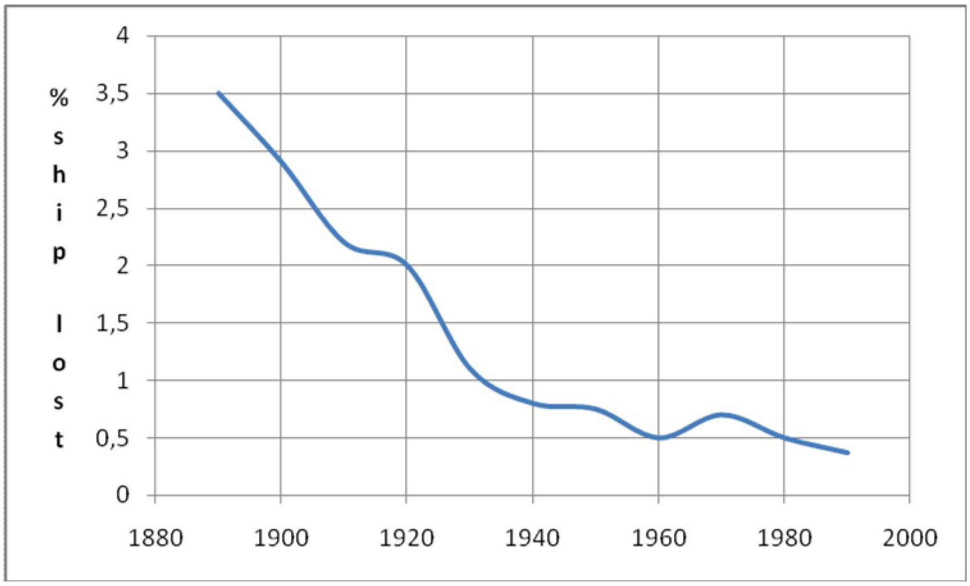

Figure 1: Ship losses since 1880 according to Lancaster [1]

Recent data on the development of the number of accidents indicate a trend that dissatisfies policy makers and authorities alike. The downward trend in the number of accidents which became manifest in the nineties of the last century stopped in the beginning of the period 2001-2003, urging policymakers to take initiatives to stop the increase in accident rates.

4.1.2. Present safety statistics

The world wide casualty statistics database was analyzed by van der Tak [2] in order to determine trends in the probability to be involved in a casualty. The next Figure is taken from a study in the framework of the research project MarNIS initiated by DGTREN in 2004. The database contains casualties from 1970 until 2007. The following casualty types are distinguished[1]:

- CN = a ship in collision with another moving ship;
- CT = a ship that strikes an object or moored ship;
- FD = a foundered ship;
- FX = a fire or explosion on board of a ship;
- WS = a wrecked/stranded ship;
- HM = a ship with hull/machinery damage.

The following areas have been analyzed:

- The MarNIS area, covering the Baltic, North Sea, Atlantic Approach and the western part of the Mediterranean;
- The whole world.

During the analysis it became clear that the probability of a Hull Machinery casualty is differently from the other casualties. The frequency of the Hull Machinery (HM) casualties is increasing during the last years, while the probability of other casualties is not. The share of the HM casualty is more than 40% of the total number of casualties. Consequently it was decided to separate the HM casualties from the others. It should be remembered that a HM casualty is in most cases an incident that has no severe consequences. Often there is time available to repair the engine in time and restore power before the failure results in a more serious casualty such as a contact or a strandings.

The results of the analysis are presented on next page. All values are presented as a percentage related to the average value of the period selected. The lines have more or less the same shape, what means the conclusions are valid within the whole world and not due to changes in the collection criterion or effort.

The conclusions are:

- The line representing all casualties at sea excluding HM has the most horizontal behavior, starting above the average value, achieving the lowest

[1] The coding used is the same as used by LMIS.

level of 80% in 1999 and ending with a rather constant level in the last years around the 100%.

- All other groups start on a higher level, achieve a minimum between 1999 and 2001 and are increasing considerably since these years to levels of 125% to 175%.
- The probability being involved in a casualty in restricted waters and ports is increasing more rapidly than the probability at sea.

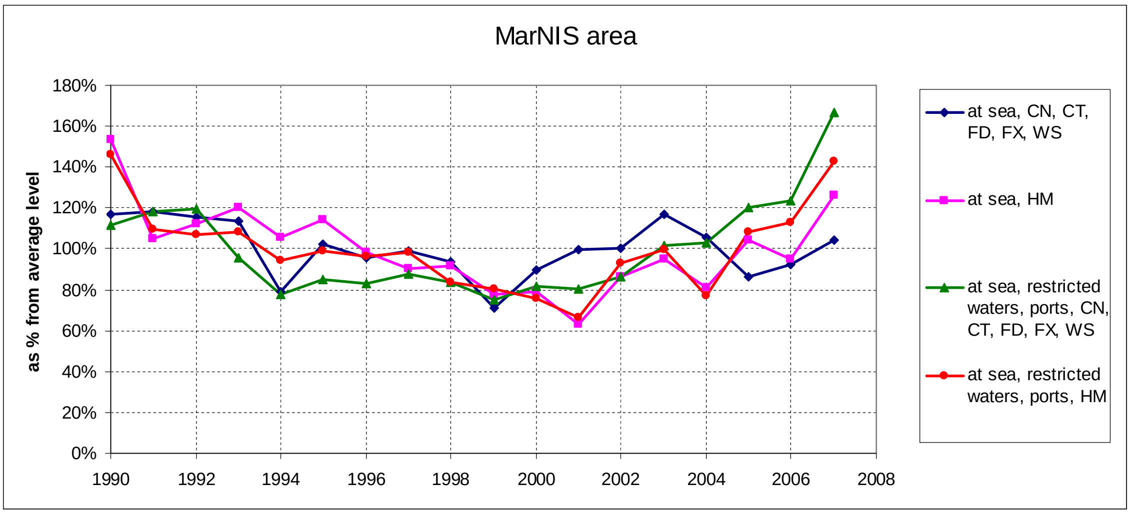

Figure 2: Development of accident levels relative to the average level between 1990 and 2007

These conclusions underline the importance of risk analysis and the attempts being made to make shipping safer and it constitutes the basis for the decision of DGTREN to study the safety at sea in more detail and to consider what measures could be taken to improve the safety of marine traffic in addition to the proposals that are made by IMO and that are accepted by a majority of member States

4.1.3. Historical development

4.1.3.1. History of risk

Although risk was introduced in the beginning of the last century risk analysis and risk management grew in importance in the last part of the century. Risk is a construct; before the notion of risk there was fate. See also Bernstein [3]. An important characteristic is that risk is based on statistics and it was closely associated with game theory: how can I prevent losing a game. This was later generalized into a definition that risk is the probability of an undesired event. This book was reviewed in the Economist and the review is cited below in toto:

“Bernstein argues that the mastery of risk is what divides modern from ancient times. The ancient Greeks, for example, adept as they were with numbers, regarded mathematics as belonging to a higher plane, unsuited for the messiness of daily life. Amazingly, Bernstein says of dice-rolling: ``Though people played these games with insatiable enthusiasm, no one appears to have sat down to figure the odds."

Someone who did try is Bernstein's first hero, Girolamo Cardano, a Milanese born around 1500 who was not only a famous physician but a compulsive gambler. His vice led to his greatest achievement: publishing the first serious work to lay out the statistical principles of probability.

From then on, things happened quickly. Over the years, the field of risk attracted such giants as Galileo, Pascal, Newton, Gauss, Poincare, von Neumann, and Keynes. Blaise Pascal, for instance, is remembered as a religious philosopher. But as a youthful mathematician, he teamed up with Pierre de Fermat- on a solution to an old conundrum: how to divide the stakes of an uncompleted gambling game. With its implications for prediction in other fields, Bernstein says, Pascal and Fermat's solution became ``the cornerstone of modern insurance and other forms of risk management."

Confidence in probability and statistics reached a high-water mark in the Victorian era. By the 20th century, confidence waned a bit. Long-run averages aren't always helpful, John Maynard Keynes famously observed, because ``in the long run, we are all dead."

Next to take a crack at risk were game theorists, led by John von Neumann, the mid-century genius of bomb-making and computing. Game theory presented life as a contest in which people seek to maximize rewards and minimize risks--while others do the same, often with conflicting objectives. Many game theorists repeated a mistake of the Victorians, by having too much faith that human behavior could be modelled mathematically. Still, their insight paved the way for modern portfolio theory, which says diversification reduces risk. Harry Markowitz put forth the theory at age 25 in a 1952 paper in the Journal of Finance.

Bernstein brings Against the Gods up to the present with an account of how some skeptical researchers--beginning with the Israeli-born psychologists Amos Tversky and Daniel Kahneman in the 1950s--trashed the classical model of rationality by exploring how people actually behave in risky situations. The bottom line: People behave irrationally, even when they know they are doing so. Bernstein relates an anecdote about a distinguished Soviet professor of statistics who showed up at an air-raid shelter during a German bombardment. Until then, he had scoffed at the prospect of being hit. What changed his mind? ``Look," he explained. ``There are 7 million people in Moscow and one elephant. Last night, they got the elephant."

Like Girolamo Cardano, Bernstein himself is a Renaissance man. He's not only an author--Against the Gods is his sixth book--but a working Wall Street economist who consults for institutional investors and companies. Against the Gods is loaded with tidbits of modern economic research and war stories from Bernstein's 40-year career, which makes for an enchanting blend of history and investment advice.

Bernstein clearly relishes this stuff. In a chapter on derivatives, he devotes two pages to describing an intricate ``cotton loan" issued in 1863 by the Confederacy. Then, he launches into the principles behind the model for the proper pricing of options that was developed in the 1960s by Fischer Black, Myron Scholes, and Robert C. Merton.

4.1.3.2. Other developments

In order to illustrate some important milestones in the technical area two examples will be mentioned: the invent of the Fault Tree Analysis in 1959 and the origin of HAZOP.

The use of FTA begun in 1965 and was rapidly accepted as a risk analysis tool in space technology as well as the nuclear industry followed by the entire industry. Watson [4] first conceived the Fault Tree Analysis in a program to study the Minute man Launch Control system. Other divisions in Boeing quickly recognized the power of the method and were not slow to use it for their own problems. Ericson [4] came to the conclusion that FTA has earned its present position in risk analysis and assessment, accident analysis and reliability. The importance of FTA has not declined over the years. FTA met with numerous critical comments but the benefits and strengths of the method have proven to outweigh the detractor arguments and the FTA is still an international used and recognized tool.

The HAZOP technique originated in the Heavy Organic Chemicals Division of the corporation Imperial Chemical Industries. In 1963 a team of 3 people met for 3 days a week for 4 months to study the design of a new Phenol plant. They started with a technique called critical examination which asked for alternatives, but changed this to look for deviations. The method was further refined within the company, under the name operability studies, and became the third stage of its hazard analysis procedure (the first two being done at the conceptual and specification stages) when the first detailed design was produced. In 1974 the first paper in the open literature was also published. Up to this time the term HAZOP had not been used in formal publications. The first to do this was Kletz [5] in 1983. By this time, hazard and operability studies had become a part of the tools for chemical engineers and were extensively used in industry.

4.1.4. Risk determination

4.1.4.1. Risk analysis, risk assessment, risk management

The use of the notions risk analysis, risk assessment and risk management is hap hazardous. The following Figure illustrates the scope of risk analysis, risk assessment and risk management as was published by HSE with a contract to DNV. See [6].

- Risk analysis - the estimation of risk from the basic activity "as is".
- Risk assessment - a review as to acceptability of risk based on comparison with risk standards or criteria, and the trial of various risk reduction measures.
- Risk management - the process of selecting appropriate risk reduction measures and implementing them in the on-going management of the activity

The Figure shows that hazard identification (HAZID) is an essential component of all three types of study.

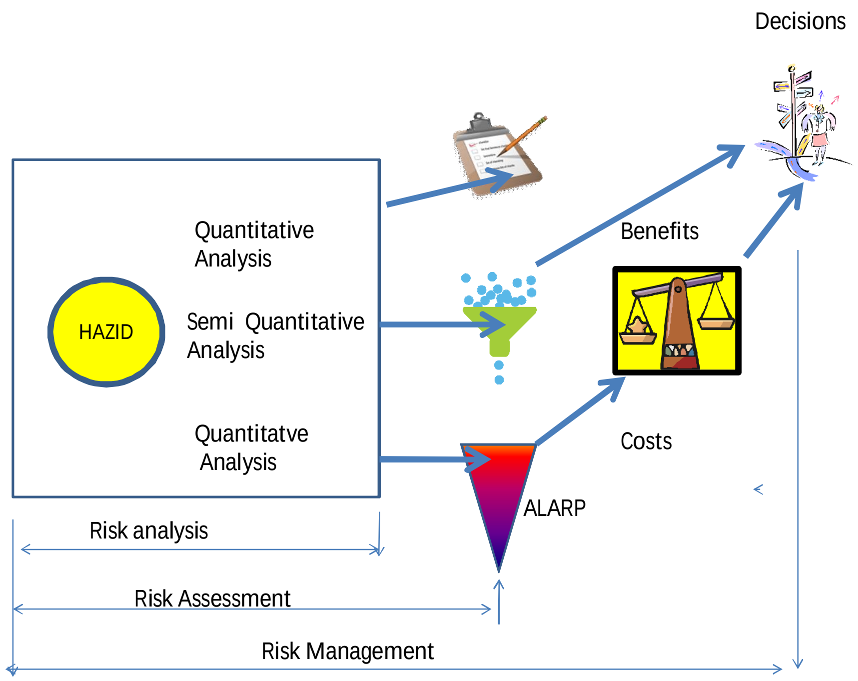

Figure 3: Schematic presentation of risk determination risk assessment and risk management

4.1.4.2. Concept of risk

There is a number of tools and techniques that can be used to when carrying out a risk analysis and a risk assessment. The concept of risk is central to all the tools that will be briefly discussed in this Chapter. There is a different meaning to the notion of safety by different people. For the purpose of this report we will use safety as the opposite of risk: a ship is safer when the risk of a vessel is smaller. Risk is evaluated as a function of the severity of the consequences and as function of its occurrence, i.e. the frequency of undesired effects.

The functional relationship is written as follows:

$$R = PC \qquad (1)$$

Where R is the risk in €/year,

P the probability of the undesired event in 1/year,

C are the consequences in € or in any other suitable measure.

P is now a function of many parameters as human factors operational conditions and engineering factors.

When the probability is small as well as the consequences the resulting risk is small and this risk may be perceived by the society as permissible or tolerable. The risks emanating from infrequent incidents but with large consequences may be either tolerable or negligible. These incidents require special attention and special measures to mitigate the risk in order to improve safety.

There is a number of risk assessment methods that are used. The following is a short summary of the most important methods.

4.1.4.3 HAZOP

A hazard and operability (HAZOP) study is a method of identifying hazards that might affect safety and operability based on the use of guidewords. A team of experts in different aspects of the installation, under the guidance of an independent HAZOP leader, systematically considers each sub-system of the process in turn, typically referring to process and instrumentation diagrams (P&IDs). They use a standard list of guidewords to prompt them to identify deviations from design intent. For each credible deviation, they consider possible causes and consequences, and whether additional safeguards should be recommended. They record their conclusions in a standard format during the sessions.

4.1.4.4. FMECA

The Failure Mode, Effect and Criticality Analysis is a systematic method to locate equipment failures and functional failure modes assessing the roots of such failures and the consequences. Their effects on the availability, reliability safety and costs of the system components under scrutiny are determined. This method is in essence a numerical method that results in failure rates and severity and criticality parameters. The FMECA is often used to identify the most effective risk reducing measures which may often assist in the pre design of a system to select the viable and cost effective options and to assess the risk associated with those failure modes, to rank the issues in terms of importance and to identify and carry out corrective actions to address the most serious concerns.

The basic steps for performing an FMEA/FMECA analysis include:

- Assemble the team;
- Establish the ground rules;
- Gather and review relevant information;
- Identify the item(s) or process(es) to be analyzed;
- Identify the function(s), failure(s), effect(s), cause(s) and control(s) for each item or process to be analyzed;
- Evaluate the risk associated with the issues identified by the analysis;
- Prioritize and assign corrective actions;
- Perform corrective actions and re-evaluate risk;
- Distribute, review and update the analysis, as appropriate.

Overall, FMECA is useful for safety-critical mechanical and electrical equipment, but should not be the only HAZOP method. Most accidents have a significant human contribution, and FMECA is not well suited to identifying these. As FMECA can be conducted at various levels, it is important to decide before commencing what level will be adopted as otherwise some areas may be examined in great detail while others are examined at the system level without examining the components. If conducted at too deep a level, FMECA can be time consuming and tedious, but it leads to great understanding of the system.

When a selection is made the results are often used to develop maintenance strategies.

4.1.4.5. Fault tree analysis

The fundamental concept of a Fault Tree Analysis is the translation of the failure behavior of a physical system into a visual diagram and a logic model The diagram segment provides a visual model that very easily portrays system relationships and root cause fault paths. The logic segment provides a mechanism for quantitative and qualitative evaluation. FTA is based on reliability theory, Boolean algebra and probability theory. A very simple set of rules and symbols provides the mechanism for analyzing very complex systems and complex relationships between hardware, software and human activity.

Fault tree analysis is relatively often used. These analyses are used to identify subsystems that are critical for the operation of a system. The use of this analysis is also extended to questions in what way undesirable events occur.

4.1.4.6. Event tree analysis

An event tree is a visual representation of all the events which can occur in a system. As the number of events increases, the picture fans out like the branches of a tree.

Event trees can be used to analyze systems in which all components are continuously operating, or for systems in which some or all of the components are in standby mode – those that involve sequential operational logic and switching. The starting point (referred to as the initiating event) disrupts normal system operation. The event tree displays the sequences of events involving success and/or failure of the system components.

In the case of standby systems and in particular, safety and mission-oriented systems, the event tree is used to identify the various possible outcomes of the system following a given initiating event which is generally an unsatisfactory operating event or situation. In the case of continuously operated systems, these events can occur (i.e., components can fail) in any arbitrary order. In the event tree analysis, the components can be considered in any order since they do not operate chronologically with respect to each other.

4.1.4.7. Accident Sequence Precursor Methods (ASPM)

The ASPM originated at the Oak Ridge National Laboratory shortly after the accident at Three Miles Island as a part of the Accident Sequence Precursor Program for light water nuclear reactors in the United States.

In a later stage there was renewed interest in ASPM. The National Academy of Engineering in the USA organized a workshop on ASPM in 2002.

The Academy defined an accident precursor as any event or group of events that must occur for an accident to occur in a given scenario. One dictionary definition (among many) is “one that precedes and indicates the approach of another.” A precursor is defined as a situation that has some, but not all, of the ingredients of a more undesirable situation. Thus, a precursor is an event or situation that, if a small set of behaviors or conditions had been slightly different, would have led to a consequential adverse event. The following is taken from a paper by Corcoran [7].

With great retro-visual acuity, experts and lay people alike can identify the precursors to *Challenger*, *Concorde*, Three Mile Island (TMI) incident, *Columbia*, and other consequential adverse events.

It has been identified during an analysis of the accident with space shuttle *Challenger* that every shuttle launch that included an O-ring blow-by before the *Challenger* explosion was a precursor to an explosion in that if the pre-launch ambient temperature had been sufficiently low the O-rings would have failed and the vehicle would have been lost.

In the case of the supersonic airplane *Concorde*, an examination of the accident history indicates about a half-dozen recorded precursors to the fatal encounter with a foreign object. These precursors involved take-offs with either foreign objects on the runway or tire blow-outs or both. Were there unrecorded times when *Concorde* took-off when there was a foreign object on the runway? Might these unknown events have been called precursors, even though they are unknown?

Has there ever been a serious, consequential adverse event that did not have precursors? Chernobyl and the Hindenburg were said to have come "out of the blue," but did they? Would sufficient access to the history of these events reveal precursors that, had they been recognized and attended to, might have averted them? An old cowhand might ask, "Why not head them off at the pass?" That is to say, why not identify and analyze the precursors and take corrective action to prevent the downstream consequential adverse event.

4.1.4.7.1. Introduction

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4.1.4.7.2. What are precursors?

The National Academy of Engineering workshop definition of an accident precursor is any event or group of events that must occur for an accident to occur in a given scenario. One dictionary definition (among many) is “one that precedes and indicates the approach of another.” For the purpose of this document, a precursor is defined as a situation that has some, but not all, of the ingredients of a more undesirable situation. Thus, a precursor is an event or situation that, if a small set of behaviors or conditions had been slightly different, would have led to a consequential adverse event. Has there ever been a consequential event, near miss, or infraction/deviation that did not have a precursor?

4.1.4.7.3. What keeps a precursor from a real accident?

A real accident is a highly consequential adverse event. When there is ‘near miss”, the real accident does not occur for one of three reasons:

1) an exacerbating factor was missing;
2) a mitigating factor was effective; or
3) both.

To express these three ideas as equations, we have:

$$\{Accident\} = \{Precursor\} + \{Exacerbating\ Factor(s)\} \qquad (1)$$

Equation (1) says that, if the next occurrence of the precursor includes specific exacerbating factors, a consequential event will result.

$$\{Accident\} = \{Precursor\} - \{Mitigating\ Factor(s)\} \qquad (2)$$

Equation (2) says that, if the next occurrence of the precursor situation does not include important defenses, barriers, or other mitigating measures, a consequential event will result.

$$\{Accident\} = \{Precursor\} + \{Exacerbating\ Factor(s)\} - \{Mitigating\ Factor(s)\}(3)$$

4.1.4.7.4. Accidents as precursors

As was illustrated in a tragic accident this accident can be a precursor, too. A woman was killed in an operating room when she was given nitrous oxide instead of oxygen. Three days later, another woman was killed in the same operating room in the same way, thus providing a tragic example of not learning from experience. Precursors of this type can be expressed by Equation (4):

$$\{Accident\}_{N+1} = \{Accident\}(N) + \{Nothing\} + \{Time\}(4)$$

This equation says that, if an adverse event is not effectively investigated and appropriate corrective action taken, the causes of the event may continue to exist. And as long as the causes continue to exist, a similar event may occur. Examples of this type include the infamous Ford Explorer-Bridgestone/Firestone episode and the tragedies of Therac-25, a radiation therapy accelerator.

Real accidents might also be considered precursors using Equation 4a:

$$\{Worse\ Accident\}(N+1) = \{Accident\}(N) + \{Nothing + \{Exacerbating\ Factor(s)\}$$

An example of this was the loss of some of the crew of the USS *Squalus* (SS-192), which was a precursor to the loss of the entire crew of the USS *Thresher* (SSN-593). Both submarines sank because of loss of hull integrity. The real accident and the precursor are related by both Equation 4 and Equation 2, which together are captured in Equation 4a.

4.1.4.7.5. Near misses

A near miss is a special kind of precursor (some people like to say “near hit” or “close call” for the same concept). In general, we think of a near miss as a precursor with ingredients that differ in only minor or in non-robust ways from those necessary for a consequential event. For instance, when the necessary exacerbating factors are highly likely, the precursor is called a near miss. For example, running a red light in a busy intersection without causing a collision is a near miss. The exacerbating factor would have been another vehicle crossing the intersection. Similarly, one would expect a precursor to be called a near miss if the mitigating factors were unlikely or not robust. For example, a steam pipe break that does not result in injuries because the workers happen to be at lunch when it happens could be considered a near miss. (This actually happened at Millstone Unit 2 in the mid-1990s.) The near miss concept suggests the following:

$$\{Accident\} = \{Near\ Miss\} + \frac{\square}{-}\{Not\ Much\} \tag{5}$$

Many people believe that investigations of near misses should be commensurate with investigations of the corresponding averted consequential events. Thus, many shuttle launches prior to *Challenger* and *Columbia* were “secret” near misses. Some *Concorde* accidents before the fatal one were also “secret” near misses.

Managers and program people should be asking what kept a near miss from being worse and how close it came to being a real McCoy. Perhaps, in the cases of *Challenger* and *Concorde*, the near misses were not obvious or fully appreciated as precursors.

4.1.4.7.6. Unveiling precursors

If it were known that a specific event was a precursor of an accident, people would certainly do something to avert the next real accident. However, many precursors that should indicate the approach of a real accident are not recognized. For example, *Concorde* program personnel kept records of precursors involving *Concorde* aircraft, but apparently they did not “connect the dots” to envision an encounter with a foreign object on takeoff that could destroy an aircraft. Precursors to *Challenger* (O-ring blow-by) and *Columbia* (foam strikes) also went unrecognized.

Notice that all of the “post-cursor” real accidents were preceded by precursors that did not sufficiently indicate their approach. If the precursors had been “unveiled” for the threats they indicated, the accidents might have been averted. To unveil something is to reveal its true nature, and clearly lives, pain, assets, and careers could be saved if organizations could unveil precursors. *People* unveil precursors when they make inferences from events and situations (because events and situations are not capable of implying anything on their own). One systematic approach to making inferences from potential precursor events and situations is root-cause analysis, which can be helpful in deconstructing events and situations to aid decision making.

In applying root-cause analysis to possible precursor events and conditions, two questions must be considered:

- how does one select events and situations as potential precursors; and
- how does one perform a root-cause analysis on selected events and situations.

Before a precursor can be analyzed, it must be recognized as an ingredient in a recipe for dire consequences. If today’s anomaly or today’s usual practice cannot be envisioned as an ingredient in such a recipe, there is no hope that it will be unveiled or detected.

4.1.4.7.7. Epilogue

The reason that on precursors more attention has been paid is that incident reporting is a tool that is insufficient. It is not sufficient to make public reports of near-incidents. Professional will read these reports but when they come in the same situation they will not remember it as well as the lessons. When one doesn’t experience a dangerous situation the experience of another person will not play a large role in shaping one’s own reaction unless similar situations are trained and become a part of the way of handling situations. When precursors are used there is an opportunity to analyze the situation and lessons may evolve and absorbed by the responsible persons.

Precursors may be used for a good purpose and near accidents used in this way are having more affects than publicizing and reading near incident reports.

4.1.4.8. Risk assessment and risk management

Health and Safety Authority of the UK produced a brief paper on the principles of risk management [7]. It stated that:

Sensible risk management **IS** about:

- Ensuring that workers and citizens are properly protected;
- Providing overall benefit to society by balancing benefits and risks, with a focus on controlling real risks – either those which arise most often or those with the most serious consequences;
- Enabling innovation and learning, not stifling them;
- Ensuring that those who create risks manage them responsibly and understand that failure to manage serious risks responsibly is likely to lead to robust action;
- Enabling individuals to understand that as well as the right to protection, they also have to exercise responsibility;

Sensible risk management **IS NOT** about:

- Creating a totally risk free society
- Generating useless paperwork mountains
- Scaring people by exaggerating or publicizing trivial risks
- Stopping important recreational and learning activities for individuals where the risks are managed
- Reducing protection of people from risks that cause real harm and suffering

4.1.4.8.1. Risk assessment

Risk assessment approach is often based on a tolerability of risk (TOR) framework (Figure 3). It applies to risk in a broad sense, including not just the risks of harm (individual and societal risks), but also the perception of hazards and associated ethical and social considerations ("societal concerns"), such as aversion to large multiple-fatality accidents. The figure is borrowed from the many publications of the Health and Safety Agency (HSE) in the UK which plays an authoritative role in safety and health issues. It divides risk into 3 regions:

- Unacceptable - risks regarded as unacceptable except in extraordinary circumstances (such as wartime), whatever their benefits. Activities causing such risks would be prohibited, or would have to reduce the risks whatever the cost.

- Tolerable - risks that are tolerated in order to secure benefits. In this region, risks are kept as low as reasonably practicable (ALARP), by adopting reduction measures unless their burden (in terms of cost, effort or time) is grossly disproportionate to the reduction in risk that they achieve.
- Broadly acceptable - risks that most people regard as insignificant. Further action to reduce such risks is not normally required.

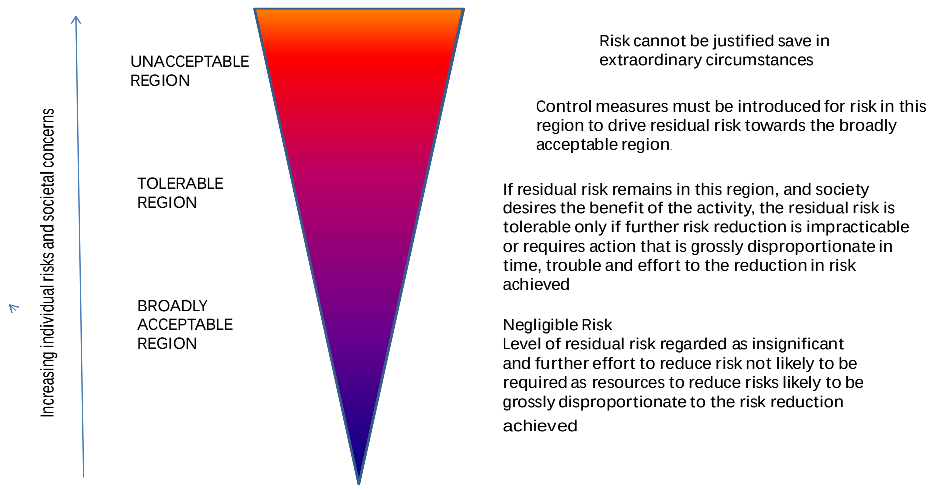

Figure 4: ALARP classification

This approach has been adopted widely in the maritime world. In order to apply it, the duty holder must first ensure that the risks are not unacceptable, and must then show that the risks are either ALARP or broadly acceptable. HSE has specified risk criteria (or "tolerability limits") to indicate the boundaries between the zones. Although these are intended to be guidelines, not rigid criteria to be complied with in all cases, in practice most offshore operators have adopted criteria based closely on them.

The collision and grounding frequency assessment methods are discussed in more detail in SKEMA Consolidation Study D2.3.2.1 "Review of collision and grounding risk analysis methods".

4.1.4.8.1.1. FSA

IMO is carrying out trial applications of formal safety assessment (FSA) as a proactive, transparent and systematic means of developing new safety regulations (IMO 1997). As defined by IMO, FSA consists of a 5-step process, involving hazard identification, risk assessment, development of risk control options, cost-benefit assessment, and making recommendations for decision-making (Figure). The purpose of FSA is to help develop risk-based regulations, and hence it should not be confused with risk assessment used in support of a safety case, although it uses many of the same techniques. FSA is applied to generic types of ship, and is seen as an alternative to a safety case approach, since it is widely believed that the shipping industry in not yet ready for the safety case approach.

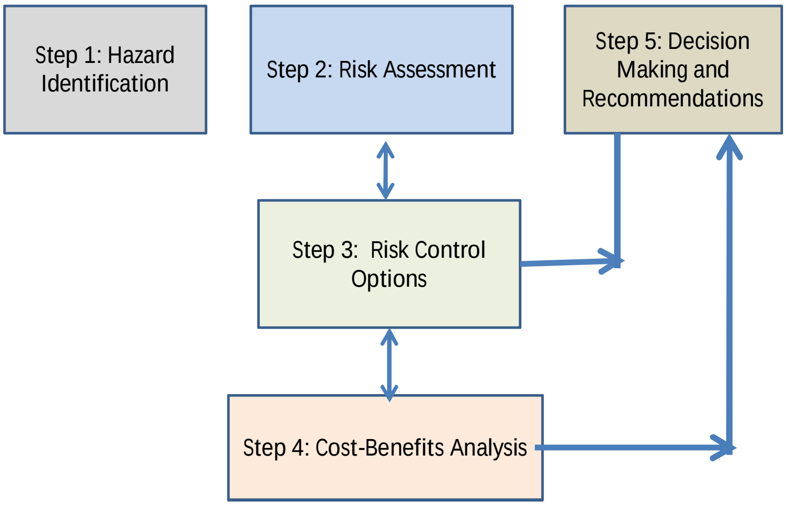

Figure 5: Block diagram of a FSA

4.1.4.8.1.2. F-N curves

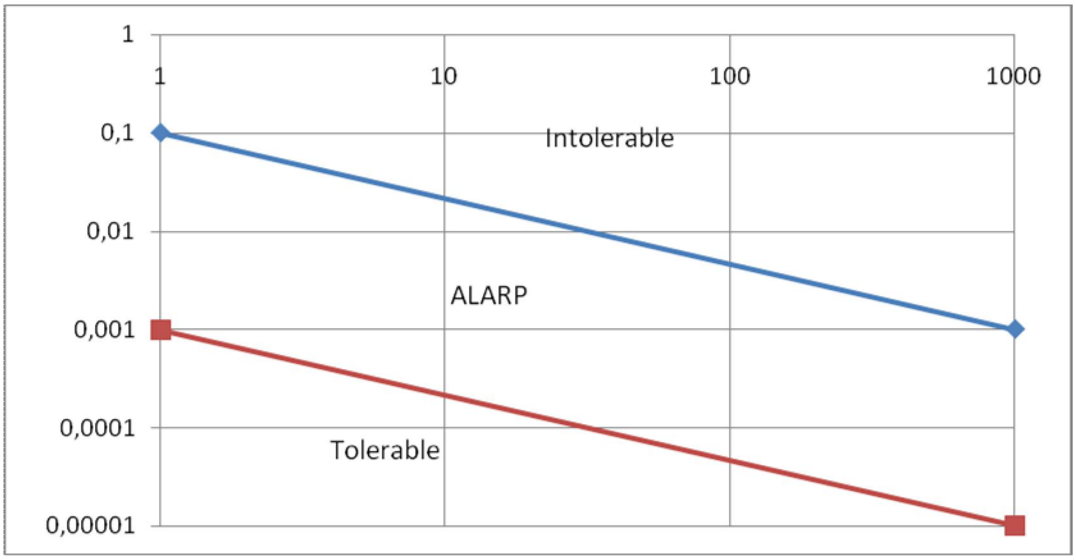

Figure 6: The different risk areas

Figure 6 indicates the areas. When the predicted number of fatalities is in the ALARP region Risk reduction measures may be needed as long as the costs are commensurate with the risk reduction.

4.1.4.8.2. Risk management

4.1.4.8.2.1. Cost benefits analysis

As different risk reduction measures may have different costs there is a large need to quantify these costs and benefits. It should be done on a comparable basis. The best suggestion is to compare these on money terms. Methods are developed to deal with the costs of human life. The next section will deal with these methods. Large objections exist on the way in which human life should be incorporated in C/B analysis. Some delegations in IMO were not happy with the concept of statistical life as used in Cost-Benefits analyses. In order to avoid the use of statistical life values according to [a] other methods are developed. Among them the Costs per Unit Risk Reduction (CURR method) and the Implied Costs of Averting a Fatality (ICAF method). The CURR method attempts to establish the lives lost over the lifetime of the measure assuming an equivalency between minor injuries, major injuries and deaths. (100 minor injuries=10 major injuries =1 death). The following equation Nett Present Value (NPV) can be written down as follows:

$$NPV = \sum_{i=1}^{n} [(B_i - C_i)(1+r)^{-i}]$$

In this equation:

B_I=sum of benefits in period t, but excluding economical benefits of reduced fatalities

C_I= sum of costs in period t

r=discount rate

t= time horizon from 1 to n

The resulting NPV is then used to calculate Cost per Unit of Risk Reduction by dividing NPV by the benefit of the estimated number of reduced equivalent fatalities. The CURR values for the different risk reduction measures can then be compared for cost effectiveness in improving human safety.

The uncertainty of the calculation should be taken into account by executing a sensitivity analysis.

The ICAF methodology is a much used .It determines the achieved risk reduction in terms of costs using the following equation:

$$ICAF = \frac{Net\ annual\ costs\ of\ measure}{Reduction\ in\ annual\ fatality\ rate}$$

The net annual costs of a measure are calculated by distributing all the costs related to implementation and operation of a measure over the measure's lifetime. This can be done by calculating the annual annuity. An alternative may be that the NPV is divided by the total reduction in fatalities. The ICAF values may be interpreted as the economic benefits of averting a fatality. A decision criterion should be used in order to evaluate whether a given risk control option is cost effective or not. This criterion must then involve in one way or another, the pricing of a human life. DNV considers that if the ICAF value is less than 2 M€ the risk measure is cost effective. See [6].

4.1.4..8.2.2. Statistical value of life

It should be noted that when the saving of a life is valued in this way, it is not the value of a particular person's life, but the small reduction in risk for a large number of people that can be expected on average to save one person's life. The valuation placed on the saving of one such life is sometimes called the value of statistical life, to emphasize that no specific person is involved, but it is also often somewhat misleadingly shortened to the value of life. The arguments are different if one specific person's life is at stake, as for example when search-and-rescue operations are mounted.

To put a monetary value to human life, there are two main methods in use in the EU Member States: the human capital method and the willingness-to-pay method. In the human capital approach, the major component of the cost of a fatality or injury is the lost economic output of the victim. The principle objection to this approach, is that most people do not value their life for its contribution to economic output, but rather because it has intrinsic value to them and to their relatives. In that case, the value of safety, or of reductions in risk to life, should be taken to be the amount that people are willing to pay for it, i.e. the willingness-to pay approach.

The willingness-to-pay approach is based on the idea that although people do not trade off their life against money or other commodities, they do trade off small changes in risk against other commodities. For example, they make decisions about whether or not to have particular safety features in their cars, and they make decisions between modes of transport, one of which may be cheaper but less safe than the other. These decisions reveal preferences about the value of safety relative to the value of other things, in the same way as trade-offs between money and time reveal information about the value of time. However, evidence about the value of safety is more difficult to obtain by than evidence about the value of time.

It is now widely accepted that in public investment and regulatory decisions the appropriate monetary value to attach to any potential effects on individual health and safety should be based upon the preferences of members of the affected population, as expressed by their individual willingness to pay (WTP) for safety improvement, or by their willingness to accept compensation (WTA) for increased risk

Studies aimed at obtaining empirical estimates of WTP-based values of safety can be classified, broadly speaking, into one of two types, namely revealed preference or contingent valuation. Essentially, the revealed preference approach seeks to elicit WTP-based values from data concerning actual choices involving explicit or implicit trade-offs of wealth for risk.

By contrast, under the contingent valuation approach, one asks members of a representative sample of the affected population more or less directly about their willingness to pay for hypothetical small improvements in their own (and possibly other people's) safety). WTP values are explicitly intended to reflect the preferences, perceptions and attitudes to risk of those members of the public who will be affected by the decisions in which the values are to be used. There are no a priori grounds for supposing that these preferences, perceptions and attitudes need necessarily be the same for road users and passengers on other public transport modes, such as the Underground..

Furthermore, a review of WTP studies shows that developing countries tend to have lower values of statistical life than do developed countries. A variety of factors could account for such an outcome, such as cultural influences on risk preferences and variations in labor market institutions. The dominant cause, however, is most likely that developing countries are poorer, and safety is a normal good. The value of a statistical life should increase with per capita income [8]. In contradiction with societal risk criteria, WTP values are normally independent of the size of the accident, i.e., the valuation of averting a fatality does not take into account the total number of fatalities.

The mean predicted VSLs from the meta-analysis regression models for the whole sample vary from M€ 3 to M€ 5.

An assessment of median predicted VSLs produced very similar results. For most regression models, the 95 percent confidence interval upper bound is double or more than the 95 percent confidence interval lower bound.

4.1.4.8.3. Other concepts: FAR

A fatal accident is an accident where people lose their lives during the accident or within a specified time after the accident. In literature on risk and safety this is often called the Potential Loss of Life (PLL). This is often used in risk studies based on models or estimation of fatalities of similar accidents. The number of fatalities might be related to an exposure measure to become meaningful. This measure is the time that a crew is exposed in hours. A standard value (Fatal Accident Rate) is obtained by dividing the values by 10^8.

4.1.5. The costs of accident consequences

O'Rathaille and Wiedemann [9] published a paper on the social costs of Marine accidents and Traffic Management systems back in 1981. It is one of the earlier examples of an integrated approach of risk reduction potential of VTS. They focus on the costs of loss of life and the costs of pollution, subjects which obtained not the attention that they deserve. Oil pollution damage can be caused by oil spilt but in many cases the clean-up effort caused more damage than the oil spilt often due to the toxic chemicals that attempt to disperse oil. It is extremely difficult to determine the damage costs, and attention needs to be given to the interests of the fishing and tourist industry. Heavy oil spills tend to smother shell fish and other marine life in the intertidal zone and in shallow water and the damage costs are difficult to estimate. It is known that £ 550,000 (1977) was paid to fish farmers for compensation of the loss of fish stocks.

The social costs of life depend on a reliable valuation of human life. The most fundamental objection is that this cannot be expressed in monetary terms, an objection that is heard on to the present day. A method that is used is take values of court awards for fatal injuries. It appears that insurance awards are also not an accurate measure since the wide range of compensations, which depend, among others of the premiums paid. The value of human life may be measured in terms of a person's expected lifetime earnings, or alternatively in the expenditure on safety measures per life saved. The first method yields a value for the life of seaman of £98,105 of 1977 prices The other valuation is based on expected lifetime earnings, measured by the present value of a seaman's output. The real rate of discount is assumed to be 10% and the annual average increase in productivity is assumed to be 3%. These calculations yield an estimate of £58,792 for the present value of a seaman's output. Assuming that officers earn 50% more than a seaman and that on every 3 seamen there is one officer the present value of the seaman's output is £68,591.

Giziakis [10] published a method to determine the costs of marine casualties also in the early eighties. The background of the research was that decision makers in the basis of a Cost/benefit analysis could take measures to improve the safety of marine traffic. The ship cost data were determined on different bases. The first was based on the pay out of the insurance companies for the losses of ships. The second method was an econometric approach. It is reasoned that the market value of a ship on the second hand market is the best indication of the present value of a vessel. A comparison of both methods indicated a more than satisfactory agreement.

The cargo costs were determined by using the market price for the commodities transported in the time span of the study. When data were missing the assumption has been made to use the weighted mean of the 10 most popular commodities was used.

The costs of a life lost were measured in terms of expected life time earnings. The monetary value was taken as k£ 120.

It is interesting to note that the pollution data are collected but that they were considered as insignificant.(!!!).

Table 1 shows the original data of Giziakis in an abridged format.

	# ships	average age	average GT	Costs of hull lost	Cost of cargo	# persons killed	cost of human life	total cost	people/ GT*1000	Total cost/GT
foundered	176	18	2,723	205,188	162,667	702	84,240	452,095	1.465	943.34
fire and explosion	287	19	6,980	343,748	300,444	443	53,160	697,352	0.221	348.11
collisions	118	12	3,550	162,725	130,471	180	21,600	314,796	0.430	751.48
grounded	346	18	6,880	438,383	409,536	115	13,800	861,719	0.048	361.99
miscellaneous	219			217,891	253,116	307	36,840	507,847	0.044	
total	1146			1,367,935	1,256,234	1747	209,640	2,833,809		
per year	286.5			341,984	314,059	437	52,410	708,452		

Table 1: Analysis of data according to the type of accident (Giziakis, 1983)

The costs of structural damage are based on data received from different sources, such as among others P&I-clubs.

Costs are fixed for each ship type, size and type of accident and include:

- delay costs (+ loss of income during repairing)
- loss of cargo
- repair costs damaged ship
- loss of ship and cargo
- salvage costs

The publications mentioned here marked the idea in the marine field should use accident data for an assessment of the efficacy of accident reduction measures apart from the insurance industry where an unlimited knowledge base exist of the financial claims of accidents and incidents.

The consequence costs of an oil accident are discussed in more detail in SKEMA Consolidation Study D2.3.2.2 “Evaluation of methods to estimate the consequence costs of an oil spill”

4.1.6. Pollution

The costs of pollution are difficult to determine. These are dependent of a variety of factors. When a spill occurs at some distance of the coast a number of physical effects will take place dependent on the viscosity of oil. Dispersion, evaporation are the main physical effects as can be seen in a simplified model of an oil spill in the Figure below. These types of graphs are necessary to determine what part of the spill will be beached and in what condition. The latter is an important regarding the costs of cleaning. The Figure also shows that if mechanical cleaning on sea is used that all attempts of cleaning will not be able to take a considerable part of the spill on board. Etkin [11] has produced numerical data from spills and these data can be used to build a model for the cleaning cost which may be used and actually is used in a number of cases. Since some parts of a spill where heavy oil is involved and since it becomes heavier than water the sea bottom may also be affected with very adverse affects for the aquatic environment these effects need to be incorporated in the cost equation.

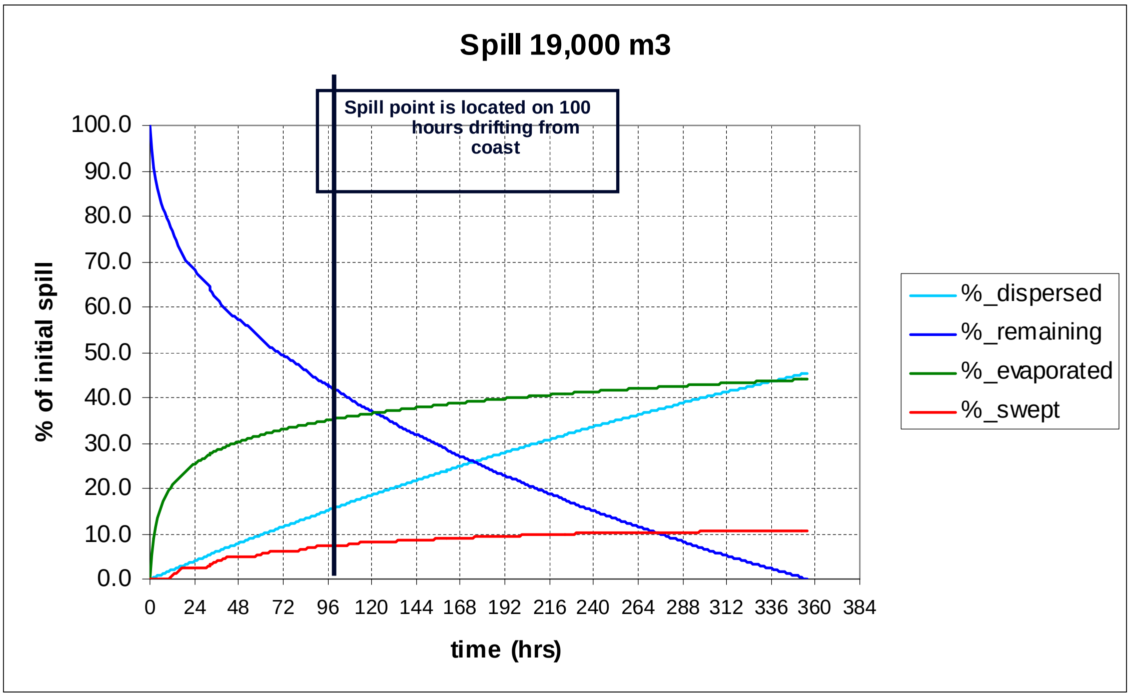

Figure 7: An example of the development of a spill of rather light crude oil.

A number of States which are exposed to bad weather sometimes use detergents to combat a spill. This technology is now much more advanced than was the case 20 years ago and the detrimental effects of spraying are now small. States located on shallow land seas, such as the Baltic refrain from spraying with a view that the water of these basins is refreshed by a small rate and the long term effects of the detergents are not fully known. Other States are dependent of their own capacity to handle such oil spills as the Netherlands and Germany. But even the States are in need of additional capacity when a large oil spill occurs in their area of responsibility. The Bonn Agreement is an example of an agreement to combat spills in their area and of mutual assistance in knowledge.

Other regional areas are having or considering similar agreements. The Helsinki agreement is important for the Baltic and under this agreement a defence system is built to mitigate any consequence of large spill in these waters. In the Mediterranean similar agreements will come in place.

EMSA have introduced Clean Sea Net as an observation system and this system of detecting spills and reports to the authorities involved, may help in finding perpetrators that dump oil residues and other pollutants by correlating the spill to vessels in the vicinity by a technology that is called back tracking. Probable polluters may be investigated by authorities when they call in a Community port.

The measures taken have resulted in a considerable reduction of oil that entered the environment. Since the seventies oil pollution is reduced by 50%.

4.1.7. Traffic Safety

4.1.7.1. Routing models

Routing models were used in order to describe vessel traffic at sea and in the approaches to ports. These route models were made by experienced masters of the Dutch merchant navy in case of the COST 301 project [12]. The job was of gigantic dimensions. For all European ports which were receiving vessels as indicated by the voyage records a network was made with links to connect these ports with all other ports. It became obvious that this task would exceed the resources that were available. It was then decided to implement a regional approach. This approach centered on a major port in a region as point of gravity for the other nearby ports. The regions were not large and the end result was that 200 regions were created. A port with a few thousand calls was considered a “region” in itself and was not a part of the designed regions. Checks of the link infrastructure were complex and it transpires that a number of links were missing. There was considerable debate on some aspects of the design of the route structure since in the shallow waters of North Western Europe routes for deep draft vessels may be quite different from the routes that are followed by small vessels. A compromise was found and the routes were thought to be suitable for vessels with drafts that could be received by the ports of destination. It should be remembered that ENCs were not yet invented although the first discussions on the creation of ENCs were taking place. In later developments ENCs were used in Embarc [13] and MarNIS [14].

The following step was the assigning of the voyage records to the route structure or in fact the link structure. Therefore a structure of size classes and types has been designed. Each vessel’s type and size was classified in a matrix. The link structure and the composition in vessel classes and sizes is the fundamental start for any marine traffic study.

The Dutch Administration was interested in the results of COST 301 and started a project called MANS (Management North Sea) and one of the issues addressed was the suitability and accuracy of the route model, which has provoked much criticism of authorities and navigation practitioners alike.

The Department of Transport was interested the traffic patterns on the Dutch part of the Continental Shelf as early as seventies. The Ministry embarked on a program of regular flights, called VONOVI (Verkeers Onderzoek Noordzee met Visuele Identificatie, Traffic Surveys North Sea with visual identification). A restart of the program in the period 1988-1991as a continuation of the observations in the period 1983-1987 was an excellent opportunity to verify the route structure [15]. The conclusions were that in 96% of the observations vessels were following a route that was assumed by the captains. In a small percentage the route structure needs small modifications. That result was encouraging although the routing measures taken did not leave an opportunity for the masters of the vessels present to choose another route without violating the Rules of the Road regarding TSSs.

The use of AIS base stations and AIS transponders on board has revolutionized marine traffic analyses to a great extent. In countries that have established an AIS network on their coasts, studies are made with respect to marine traffic and risk analysis. The use of an AIS data repository in Denmark is helpful for the execution of these studies in Northern waters.

The European projects EMBARC and MarNIS have used AIS data as far as possible. There are a large number of difficulties to overcome since many Administrations don't want to provide data to foreign research establishments, even when they promise not to use the data for commercial purposes. Even national research establishments suffer from restriction of their use.

4.1.7.2. COST 301

4.1.7.2.1. Introduction

COST 301 was a study on VTS initiated by the European Commission to study the complex subject of marine traffic [12]. Accidents have large consequences and these led to the desire of implementing effective measures to reduce adverse consequences to crew, passengers and environment.

The objectives of the project were:

- To increase the knowledge of marine traffic in European waters;
- To provide a framework of concepts and associated parameters for assessment and implementation studies.

A major result of the project was the determination of the number of vessels at any one time in the COST 301 area. The COST 301 area consisted of the area around the west European countries until roughly the 200 nm boundary, as well as the total area of the Mediterranean and the Baltic. This was the first time that a reasonable estimation could be made of this number of vessels on the basis of voyage records collected in a database by LMIS[2i]. It took another 20 years before similar data from AIS became available. Since the introduction of AIS base stations along the coasts of the member States the number of AIS-vessels in a given area is easy to determine with the software developed in the meantime by AIS equipment suppliers.

4.1.7.2.2. Number of vessels present at any one time

As an example of the number of vessels present at any one moment is given in Table 3. The results were based on database in which the voyage records were stored as collected by local agents. The results did not contain data on ferry connections national as well as international and data on the national trade (cabotage). Additions to these numbers were made in order to arrive at the best possible estimate. It should be noted that the numbers given in Table 1 don't comprise the vessels that are in port. This number is probably of the same order of magnitude as the number of vessels in ports.

size classes in GT		100-	500-	1600-	10000-	60000-	100000+	
ship type		499	1599	9999	59999	99999		Total
Tankers (oil-bulk-ore)				1.9	20.3	10.7	1.6	34.5
Tankers (chemical)		5.9	72.1	45.2	19.6			142.8
Tankers (water, wine, replenishment)		12.9	9.7	4.3	0.9			27.8
Tankers (oil)		81.4	87.6	54.5	178.5	22.9	23.8	448.7
LNG carriers			1.7	1.2	2.6	1.3		6.8
LPG carriers		4.6	16.0	32.0	8.5			61.1
Gas tankers remaining		0.4	0.2	2.1	0.3			3.0
Bulkers		1.2	3.8	48.4	291.6	7.9	0.4	353.3
Unitised (excluding passenger ferries)		8.6	82.8	133.1	68.7			293.2
General dry cargo		822.0	636.0	772.1	145.2	0.4		2375.7
Passenger ships		11.2	6.7	32.8	1.3			52.0
Ferries		14.0	14.1	132.7	28.3			189.1
Total		962.2	930.7	1260.3	765.8	43.2	25.8	3988.0

Table 2: Average number of vessels present at any one time in the COST 301 area in 1984/1985

[2] Lloyds Maritime Information Service

For statistical purposes as well as for risk analysis purposes the total ship-miles covered in a year is of great interest in order to calculate casualty rates. The next Table provides the results of ship-miles sailed. One should keep in mind that the figures are under estimating the real values since there is a strong underreporting on voyages in the small size classes. The reporting agency exempted vessels in the local trade, ferries and no agents were present for very small ports to report vessels' movements to the central database.

size classes in GT ship type		100-499	500-1599	1600-9999	10000-59999	60000 +	Total
Tankers (oil-bulk-ore)				165	2,515	1,547	4,227
Tankers (chemical)		1,456	8,042	5,550	2,588		17,636
Tankers (water, wine, replenishment)		6,302	7,915	5,626	22,306	5,881	48,030
Tankers (oil)		409	1,717	4,071	1,546	212	7,955
Gas carriers		409	1,717	4,071	1,546	212	7,955
Bulkers		84	334	5,309	35,273	991	41,991
Unitized (excluding passenger ferries)		756	9,075	16,850	11,191		37,872
General dry cargo		66,285	60,516	90,279	20,381	79	237,540
Passenger ships/Ferries		2,328	2,303	23,210	4,265		32,106
Total		78,029	91,619	155,131	101,611	8,922	435,312

Table 3: Number of ship-miles covered by vessels I 1985 in the COST 301 area. Unit is 1000 nm.

In Volume 3 of this report more information on the casualty rates can be found.

4.1.7.2.3. Exposure models

There are some models to calculate the encounters. Use has been made of the model developed in [16].

This model is extensively used in the COST 301 studies and it formed the basis for the MANS model which was later updated to the SAMSOM model. The model was used and perfected in successive projects. It played a role when the collision risk of platforms in the North Sea was calculated using different models for the route structure leading to erratic results. Presently analogous problems are encountered regarding wind parks in the shallow parts of the North Sea and the Baltic. Again a wide variety of results are apparent. The Dutch Administration took the decision that the risk of all intended wind parks in areas under Dutch jurisdiction should be evaluated in the same manner. A commission then advices the responsible minister on the suitability of the location of wind parks taking all relevant factors into account.

4.1.7.2.4. VTS efficacy

When one uses the “encounter” notion in studying the efficacy of VTS one may compare the calculated collisions with the collisions that are recorded in area where VTS and pilotage is present [17].

The following Table was derived from COST 301 results. It shows the MCR s per 100, 000 encounters in the entire COST 301 area, in the VTS areas and in the COST 301 areas which have no VTS.

type	MCR (COST 301)	MCR (VTS)	MCR(no VTS)	Efficacy
Meeting	0.589	0.310	0.636	0.487
Crossing	4.381	3.888	4.500	0.864
Overtaking	0.640	0.104	0.765	0.136
All encounters	0.818	0.533	0.871	0.612

Table 4: The Mean Collision Rate per 100,000 encounters in the COST 301 area[3].

The effectiveness is around 60%; this means that a reduction of 40% has been attained. It is also at the same order as the results of a questionnaire in EMBARC. This questionnaire was designed to collect expert opinions of the effect of pilotage, shore based pilotage and VTS on the number of accidents to determine the best risk option.

4.1.7.2.5. Number of ship miles sailed between encounters

In order to understand the meaning of encounters and the density of traffic the average distance sailed between encounters, Table 5 was produced. This Table was helpful to envisage the situation on the bridge of a vessel in dense and less dense traffic.

type	COST 301	VTS	no VTS	Increase
Meeting	21.1	4.4	23.9	5.4
Crossing	283.2	44.4	340.9	7.7
Overtaking	105.2	16.9	125.8	7.4
All encounters	16.55	3.25	0.871	5.8

Table 5: Average distance sailed between encounters

[3] The COST 301 area was defined in the final report, but to get an idea of the size of this area it is of the same magnitude of the sum of all SRRs.

The traffic in an approach area to a port is busier than at sea. If we assume a speed of 12 knots then in a VTS area every 15 minutes an encounter will take place whilst this happens on average every 80 minutes.

These types of calculations are useful to determine the average workload of the watch officer and the need to assist the navigator on the bridge of a merchant vessel.

4.1.7.2.6. The effect of the navigator on collision avoidance

The following Tables display the effectiveness of the navigator and his navigation equipment in avoiding collisions in the three modes: meeting, crossing, and overtaking. The effectiveness is defined by the ratio of hard encounters and the number of collisions. A hard encounter is a collision of two vessels in which neither navigator takes avoiding action. The domain of the vessel is equal to the area of length and beam of the vessel.

Type of vessel	Meeting	Crossing	Overtaking	All encounters
Passenger vessels And ferries	22,339	5,104	18,614	13,142
Unitized vessels	8,975	2,090	13,417	7,042
Dry cargo vessels	7,537	1,346	6,914	5,586
Chemical tankers	5,836	933	3,290	3,870
Bulk vessels	2,833	1,401	4,428	2,642
Oil tankers	3,579	650	3,345	2,598
Gas tankers	3,477	738	2,252	2,439
Tankers/oil/bulk/ore	765	643	1,484	812

Table 6: Factor of Effectiveness of the navigator in avoiding collisions as function of type of vessel

Size of vessel in GT	Meeting	Crossing	Overtaking	All encounters
100-499	19,029	2,377	19,687	13,426
500-1,599	8,109	1,359	5,779	5,508
1,600-9,999	4,819	1,509	4,585	3,748
10,000-59,999	2,518	1,064	3,376	2,253
60,000+	1,702	763	2,996	1,517
All vessels	6,287	1,456	6,088	4,765

Table 7: Factor of Effectiveness of the navigator in avoiding collisions as function of size of vessel

As can be seen in Tables 6 and 7 passenger vessels and ferries have a “favorable” on board factor, opposite to tankers. Ferries and passenger vessels are frequently sailing the same routes. The navigators of these vessels may have accumulated a high amount of local knowledge relative to the traffic patterns on their journeys

Table 7 shows a marked decrease of the factor of effectiveness with the size of the vessel. This might be due to the maneuvring characteristics of these vessels.

The general effectiveness of the on-board factors in terms of avoidance of collision is approximately 10^{-3}. This factor may be regarded as representative for the whole process of collision avoidance: detection of targets, evaluation of the probability of collision, decision as to make what maneuver and when, appropriate implementation of that decision and monitoring of the progress of the implemented maneuver.

It should be remarked that the figures are related to 1986. Safety figures improved until 2006 with 1.5%-2%.

4.1.7.2.7. Epilogue

The information of COST 301 is outdated. The basic information is at least 25 years old and as such is not relevant for the solution of present questions. But COST 301 provides invaluable concepts with respect to marine traffic, accidents and densities that were in the pre-COST 301 undreamt of. In COST 301 for the first time it was possible to calculate the number of vessels presents at any one time in any arbitrary area and it was possible to determine the composition of these vessels. The use of surveys to collect data about the behavior of vessels could be reduced and risk analyses could be easier performed. The accuracy of the links (connection from waypoint to waypoint) was high due to the expertise of the masters which were defining waypoints and links. It was a relief that use could be made of visual observations of vessels from a coastguard plane which patrols special areas for oil pollution and identified perpetrators. Comparison with the results of aerial observations and the links appeared to be very good and only 3% of the links was repositioned, sometimes no more than a few cables.

The use of traffic on links enables the calculation of total distance sailed and the calculation of potential encounters. This was a major effort to do that correctly and was the basis for accident analysis and the calculation of collision rates. The invention and the use of ECDIS was a major step forward. The routes could be plotted on a chart and a scrutiny of the drafts of the vessels in relation to the available depths indicated in what positions the maneuvring room was restricted.

4.1.8. Risk equation and applications

4.1.8.1. Background

In the European project EMBARC the question was discussed in what way AIS could be used to identify vessels which pose a larger risk to the environment and to the passenger and crew and in what way this risk can be used by traffic operators to make recommendations to these vessels. The development used different tracks. The first development was the construction of a so-called risk equation. It was reasoned that sufficient statistical material was now available to construct such an equation. A second step was the choice of the dimension of the risk. Should it be indicated in €/(unit of time) or in any other system that can compare risk and classify it? The expression of risk in €/ (unit of time) is convenient and readily understandable for everybody but involves a lot of decisions regarding the valuation of the costs of pollution and the costs of loss of human life. Having studied the results of multi criteria method it was finally decided to take the more challenging method of the use of risk expressed in €/(unit of time).

The basic document was part of the activities in WP 3 of EMBARC and it was the beginning of a large flow of publications. These reflect the development since then. Although the use of the statistical value of life is simple, there is lot of discussion on the use of these values. It is reported that member States in IMO were very critical on the use of this value because they found its use unethical. Later attempts to determine this value have given more precise description of this value and in safety literature this value is more used.

In order to demonstrate the use of the risk equation in a port environment, examples were given for the ports of Goteborg, Genova and Rotterdam. The Dutch Administration wanted to have an analytical tool to determine what vessel should be inspected when it called at a Dutch port in excess and above the rules of Port State Control. The developed method was not seen as suitable since many factors were implied from statistics and not from observation on board. The method finally is applied on the use of VTS and pilotage, on shore pilotage not excluded.

The costs of pollution are also a hotly debated subject. The first estimations used a general value for clean up in €/(ton of oil beached) but as statistical material became available in databases a successful attempt was made to calculate the costs of a spill.

In MarNIS this method was taken as part of the calculation of the costs of oil pollution as function of type of oil, weather conditions, quantity of oil spilt, distance to the coast and nature of the coast. The long term effects of an oil spill are also taken into account, but it is doubtful whether these effects are properly modeled, given the wide variety of opinions that are often affected by political opinions.

The risk equation leads also to a development in the legal treatment of risk. Sage [22] played a large role in the discussion of developments that Governments may intervene in situations where Risk Vessels are involved. The major tools were UNCLOS using a more flexible interpretation of the duty of the contracting parties to avoid pollution as well as the use of the precautionary principle. This development is for the time being concluded [t]. The basis is used to develop a practical approach for so-called Alert Vessels and High Risk Vessels (HRVs).The precautionary principle is part of European law and recognized by IMO.

In MarNIS the use of risk values was promoted in an experiment in the MRCC Milford Haven. The supplier of the AIS system around the British Isles took the opportunity to implement the display of risk values using web services. Valuable opinions were collected and it became clear that trainings requirements need to be reviewed and new training modules introduced in order to initiate risk based monitoring and action when risks are exceeding thresholds. During the VTS symposium in Bergen in 2008 the system was shown to prospective users.

The developments on the risk equation and the use of it in port case are further discussed in the following sections.

The project MarNIS illustrated the use of the risk equations and in 2008 some results were shown during a demonstrator in Genova. The demonstrator was successful.

It is clear that EMBARC and MarNIS were the focal points of the development of individual risk of vessels in their environment with a view of monitoring and mitigating risk of vessels in the coastal seas, but are there other initiatives with respect to individual risk of vessel?

A search in literature provided an interesting paper that was partly based on MarNIS [18].

This paper presents a new approach of the maritime risk assessment for safety at sea based on a risk factor determined by a fuzzy expert system. The objective is to design a new and flexible decision tool to be fitted to existing vessel traffic monitoring and information systems (VT(MI)S) or naval communication and information system

(CIS). More precisely, the paper proposes an approach to evaluate the casualty risk. The identification of risky ships is, nowadays, an important research theme. Like this, a few studies have been realized to identify high risk ships [19], [20], [21], and [22]. Degré proposed a risk factor which is an individual index allowing the risk rating to be quantified for each ship. He defined an individual ship risk index for safety at sea (IRIS). Moreover, Degré and Benabbou (2005, 2004) determined the general expression of this index and showed that it was possible to assess risk in real time. So, automatic detection of high risk vessels can be realized and decision process of authorities in charge of safety at sea be improved. In his study, Degré made a data analysis of maritime accidents listed by the International Maritime Organization (IMO) for several years. Thanks to this analysis, he proposed to take into account not only the static parameters (such as the ship's age, type, flag) but also the dynamic parameters (such as the meteorological conditions).

These research perspectives are very attractive because this kind of system allows an individual ship's risk factor to be determined to generate visual alarms in a maritime surveillance zone, in real time. This is an essential issue for environment protection. Next step will be to apply these results to oil pollution prevention at sea. In this case, it will be necessary to consider other dynamic parameters such as, for example, the speed evolution of ships.

4.1.8.2. Introduction

Risk based studies were introduced in the recommendation to use Formal Safety Assessment .The idea was to compensate structural safety shortages in an effective fashion. Several innovations could be recommended, among others, increase in freeboard in the f'c'sle to reduce the possibility that hatch covers are smashed in and the vessel eventually founders.

Based on some studies recently being carried out in a number of member States, it was thought that sufficient statistical information was available to determine a risk index for vessels of a certain type and size class. These studies show that the accident sensitivity may be also dependent on age and classification society.

If one analyses the large disasters along the coast that had crucial consequences, one finds often the same pattern: older vessels that transport dangerous goods and have changed their nationalities and owners often.

The risk index may also have applications in other problems, such as:

- Determination of vessels that should be carefully monitored in the littoral sea;
- Determination of required nautical support of vessels arriving in a port, number of pilots, remote pilotage or certificate of exception for a ferry captain;
- Determination of the insurance premiums based on risk by insurers.

The first issue is of great importance for Vessel Traffic Management at sea. It will be discussed in the remainder of this section.
The second issue can only be discussed when the interaction between the vessel and the port's infrastructure can be sufficiently accurate described. This requires an in-depth analysis of the risk of a vessel in a port and the effects of a number of issues, such as:

- Quality of crew;
- Status of equipment;
- Construction of the vessel;
- Knowledge of the lay-out of a port and knowledge of local (communication) procedures;
- Manoeuvrability of the vessel in restricted waters;

On the basis of a number of risk control options (RCO) such as:

- VTS
- VTS and pilotage
- Remote pilotage;
- VTS and two pilots on board, and
- Tug assistance.

it should be possible to determine the risk reduction of each option. It is now possible to calculate the costs of each option: the remaining risk in monetary units and costs of the RCO (costs of VTS, pilotage, remote pilotage and tug assistance). The preferred option is the option with the lowest consolidated costs.

Weather effects are important because high winds may increase the risk with a factor 5. This would signify that some vessels don't require, apart from VTS which is customary and often mandatory, a pilot or tugs, but in bad weather, for example BF 7, do require a pilot and tugs.

4.1.8.3. Risk in ports

Part C of this report describes the execution of a FSA in a port environment with respect to the required Navigation Support Services. This report is an improved and extended version of the report that was published in the EMBARC project. The term Navigation Support Services comprises all navigation services that are used to make a call in a port efficient and safe.

These services comprise, VTS and pilotage, but tugs and mooring gangs are also important and are addressed in the FSA.

EMBARC has developed a FSA to determine the level of nautical assistance of a vessel that calls in a port. These nautical services normally comprise VTS services, shore-based pilotage, pilot on board and pilot on board with a PPU[4].

The FSA consists of the determination of the risk of a vessel that will enter a port without any assistance. The risk is based on the determination of frequency of an accident and the average consequences of an accident. Seven types of accidents are distinguished. Each has its own accident rate. The frequency of accidents is dependent on distinct factors, such as age, classification society, flag and type. Weather and fog are time dependent factors which are also taken into account.

The nautical services are seen as Risk Control Options. Pilots and other experts have determined the risk reduction factor, and also the multiplication factors that need to be applied on the average risk level.

For each vessel dependent on the distance sailed in a specific port a monetary value of the risk is determined. The effect of wind and fog are considered as time varying risk increasing factors. These effects will also be apparent in a longer time needed to navigate to or from the berth and the time required for berthing and unberthing. In order to optimize i.e. to determine the optimal nautical support for each arriving or

[4] PPU is Personal Pilot Unit

departing vessel, the costs of each form of assistance in monetary terms are calculated. That form of assistance is chosen that minimizes the monetary values of risk the ship's time and the costs of assistance rendered as function of the wind force.

The method has originally been programmed for the port of Rotterdam, but many improvements have been made. The method is also being used in Genova and Göteborg.

As an example, the results of the method are available in www.cetle.info for inspection of the different areas and vessels.

The dynamic risk assessment in ports is presented in more detail in SKEMA Consolidation Study D2.3.2.3b "Dynamic risk management methods – ship risk indexes Part 2".

4.1.8.4. Risks at sea

Part C of this report deals with risk at sea.

This report attempts to clarify the concepts of an alert vessel and H(igh) R(isk) V(essel) that are introduced by MarNIS. This project dealt with MOS centers as the national center where under one roof all authorities with a maritime interest can follow maritime traffic in the area of responsibility of a member State seen from different perspectives. In other SKEMA reports many of the innovations and coordination issues are discussed. This report focuses on the mechanisms that may be used to designate a vessel as an alert vessel. The designation has no juridical consequences. The traffic display in use by the MOS-operator might show that the risk of some vessels is increased and a change in color may indicate the "alert status" of the ship. When the MOS-operator, according to the standing orders of the MarNIS representative, finds that the situation requires risk reducing measures, he may take them. According to UNCLOS and the developments of international environmental law the competent authority of the member State i.e according to MarNIS, the MarNIS representative may instruct the vessel to take another track. This is a consequence of the Precautionary Principle. It is obvious that there are many areas where instructions to vessels will add to confusion and that these instructions should not be given to vessels. The southern part of the North Sea is among the areas which are not suitable for instructions regarding new tracks to be followed by HRS. The coasts of Norway, France and Portugal are suitable to implement these measures to reduce risk.

A competent authority may also declare a vessel a HRS when there are conditions and circumstances that may imply the competent authority to believe that the vessel is posing a risk. Normally the procedure of declaring a vessel a HRS is a follow on of being an alert vessel but the competent authority needs to have the power to interfere when the environment is threatened. The next step may be that under all circumstances of high risk including the loss of life or the loss and/or the risk of the loss of a vessel the MOS-operator may declare a vessel an alert vessel or a HRS

The major innovation is the way in which risk mitigation is proposed to be implemented in a MOS-centre. A risk index is introduced that indicates the risk of the vessel. It is based on ideas generated in an earlier European project. The idea is that the probability is dependent on a number of static parameters, but also on weather parameters. The societal consequences can be calculated based on available figures on fatalities on board vessels as a percentage of the crew and the number of passengers and the consequences of a spill. These spills may be cargo spills or spills due to rupture of fuel tanks. The valuation of spills requires massive spill data as well as costs of cleaning up operations. The results are given in €/hr. MarNIS has analyzed the risk equation as developed in EMBARC. Especially the multiplicative character was checked and the result was that this character was the best fit for a calculation model.

The risk is divided in three parts. The first part is the risk associated with the loss of life. Another part is associated with pollution. This part may be indicative for the risk of pollution. International environmental law and the use of the precautionary principle allow the relevant authority to designate the vessel as High Risk Ship, which means that this authority may give instructions to the master of the vessel. The European directive 2002/59/EC provides the possibility that a competent authority can instruct the master of a vessel to stay in port as the weather conditions at sea are abominable. The last part is the material damage indicator.

The invention of computers was the genesis of real data collection and later data analysis. After 25 years, sufficient data are available to analyze and determine the parameters of the risk index. But an on-line calculation was only possible when the position of the vessel was instantly known and could be combined with ship parameters. SRR technology, such as AIS, and reporting procedures, such as MIM are developed and proposed by MarNIS. The information regarding the dangerous substances needs to be provided by SafeSeaNet in order to complete the required information.

Display technology has advanced in such a way that based in an ENC graphical information can be shown on a screen. Advances in technology have also been used to overlay weather information in an ENC. This allows the MOS operator to assess a situation in relation to the weather. This information may be provided by a weather provider in a format that allows to using overlays.

The risk can be calculated on line using the database information and the SSN information as well as the information of the AIS. The weather information can be provided by a weather server. The update time is dependent on the number of targets, but generally is less than 30 seconds. The target moves with the speed of updating of the AIS position and the risk value is updated when the calculation is finished.

The MOS operator obtains a traffic image with AIS targets labeled as appropriate with a risk value and clicking on the target the three components of the risk can be seen. What can the MOS-operator do with this information?

A MOS-operator might declare a vessel a High Risk Ship when the pollution risk is significantly higher than the average risk, the MOS operator may do so when he believes that there is a manner to reduce the risk. In MarNIS an intensive debate was held on the use of mitigating measures.

In MarNIS the problem is partly solved to determine the sensitivity of the coast with a ranking method, although the costs of damage could not be determined and the calculation of the damage costs of pollution was based on cleaning costs and the damage to the water column than on the functional loss of the coast.

The only viable option to reduce the risk of a vessel is to change the track of the vessel and for anti pollution reasons to select a track with a larger distance to the coast. If a track is selected that is too far from the coast when the vessel has become a HRS the costs of implementation might be disproportional.

MarNIS has adopted a new method to determine the distance from the coast of a risk vessel. It consists of the minimization of the risk costs and the operational costs of the vessel. The operational costs are not known, but can be estimated with relative ease once a decision is made regarding a uniform manner of calculation. The MOS-operator can use the method and calculate an optimal distance from the coast. It appears that the risk can be reduced when the legs of the route are long. The results of the calculation show that only in cases of bad weather the distances from the coast are considerable; this type of weather occurs in 20% of the time. In the remaining time a route may be selected closer to the coast.

A calculation of the position of the Vardø TSS in North Norway indicated that the TSS was in the right position for about 20% of the time and could be located nearer to the coast in the remaining time. The criticism often heard is that a risk approach is detrimental for ship owners. This is not correct. On the contrary, use of these methods will provide benefits to the ship owner since the incidence of relatively good weather is more frequent than bad weather. These results deserve a fundamental discussion and might be the beginning of revalidation some of the principles of routing in non dense traffic areas.

Since the risk approach is one of the major issues of this report a lengthy chapter is included on the background of risk in this report.

VTS is much more interactive in that information can be provided by the MOS operator. It is assumed that the information from the shore is so complete that general information to particular vessels will seldom provided by a MOS-operator with a VTS task. A VTS area can be established as a part of a SRR and the normal procedures are valid. When a part or the whole area of the VTS is in territorial waters instructions may be given to masters. When in international waters no instructions can be given to masters, unless the alert value exceeds a given threshold, the vessel is declared a HRS and the MOS-operator thinks that a new track is feasible. It should be assumed that in territorial seas this is seldom the case near an approach of a port. In international waters the MOS-operator disguised as a MOS-operator might declare a vessel a HRS and take measures as a new track to be followed. Generally speaking: in an offshore area where the competent authority finds that the establishment of a VTS is necessary, the chances to find a new track for risk vessels are small.

A basic consideration is that a VTS for rendering assistance/information to vessels a need to have a complete traffic image. Since small vessels and leisure craft are not yet obliged to carry AIS there is a need to obtain other images of the traffic. A non co-operative system as radar and sensor fusion technology is the solution to get the required image. When the traffic composition is known, one may think that only AIS as sensor is acceptable when the traffic participants know the capabilities of the VTS and know that they are completely ignored and that certain categories of vessels may

need to take care of themselves. This can be done in ports and approaches where no inland navigation traffic takes place and the presence of leisure craft is exceptional.
Directive 2002/59/EC states that the competent authority can instruct vessels not to proceed to sea when the weather is so bad as to endanger the safety of life at sea. UNCLOS provides the possibility that for environmental reasons the master is instructed to take another route. When a passenger vessel or a ferry with many travelers on board gets a value of the risk to people is too high when in international waters, there is no possibility that measure against the vessel are taken.
The division in AIS monitoring and VTS has also a practical significance. When an operator monitors traffic to detect symptomatic events, he may be able to monitor 100+ vessels. The assumption is that the operator is assisted by software that enables him to detect these symptomatic events. When a VTS area is guided by an operator 30 vessels at one time is the maximum which he can guide, based on experience in a port VTS. Monitoring with AIS is the best option in order to keep the amount of personnel manageable.

The dynamic risk assessment at sea is presented in more detail in SKEMA Consolidation Study D2.3.2.3a "Dynamic risk management methods – ship risk indexes Part 1".

4.2. Contributions by related EU projects

Three projects have substantially contributed to the work of determining marine risk. The first is COST 301 (1986) which indicated the way in which voyage data are analyzed in order to get a routing model. Also the collection of accident data to be used to construct risk distributions was a milestone. This was possible by the theory of encounters and their calculations and the use of computers that were able to make for each link in the routing model s composition of the fleet of vessels that were using that link.

The invention and the use of AIS has made the analysis of traffic data much easier bit the routing model developed by experienced retired masters was rather accurate and needed small modifications as compared to the AIS routing, especially in the North Sea.

Cost 301 marked also the beginning of an era where risk was slowly reduced to 2005 levels. Since then the reduction of risk stopped and there are tendencies that the risk since then is increasing. COST 301 marked also the usefulness of quantification in maritime risk and safety issues.

EMBARC was the first project that discusses a ”risk equation”. This was due to future use of AIS by coastal authorities and the monitoring of traffic. Given the fact that for monitoring purposed the number of monitoring personal is way too small to have a real authoritative monitoring process of traffic could a method be devised that indicate the risk of a vessel? That would assist the operator in dividing his attention to risky vessels and vessels that are supposed to be less risky.

The use of dynamic risk was demonstrated in a port environment. When the principles of FSA and ALARP are used, it was possible to determine the situation where “risk costs” and “exploitation costs” were minimal as function of the risk mitigating systems, such as port VTS, Pilotage, Shore based Pilotage.

The method gave realistic results: a shortcoming was the variability in the need for pilots mostly as a result of weather. A smaller number is required when the weather is good and a large number is required when there is bad weather but still good enough for the vessel to enter the port.

MarNIS was a large project. It was divided in Maritime Information Management (MIM) and Maritime Operational Services (MOS). Although the former is important for the information that is used by a MOS center, the emphasis in MOS was placed in proactive activities in order to minimize pollution. Other tasks of the MOS center, such as SAR and OPRC were not essentially changed. The proactive activities of a MOS are based on the value of the risk of the vessel under consideration and the implementation of risk mitigating measures.

This method may be applied by MOS centers, when sufficient information is available, among them AIS and space AIS.

When the mechanisms of oil spill are studied in detail then it becomes clear that the only way to affect the amount of oil beached on a coast as a result of point source of oil entering the water as a result of an accident is to let the accident happen as far from the coast as possible. Since the frequency of accidents is a function of the weather conditions a solution is to send vessels farther away from the coast. For small vessels this might not be a sensible method since in the open seas the frequency of mishaps is larger. For these vessels MOS can intervene by forbidding that under anomalous conditions set sail and the permission to leave a port or a safe haven will be granted when the weather conditions improve according to Directive 2002/59/EC.

The power to send vessels away to ne new track does exist now under application of the Precautionary Principle as accepted by the EC as well as IMO. Some experts also believe that the provisions of UNCLOS in themselves are able to provide authority to a member State to send a vessel away from the coast when explicitly these powers are given to a competent authority. The measures taken by that authority are based on environmental grounds but they need to be proportional to the environmental danger.

The use of the ALARP principle may be applied. This is done to recommend a track that is the result of a minimum of the exploitation costs and the risk costs.

The principle needs to be implemented with care and to avoid excessive claims very accurate weather forecasts are necessary so that authorities don’t give a new sudden track to a vessel that is uneconomical for society.

Although the principles are clear there are a lot of implementation details that need to be studied. The results of MarNIS with regard to the proactive monitoring and MOS are presently considered by the EC. Which recommendations will be supported to be discussed in international forums is not known.

4.3. Recommendations

The most important recommendation is that member States and other authorities making use of maritime risk analysis start using a dynamic risk model. These applications will be enhanced when accurate numerical data regarding vessels, routes become available. The use of AIS and MOS centers is a very important step to collect this information for future risk management work

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Maritime Transportation: Safety Management and Risk Analysis
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5.3. Key projects

- COST 301
- EMBARC
- MARNIS

5.4. Related projects

None

5.5. Key journals, conferences / events,

5.6. Key web sites

The COST 301 project was launched in the period that internet was being used by a limited number of scientific users. Consequently there is and was no website. EMBARC had an own website but this website ceased to exist when the results of the project were approved and the final administrative formalities were finalised. CETLE decided that the tangible results of the project should survive. These results can be found under
http://www.cetle.info/author/.magnolia/pages/adminCentral.html

The user name and password are:
username is: sma_guest
password: stockholm2010

The project website of MarNIS is still in the air: www.marnis.org

Annexes

In this Annex anecdotal background is given to the examples given by Corcoran [6]. They are based on information available on Internet and serve the purpose to elucidate the line of reasoning as developed in [6].

1. The Three Miles Incident

The Three Mile Island accident of 1979 was a partial core meltdown in Unit 2 (a pressurized water reactor manufactured by Babcock & Wilcox) of the Three Mile Island Nuclear Generating Station in Dauphin County, Pennsylvania near Harrisburg. It was the most significant accident in the history of the American commercial nuclear power generating industry, resulting in the release of up to 481 PBq (13 million curies) of radioactive gases, but less than 740 GBq (20 curies) of the particularly dangerous iodine-131.

The accident began at 4:00 a.m. on Wednesday, March 28, 1979, with failures in the non-nuclear secondary system, followed by a stuck-open pilot-operated relief valve (PORV) in the primary system, which allowed large amounts of reactor coolant to escape. The mechanical failures were compounded by the initial failure of plant operators to recognize the situation as a loss of coolant accident due to inadequate training and ambiguous control room indicators. The scope and complexity of the accident became clear over the course of five days, as employees of Metropolitan Edison (Met Ed, the utility operating the plant), Pennsylvania state officials, and members of the U.S. Nuclear Regulatory Commission (NRC) tried to understand the problem, communicate the situation to the press and local community, decide whether the accident required an emergency evacuation, and ultimately end the crisis.

In the end, the reactor was brought under control, although full details of the accident were not discovered until much later, following extensive investigations by both a presidential commission and the NRC. These reports concluded that either there will be no case of cancer or the number of cases will be so small that it will never be possible to detect them. Several epidemiological studies in the years since the accident have supported the conclusion that radiation releases from the accident had no perceptible effect on cancer incidence in residents near the plant.

Public reaction to the event was probably influenced by the release (12 days before the accident) of a movie called *The China Syndrome*, depicting an accident at a nuclear reactor. Communications from officials during the initial phases of the accident were felt to be confusing.http://en.wikipedia.org/wiki/Three_Mile_Island_accident - cite_note-4 The accident was followed by a cessation of new nuclear plant construction in the US.

2. The case of St Rafael hospital

In a record settlement between a Connecticut hospital and state regulators, New Haven's Hospital of St. Raphael agreed T to pay $250,000 to end the state's investigation of a case involving the deaths of two patients last winter. Both women suffocated in January because the oxygen mask used during a routine heart procedure was mistakenly hooked up to a source of nitrous gas. Two other patients also accidentally got the potent anesthetic instead of oxygen before the error was discovered, but both survived.

A woman, 72, and one of 68, died in January during cardiac catheterization, a procedure which involves inserting a line through an artery in the groin and guiding it into the heart to detect, or clear, blockages.

The death originally was attributed to her age and frail health, and put down as "natural" by an assistant state medical examiner who filled out her death certificate.

In fact, a hospital technician had mistakenly attached the oxygen line leading from the mask to a tank of nitrous gas. While the nozzle for an oxygen line has special prongs that prevent any other kind of gas tank to be hooked up, one of those prongs was broken off in this case. The mistake was discovered four days after the death, when another patient's oxygen level and heart rate plummeted during the same procedure in the same lab. Hospital staff noticed the faulty hookup after they had spent minutes trying to revive the patient with even more "oxygen" that was, in fact, the deadly nitrous gas. The day before her death, medical staff noticed that two other patients hooked up to the same equipment suffered low oxygen levels and lowered heart rate during their catheterizations, but did not determine the cause of the problem.

3. Ford Explorer-Bridgestone/Firestone case

The Firestone tire recall is perhaps the most deadly auto safety crisis in American history. US regulators on 16 October, 2000 have raised the death count to 119 (the death count has steadily risen from 62, later to 88 and 101 deaths reported on 9/20/2000). Experts believe there may be as many as 250 deaths and more than 3000 catastrophic injuries associated with the defective tires. Most of the deaths occur in accidents involving the Ford Explorer which tends to rollover when one of the tires blows out.

In May 2000, the National Highway Transportation Safety Administration issued a letter to Ford and Firestone requesting information about the high incidence of tire failure on Ford Explorer vehicles. During July, Ford obtained and analyzed the data on tire failure. The data revealed that 15" ATX and ATX II models and Wilderness AT tires had very high failure rates: the tread peels off. Many of the tires were made at a Decatur, Illinois plant. Worse, when the tires fail the vehicle often rolls over and kills the occupants.
Ford Officials estimate the *defect rate is 241 tires per million for 15-Inch ATX and ATX II tires*. By contrast Ford says there are no defects in 16 Inch tires per million and only 2.3 incidents per million on other tires.

On August 9 both companies decided on the recall. Ford and Firestone disagreed as to how to break the news. Bridgestone/Firestone officials wanted to read a statement at a joint briefing without answering any questions. Ford strongly disagreed with this strategy and warned of disaster if they refused questions. Ultimately questions were asked, many of them remain unanswered.

Bridgestone executives continue to deny problems and downplayed the significance of the failure.
"No specific problem was found with the design or production method of our tires." According to Tadakazu Harda, Bridgestone, Vice President of overseas operations quoted during a news conference in Japan on 9 August 2000. Indeed Bridgestone still continued to maintain that the tires were not defective. Mr. Harada stated: "judging from the fact that most of the accidents occurred in Southern states, we estimate that driving in high temperate, at high speeds and under tire pressure are factors in these

accidents."
Ironically Ford itself countered this suggestion. First, Ford pointed out from 1995 to 1997, a rival company Goodyear also supplied two million tires using the same specifications Firestone was using. Nearly 500,000 were equipped on Ford Explorers with any evidence of failure, according to Ford officials.

Ford's Role: Did they Know?

Ford Motor Company documents indicate that company officials had data that Firestone tires installed on Explorer sport-utility vehicles had little or no margin for safety in top-speed driving at the tire pressures Ford recommended.

The papers were part of a collection of documents that Congressional investigators released before the third round of Congressional hearings investigating Ford's and Bridgestone/Firestone Inc.'s handling of tire failures now linked to more than 130 deaths in the U.S. and other countries.

The documents raise questions about Ford's position that accidents involving the Explorer and Firestone tires aren't related to Ford's recommended tire pressure for the Explorer.

Tire Pressure?

Bridgestone argued that under inflated tires may have played a role in the accidents and stated that a tire pressure of 30 psi was needed.

However, Ford officials believed the tire pressure issue was a red herring[5]. Tire pressure had not emerged as an issue in the data and Ford found that most drivers maintain a pressure at 28-31psi. Furthermore rival Goodyear's recommendation of a lower pressure of 26 psi was maintained with a spotless record. A Ford official quipped: "We decided to drop the Goodyear blimp on them [Firestone]." After August 10 chaos erupted at Ford dealerships as consumers scrambled to replace their tires, Ford Explorer sales plunged. Ford says sales have dipped 6% in August.

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[5] An attempt to divert attention

Is the Ford Explorer Part of the Problem?

The Ford Explorer sport-utility vehicle rolls over more often than other SUV's do in tire-tread accidents and it has vibration and suspension problems that Ford can't always explain and sometimes can't fix. Those flaws raise the suspicion that the Explorer itself is contributing to the sometimes fatal accidents that forced the Bridgestone/Firestone recall. An internal memo from Ford of Venezuela says that the Explorer "turned over unexpectedly" when Firestone tires lost their treads, but that other SUV's didn't in similar circumstances**.** About 31% of Explorer complaints cited mysterious vibrations. Many could not be cured, even after dealers changed tires, shock absorbers and drive-shafts. Less frequent is an odd tire-wear pattern called "cupping." It shows up in less than 2% of Explorer complaints, but never shows up in most other Ford truck models.

Venezuela

People in Venezuela also driving Ford Explorers and the Firestone tires equipping held that accidents with these vehicles should be linked to an additional 46 fatalities. Venezuelan officials believe Ford and Firestone knew about the problems with the tires but failed to warn owners until May, 2000, when they quietly began to offer free tire exchanges for Wilderness and ATX tires sold with Explorers since 1997.

4. The Therac case

The Therac-25 was a medical linear accelerator, a linac, developed by the AECL (Atomic Energy of Canada Limited) and CGR, a French company. It was the newest version of their previous models, the Therac-6 and Therac-20. These machines accelerated electrons that created energy beams that destroyed tumors. For shallow tissue penetration, the electrons are used; and to reach deeper tissue, the beam was converted into x-ray form.

The Therac-25 was a million dollar machine built to give radiation treatments to cancer patients. Most of these patients had already undergone surgery to remove the majority of the tumor, and were receiving the radiation to remove any leftover growth. This high energy radiation machine was computer controlled from a separate room to protect the operator from any unnecessary doses of radiation. Patients usually came in for a series of low energy radiation treatments to gradually and safely remove any remaining cancerous growth.

The Therac-25 had two main types of operation: a low energy mode and a high energy mode. The first mode consisted of an electron beam of 200 rads that was aimed at the patient directly. The second, higher energy mode, used the full power of the machine at 25 million electron volts. When used on patients, a metal plate was inserted between the beam and the patient, which would transform the beam into an x-ray.

There are some features of the Therac-25 that are necessary to review in relating the machine to the accidents. The Therac-25 was designed to be solely computer controlled. The previous versions were related to other machines. Another feature was that the software used had more responsibility in controlling safety. Again, the previous machines had separate pieces of machinery and hardware to monitor safety factors. The designers believed that they could save time and money in the Therac-25 by using only software safety control. A final feature was that some of the old software used in Therac-6 and Therac-20 was used in the Therac-25. A "bug" that was discovered in Therac-25 was later also found in the Therac-20.

The Failure of the Therac-25

In 1986, Ray Cox went into the clinic for his usual radiation treatment in his shoulder. The technician mistakenly typed "x" into the computer, which signified x-ray beam, then immediately realizing the error, changed the "x" into an "e" for electron beam, and hit "enter", showing the machine that they were ready to start treatment. This sequence occurred in less than 8 seconds. (This particular sequence, in this time frame, was never tried in the original testing of the machine.) The computer gave the signal of "beam ready", and the technician pressed "b" to deliver the beam to the patient. But then the computer responded with an error message. Usually this message meant that the treatment had not been delivered. So the technician repeated the process and delivered another beam to the patient. And yet again, an error message occurred. Meanwhile, Ray felt sharp stabbing pains in his back, which was much different than his usual treatments, and removed himself after three shocking attempts.

Because the commands were changed in such a short period of time, the computer did not respond properly. The metal plate moved away showing the technician that it was in low energy
electron beam mode. But the beam that actually came from the machine was a blast of 25 000 rads with 25 million electron volts, the maximum setting, which is more than 125 times the regular dose.

Ray’s health quickly became worse, and he died 4 months later from complications of major radiation burns.

Ray was not the only unlucky victim of the Therac-25. At least 5 more similar incidents occurred in that fateful two year span from 1985-1987. Nobody knew why patients were having such adverse reactions to the supposed low energy electron beam. Little did they know, that patients were being exposed to many times the normal dosages of radiation, leaving terminal effects. And when someone finally discovered the real problems, it was too little too late, and six innocent lives had already been lost.

Causes of the Disaster

Some of the possible causes of the failure of the Therac-25 are:

- failure to properly assess the old software when using it for new machinery
- not well designed error and warning messages

- did not fix or even understand the frequent recurring problems
- should have installed proper hardware to catch safety glitches
- manufacturer would not believe that machine could fail
- lack of communication and organization between hospitals, government and manufacturer

How they Solved the Problem

On February 10, 1987, the Health Protection Branch of the Canadian government along with the United States Food and Drug Administration (FDA) announced that Therac-25's were dangerous to use, and were to be shut down until permanent changes could be made. Finally on July 21, 1987, after many revisions, some final recommendations were given by the AECL on how to repair the Therac-25 to no longer be a health threat. Some of these recommendations are:

- operators cannot restart machine without re-entering information
- ensuring that metal plate is in place if x-ray beam is selected
- error messages will be made clearer
- dose administered clearly shown to operator
- limiting editing keys to limit any accidental type ins
- all manuals rewritten to reflect new changes

5. The US Squalus

On 12 May, following a yard overhaul, *Squalus* began a series of test dives off Portsmouth, New Hampshire. After successfully completing 18 dives, she went down again off the Isles of Shoals on the morning of 23 May at 42°53′N 70°37′W. Failure of the main induction valve caused the flooding of the aft torpedo room, both engine rooms, and the crew's quarters, drowning 26 men immediately. Quick action by the crew prevented the other compartments from flooding. *Squalus* bottomed in 74 m of water.http://en.wikipedia.org/wiki/USS_Sailfish_(SS-192) - cite_note-Blair.2C_p._67-4

Squalus was initially located by her sister ship, *Sculpin*. The two submarines were able to communicate using a telephone marker buoy until the cable parted. Divers from the submarine rescue ship *Falcon*, under the direction of the salvage and rescue expert Lieutenant Commander Charles B. Momsen, employing the new Rescue Chamber he had invented years earlier but which the US Navy command had repeatedly blocked. The Senior Medical Officer for the operations was Dr. Charles Wesley Shilling. They were able to rescue all 33 surviving crew members from the sunken submarine. Four enlisted divers earned the Medal of Honor for their work during the rescue and subsequent salvage.

The navy authorities felt it important to raise her as she incorporated a succession of new design features. With a thorough investigation of why she sank, more confidence could be placed in the new construction, or alteration of existing designs could be undertaken when cheapest and most efficient to do so. Furthermore, given similar previous accidents in *Sturgeon* and *Snapper*, it was necessary to determine a cause.

Squalus was refloated using cables passed underneath her hull and attached to pontoons on each side. Overseen by researcher Albert R. Behnke, the salvage divers used recently developed heliox diving schedules and successfully avoided the cognitive impairment symptoms associated with such deep dives, thereby confirming Behnke's theory of nitrogen narcosis.] After initially being brought to the surface, she slipped the cables and went back to the bottom. After overcoming tremendous technical difficulties in one of the most grueling salvage operations in U.S. Navy history, *Squalus* was raised, towed into Portsmouth Navy Yard on 13 September, and decommissioned on 15 November.

One result of the *Squalus* sinking was redesigning the diving controls, so that the main induction and negative tank flood levers could be easily distinguished by touch even in total darkness. Though unconfirmed, one theory was that the vent operator had accidently opened the induction when he attempted to close the negative flood valve, which is located next to it.

6. The USN Thresher

On 9 April 1963, *Thresher*, commanded by Lieutenant Commander John Wesley Harvey, began post-overhaul trials. Accompanied by the submarine rescue ship *Skylark*, she sailed to an area some 190 nm East of Cape Cod, Massachusetts, and on the morning of 10 April started deep-diving tests. As *Thresher* neared her test depth, *Skylark* received garbled communications over underwater telephone indicating "... minor difficulties, have positive up-angle, attempting to blow. When *Skylark* received no further communication, surface observers gradually realized *Thresher* had sunk. Publicly it took some days to announce that all 129 officers, crewmen, and military and civilian technicians aboard were presumed dead.

After an extensive underwater search using the bathyscaphe *Trieste*, oceanographic ship *Mizar* and other ships, *Thresher*'s remains were located on the sea floor, some 2,600 m below the surface, in six major sections. The majority of the debris had spread over an area of about 134,000 m^2. The major sections were the sail, sonar dome, bow section, engineering spaces section, operations spaces section, and the stern planes.

Deep sea photography, recovered artifacts, and an evaluation of her design and operational history permitted a Court of Inquiry to conclude *Thresher* had probably suffered the failure of a joint in a salt water piping system, which relied heavily on silver brazing instead of welding; earlier tests using ultrasound equipment found potential problems with about 14% of the tested brazed joints, most of which were determined not to pose a risk significant enough to require a repair. High-pressure water spraying from a broken pipe joint may have shorted out one of the many electrical panels, which in turn caused a shutdown ("scram") of the reactor, with a subsequent loss of propulsion. The inability to blow the ballast tanks was later attributed to excessive moisture in the ship's high-pressure air flasks, which froze and plugged the flasks' flow paths while passing through the valves. This was later simulated in dock-side tests on *Thresher*'s sister ship, *Tinosa*. During a test to simulate blowing ballast at or near test depth, ice formed on strainers installed in valves; the flow of air lasted only a few seconds. Air driers were later retrofitted to the high pressure air compressors, beginning with *Tinosa*, to permit the emergency blow system to operate properly.

Unlike diesel submarines, nuclear subs rely on speed and deck angle rather than de-ballasting to surface; they are "driven" at an angle towards the surface. Ballast tanks were almost never blown at depth, and to do so could cause the ship to rocket to the surface out of control. Normal procedure was to drive the ship to periscope depth, raise the periscope to verify the area was clear then blow the tanks and surface the ship.

At the time, reactor-plant operating procedures precluded a rapid reactor restart following a scram, or even the ability to use steam remaining in the secondary system to "drive" the ship to the surface. After a scram, standard procedure was to isolate the main steam system, cutting off the flow of steam to the turbines providing propulsion and electricity. This was done to prevent an over-rapid cool-down of the reactor. *Thresher*'s Reactor Control Officer, Lieutenant Raymond McCoole, was not at his station in the maneuvering room, or indeed on the ship, during the fatal dive. McCoole was at home caring for his wife who had been injured in a household accident — he had been all but ordered ashore by a sympathetic Commander Harvey. McCoole's trainee, Jim Henry, fresh from nuclear power school, probably followed standard operating procedures and gave the order to isolate the steam system after the scram, even though *Thresher* was at or slightly below her maximum depth and was taking on water. Once closed, the large steam system isolation valves could not be reopened quickly. Reflecting on the situation in later life, McCoole was sure he would have delayed shutting the valves, thus allowing the ship to "answer bells" and drive herself to the surface, despite the flooding in the engineering spaces. Admiral Rickover later changed the procedure, allowing steam to be withdrawn from the secondary system in limited quantities for several minutes following a scram.

There was much (covert) criticism of Rickover's training after *Thresher* went down the argument being his "nukes" were so well conditioned to protect the nuclear plant they would have shut the main steam stop valves— depriving the ship of needed propulsion — even at great depths and with the ship clearly in jeopardy. Nothing enraged Rickover more than this argument. Common sense, he argued, would prove this to be untrue.[]

It's more likely that the engine room crew was simply overwhelmed by the flooding casualty, or took too long to contain it[] In a dockside simulation of flooding in the engine room, held before *Thresher* sailed, it took the watch in charge 20 minutes to isolate a simulated leak in the auxiliary seawater system. At test depth, taking on water, and with the reactor shut down, *Thresher* would not have had anything like 20 minutes to recover. Even after isolating a short-circuit in the reactor controls it would have taken nearly 10 minutes to restart the plant.

Thresher likely imploded at a depth of 400–610 m.

Over the next several years, the Navy implemented the SUBSAFE program to correct design and construction problems on all submarines (nuclear and diesel-electric) in service, under construction, and in planning. During the formal inquiry, it was discovered that record-keeping at the Portsmouth Naval Shipyard was far from adequate. For example, no one could determine the whereabouts of hull weld X-rays made of *Thresher*'s sister ship *Tinosa*, nearing completion at Portsmouth, or, indeed, whether they had been made at all. It was also determined that the engine room layout was awkward, in fact dangerous, as there were no centrally-located isolation valves for the main and auxiliary seawater systems. Most subs were subsequently equipped or retrofitted with flood control levers, which allowed the Engineer Officer of the Watch in the maneuvering room to remotely close isolation valves in the seawater systems from a central panel, a task necessarily performed by hand on *Thresher*. Hand-power valves might not even have been accessible during a flooding casualty: at such depths, the blast of water from even a small leak (a "water spike") can dent metal cabinets, rip insulation from cables, and even cut a man in half. (Water pressure at 300 m is about 3,100 kPa.

SUBSAFE would prove itself to be a crucial part of the Navy's safe operation of nuclear submarines, but was disregarded just a few years later in a rush to get another nuclear sub, *Scorpion*, ready for service as part of yet another program meant to increase nuclear submarine availability. The subsequent loss of *Scorpion* reaffirmed the need for SUBSAFE, and apart from *Scorpion*, the U.S. Navy has suffered no further losses of nuclear submarines.

The Navy has periodically monitored the environmental conditions of the site since the sinking and has reported the results in an annual public report on environmental monitoring for U.S. Naval nuclear-powered ships. These reports provide specifics on the environmental sampling of sediment, water, and marine life which were taken to ascertain whether *Thresher*'s nuclear reactor has had a significant effect on the deep ocean environment. The reports also explain the methodology for conducting deep sea monitoring from both surface vessels and submersibles. The monitoring data confirms that there has been no significant effect on the environment. Nuclear fuel in the submarine remains intact.

According to newly declassified information, the Navy sent Commander (Dr.) Robert "Bob" Ballard, the oceanographer credited for the successful search for the wreck of RMS *Titanic*, on a secret mission to map and collect visual data on both *Thresher* and *Scorpion* wrecks. The Navy used Ballard's search for *Titanic* as a screen to hide the mission. Ballard approached the Navy in 1982 for funding to find *Titanic* with his new deep-diving robot submersible. The Navy saw the opportunity and granted him the money on the condition he first inspect the two submarine wrecks. Ballard's robotic survey discovered that *Thresher* had sunk so deep it imploded, turning into thousands of pieces. His 1985 search for *Scorpion*, which was thought to be a victim of a Soviet attack, revealed such a large debris field that it looked "as though it had been put through a shredding machine." The survey data revealed the most likely cause of the loss of *Scorpion* was one of its own torpedoes exploding inside the torpedo room. Once the two wrecks had been visited, and the radioactive threat from both was established as small, Ballard was able to search for *Titanic*. Due to dwindling funds, he had just 12 days to do so, but he used the same debris-field search techniques he had used for the two subs, which worked, and *Titanic* was found.]

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