GUIDANCE NOTES
GD016-2025

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INTERNATIONAL SHIP CLASSIFICATION

GUIDELINES FOR APPLICATION OF FORMAL SAFETY ASSESSMENT TO SHIPS

2025

Effective from 1 October 2025

CONTENTS

PREFACE

The International Maritime Organization (IMO) proposed to introduce and apply the Formal Safety Assessment (FSA) in the maritime industry. As a strategy, FSA has been widely applied in the development of conventions and regulations for maritime safety and protection of the marine environment, in the safe operation management of ships and the design of ships.

FSA is a structured and systematic methodology, which is applied in the development of rules and regulations, aimed at continuously enhancing ship safety by using risk analysis and cost-benefit assessment which consider various safety factors in a comprehensive manner and raise reasonable technical requirements capable of effectively controlling risks.

The Maritime Safety Committee, at its ninety-first session, and the Marine Environment Protection Committee, at its sixty-fifth session, approved Revised guidelines for Formal Safety Assessment (FSA) for use in the IMO rule-making process (MSC-MEPC.2/Circ.12), where were subsequently revised at MSC 94 and MEPC 68, MSC 98 and MEPC 72, MSC 109 and MEPC 83.

In order to facilitate the implementation of the circular and enhance the capability of ISC of applying FSA in the development of rules and regulations, the Guidelines are developed on the basis of ISC Guidelines for Application of Formal Safety Assessment to Ships (2015) and in conjuction with IMO revisions and application experience over recent years.

The Guidelines are aimed at making relevant management personnel and technical personnel understand the idea of FSA, establish a new concept of considering problems comprehensively which is based on risk awareness, and gradually participate in and carry out FSA application in each field of expertise, including the safe operation management and design of ships, so as to promote the application of FSA in China.

CHAPTER 1　GENERAL

1.1　Purpose of FSA

1.1.1　Formal Safety Assessment (FSA) is a structured and systematic methodology, aimed at enhancing maritime safety, including protection of life, health, the marine environment and property, by using risk analysis and cost-benefit assessment.

1.1.2　FSA can be used as a tool to help in the evaluation of new regulations for maritime safety and protection of the marine environment or in making a comparison between existing and possibly improved regulations, with a view to achieving a balance between the various technical and operational issues, including the human element, and between investment costs and output benefits. The research results of FSA may serve as the background information of development or revision of regulations and rules, which can provide necessary support to the development or revision of ISC rules so as to enhance the level of ISC rules.

1.1.3　During the process of development or revision of regulations and rules, FSA may be used to evaluate the effect of proposed rule revisions in terms of benefits (e.g. expected reduction of lives lost or of pollution) and related costs incurred for ISC and for affected individual parties, thus making decisions on whether the development or revision of rules will satisfy intended requirements. FSA should facilitate the development or revision of rules equitable to the various parties thus aiding the achievement of consensus.

1.1.4　A formal report (see Chapter 4 of the Guidelines) on the FSA process is to be submitted in a uniform and systematic manner in order to maintain the consistency of FSA application and ensure the transparency of FSA process. Such report is to be understood by personnel from various interested parties.

1.1.5　The FSA is a methodology that utilizes risk assessment for the development of regulations; however, the FSA by itself is not a risk assessment technique.

1.2　Scope of application

1.2.1　The Guidelines are intended to outline the FSA methodology as a tool, which may be used in the process of development or revision of regulations and rules. Such methodology may be applied to:

(1) participation in the maritime legislation (conventions, regulations etc.) at the domestic or international level;

(2) development and revision of ISC rules (rules, guidance notes etc.);

(3) assessment of technical designs related to safety and environmental protection of ships and offshore engineering;

(4) safety assessment of operation related to ships and offshore engineering in complex scenarios at sea;

(5) risk assessment in equivalent and alternative design of ships;

(6) assessment related to safeguarding the safe operation of ships, especially the management of human element (e.g. regulatory framework, personnel organization, use and training, ship maintenance etc.) in the shipping management system;

(7) equivalency and exemption related to ISC plan approval.

1.2.2　During the development of new rules or revision of existing rules, the following should be taken into account:

1.2.2.1 All technical requirements should be analyzed by following the principles of FSA insofar as practicable, especially for the development of rules for special or novel ship types or development of provisions for safe survey for specific operation.

1.2.2.2 The revised rule requirements should be compared with existing ones by applying the FSA methodology insofar as practicable so that technical personnel of rules will have a clear understanding of the effectiveness of rule revision and the benefit arising therefrom.

1.2.3 It is not intended that FSA should be applied in all circumstances, but its application would be particularly relevant to proposals which may have far-reaching implications in terms of either costs, or the legislative and administrative burdens which may result. FSA may also be useful in those situations where there is a need for risk reduction but the required decisions regarding what to do are unclear.

1.2.4 All or some of the steps of the FSA methodology may be applied in accordance with practical conditions.

1.3 Terms and definitions

1.3.1 For relevant terms and definitions related to FSA, see Appendix 7 of the Guidelines.

CHAPTER 2 PREPARATION FOR FSA IMPLEMENTATION

2.1 Preparation prior to the application of FSA

2.1.1 Prior to the FSA study, the decision makers should firstly define the problem to be assessed along with any relevant boundary conditions or constraints. These are presented to the group who will carry out the FSA and provide results to the decision makers for use in their resolutions. An FSA may address risks posed by all accident categories or focus only on a specific accident category. In cases where decision makers require additional work to be conducted, the problem statement or boundary conditions or constraints should be revised and resubmitted to the group and the assessment process should be repeated as necessary.

2.1.2 An FSA working group is established. The chairman or coordinator of the group should generally have rich experience, be responsible for the preparation work, facilitate the teamwork among experts and bring into full play the specialty of each expert. Members of the group may include experts in terms of safety, design or operation required for the FSA study, e.g. ship designer, structural engineer, mechanical engineer, surveyor, maritime officer, human element expert, assistant and recording personnel. The composition of members in based on the problem under analysis and their professionalism should be commensurate with the level of complexity of the FSA study to be carried out, in order to reflect the range of influences and the nature of the problem being addressed.

2.1.3 Work at the preparation stage

2.1.3.1 Definition of the problem: the purpose is to define the analysis scope so as to determine the depth and extent of FSA study. The definition of the problem should be consistent with operational experience and current requirements by taking into account all relevant aspects. Those which may be considered relevant when addressing ships are:

(1) ship category (e.g. type, length or gross tonnage range, new or existing, type of cargo);

(2) ship systems or functions (e.g. layout, subdivision, type of propulsion), equipment operation and skills of the crew;

(3) ship operation (e.g. operations on high seas, in greater coastal service area, in inland waterways service area or in port and/or during navigation, routeing);

(4) external influences on the ship (e.g. Vessel Traffic System, weather forecasts, reporting);

(5) accident category (e.g. collision, grounding, explosion, fire);

(6) risks associated with consequences such as injuries and/or fatalities to passengers and crew, environmental impact, damage to the ship or port facilities, or commercial impact.

2.1.3.2 Preparation of data and information: the statistical data of relevant accidents and incidents as well as the reliability data of system and equipment should be collected as necessary in order to include previous experience in the FSA study. In principle, data and information should be as much as possible. When data is not sufficient, expert judgment, physical models and numerical simulations may be used. As a result, how to prepare data and what kind of data to be prepare has become an important link at the FSA preparation stage and even in the whole process. For a novel problem for which there is a lack of relevant experience and accident statistical data, consideration may be given to data and information of other industries which might be used for reference. For a problem with experience, consideration may be given to obtaining relevant failure information from statistical data of accidents and incidents. Such information may include:

(1) functional requirements;

(2) general arrangement of ship;
(3) drawings of ship/system;
(4) instructions of equipment;
(5) onboard operational instructions and lists;
(6) task description;
(7) operation flowchart;
(8) relevant accidents, incidents and failure data.

2.1.3.3 Determination of risk analysis methods: hazard attributes and risk levels should be assessed by using qualitative or quantitative methods in accordance with the scope and nature of the problem under analysis, the available data and information as well as the required results. The analysis should generally be both qualitative and quantitative, i.e. with both qualitative description and quantitative results by means of mathematical methods.

2.1.3.4 Determination of the risk acceptability criteria: The acceptability of the identified risk should be assessed during FSA, so as to provide reference basis for risk reduction measures; therefore the risk acceptance criteria should be defined explicitly. It should be noted that there is no risk acceptance criterion that is universally accepted at present. However, as long as the acceptance criteria of FSA study are defined and documented, the decision-making based on such criteria can be traced back to the latest stage.

2.2 Information and data

2.2.1 The availability of suitable data necessary for each step of the FSA process is very important for the purpose of making more balanced, proactive and cost-effective regulations. Authentic and accurate objective data is the most important one during the FSA study. The objective data may be obtained by means of on-site observation, investigation and statistics, database etc. When data are not available, expert judgment, physical models and numerical simulations may be used to achieve valuable results in order to supplement the objective data. Big data analysis, artificial intelligence, and other methods can also be used to expand the volume of information and data if necessary.

2.2.2 Data required for the FSA study may include casualty data of accidents, incident/near miss and reliability data of operational failures, repair work sheets and operational records, internal reports and industry announcements.

2.2.3 The accident database is a very important tool to assess ship safety. The weak link in the operational process and design problems can be determined by means of study and analysis of historical data, so as to provide references for developing rules and preventive measures. There are many historical databases at present, of which the most commonly used database is IHS-Fairplay, providing the most comprehensive information regarding merchant fleets of 100 GT or over worldwide at present. Other maritime databases are given in Table 2.2.3.

Maritime Database **Table 2.2.3**

Database	Availability	Data type	Human element
Global Integrated Shipping Information System（GISIS）	Public	Statistics	No
Lloyd’s Maritime Information Service（LMIS）	Public	Statistics	No

Marine Accident Reporting Scheme（MARS）	Public	Narration	Partial
Marine Accident Investigation Branch（MAIB）	Public	Narration, partial statistics	Partial
Marine Incident Investigation Unit（MIIU）	Public	Narration	Partial
Marine Investingations Module（MINMOD）	Not public	Narration, statistics	Partial
Data Management International（DAMA）	Public	Narration, partial statistics	No
Safety and Improvement Reporting System（SAFIR）	Not public	Narration, statistics	Yes

2.2.4 During the FSA study, it is most ideal to use data of ships of the same type, which may be limited or difficult to obtain in most cases. As a result, the scope of data may be extended as necessary, e.g. the data of ro-ro passenger ship extended to the application of cruise ship. In addition, relevant data of other industries may also be used if it is feasible upon judgment.

2.2.5 The quoted data must be reviewed objectively and their reliability, uncertainty and validity assessed and reported. The assumptions and limitations of these data must also be reported, e.g. failure and accident category, ship type etc.

2.2.6 The evaluation of rare events where there is inadequate historical data is reached through the probabilistic modelling of failures and development of accident scenarios. A rare event is decomposed into more frequent events for which there is more experience available (e.g. evaluate system failure based on component failure data).

2.2.7 Equally, consideration should also be given to cases where the introduction of recent changes (e.g. regulatory, design, operation, construction/manufacturing) may have affected the validity of historic data for assessing current risk.

2.3 Expert judgment

2.3.1 During the FSA study, expert judgment needs to be carried out by experts based on their respective experience It not only contributes to the proactive nature of the methodology but is also essential in cases where there is a lack of historical data. In such cases, data can be enhanced or completed by (1) further consideration of information/data and (2) the use of expert judgement by which the quality of the original historical data may be improved. The subsequent improvements support quantitatively the whole FSA process. It is to be particularly noted that the assumptions and rationale used for arriving at the expert judgement should be documented.

2.3.2 In applying expert judgment, different experts may be involved in a particular FSA study. It is unlikely that the experts' opinions will always be in agreement. It might even be the case that the experts have strong disagreements on specific issues. Preferably, a good level of agreement should be reached. It is highly recommended to report the level of agreement between the experts in the results of an FSA study. It is important to know the level of agreement, and this may be established by the use of a concordance matrix or by any other methodology. See 1.3 of the Appendix of the Guidelines for details.

2.3.3 The use of expert judgment may be needed at various stages of the FSA study, e.g. hazard identification, risk control options and cost-benefit assessment etc.

2.4 Screening approach

2.4.1 The depth or extent of application of FSA should be commensurate with the nature and significance of the problem. Generally the assessment object of FSA should be defined. To enable the FSA to focus on those areas that deserve more detailed analysis, a preliminary coarse qualitative analysis is suggested for the relevant ship type or hazard category, in order to include all aspects of the problem under consideration. Whenever there are uncertainties, e.g. in respect of data or expert judgement, the significance of these uncertainties should be assessed.

2.4.2 Characterization of hazards and risks should be both qualitative and quantitative, and both descriptive and mathematical, consistent with the available data, and should be broad enough to include a comprehensive range of options to reduce risks.

2.4.3 A hierarchical screening approach may be utilized. This would ensure that excessive analysis is not performed by utilizing relatively simple tools to perform initial analyses, the results of which can be used to either support decision-making (if the degree of support is adequate) or to scope/frame more detailed analyses (if not). The initial analyses would therefore be primarily qualitative in nature, with a recognition that increasing degrees of detail and quantification will come in subsequent analyses as necessary.

2.4.4 The common risk assessment methods should generally include fault trees, event trees and risk contribution trees linking the risks of the first two trees. The study of an accident scenario is actually the analysis of the sequence of events. Firstly analyze and study the initiating failure which might occur in the system, which is defined as the “basic event” of fault trees. Such basic events will lead to response of the system and become the “top event” of fault trees. Some top events may be the reason for the severity of accident. With the top event as the initiating condition, a complete event tress may be formed by logic deduction based on causality.

2.4.5 A review of historical data may also be useful as a preparation for a detailed study. For this purpose a loss matrix may be useful. An example can be found in Table 2.4.5 below.

Example of Loss Matrix **Table 2.4.5**

Ship accident loss（million RMB/ship year）

Accident type	Ship accident cost million RMB	Environmental damage and clean up million RMB/ tonne × number oftonnes	Risk to life Fatalities× million RMB/person	Risk of injuries and ill health DALY[1]×million RMB Y	Total cost million RMB
Collision Contact Foundered Fire/explosion Hull damage Machinery damage War loss Grounding Other ship accidents Other oil spills Personal accidents					
TOTAL					

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[1] DALY = Disability-Adjusted Life Years. One DALY represents the loss of the equivalent of one year of full health. DALYs for a disease or health condition are the sum of the years of life lost to due to premature mortality (YLLs) and the years lived with a disability (YLDs) due to prevalent cases of the disease or health condition in a population. (World Health Organization (WHO) Statistics; https://www.who.int/data/gho/data/themes/mortality-and-global-health-estimates/global-health-estimates-leading-causes-of-dalys)

2.5 Incorporation of the human element

2.5.1 The human element is one of the most important contributory aspects to the causation and avoidance of accidents. Statistically, 80% ship accidents are affected or directly caused by human element. Human element issues should be systematically treated within the FSA framework, associating them directly with the occurrence of accidents, underlying causes or influences. The human element can be incorporated into the FSA process by using human reliability analysis (HRA). Guidance for the use of HRA within FSA is given in Appendix 5 of the Guidelines.

2.6 Generic model

2.6.1 For application of FSA, a generic model should therefore be defined to describe the functions, features, characteristics and attributes which are common to all ships or areas relevant to the problem in question.

2.6.2 In general, the problem under consideration should be characterized by a number of functions. Where the problem relates for instance to a type of ship, these functions include carriage of payload, communication, emergency response, manoeuvrability, etc. Alternatively, where the problem relates to a type of hazard, for instance fire, the functions include prevention, detection, alarm, containment, escape, suppression, etc.

2.6.3 The generic model should not be viewed as an individual ship in isolation, but rather as a collection of systems, including organizational, management, operational, human, electronic and hardware aspects which fulfil the defined functions. The functions and systems should be broken down to an appropriate level of detail. Aspects of the interaction of functions and systems and the extent of their variability should be addressed in order to consider all influences characterizing the problem under consideration, for instance ship size and/or type or different system designs.

2.6.4 A comprehensive view should be taken, recognizing that the ship's technical and engineering system, which is governed by physical laws, is in the centre of an integrated system. The technical and engineering system is integrally related to the passengers and crew which are a function of human behaviour. The passengers and crew interact with the organizational and management infrastructure and those personnel involved in ship and fleet operations, maintenance and management. These systems are related to the outer environmental context, which is governed by pressures and influences of all parties interested in shipping and the public. Each of these systems is dynamically affected by the others. Figure 2.6.4 shows the components of the integrated system.

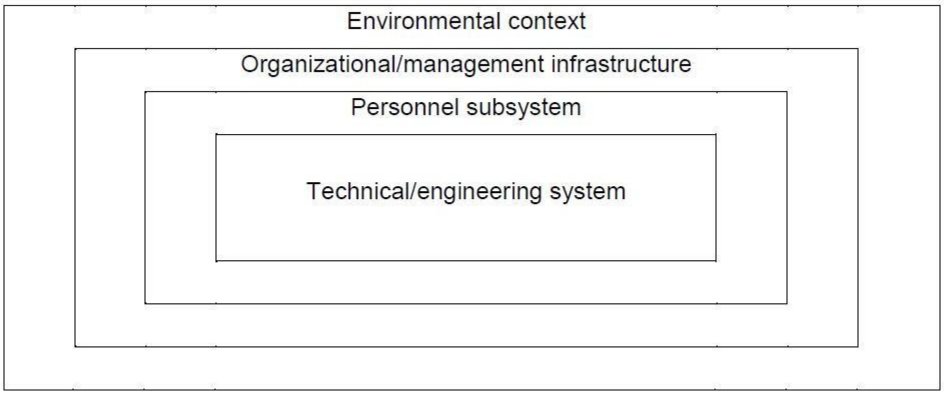

Figure 2.6.4 Components of the Integrated System

CHAPTER 3 FSA PROCESS

3.1 FSA steps

3.1.1 FSA is a risk-based methodology comprising 5 inherent steps as shown in Figure 3.1.1:

(1) identification of hazards;

(2) risk analysis;

(3) risk control options;

(4) cost-benefit assessment;

(5) recommendations for decision-making.

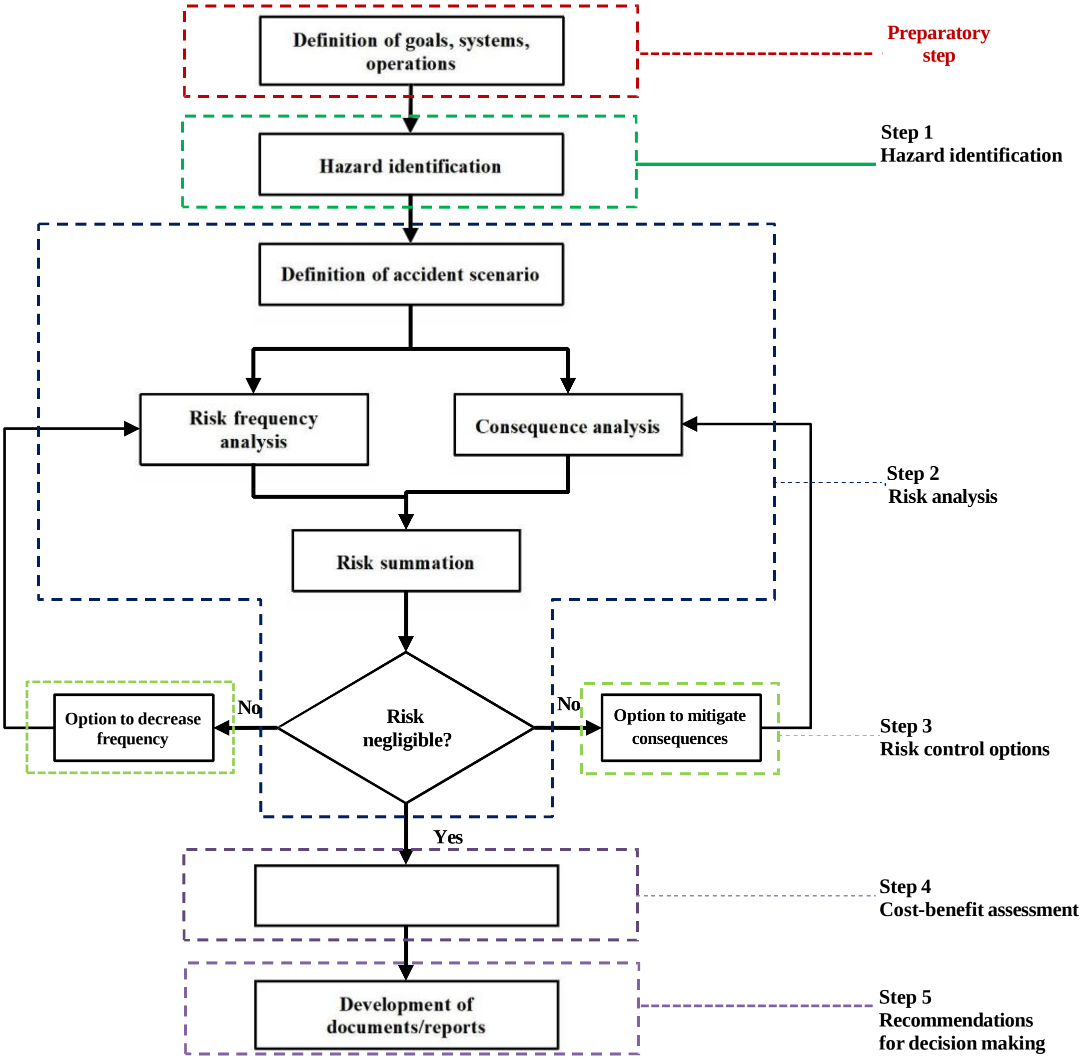

Figure 3.1.1 FSA Steps

3.1.2 The FSA process begins with the decision makers defining the problem to be assessed along with any relevant boundary conditions or constraints. These are presented to the group who will carry out the FSA and provide results to the decision makers for use in their resolutions. In cases where decision makers require additional work to be conducted, they would revise the problem statement or boundary conditions or constraints, and resubmit this to the group and repeat the process as necessary. It is to be noted that for actual project, all or some relevant steps may be taken based on needs to carry out assessment, in order to arrive at decision- making recommendations. The group carrying out the FSA process should comprise suitably qualified and experienced persons to reflect the range of influences and the nature of the "event" being addressed.

3.1.3 FSA application personnel carry out analysis of safety by means of estimation of risks related to certain aspect (e.g. specific operation). The final analysis results are used as technical support or reference basis for developing new rules or revising existing rules.

3.2 FSA step 1- identification of hazards

3.2.1 Purpose and scope

3.2.1.1 The purpose of identification of hazards (HAZID) is to identify a list of hazards and associated scenarios prioritized by risk level specific to the problem under review, so as to further analyze principal hazards and create corresponding risk control options.

3.2.1.2 This purpose is achieved by the use of standard techniques to identify hazards which can contribute to accidents in accordance with accident type and basic mode, and by screening these hazards using a combination of available data and expert judgement.

3.2.1.3 The hazard identification exercise should be undertaken in the context of the functions and systems generic to the ship type or problem being considered, which were established in paragraph 2.6 by reviewing the generic model.

3.2.2 Methods of identification

3.2.2.1 The approach used for hazard identification generally comprises a combination of both brainstorming and standard analytical techniques, the aim being to identify all relevant hazards. The brainstorming is to ensure that the process is proactive and not confined only to hazards that have materialized in the past. Especially an experienced group should be established to complete the work, so as to identify the causes and effects of accidents and relevant hazards. The group should include experts (generally a representative composition of 7-10 persons) in the various appropriate aspects, such as ship design, operations and specialists to assist in the hazard identification process and incorporation of the human element as necessary. The analytical element ensures that previous experience is properly taken into account, and typically makes use of background information (for example applicable rules, available statistical data on accident categories and lists of hazards to personnel, hazardous substances, ignition sources, etc.).

3.2.2.2 A coarse analysis of possible causes and initiating events and outcome of each accident scenario should be carried out. Common analytical methods include checklists, what if analysis technique, failure mode and effect analysis (FMEA), Hazard and Operability Studies (HAZOP) and Preliminary Hazard Analysis (PHA). See Appendix 1 of the Guidelines for details.

3.2.2.3 Appropriate hazard identification is selected in accordance with the type of problem under analysis, in order to initially analyze the potential cause, development process, affecting factors and final outcome of hazard, which is consistent with the scope of FSA. In general, what if analysis technique may be used when there is not much data and information available for use; FMEA and HAZOP may be used when there is detailed design information available for use; Task analysis may be used in special circumstances, e.g. when personnel behavior needs to be analyzed in detail. It needs to be emphasized that there is no single standard technique that can guarantee thorough hazard identification, which should rely on the combination of sound engineering judgement and rich practical experience.

3.2.2.4 The hazard identification sessions and correspondence can also take advantage of the availability of the experts and be used to elaborate a preliminary list of risk control measures that could be investigated further in step 3 based on the step 2 quantitative assessment.

3.2.3 Implementation process

3.2.3.1 Sort out collected information in accordance with ship and system functions defined by the generic model within the determined analysis scope, e.g. determining applicable conventions, codes, rules, provisions etc.; sort out and make a list of hazards and coarse hazard categorization in accordance with known accidents, accident statistical information or other relevant information leading to accidents (e.g. technology glitches, operational or human errors).

3.2.3.2 Organize relevant experts to attend a hazard identification meeting (or in the form of investigation and discussion) and identify hazards systematically through brainstorming. The hazard identification meeting should be organized by a person understanding the FSA methodology and a designated person should be appointed to record the contents and process of meeting. The recorded list of hazard identification may differ from that of a different hazard identification method. Refer to Appendix 1 of the Guidelines for details. The hazard identification meeting generally lasts for not more than 3 days, with the meeting time of each day not exceeding 5-6 hours.

3.2.3.3 Rank the identified hazards (refer to Appendix 1 of the Guidelines). A large number of hazard scenarios may be identified by HAZID, which may be difficult to deal with due to budget, technical capabilities, time and other limiting conditions. It needs to be confirmed which scenarios are the most important so that they will be further analyzed in detail in the following FSA steps. The identified hazards need to be ranked in accordance with the risk level of scenario (personnel, property or environmental risk):

(1) The frequency and consequence of the scenario outcome are assessed in accordance with accident statistical data and expert judgement. Scenarios judged to be of minor significance are discarded.

(2) Rank from high to low in accordance with severity based on frequency value and possible outcome.

(3) Hazards (RI) may be ranked by using the risk matrix. When the risk matrix is used, the categorization and definition of frequency (FI) and severity (SI) should be determined in accordance with the problem under analysis and available data.

(4) Hazards with relatively high RI value are selected (sometimes hazards with very high SI value are selected additionally) to further carry out risk analysis.

(5) Special attention should be paid to severe or catastrophic events that are expected to occur with a very low frequency (extremely remote) and for which no historical data is available. The actual occurrence of an extremely remote event requires either larger samples or longer observation periods both of which are often not available. Such events should not be discarded due to their low frequency, especially when they are severe or catastrophic, but should be properly assessed in the ranking.

3.2.3.4 Notwithstanding the above, ranking of hazards may not be necessary , if all the identified hazards relevant to the problem definition are included in the risk analysis step 2.

3.2.3.5 For hazards which will be further assessed in FSA step 2, the process from initiating event to the final outcome should be described.

3.2.4 Output results

The output from step 1 is a list of hazards ranked in accordance with severity, including:

(1) cause of hazards;

(2) preliminary explanations on a hazard scenario developing from initiating event to the final outcome;
(3) estimation of frequency of occurrence and severity of outcome of hazards;
(4) ranking of hazard risks.

3.3 FSA step 2- risk analysis

3.3.1 Purpose and scope

3.3.1.1 The purpose of the risk analysis in step 2 is a detailed investigation of the causes and initiating events and consequences of the more important accident scenarios identified in step 1, determination of risk distribution and evaluation of factors which influence the level of risk. This allows attention to be focused upon high-risk areas and to identify and major factors which influence the level of risk. At the same time the relationship between the rules system and occurrence of accidents and their consequences is identified so as to make appropriate revisions to the rules to reduce the risk.

3.3.1.2 Different types of risk should be addressed as appropriate to the problem under consideration. Measures or activities related to risk are controlled within the acceptable range of risk by means of analysis and evaluation.

3.3.2 Risk types and risk measurement units

Different types of risk may be addressed as appropriate to the problem under consideration, e.g. risk to people (including individual risk and societal risk), risk to the environment or risk leading to economic loss. Different risks should be expressed by appropriate risk measurement units. Several types of risk may be analyzed respectively in one study. (see Appendix 3 of the Guidelines)

3.3.3 Risk models and assumptions

Risk models and assumptions may be established by means of previous accident statistical data, model test or numerical simulation or experience and judgement of experts. Risk models and assumptions may influence analysis results directly and therefore they should comply with practical conditions insofar as practicable.

Notwithstanding the accurate selection of input data, it is recommended to verify the accuracy of the risk model output against other available information to avoid erroneous overestimation or underestimation of risk. To consider the issue of underreporting within historical data, typical risk models should overestimate the risk calculated by means of historical data.

3.3.4 Risk analysis methods

There are several methods/tools that can be used to perform a risk analysis. The scope of the FSA, types of hazards identified in step 1, and the level of failure data available will all influence which method/tool works best for each specific application. Examples of the different types of risk analysis methods/tools are outlined in Appendix 2 of the Guidelines.

3.3.5 Risk contribution tree

RCT may be used as a mechanism for displaying diagrammatically the distribution of risk amongst different accident categories and sub-categories during risk analysis. As a useful tool, RCT displays a logic diagram consisting of fault trees and event trees. Such method analyzes the cause of accidents (using fault trees) and analyzes how accidents may progress further to result in different magnitudes of loss (using event trees), so as to analyze the risk in a comprehensive manner.

3.3.6 Risk acceptance criteria

The risk level obtained by analysis should be compared with risk standards to determine whether the existing rules are reasonable and whether new rules need to be developed to reduce the risk. In order to determine whether the risk is within the tolerable scope (see Appendix 3 of the Guidelines), appropriate and reasonable risk standards need to be selected as the criteria of judgement. In general, decisions should not be made in accordance with a single acceptable risk standard and instead, standards divided in accordance with the scope should be used, e.g. individual risk, societal risk etc. When acceptable risk standards are not available, reference may be made to applicable standards of other industries.

3.3.7 Sensitivity analysis and uncertainty analysis

3.3.7.1 Sensitivity analysis and uncertainty analysis should be considered in risk assessment and the results should be reported together with the quantitative data and explanation of models used. Methodologies of sensitivity analysis and uncertainty analysis would depend on the method of risk analysis and risk models used.

3.3.7.2 Sensitivity analysis is the study of how the uncertainty in the output of a model can be apportioned to different sources of uncertainty in the model input, i.e. an estimation of the extent of contribution of the uncertainty in input parameters to the uncertainty in the output of a model. A related practice is uncertainty analysis which focuses rather on quantifying uncertainty in model output. Ideally, uncertainty and sensitivity analysis should be run in tandem.

3.3.7.3 Uncertainty analysis investigates the uncertainty of variables that are used in decision-making problems. Factors of uncertainty include random uncertainty (randomness of behavior of things, e.g. probability distribution of wave load limit value that ships and offshore engineering structures might encounter during a certain period) and knowledge uncertainty (incompleteness of expressed knowledge, e.g. personnel behavior and structural fatigue principle in the extreme environment). Uncertainty analysis aims to make a technical contribution to decision-making through the quantification of uncertainties in the relevant variables.

3.3.8 Implementation process

(1) determination of risk types and risk measurement units under analysis;

(2) establishment of risk models and relevant assumptions. Risk contribution tree, FTA, ETA or other types of risk model may be used as appropriate;

(3) determination of risk distribution of various accident types and various factors affecting the risk by means of quantification of RCT or statistical analysis of accident data. Accident statistical data used for analysis should be representative and correspond to the scope of problem under analysis;

(4) analysis of the effect of existing rules on high-risk areas and main factors affecting the risk while identifying and evaluating high-risk areas and main factors affecting the risk;

(5) calculation of risk values by means of appropriate methods. In general, societal risk is expressed as FN-diagrams or Potential Loss of Life (PLL) and individual risk is expressed as Fatal Accident Rate (FAR);

(6) selection of appropriate risk standards for comparison, evaluation and explanation of the scope to which the risk result under analysis belongs, i.e. “negligible”, “intolerable” and “ALARP area”.

3.3.9 Output results

The output from step 2 comprises:

(1) the identification of the high-risk areas which need to be addressed;

(2) the identification of main factors affecting the risk level;

(3) the explanation of the scope to which the risk result under analysis belongs;

(4) the explanation of risk models;
(5) the result of re-evaluating risks for RCOs in step 3.

3.4 FSA step 3- risk control options

3.4.1 Purpose and scope

3.4.1.1 The purpose of step 3 is to, based on hazard identification and risk assessment, first identify effective and feasible Risk Control Measures (RCMs) for reducing risks and then to group them into Risk Control Options (RCOs) for practical use.

3.4.1.2 The proposed risk control options should address both existing risks and risks introduced by new technology or new methods of operation.

3.4.2 Implementation process

(1) focusing on risk areas needing control;
(2) identifying potential RCMs;
(3) evaluating the effectiveness of the RCMs in reducing risk by re-evaluating step 2;
(4) grouping RCMs into practical RCOs, i.e. establishment of requirements of rules or revision plan of rules.
(5) identifying relevant interested entities affected by selected RCOs.

3.4.3 Determination of areas needing control

The output of step 2 is screened so that the effort is focused on the areas most needing risk control. The main aspects to making this assessment are to review:

(1) probability, by identifying the areas of the risk model that have the highest probability of occurrence. These should be addressed irrespective of the severity of the outcome;
(2) severity, by identifying the areas of the risk model that contribute to highest severity outcomes. These should be addressed irrespective of their probability;
(3) risk levels, by considering frequency of occurrence together with the severity of outcomes. Accidents with an unacceptable risk level become the primary focus;
(4) confidence, by identifying areas where the risk model has considerable uncertainty either in risk, severity or probability. These uncertain areas should be addressed.

3.4.4 Risk control measures

3.4.4.1 Structured review techniques are typically used to identify new RCMs for risks that are not sufficiently controlled by existing measures. These techniques may encourage the development of appropriate measures and include risk attributes and causal chains. Risk attributes relate to how a measure might control a risk, and causal chains relate to where, in the "initiating event to fatality" sequence, risk control can be introduced.

3.4.4.2 RCMs (and subsequently RCOs) have a range of attributes. These attributes may be categorized according to the examples given in Appendix 4. In general, preventive RCMs are superior to mitigating RCMs (prevention of occurrence of fire is always better than mitigating fire consequence); passive RCMs are more reliable than active RCMs (e.g. fixed firewall and water curtain).

3.4.4.3 The prime purpose of assigning attributes is to facilitate a structured thought process to understand how an RCM works, how it is applied and how it would operate. Attributes can also be considered to provide guidance on the different types of risk control that could be applied. Many risks will be the result of complex chains of events and a diversity of causes. For such risks the identification of RCMs can be assisted by developing causal chains which might be expressed as follows:

causal factors → failure → circumstance → accident → consequences

3.4.4.4 RCMs should in general be aimed at one or more of the following:

(1) reducing the frequency of failures through better design, procedures, organizational polices, training, etc.;

(2) mitigating the effect of failures, in order to prevent accidents;

(3) alleviating the circumstances in which failures may occur;

(4) mitigating the consequences of accidents.

3.4.4.5 Identification of RCMs may also take into account anticipated advances or ongoing developments in technologies, as well as operability of measures in application.

3.4.5 Risk control options

3.4.5.1 The purpose of this stage is to group the RCMs into a limited number of well thought out and practical Risk Control Options (plan of rules). There is a range of possible approaches to grouping individual measures into options. The following two approaches, related to likelihood and escalation, can be considered:

(1) "general approach" which provides risk control by controlling the likelihood of initiation of accidents and may be effective in preventing several different accident sequences;

(2) "distributed approach" which provides control of escalation of accidents, together with the possibility of influencing the later stages of escalation of other, perhaps unrelated, accidents.

3.4.5.2 In generating the RCOs, the interested entities, who may be affected by the combinations of measures proposed, should be identified.

3.4.5.3 Some RCMs/RCOs may introduce new or additional hazards, in which case steps 1, 2 and 3 should be reviewed and revised as appropriate.

3.4.5.4 Before adopting a combination of RCOs for which a quantitative assessment of the combined effects was not performed, a qualitative evaluation of RCO interdependencies should be performed. Such an evaluation could take the form of a matrix as illustrated in the following table:

Interdependencies of RCOs **Table 3.4.5**

RCO	1	2	3	4
1		Strong	No	Weak
2	Weak		Weak	No
3	No	Weak		No
4	Weak	No	No	
Note: dependence of RCOs in each column on RCOs in each row				

The above matrix table lists the RCOs both vertically as horizontally. Reading horizontally, the table indicates in the first row any dependencies between RCO 1 and each of the other proposed RCOs (2 to 4). For example, in this case the table states that if RCO 1 is implemented, RCO 2, being strongly dependent on RCO 1, needs to be re-evaluated before adopting it in conjunction with RCO 1. On the other hand, RCO 3 is not dependent on RCO 1, and therefore its cost-effectiveness is not altered by the adoption of RCO 1. RCO 4 is weakly dependent on RCO 1, so re-evaluation may not be necessary. In principle, one dependency table could be given for cost, benefits and risk reduction. The interdependencies in the above matrix may or may not be symmetric.

3.4.5.5 Where more than one RCOs are proposed to be implemented at the same time, the effectiveness of such combination in reducing the risk should be assessed.

3.4.5.6 Sensitivity analysis and uncertainty analysis should be considered in the analysis of effectiveness of RCMs and RCOs, and the results of sensitivity analysis and uncertainty analysis should be reported.

3.4.6 Output results

The output from step 3 comprises:

(1) a list of RCOs;
(2) effectiveness of RCOs in reducing risk;
(3) a list of interested entities affected by the identified RCOs.

3.5 FSA step 4- cost-benefit assessment

3.5.1 Purpose

The purpose of step 4 is to estimate and evaluate costs, benefits and reduced risk associated with the implementation of each RCO identified and defined in step 3.

3.5.2 Costs, benefits and risk reduction

3.5.2.1 Costs ΔC mean additional costs as a result of adopting relevant RCO, which may be expressed in terms of life cycle costs and may include initial, operating, decommission, etc. In general, costs of RCO may include:

(1) costs of purchasing new equipment (investment costs);
(2) costs of redesign and construction;
(3) costs of certification;
(4) costs of training;
(5) costs of survey, maintenance and drill;
(6) cost of audit;
(7) loss due to termination of business;
(8) costs due to operational limitation.

Discount rate (approximately 5%) and the influence of some commercial factors should also be considered during the calculation of costs. As some RCOs mature and relatively large scale markets are established, the initial large costs will be reduced. A great number of update demands that are unexpected may increase costs by breaking the balance of supply and demand. When the same RCO is applied to new and existing ships, the costs may not be the same. A reasonable mean value should be used taking into account all the above factors during the FSA study. Sensitivity analysis may be carried out to important cost factors as necessary.

3.5.2.2 Benefits ΔB mean relevant earnings obtained after the risk is reduced, which include reductions in casualties, property loss, environmental damage, indemnity of third party liabilities, etc. and an increase in the average life of ships and exclude the reduction in insurance costs.

3.5.2.3 Risk reduction ΔR means the reduction of risk after adoption of RCO (e.g. reductions in casualties ΔPLL, property loss or environmental damage), which may understood as the risk reduction rate.

3.5.2.4 Costs ΔC and benefits ΔB should be apportioned to the whole life cycle of ships, which is generally assumed to be 25 years. The costs of some RCOs may be once a year while others might exist only in a specific period. As a result Net Present Value (NPV) in relation to costs or benefits should be calculated in accordance with the following formula:

$$NPV = A + \frac{X}{(1+r)} + \frac{X}{(1+r)^{2}} + \frac{X}{(1+r)^{3}} + \cdots + \frac{X}{(1+r)^{T}} = A + \sum_{t=1}^{T} \frac{X}{(1+r)^{t}}$$

where: X is the cost or benefit of the RCO in a specific year; A is the initial cost of implementing the RCO (to be taken as 0 for calculation of earnings); r is the discount rate, generally taken as 5%.

3.5.2.5 It should be noted that due consideration should be given to the estimation of costs and benefits, and related uncertainty because of the importance of both parameters for demonstrating cost-effectiveness.

3.5.3 Interested entity

3.5.3.1 In general, an interested entity can be defined as the person, organization, company, flag State, etc., who is directly or indirectly affected by an accident or by the cost-effectiveness of the proposed new regulation. Different interested entities with similar interests can be grouped together for the purpose of applying the FSA methodology and identifying decision-making recommendations.

3.5.3.2 The evaluation of the above costs and benefits can be carried out by using various methods and techniques. Such a process should be conducted for the overall situation and then for those interested entities which are the most influenced by the problem in question.

3.5.4 Principle of evaluation of cost effectiveness

3.5.4.1 When only property loss or environmental pollution is considered, the following principle may be used. The lower the cost/benefit ratio is, the more preferably it should be used:

$$\Delta \mathrm{C} < \Delta \mathrm{B}$$

3.5.4.2 When the safety of life is considered, it is controversial to convert loss of life/injuries to currency and as a result, it is not suitable to use the above principle as the judgement criterion. The general criterion for evaluation of cost effectiveness is GCAF and NCAF:

(1) the gross cost per unit risk reduction GCAF:

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

(2) the net cost per unit risk reduction NCAF:

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

3.5.4.3 When only the environmental risk due to oil spill is considered, the following principle may be used for evaluation of cost effectiveness of RCO:

$$\Delta \mathrm{C} < \Delta \mathrm{SC}$$

where: ΔC is investment cost of RCO; ΔSC is earnings obtained from implementation of RCO, i.e. the cost of oil spill treatment before implementation of RCO minus that after implementation of RCO. Specific calculation methods are given in Appendix 3 of the Guidelines.

When both oil spill and safety of life are considered, the following principle may be used for evaluation of cost effectiveness of RCO:

$$\mathrm{NCAF} = \frac{\Delta \mathrm{C} - \Delta \mathrm{SC}}{\Delta \mathrm{PLL}}$$

where: ΔC is investment cost of RCO; ΔSC is earnings of oil spill treatment obtained from implementation of RCO; △PLL is reduction of loss of life due to implementation of RCO.

In case there is an economic benefit (ΔB), ΔC should be replaced by ΔC-ΔB.

3.5.4.4 In principle, either of the two criteria (GCAF or NCAF) can be used. However, it is recommended to firstly consider GCAF instead of NCAF. The reason is that NCAF also takes into account economic benefits from the RCOs under consideration. This may be misused in some cases for pushing certain RCOs, by considering more economic benefits on preferred RCOs than on other RCOs. NCAF adds another source of uncertainty into the evaluation which can be avoided when an RCO is already cost-efficient according to GCAF. If the cost-effectiveness of an RCO is in the range of criterion, then NCAF may be also considered.

3.5.4.5 The proposed values for NCAF and GCAF were derived by considering societal indicators (refer to document MSC 72/16, UNDP 1990, Lind 1996). The values provided in Table 3.5.4 were updated in 2024 based on the recent studies[2,3] and are provided for illustrative purposes only. The specific values selected as appropriate and used in an FSA study should be explicitly defined. These criteria given in Table 3.5.4 are not static, but should be updated every year according to the average risk free rate of return (approximately 5%) or by use of the formula based on LQI (Nathwani et al. (1997), Skjong and Ronold (1998, 2002), Rackwitz (2002). The values shown in Table 3.5.4 were determined using the 2019 data (Hamann and Cichowicz, 2023).

Cost-Effectiveness Criteria **Table 3.5.4**

	NCAF（$）	GCAF（$）
Criterion covering risk of fatality, injuries and ill health	8.7 million	8.7 million
Criterion covering only risk of fatality[4]	4.35 million	4.35 million
Criterion covering only risk of injuries and ill health[3,5]	4.35 million	4.35 million

3.5.4.6 For GCAF and NCAF of each RCO (RCM) obtained from calculation:

(1) RCO is cost-effective in terms of economic benefit if NCAF<0;

(2) RCO is cost-effective in terms of safety of life if GCAF<criteria value;

(3) RCO is cost-effective by comprehensively considering safety of life and economic benefit if 0<NCAF< criteria value;

(4) RCO is not cost-effective if NCAF> criteria value.

3.5.4.7 RCOs passing the criteria with GCAF, or NCAF, or with negative NCAFs should always be considered in connection with the associated risk reduction capability ΔR and, when prioritized, this should be done according to Δ R. When clear conclusions cannot be drawn from the initial ranking, other criteria may be used, e.g. benefit-cost-ratio (BCR = ΔBenefit / ΔCost).

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[2] R. Hamann, J. Cichowicz.(2023): Updating Threshold for IMO Cost Benefit Assessment. Ship Technology Research, https://doi.org/10.1080/09377255.2023.2184049.

[3] European Maritime Safety Agency (2023), Study investigating cost-efficient measures for reducing the risk of cargo fires on container vessels (CARGOSAFE) EMSA, Lisbon.

[4] NCAF and GCAF criteria are normally used covering not only fatalities from accidents, but implicitly also injuries and/or ill health from them. This is an adequate approach, because, as was mentioned above, many accidents involve both consequence categories: fatalities and injuries/ill health.However, if accidents are analysed that involve only one of the two categories, the criteria should be adjusted to cover explicitly only the category relevant to the accident under consideration. In document MSC 72/16 a proposal was made, that the NCAF and GCAF criteria are split equally for the two consequence categories.

[5] Refer also to QALY approach.

3.5.4.8 Sensitivity analysis and uncertainty analysis should be considered in the cost-benefit analysis and cost-effectiveness, and the results should be reported.

3.5.5 Implementation process

3.5.5.1 Consider the risks assessed in step 2, both in terms of frequency and consequence, in order to define risk levels of the situation under consideration, i.e. identify the base case prior to implementation of RCO.

3.5.5.2 Estimate the extent of risk reduction by implementing each RCO and compare the result with the base case.

3.5.5.3 Estimate the pertinent costs of each RCO, considering direct costs (e.g. survey costs) and indirect costs (e.g. costs related to operation, training and adaptability to provisions).

3.5.5.4 Estimate the benefits of each RCO and if possible, list the benefit of interested entities which are the most influenced by the RCO.

3.5.5.5 Estimate the cost effectiveness (cost-benefit ratio) of each RCO, i.e. gross and net cost per unit risk reduction and compare the cost-benefit ratio of each RCO.

3.5.5.6 Rank the RCOs from a cost-benefit perspective in order to facilitate the decision-making recommendations in step 5 (e.g. to screen those which are not cost-effective or impractical).

3.5.6 Output results

The output from step 4 comprises:

(1) costs and benefits for each RCO identified in step 3 from an overview perspective, in terms of the cost per unit risk reduction (i.e. cost-benefit ratio);

(2) costs and benefits for those interested entities which are the most influenced by the problem in question;

(3) comparing the results of all RCOs and ranking the RCOs.

3.6 FSA step 5- recommendations for decision-making

3.6.1 Purpose

The purpose of step 5 is to define recommendations which would be based upon the comparison and ranking of all hazards and their underlying causes; the comparison and ranking of risk control options as a function of associated costs and benefits; and the identification of those risk control options which keep risks as low as reasonably practicable.

3.6.2 Implementation process

3.6.2.1 Carry out systematic and objective comparison and evaluation of results from the previous 4 steps from the perspective of risk control effectiveness and cost benefit effectiveness.

3.6.2.2 Carry out risk balance analysis of each RCO to identify one or several options with good cost-benefit ratio.

3.6.2.3 Start with RCOs with good cost-benefit ratio, analyze the extent of influence on interested entities after implementation of new options and consider the balance between the investment and return of interested entities insofar as practicable.

3.6.2.4 Propose reasonable recommendations by considering the effectiveness of options and balance of interest of each party.

3.6.3 Output results

(1) an objective comparison of alternative options, based on the potential reduction of risks and cost-effectiveness;

(2) recommended practical RCO or specific selectable suggestions for development or revision of rules. The extent of complexity or difficulty of developed recommendations is based on

decision-making level and demand and the recommendations should be understood by all parties;
(3) presentation of FSA results: the FSA report and its format is given in Chapter 4.

CHAPTER 4 FSA REPORT AND ITS STANDARD FORMAT

4.1 Submission of FSA results

4.1.1 Upon the completion of an FSA application, a clear and concise report should be submitted. The report should include the most significant results of FSA process, which can also be understood by other personnel or organizations not having the same experience in the application of risk assessment techniques.

4.1.2 The report should contain an executive summary and the following sections: definition of the problem, background information, method of work, description of the results achieved in each step and final recommendations arising from the FSA study. The level of detail of the report depends on the problem under consideration.

4.1.3 The report should list the principal hazards, risks before and after adoption of RCO, costs and benefits of adopted RCO identified during the assessment; provide a clear statement of the final recommendations, ranked and justified in an auditable and traceable manner.

4.1.4 The report should explain and reference the basis for significant assumptions, limitations, uncertainties, data models, methodologies and inferences used or relied upon in the assessment or recommendations, results of hazard identifications and risk analysis, risk control options and results of cost-benefit analysis to be considered in the decision-making process. For relevant information and data referenced in the report, its source should be disclosed for check if necessary.

4.1.5 The report should describe the sources, extent and magnitude of significant uncertainties associated with the assessment or recommendations.

4.1.6 All supporting documentation and information may be attached to the report as annex if necessary, see 4.2.8.

4.1.7 In order that the submitted FSA reports have a uniform format, the report should be prepared in accordance with the standard format given in 4.2.

4.2 Standard reporting format

4.2.1 Title

(1) The problem applied should be explicitly defined.

(2) The scope of the FSA application should be reflected. If only some of the FSA steps are applied, one or several steps applied should be identified.

4.2.2 Opening and ending format

(1) The FSA executive summary should be given in part 1 of the report, including scope of application, assessment object, followed basis, important assumptions and limitations and results.

(2) The main body of the report should end with recommendations or actions requested, including type of action requested (e.g. as documentation or as basis for proposing revision) and summary of the final recommendations.

(3) References and all supporting documentation should be listed in the form of annex after the main body of the report.

4.2.3 Definition of the problem

(1) Definition of the problem to be assessed under consideration should be determined.

(2) Reference to rules or relevant documents affected by the proposal to be reviewed or developed (in an annex).

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

4.2.4 Background information

(1) Lessons learned from recently introduced measures to address similar problems (if any).

(2) Casualty statistics concerning the problem under consideration (e.g. ship types or accident category) including data analysis.

(3) Source of data and information.

4.2.5 Method of work

(1) Composition and expertise of those having performed each step of the FSA process by providing the unit, department, expertise and title of personnel.

(2) Description of how the assessment has been conducted in terms of meetings held, working groups and method of decision-making.

(3) Start and finish date of the assessment.

4.2.6 Description each step

For each step, describe:

(1) method and techniques used to carry out the assessment;

(2) assumptions, limitations (if any) or uncertainties and the basis for them;

(3) outcomes of each step of the FSA methodology, including:

Step 1-hazard identification: prioritized list of hazards and description of their associated scenarios; identified significant accident scenarios including causes and initiating events.

Step 2-risk analysis: types of risk (e.g. individual, societal, environmental, business); presentation of the distribution of risks depending on the problem under consideration; identified significant risks; principal influences that affect the risks; sources of accident and reliability statistics.

Step 3-risk control options: what hazards are covered by current rules; identified risk control options; assessment of the control options as a function of their effectiveness against risk reduction; details of the risk control measures identified.

Step 4-cost-benefit assessment: identified types of cost and benefits involved for each risk control option; cost-benefit assessment for the entities which are influenced by each option; identification of the cost-effectiveness expressed in terms of gross/net cost per unit risk reduction.

Step 5- recommendations for decision-making: objective comparison of alternative options; discussion on how recommendations could be implemented by decision-makers.

4.2.7 Final recommendations for decision-making

List of final recommendations, ranked and justified in an auditable and traceable manner. Experience has shown that IMO submissions present results in different format. IACS suggests standardizing the presentation of final results. The table below proposes a format that could be used:

Standard Reporting of final results (MSC78/19/1) **Table 4.2.7**

RCO	Description	PLL (Lifetime)	ΔB (Lifetime)	ΔC (Lifetime)	ΔPLL (Lifetime)	GCAF	NCAF
1							
2							

4.2.8 Annex (as necessary)

(1) explanation of the background of each expert (e.g. a short curriculum vitae) and the basis of selection of the experts;

(2) list of references;

(3) sources of data;

(4) accident statistics;

(5) technical support material (e.g. investigation report, internal information, plans and documents and comments of experts);

(6) any further information.

Appendix 1 IDENTIFICATION AND EXAMPLES OF HAZARDS

1 Flow of identification of hazards

Hazard means potential possibility that might lead to the occurrence of accidents, thereby giving rise to casualties, property loss or environmental pollution. Accidents occur randomly, but the law of occurrence and development of accidents needs to be understood by applying scientific theories and methodologies. The prevention of occurrence of accidents is to identify and control hazards.

The purpose of identification of hazards is to determine all hazards that might exist by using certain hazard identification methods, identify causes of accidents and possible consequences, as well as determine the level of each type of hazard and rank the hazards, so as to further analyze principal hazards in subsequent steps and create corresponding risk control options. The flowchart of identification of hazards is shown below:

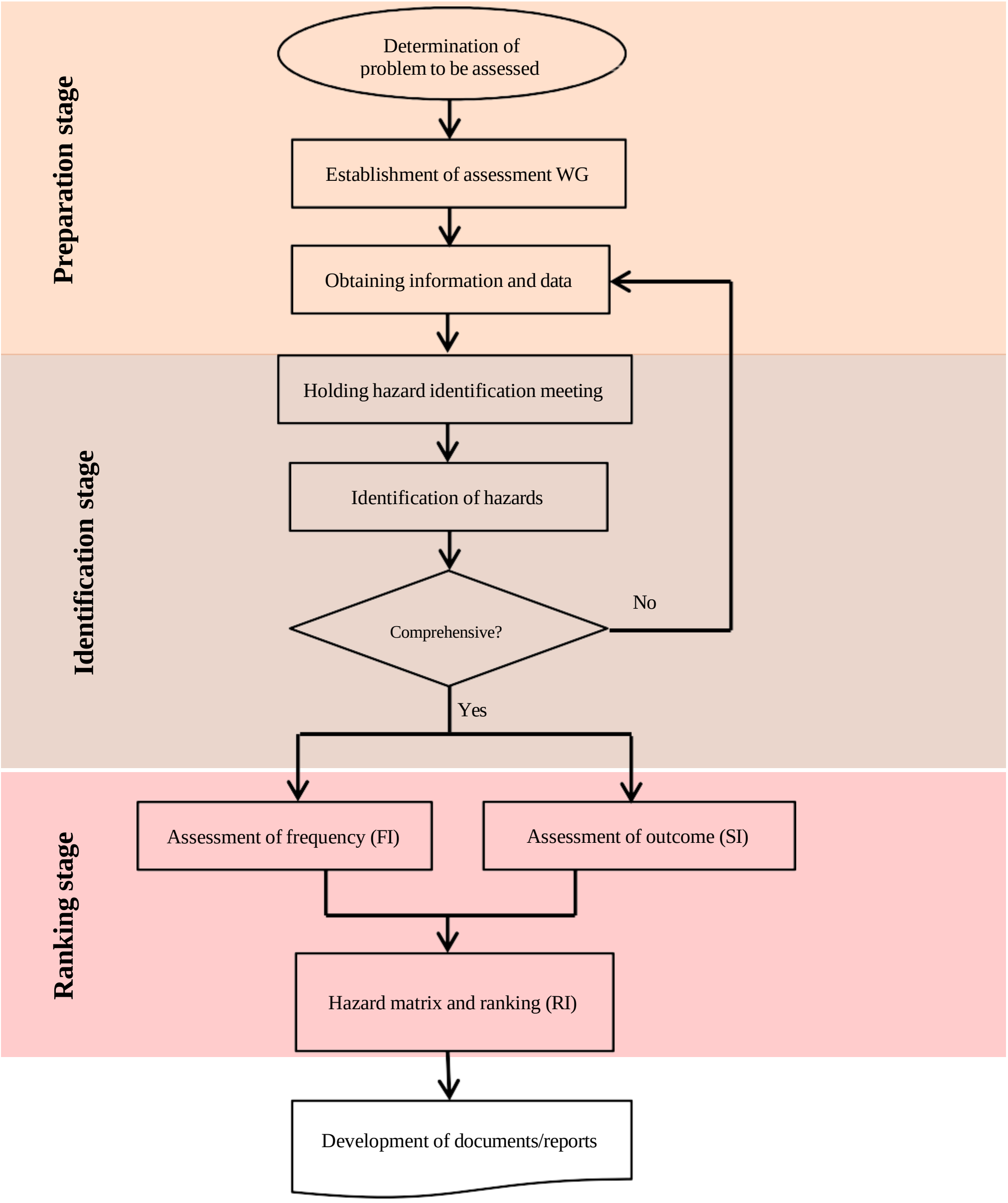


Figure 1.1 Flowchart of Identification of Hazards

The identification of hazards is the beginning of an FSA process carried out for a problem. All potential hazards related to the problem under assessment should be identified. The most basic understanding is: what might go wrong?

When carrying out the identification of hazards, the typical questions raised include: what might go wrong? How will the accident happen? In case accidents might happen: why? What is the cause of accident? How often does the accident happen? What is the consequence of accident? What is the impact? Is there any measure to prevent the occurrence of accident or mitigate the consequence? The answers to these questions will help experts to obtain a comprehensive understanding and identification of possible cause and consequence of potential accidents.

2 Methods of identification of hazards

Common methods of identification of hazards which are recommended by IMO at present include checklist method, what if analysis technique, Hazard and Operability Studies (HAZOP), failure mode and effect analysis (FMEA), Delphi method etc.

2.1 Checklist method

Checklists are lists of hazards, risks or failures under control, which are generally prepared by relying on expert experience (in accordance with previous results of risk assessment or previous failures). The checklist method may be used to identify hazards or evaluate the effect of risk control and applied at any stage of the life cycle of ships or associated systems. Checklists may be used in conjunction with other risk assessment techniques, the main purpose of which is to check if there is any omitted problem after applying a more imaginative technique intended for identifying new problems.

The specific steps of checklist method are as follows:

(1) determination of the activity scope;

(2) selection of a checklist that can fully cover the whole scope. As a result, a checklist should be carefully selected. E.g., a standard controlled checklist cannot be used to identify new hazards or risks;

(3) Personnel or group using the checklist should be familiar with factors of the process or system and check if there is any missing item on the checklist.

The output result of checklist method depends on the stage of risk control process using such result. E.g., the output result may be an incomplete control list or risk list.

The advantages of checklists include:

(1) checklists can be used by non-experts.

(2) if well prepared, they incorporate various expertise into a system convenient to use;

(3) they help to ensure that common problems are not omitted.

The limitations of checklists include:

(1) they limit the imagination during the process of hazard identification;

(2) they prove “known factors that are known” rather than “unknown factors that are known” or “unknown factors that are unknown”;

(3) they encourage the habit of “ticking in the box”;

(4) they are often based on observed situations and as a result problems that are not observed will be omitted.

2.2 What if analysis technique

What If Analysis Technique is a non-structured methodology analyzing accidents which might lead to unfavorable results. By asking questions starting with "what if?", such methodology obtains possible consequence. The proposed assumption should be realistic and based on the rich practical experience of experts, or else it might lead to some unrealistic scenarios.

What If Analysis Technique is a hazard identification technique suited for use in a hazard identification meeting. Firstly the system, function or operation under consideration is discussed in detail. The experts may have to clarify to each other how the details of the system, function or operation work and may fail. Next, questions starting with "what if?" are asked, spanning topics like operation errors, equipment malfunction and maintenance, which are supplemented by historic data. With regard to each assumption, the results and mutual influence are considered. At last, consensus is reached at the meeting and a report is developed.

What If Analysis Technique may be used at the design, revision and operation stage of a plan. The final results are a list that might lead to hazards and methods and improvement measures that should be adopted to mitigate the consequence caused by hazards. What If Analysis Technique is usually used in conjunction with the checklist method, i.e. SWIFT (Structured What If Technique). For example, a SWIFT analysis is carried out to a ballast water system:

I. SWIFT defines relevant operations and next brainstorming is carried out:

(1) What if the ballast water system is insufficient in design?
(2) What if a valve malfunctions?
(3) What if a pump malfunctions?
(4) What if a pipeline malfunctions?
(5) What if the pressure of water tank is too high?
(6) What if the operation of remote system malfunctions?
(7) What if power malfunctions?

……

II. A checklist is established to identify additional hazards:

(1) operation error and other human factors;
(2) measurement error;
(3) equipment/instrument malfunction;
(4) maintenance;
(5) loss of integrity or tightness;
(6) emergency operation;
(7) external factors or influences.

……

III. Worksheet of hazard identification ranked in logical order:

Worksheet of Hazard Identification Table 1.1

No.	What if	Cause	Consequence	Measure	Suggestions
1	Deficiency of system design	Shipyard's lack of experience; lack of rules requirements; design process or quality testing not satisfactory; insufficient fund	Pump capacity is too low; Ballasting efficiency is not sufficient	Rules of classification society/IMO, review process of plans	
2	System malfunction	Malfunction of pumps, valves and pipelines; clogging of suction pipes	Ballasting capacity is insufficient or decreased; Heel is	Redundant design, maintenance	Inspection of operation and performance test should be

			not correct		carried out for the ballast water system
3	Deficiency of operational process	Lack of training; lack of time; wrong weather forecast	Leading to mistakes of ballast operation	Training procedure	The hazard of ballasting should be emphasized in training
4	Misoperation of system	Not carried out in accordance with ballasting plan; ballasting procedure is not clear; misoperation of valves; incorrect operation sequence of valves; lack of training; lack of time	Unfavorable heel/trim/pumping	Training procedure, plan monitoring	Monitoring requirements should be included in the ballasting procedure

2.3 Hazard and Operability Studies

By synthesizing opinions of several experts, HAZOP identifies deviations of system processes or conditions, analyzes causes and possible consequence and put forward corresponding preventative measures. These studies are carried out to analyze the hazards in a system at progressive phases of its development from concept to operation. The aim is to eliminate or minimize potential hazards. The implementation steps are as follows:

(1) establish an analysis team consisting of experts from various fields such as operation, management, technology, design and supervision based on the object of study, and designate a responsible person;

(2) collect relevant information and materials extensively with regard to the object of study;

(3) divide the object of study into several units, define the function of each unit and describe its operating condition and process;

(4) define key words of HAZOP, based on which possible deviations of each unit is analyzed one by one;

(5) analyze the cause of deviation and its consequence;

(6) develop corresponding measures.

Key words of HAZOP are defined with regard to deviations that might occur:

Key words of HAZOP **Table 1.2**

Key words	Deviation
No or not	No source of power, no flowing of fuel oil, cargo oil tank is not cleaned
Large, high	The pipeline pressure is too large, the fuel oil temperature is too high
Small, low	The injection pressure of fuel oil is too small, the pressure of fuel oil tank is too low
And	Discharge clean water and oily water to the sea
Opposite	Flowing
Other	Normal operation
……	……

Identified hazards, operability problems and potential consequences are listed through HAZOP while recommendations for further analysis are given. A typical HAZOP worksheet is as follows:

Worksheet of HAZOP **Table 1.3**

Team:____________________ No. of drawings:________

Meeting time:________________ Revision No.:________

No.	Deviation	Cause	Consequence	Risk control option	Action taken
1					
2					
3					

2.4 Failure mode and effect analysis

FMEA is a method in which the system to be analysed is defined in terms of functions or hardware. Each item in the system is identified at a required level of analysis. This may be at a replaceable item level. The effects of item failure at that level and at higher levels are analysed to determine their severity on the system as a whole. Any compensating or mitigating provisions in the system are taken account of and recommendations for the reduction of the severity are determined. The analysis indicates single failure modes which may cause system failure.

Basic steps of FMEA:

(1) define the system and its functions, draw the diagram of functions;

(2) analyze the failure mode, i.e. manifestation of failure;

(3) analyze the cause of failure;

(4) analyze the effects of failure, i.e. various consequences caused by the failure, including effects on the item, on the system and on the ship as a whole;

(5) identify failure detection methods;

(6) propose possible preventative and improvement measures;

(7) complete FMEA worksheet an develop FMEA report.

Identified failure modes, the cause and possible effects are listed through FMEA while recommendations for further analysis are given. A typical FMEA worksheet is as follows:

Worksheet of FMEA **Table 1.4**

Time: __________________ Page: ______ of ________

Ships: __________________ System: __________________

Referenced literature: ________________ Team members: ________________

Equipment	Function	Failure mode	Cause	Effect	Risk control option	Recommended actions to be taken

2.5 Delphi method

Delphi method seeks the predictive opinions of members of an expert meeting by using the back-to-back communication method. After several rounds of consultation, the predictive opinions of expert meeting tend to be synthesized. At last predictive conclusions complying with actual law are drawn. Delphi method can conduct expert investigation for various tasks and problems, especially for cases where there is a lack of historic data; therefore it is also called Expert opinion method or Expert investigation method by correspondence.

Delphi method adopts the way of expressing opinions anonymously in accordance with systematic procedures, i.e. team members cannot discuss with each other nor do they have any lateral linkage; they only have relations with the investigator. By completing questionnaires repeatedly, collecting the consensus of persons completing questionnaires and collecting opinions of various parties, the communication process of a team is established. It is a managerial technique to deal with complex tasks and problems.

For this method, a questionnaire is prepared by the investigator. Members of the expert group are consulted respectively by correspondence in accordance with established procedures. Members of the expert group submit their opinions anonymously (by correspondence). After several rounds of consultation and feedback, the opinions of experts tend to be synthesized. At last a collective judgement result with a very high degree of accuracy is obtained. Such method is usually used in conjunction with analytic hierarchy process.

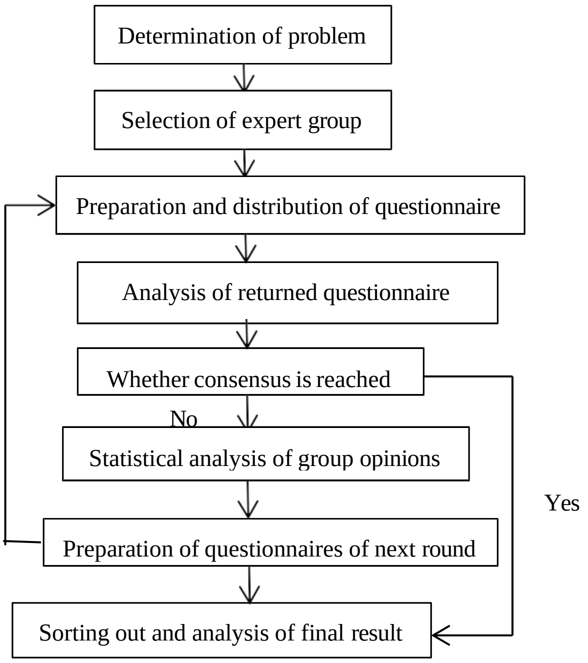


Figure 1.2 Flowchart of Delphi Method

3 Ranking of identified hazards

After potential hazards are identified, hazards and their associated scenarios should be ranked. When hazards are ranked, their ranking should be listed under each risk category respectively in accordance with the type of risk under consideration.

The method of ranking is mainly carried out in accordance with historic statistical data and expert judgement. Risk matrix and expert ranking methods are recommended by IMO.

(1) Risk matrix method. It is recommended to use logarithm to define the frequency and severity (consequence) of occurrence of accidents.

$$\text{Risk} = \text{Frequency} \times \text{Consequence}$$

$$\log(\text{risk}) = \log(\text{frequency}) + \log(\text{consequence})$$

Risk index（RI）=frequency index（FI）+severity index（SI）

The frequency of occurrence and degree of severity are divided into several levels. The frequency and associated consequence are placed in a matrix, i.e. risk matrix. Such method can generally be used when historic statistical data and relevant information are sufficient. A risk matrix may be divided into three area: high risk area, low risk area and critical area between those two area, see figure below:

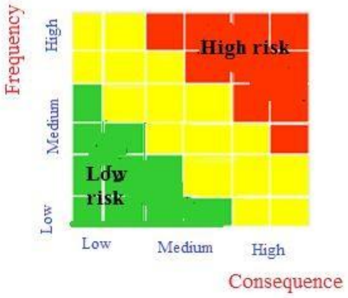


Figure 1.3 Risk Matrix

The following table (excerpted from MSC-MEPC.2/Circ.12) gives an example of a logarithmic frequency index.

Alternatively, the frequency index (FI) can be directly calculated from the frequency of occurrence using the below formula:

$$\mathrm{FI} = 6 + \log(\mathrm{F})$$

Definitions and Values of Frequency Index **Table 1.5**

Frequency index			
FI	Frequency	Definition	F (per ship year)
7	Frequent	Likely to occur once per month on one ship	10
6	Highly probable	Likely to occur once per year on one ship	1
5	Reasonably probable	Likely to occur once per year in a fleet of 10 ships, i.e. likely to occur a few times during the ship's life	10^{-1}
4	Probable	Likely to occur once per year in a fleet of 100 ships, i.e. likely to occur during the ship's life	10^{-2}
3	Rare	Likely to occur once per year in a fleet of 1,000 ships, i.e. likely to occur in the total life of several similar ships	10^{-3}
2	Remote	Likely to occur once per year in a fleet of 10,000 ships	10^{-4}
1	Extremely remote	Likely to occur once in the lifetime (20 years) of a world fleet of 5,000 ships.	10^{-5}

The following table (excerpted from MSC-MEPC.2/Circ.12) gives an example of a logarithmic severity index, scaled for a maritime safety issue. Consideration of environmental issues or of passenger vessels may require additional or different categories.

Alternatively, the severity index (SI) for fatalities can be directly calculated from the equivalent number of fatalities (S) using the below formula

$$\mathrm{SI} = 3 + \log(\mathrm{S})$$

Definitions and Values of Severity Index **Table 1.6**

Severity index				
SI	Severity	Effects on human safety	Effects on ship	S (Equivalent fatalities)
1	Minor	Single or minor injuries	Local equipment damage	0.01
2	Significant	Multiple or severe injuries	Non-severe ship damage	0.1
3	Severe	Single fatality or multiple severe injuries	Severe damage	1
4	Catastrophic	Multiple fatalities	Total loss	10
Severity indices > 4 are suggested to be used for accidents with a higher number of fatalities				

In case of FSA on prevention of oil spill from ships, the following severity index can be used (excerpted from MSC-MEPC.2/Circ.12):

Definitions and Values of Severity Index of Oil Spill Accident **Table 1.7**

Severity index		
SI	Severity	Definition
1	Category 1	Oil spill size < 1 tonne
2	Category 2	Oil spill size between 1-10 tonnes
3	Category 3	Oil spill size between 10-100 tonnes
4	Category 4	Oil spill size between 100-1,000 tonnes
5	Category 5	Oil spill size between 1,000-10,000 tonnes
6	Category 6	Oil spill size >10,000 tonnes

The following table gives an example of a risk matrix based on the tables above.

Values of Risk Index **Table 1.8**

Risk index					
FI	Frequency	Severity (SI)			
		1	2	3	4
		Minor	Significant	Severe	Catastrophic
7	Frequent	8	9	10	11
6	Highly probable	7	8	9	10
5	Reasonably probable	6	7	8	9
4	Probable	5	6	7	8
3	Rare	4	5	6	7
2	Remote	3	4	5	6
1	Extremely remote	2	3	4	5

For example: an event rated "remote" (FI=3) with severity "Significant" (SI=2) would be RI=FI+SI=5.

For practical application, a hazard with a high severity index is sometimes listed in the severity level at the same time.

(2) Expert ranking method. A group of experts compare a series of identified hazards respectively. Each expert ranks the hazards from high risk level to low risk level in accordance with his/her own judgement. At last, with regard to each hazard, the rankings from all experts are added together to obtain the final ranking results in the order of small to large. Such method can generally be used when historic statistical data and relevant information are insufficient.

Experts compare and rank hazards in accordance with their own experience an understanding. Experts are sometimes used to rank risks associated with accident scenarios, or to rank the frequency or severity of hazards. This is a subjective ranking, where each expert may develop a ranked list of accident scenarios, starting with the most severe. The level of understanding of the problem and knowledge background of experts will lead to disagreement in their assessment opinions. To enhance the transparency in the result, the resulting ranking should be accompanied by a concordance coefficient, indicating the level of agreement between the experts.

Assume that a number of experts (J experts in total) have been tasked to rank a number of accident scenarios (I scenarios), using the natural numbers (1, 2, 3, .. , I). Expert "*j*" has thereby assigned rank x_{ij} to scenario "*i*". The concordance coefficient "*W*" may then be calculated by the following formula:

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

The coefficient *W* varies from 0 to 1. *W*=0 indicates that there is no agreement between the experts as to how the scenarios are ranked. *W*=1 means that all experts rank scenarios equally by the given attribute.

The level of agreement is characterized in table below:

Concordance coefficients **Table 1.9**

W	> 0.7	Good agreement
W	0.5 – 0.7	Medium agreement
W	< 0.5	Poor agreement

Tables 1.10 to 1.12 are examples. In each example there are 6 experts (J=6) that are ranking 10 scenarios (I=10). In order to show the role of the concordance coefficient, the final combination by Σx_{ij} constructed by the importance of hazards 1- 10 for all three groups. From Tables 1.9 to 1.11 it is quite evident how various degrees of concordance have been formed.

Assessment of significance of the concordance coefficient is determined by parameter Z:

$$\mathrm{Z} = \frac{1}{2}ln\frac{(J-1)W}{1-W}$$

which has Fischer distribution with degrees of freedom $v_1 = I - 1 - \frac{2}{J}$ and $v_2 = (J-1)v_1$. If I > 7, Pearson's criteria χ^2may be used. The value of $J\,(I - 1)\,W$ has a χ^2distribution with $v = I - 1$ degrees of freedom.

Group of experts with high degree of agreement **Table 1.10**

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

Calculations based on Table 1.10 result in $W = 0.909$; $\chi^2 = J\,(I - 1)\,W = 47.5$; Confidence level of probability $\alpha = 0.999$.

Group of experts with medium degree of agreement **Table 1.11**

Hazards Experts	1*	2	3	4	5	6	7	8	9	10
1	1	6	8	4	2	3	5	7	9	10
2	2	3	1	5	6	4	7	8	10	9
3	3	4	1	2	5	8	9	10	6	7
4	4	5	6	1	8	2	3	10	7	9
5	4	3	1	9	2	5	7	10	6	8
6	5	1	7	4	3	9	8	2	10	6
$\sum x_{ij}$	19	23	24	25	26	31	39	47	48	49

Calculations based on Table 1.11 result in $W = 0.413$; $\chi^2 = 25.4$; $\alpha = 0.999$.

Group of experts with low degree of agreement **Table 1.12**

Hazards Experts	1*	2	3	4	5	6	7	8	9	10
1	5	9	3	8	2	1	7	10	6	4
2	1	5	7	4	8	9	3	6	2	10
3	6	2	8	3	9	10	4	1	5	7
4	1	4	3	2	7	5	9	6	10	8
5	6	1	3	5	2	8	4	9	7	10
6	3	7	5	8	4	2	10	6	9	1
$\sum x_{ij}$	22	28	29	30	32	35	37	38	39	40

Calculations based on Table 1.12 result in $W = 0.102$; $\chi^2 = 5.4$; $\alpha = 0.20$.

4 Examples of shipboard hazards

4.1 Shipboard hazards to personnel

(1) asbestos inhalation;
(2) burns from caustic liquids and acids;
(3) electric shock and electrocution;
(4) falling overboard;
(5) pilot ladder/pilot hoist operation.

4.2 Hazardous substances on board ship

4.2.1 Accommodation areas:

(1) combustible furnishings;
(2) cleaning materials in stores;
(3) oil/fat in galley equipment;

4.2.2 Deck areas:

(1) cargo;
(2) paint, oils, greases etc., in deck stores;

4.2.3 Machinery spaces:

(1) cabling;
(2) fuel and diesel oil for engines, boilers and incinerators;
(3) fuel, lubricating and hydraulic oil in bilges, save alls, etc.;
(4) refrigerants;
(5) thermal heating fluid systems.

4.3 Potential sources of ignition

4.3.1 General:

(1) electrical arc;
(2) friction;
(3) hot surface;
(4) incendiary spark;
(5) naked flame;
(6) radio waves;

4.3.2 Accommodation areas (including bridge):

(1) electronic navigation equipment;
(2) laundry facilities – irons, washing machines, tumble driers, etc.

4.3.3 Deck areas:

(1) deck lighting;
(2) funnel exhaust emissions;
(3) hot work sparking;

4.3.4 Machinery spaces:

(1) air compressor units;
(2) generator engine exhaust manifold.

4.4 Hazards external to the ship

(1) storms;
(2) lightning;
(3) uncharted submerged objects;
(4) other ships.

Appendix 2 RISK ASSESSMENT METHODS AND EXAMPLES

1 Summary

There are many types of risk assessment methods, which generally consist of three categories, i.e. qualitative analysis method, semi-quantitative analysis method and quantitative analysis method. The introduction of the concept of "quantity" serves as the basis of analysis and comparison. Accident probability calculation based on statistical method and accident consequence calculation based on numerical simulation should serve as the basis of a strict quantitative analysis. Due to a lack of accident data and limitation of time and cost, it is difficult to accurately calculate the probability and consequence of accidents and in most cases it is impossible to obtain such probability and consequence. A qualitative analysis method carries out systematic and careful examination of the hazard condition of the object under analysis and performs general evaluation of hazard in accordance with examination results. The hazard condition of an object is expressed as a type of division value in the semi-quantitative analysis method, so as to distinguish between extent of hazard of different objects.

The use of qualitative or quantitative method depends on the amount of information during the process of risk analysis. Qualitative and semi-quantitative analysis methods are generally used at FSA step 1- identification of hazards, so as to select some important hazards for further analysis in detail. Quantitative analysis method is used at FSA step 2- risk analysis.

The risk evaluation study was applied to the shipping industry at a relatively late stage. As the status of the shipping industry improves, various traditional risk analysis methods have been widely applied sine mid-1990s. At present common methods used in FSA study include Event Tree Analysis (ETA), Fault Tree Analysis (FTA), Risk Contribution Tree (RCT), influence diagrams, and Bayesian network etc.

2 Common risk assessment methods

2.1 Event tree analysis method

Event tree analysis method explores the development or escalation of an accident, a failure or an unintended event. Analysis is carried out step by step in phases in accordance with the development sequence of an accident. Consideration is given to two possible consequences, i.e. success or failure in each step until the final result is identified. The condition under analysis is shown by a dendrogram, and therefore it is called an event tree, through which the dynamic development process of the event can be understood qualitatively and the probability of each phase can be obtained by quantitative calculation so as to eventually evaluate the probability of occurrence (likelihood) of each consequence.

The basic procedures of event tree analysis may be summarized as four steps below:

(1) Determine the system and its constituent elements, i.e. define the required object and scope and identify elements of system (sub-system) to facilitate analysis.

(2) Analyze the causal relationship of each element and two conditions, i.e. success and failure.

(3) Starting from the initial condition or activating event of system, prepare and develop the event tree gradually from left to right in accordance with the order of elements forming the system.

(4) Mark the probability value of success and failure of each node as necessary, carry out quantitative calculation to obtain the "probability of occurrence" of an accident due to failure.

Initiating event of an event tree is the first of a sequence of events leading to a hazardous situation or accident, which is an undesired event leading to ship damage or casualty. The initiating event is usually identified at FSA step 1. Each initiating event gives rise to a separate event tree, .e.g. collision event tree, fire event tree, etc.

Consequence of an event tree: each possible outcome of an event tree is set as a scenario (final condition). The consequence of scenario may be determined by professional software, e.g. damage stability, CFD calculation, fire simulation, spreading of smoke, personnel evacuation simulation and strength calculations.

Probability of an event tree: The success or failure probability of each step in the sequence of events may be obtained by means of accident data statistics, system reliability and expert judgement. Multiplying the probability of each branch event by the probability of occurrence of the initiating event gives the frequency of occurrence of the final scenario.

An example of collision event tree is given below (excerpted from EU GOALDS project, SLF 55/INF.9). The collision event tree was developed by considering 5 levels of subsequent event sequences after the collision accident. The collision event tree is shown in Figure 2.2. Dependent probabilities were determined based on the information provided by the casualty reports.

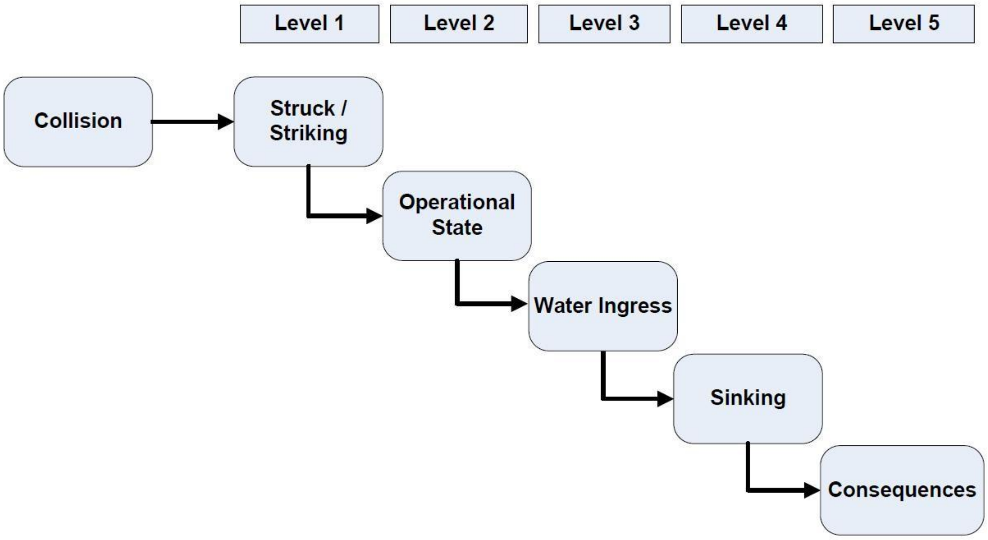


Figure 2.1 High Level Event Sequence for Accident Category Collision

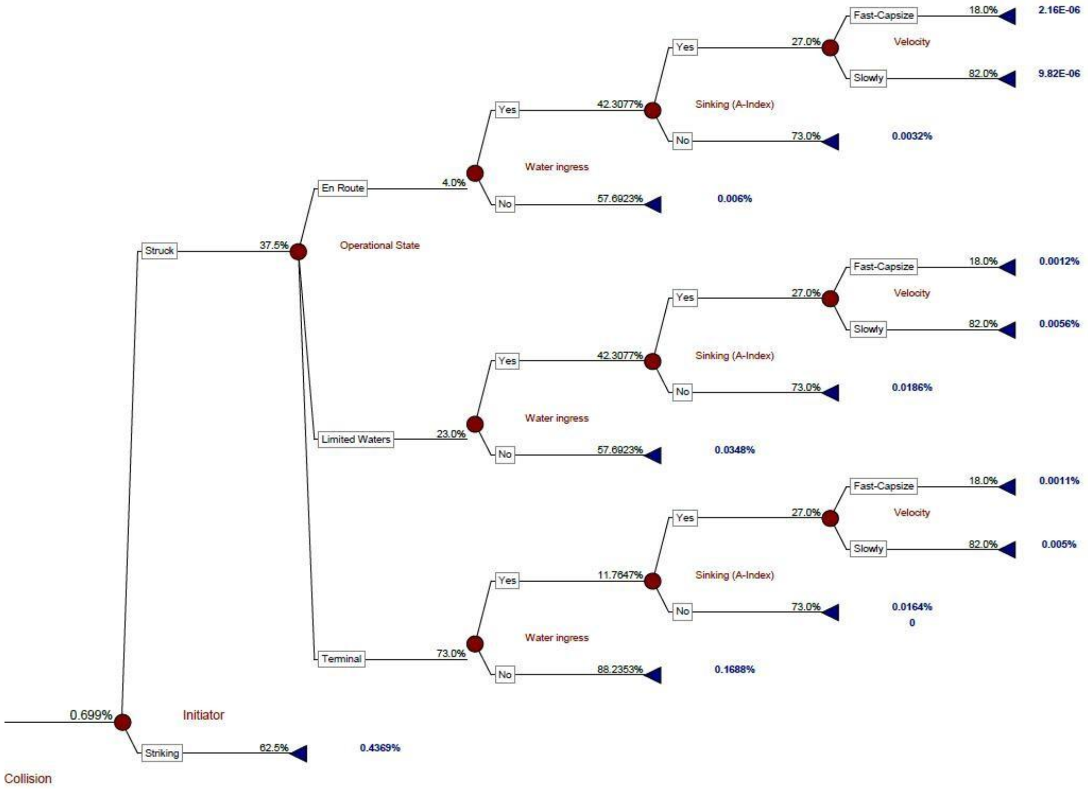
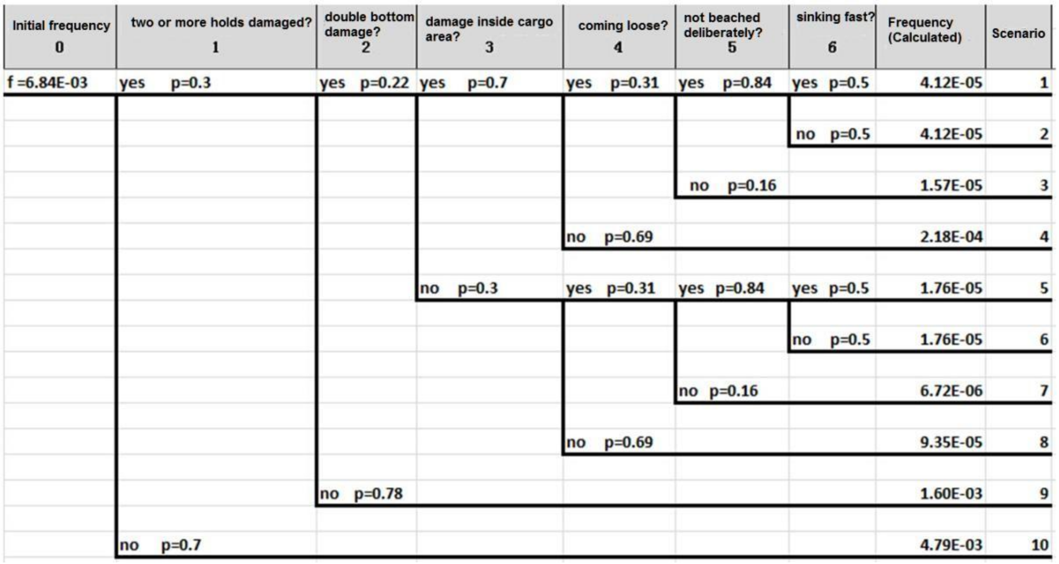


Figure 2.2 Example of Collision Event Tree of Ship

An example of contact event tree is given below (excerpted from SAFEDOR project, MSC83/INF.8):



Initial frequency 0	two or more holds damaged? 1	double bottom damage? 2	damage inside cargo area? 3	coming loose? 4	not beached deliberately? 5	sinking fast? 6	Frequency (Calculated)	Scenario
f =6.84E-03	yes p=0.3	yes p=0.22	yes p=0.7	yes p=0.31	yes p=0.84	yes p=0.5	4.12E-05	1
						no p=0.5	4.12E-05	2
					no p=0.16		1.57E-05	3
				no p=0.69			2.18E-04	4
			no p=0.3	yes p=0.31	yes p=0.84	yes p=0.5	1.76E-05	5
						no p=0.5	1.76E-05	6
					no p=0.16		6.72E-06	7
				no p=0.69			9.35E-05	8
		no p=0.78					1.60E-03	9
	no p=0.7						4.79E-03	10

Figure 2.3 Example of Contact Event Tree of Ship

An example of event tree of fire in a compartment of ship is given below:

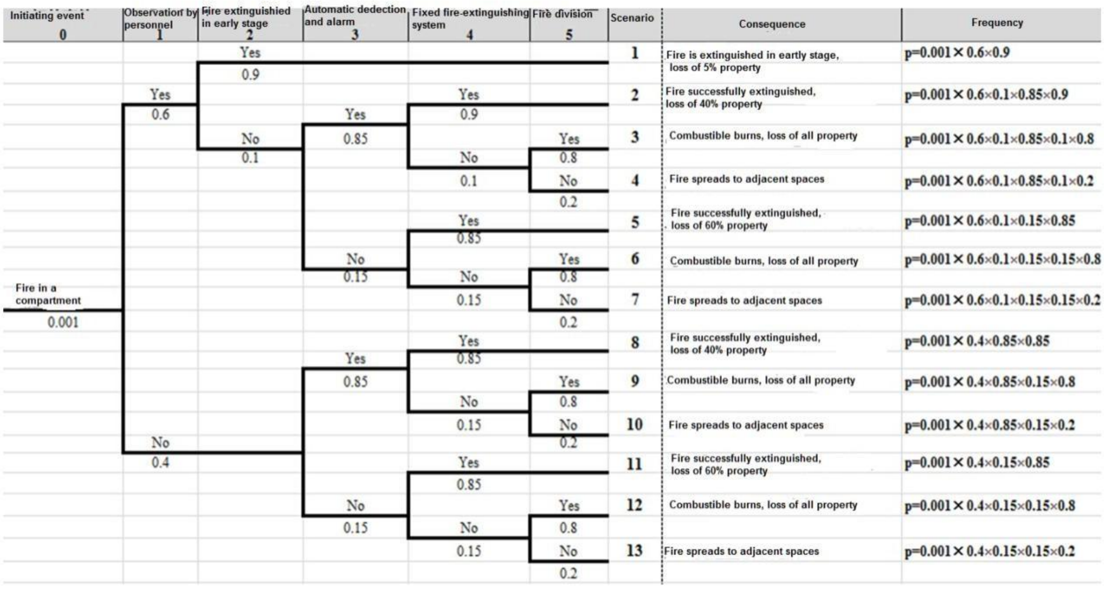


Figure 2.4 Example of Fire Event Tree of Ship

2.2 Fault tree analysis method

Fault tree analysis method (also called accident tree analysis method) carries out logical analysis of the cause and outcome of an accident by applying the principle of operational research. By starting from the accident, such method carries out a top-down deduction level by level, in which all the events that occur are linked together by logical relationship and all elements that might lead to an accident and the mutual relationship are described in a comprehensive, systematic, concise and vivid manner.

As a flexible tool, the fault tree analysis applies to both quantitative and qualitative analysis and it is easy to use and understand. The accident analysis is a top-down working process: assume that an accident occurs in a system and then try to identify the cause of accident. Through inverse operation, it tries to determine which events with reasonable combination might lead to accidents; therefore, a system accident becomes a top event of fault tree and the failure of individual components becomes a basic event. They are combined by the network of logic gates, .e.g. “and” and “or”, showing the relationship between the accident and its cause. A top event is a type of accident or unintended hazardous outcome. A basic event is generally a failure or expected event that occurs during the normal operation of a system. Fault tree analysis consists of two parts: qualitative (logic) analysis and quantitative (probability) analysis. With regard to qualitative analysis, the logical expression of the fault tree is simplified to the minimum cut set, which is the minimum possible combination required which might cause a main event. With regard to quantitative analysis, the probability of occurrence of a main event is calculated by the probability of occurrence of known basic events.

The potential cause and final accident can be connected through the intermediate connection links by applying the fault tree analysis method so that the responsibility of accident can be identified, which provides a basis for taking corrective measures. Main and secondary causes leading to the accident and the element of combined causes can be identified by logical analysis of causes. By controlling a limited number of key causes, the occurrence of major accidents can be effectively prevented, the management efficiency can be improved and manpower and material resources can be saved.

The basic procedures of fault tree analysis may be summarized as five steps below:

(1) Define the system under analysis, the purpose of which is to define the research object, including the function, composition, boundary and failure mode of system.

(2) Select the most serious failure mode of the system as the top event. There may be more than one failure modes and each failure mode has different effect on the system. As a result, the failure mode with the most serious effect on the system should be selected for fault tree analysis.

(3) Develop the fault tree. The top event is analyzed. Firstly the direct cause for the top event is identified, which is treated as the second-level event leading to the top event. More detailed analysis is carried out downwards until the lower boundary of system is reached and bottom events leading to the occurrence of top event can be obtained.

(4) Carry out qualitative and quantitative analysis of the fault tree. The purpose of qualitative analysis is to find the minimum cut set of the fault tree. The minimum cut set may be a combination of several bottom events or formed by a single bottom event. The order of the minimum cut set is determined in accordance with the number of elements in the minimum cut set. The smaller the order is, the more important the minimum cut set is. The next step research should be carried out firstly. The purpose of quantitative analysis is to calculate the probability of occurrence of the top event and importance of bottom events in accordance with the structural function of fault tree based on the probability of occurrence of bottom events. And then bottom events are ranked in accordance with their importance.

(5) Carry out research on remedial measures to be taken.

Logic gates of the fault tree: the logic gates determine the addition or multiplication of probabilities (assuming events A, B and C are mutually independent) to obtain the values for the top event. They mainly consist of “and” gate and “or” gate.

(a) “And” gate (b) “Or” gate

Figure 2.5 Logic Gates of the Fault Tree

① “And” gate: branch events under the symbol occur simultaneously to cause the event above the symbol. If two or more lower events need to occur to cause the next higher event, this is shown by a logic "and" gate.

$$\mathrm{P(and\ gate) = P(a) \times P(b|a) \times P(c|a, b)}$$

When events a, b, c are independent from each other,

$$\mathrm{P(and\ gate) = P(a) \times P(b) \times P(c)}$$

② “Or” gate: any one of branch events under the symbol occurs to cause the event above the symbol. If any one of two or more lower events can cause the next higher event, this is shown by a logic "or" gate.

$$\mathrm{P(or\ gate) = P(a) + P(b) - P(a) \cdot P(b)}$$

When events a, b, c are independent from each other,

$$\mathrm{P(or\ gate) = P(a) + P(b)}$$

Examples of fault trees of fire in a compartment of ship are given below:

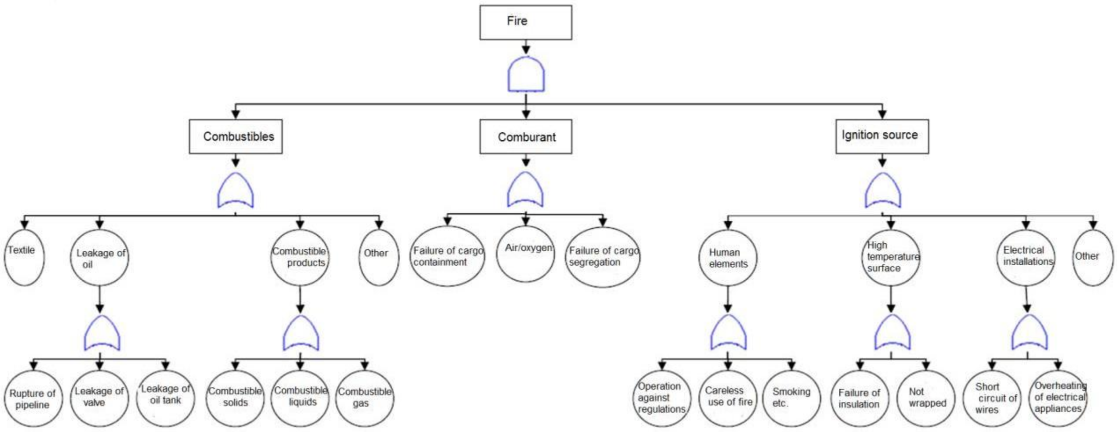


Figure 2.6 Occurrence of Fire in a Compartment

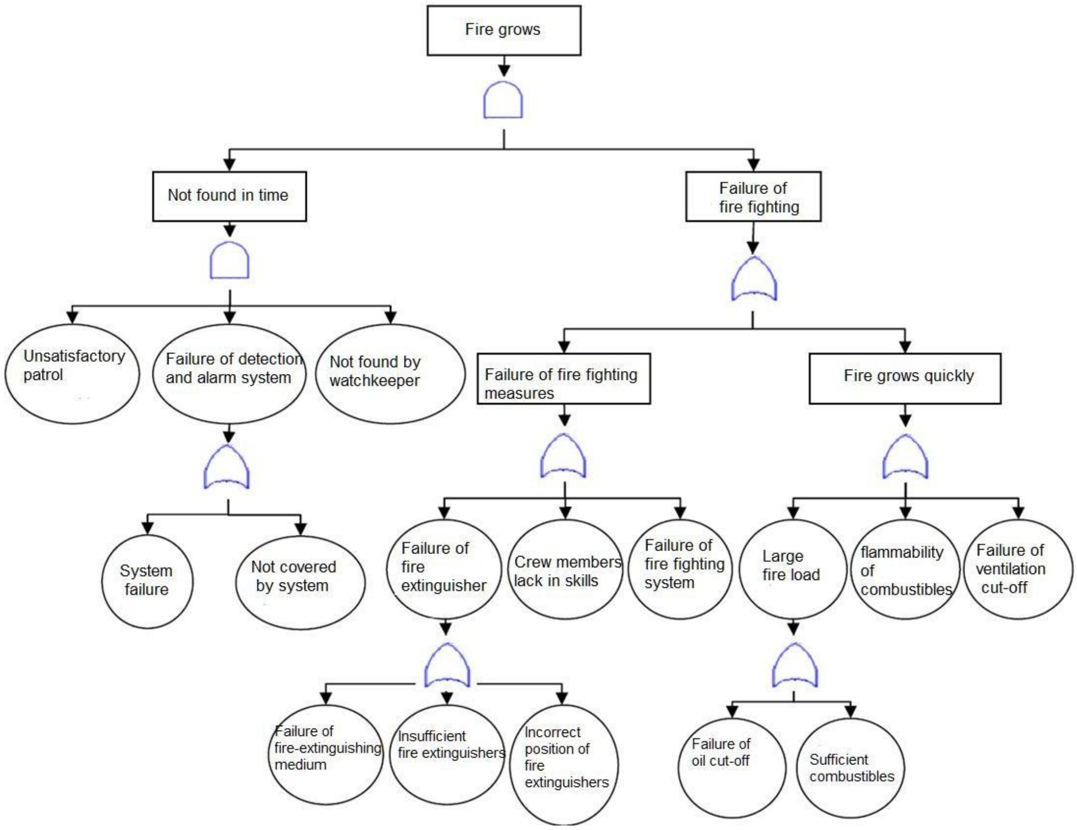


Figure 2.7 Fire Grows in a Compartment

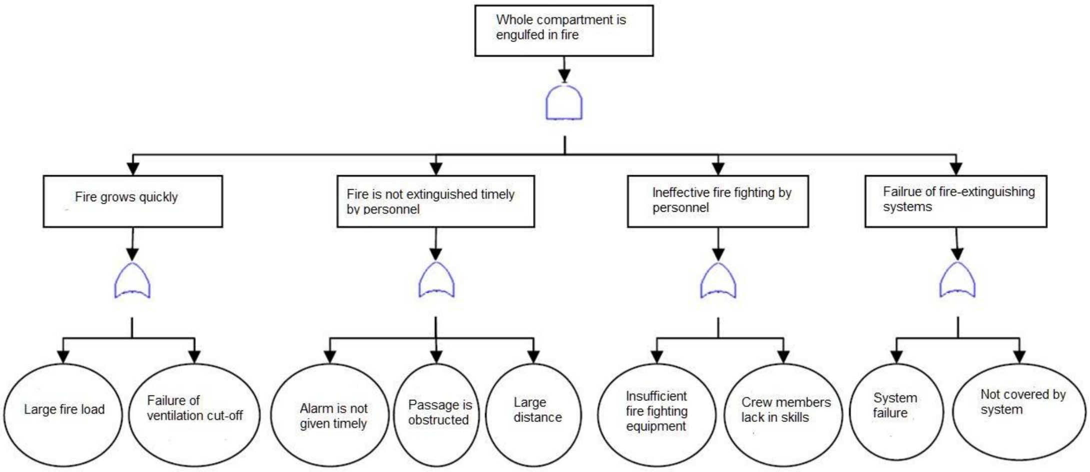


Figure 2.8 Whole Compartment is Engulfed in Fire

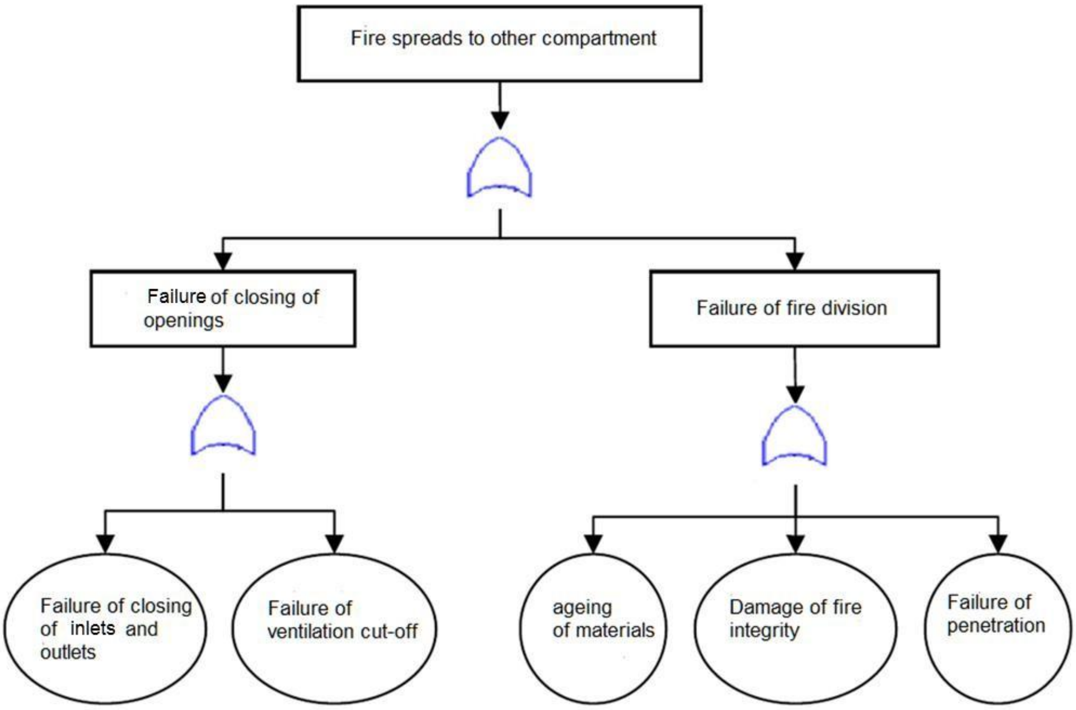


Figure 2.9 Fire Spreads to Other Compartment

2.3 Risk contribution tree (RCT)

RCT may be used as a mechanism for displaying diagrammatically the distribution of risk amongst different accident categories and sub-categories, as shown in the figure below. Structuring the tree starts with the accident categories, which may be divided into sub-categories to the extent that available data allow and logic dictates. The preliminary fault and event trees can be developed based on the identified hazards to demonstrate how direct causes initiate and combine to cause accidents (using fault trees), and also how accidents may progress further to result in different magnitudes of loss (using event trees). Whilst the example makes use of fault and event tree techniques, other established methods could be used if appropriate.

Quantifying the RCT is typically undertaken in three stages using available accident statistics:

(1) categories and sub-categories of accidents are quantified in terms of the frequency of accidents;

(2) the severity of accident outcomes is quantified in terms of magnitude and consequence;

(3) the risk of the categories and sub-categories of accidents can be expressed as F-N curves (see appendix 3 of the Guidelines) or potential loss of lives (PLL) based on the frequency of accidents and the severity of the outcome of the accidents. Thus, the distribution of risks across all the sub-categories of accidents is determined in risk terms, so as to display which categories contribute how much risk.

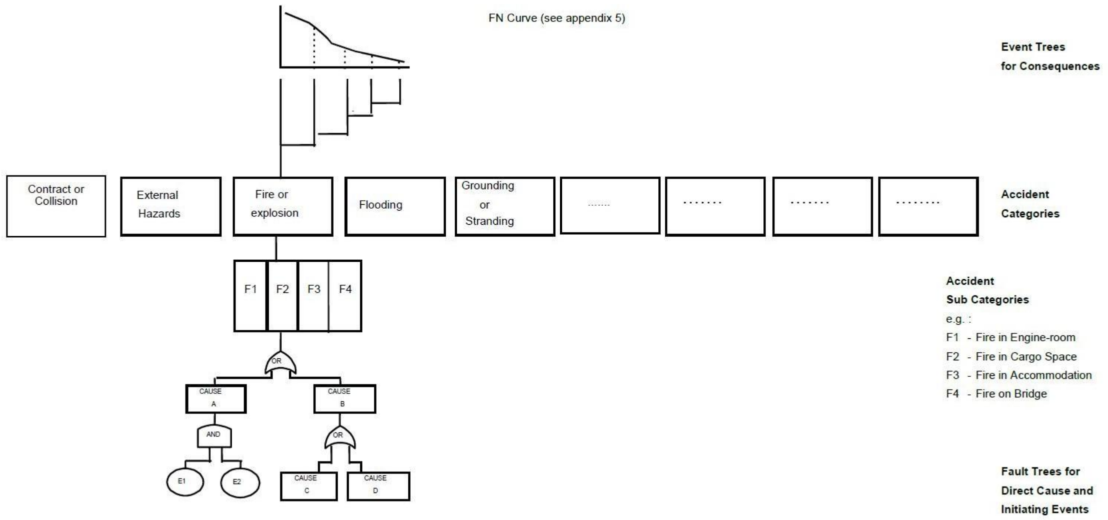


Figure 2.10 Example of A Risk Contribution Tree

The fire/explosion risk model given by IACS in general cargo ship formal safety assessment (MSC87/INF4) is as follows:

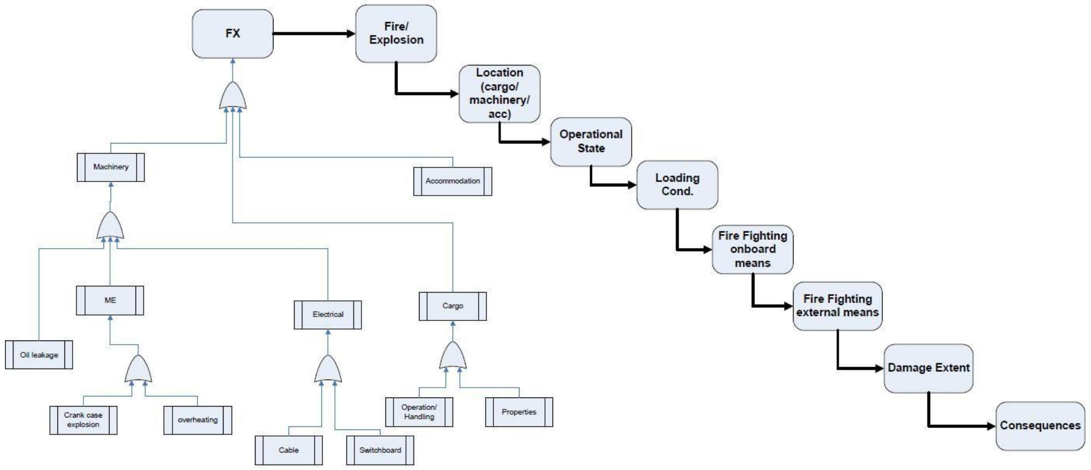


Figure 2.11 Example of Fire/Explosion Risk Model

2.4 Influence diagrams approach

The purpose of the Influence Diagram approach is to model the network of influences on an event. These influences link failures at the operational level with their direct causes, and with the underlying organizational and regulatory influences. The Influence Diagram approach is derived from decision analysis and, being based on expert judgements, is particularly useful in situations for which there may be little or no empirical data available. The approach is therefore capable of identifying all the influences (and therefore underlying causal information) that help explain why a marine risk profile may show high risk levels in one aspect (or even vessel type) and low risk level in another aspect. As the Influence Diagram recognizes that the risk profile is influenced, for example by human, organizational and regulatory aspects, it allows a holistic understanding of the problem area to be displayed in a hierarchical way.

2.5 Bayesian network analysis method

With regard to quantitative analysis methods of risk, apart from technicalized fault tree and event tree analysis methods, there is Bayesian network analysis method of net structure. As compared with the net structure, the tree structure has relatively more limitations. The tree structure is suitable for displaying the hierarchical structure of system, but it cannot show the relationship between elements at the same level, which can be achieved by the net structure.

Bayesian network is a probabilistic graphical model (a type of statistical model) that represents a set of random variables and their conditional dependencies via a directed acyclic graph (DAG; see diagram below). In the directed acyclic graph, when a parent node of a certain node is given, such node is independent from its non-descendant node. Local probabilistic distribution is the set of local probabilistic distribution associated with each variable. The element in local probabilistic distribution is the parent node of each given variable. Such node is taken as the Conditional Probability Table (CPT) of different values. CPT embodies the characteristics of quantification of domain knowledge.

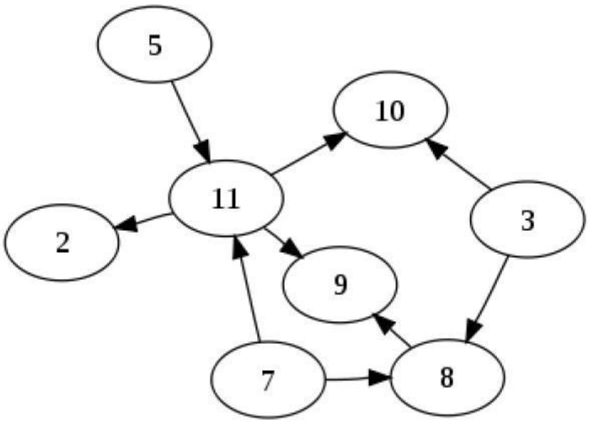


Figure 2.12 Diagram of Bayesian Network

The main tasks associated with the modelling of Bayesian network include the determination of the topological structure of network and the distribution of conditional probability of each node in the network. The distribution of conditional probability of all nodes in the network is called the probabilistic parameter of network. The modelling of Bayesian network includes a qualitative process (determination of topological structure) and a quantitative phase (determination of probabilistic parameter).

The inference of Bayesian network is mainly based on Bayesian formulae:

$$P_A = \sum_{i=1,2,\ldots,n} P(\mathrm{A} \mid \mathrm{B_i}) P(\mathrm{B_i})$$

$$P(\mathrm{A} \mid \mathrm{B}) = \mathrm{P(B \mid A) \times P(A) / P(B)}$$

The main tasks associated with the inference of Bayesian network include the boundary probability of a single variable, the combined probabilistic distribution of variable set, the conditional probability of nodes, the most probable interpretation of model, the maximum posterior probability, sensitivity analysis, etc. Based on different causal roles played by evidence variables and query variables, the probabilistic inference has the following 4 different types. The probabilistic inference usually referred to is the posterior probability.

(1) diagnostic inference from result to cause;
(2) predictive inference from cause to result;
(3) intercausal inference between different cause s for the same result;
(4) mixed inference including the types above.

Advantages of Bayesian network:

(1) Intuitive and easy to understand, easy for discussion and establishment of models. The Bayesian network provides a model of the inference process of the human brain, as dependence and independence are the basis for routine inference. The basic structure of human knowledge can also be shown by the dependence graph. The Bayesian network uses graphs to show each element, which can clearly indicate the probabilistic interdependence between the variable set and information flow in the model. Being concise and intuitive, it emphasizes the relationship between variables and shows probabilistic description of all problems.

(2) Bidirectional inference ability. The mature algorithm is mixed with newly-added evidences and the importance of each cause to the result is predicted by means of the posterior probability, which not only can carry out decision-making on safety quickly and implement safety measures, but also can identify weak links in the system and provide reliable basis for developing safety measures of a complex system.

(3) Multi-state system. The fault tree analysis can only deal with a two-state system, i.e. normal and failure state. But the Bayesian network is not restricted in this regard. When polymorphism is shown by the system or its components, only relevant nodal property needs to be revised.

(4) Relevant failure. The net structure can satisfactorily describe the relevance and relevant failure between nodes.

(5) Strict data theory. Suitable for computer processing and easy for updating.

Disadvantages of Bayesian network:

(1) The random variable state space needs to be limited to an independent state.

(2) With the expansion of analysis scope, more prior probability data needs to be input. In case there is a lack of data, only the subjective probability of experts can be used as the prior probability.

(3) With the increase of parent node, the scope of Conditional Probability Table will be expanded, making the inference and calculation process very complex.

(4) Data with incomplete perception (i.e. partial reliability) cannot not be expressed.

3 Uncertainty and sensitivity analysis

In risk analysis, a determined value is usually used to describe the probability and outcome of an incident or accident. But it is not always accurate, because incidents occur randomly. A probability distribution is assigned to each basic event in the risk model and therefore the aleatory uncertainty can be transmitted through the logic model. The reliability of risk model can be investigated by means of uncertainty and sensitivity analysis. Ideally, uncertainty and sensitivity analysis should be run in tandem.

Uncertainty analysis investigates the uncertainty of variables that are used in decision-making problems in which observations and models represent the knowledge base. Uncertainty analysis involves the definition of variance or deviation of the result of risk analysis. In other words, uncertainty analysis aims to make a technical contribution to decision-making through the quantification of uncertainties in the relevant variables. Uncertainty elements include Aleatory Uncertainty and Epistemic Uncertainty. Aleatory Uncertainty means the randomness of the behavior of an object itself, e.g., the probabilistic distribution of wave load limits that ships and offshore engineering structures might encounter during a certain period, the position and scope of fire, etc. Epistemic Uncertainty means the incompleteness of expressed knowledge, e.g. human behavior in extreme environment, structural fatigue mechanism etc.

Monte Carlo simulation method is one of the most commonly used methods for parametric uncertainty research in the quantitative risk analysis. Monte Carlo simulation method firstly structures a probability density function for each input parameter with uncertainty in the mathematical mode and a large quantity of random numbers are generated based on the probability density function for each input parameter; meanwhile each random number is substituted in the model to generate a large quantity of output values, based on which the statistical analysis is carried out to draw conclusions.

A practice closely related to uncertainty analysis is sensitivity analysis, which determines the extent and significance of effect of a change in a parametric input on the risk level, i.e. it is the study of how the uncertainty in the output of a model (numerical or otherwise) can be apportioned to different sources of uncertainty in the model input, in order to estimate the extent of contribution of uncertainty elements to the uncertainty of results and identify main contribution elements to the uncertainty of results so that accuracy is guaranteed.

During the process of FSA study, the data used has a degree of uncertainty. For example, uncertainty exists in the probability of occurrence of various accidents and relevant costs in the cost-benefit assessment (e.g. the repair cost of ship is closely related to the outcome of an accident). In general, sensitivity analysis may be carried out to the following items:

(1) difference between the maximum and minimum value of cost involved in risk control measures;

(2) high and low boundary of frequency of occurrence of various types of accidents;

(3) Maximum and minimum value of risk reduction involved in risk control options.

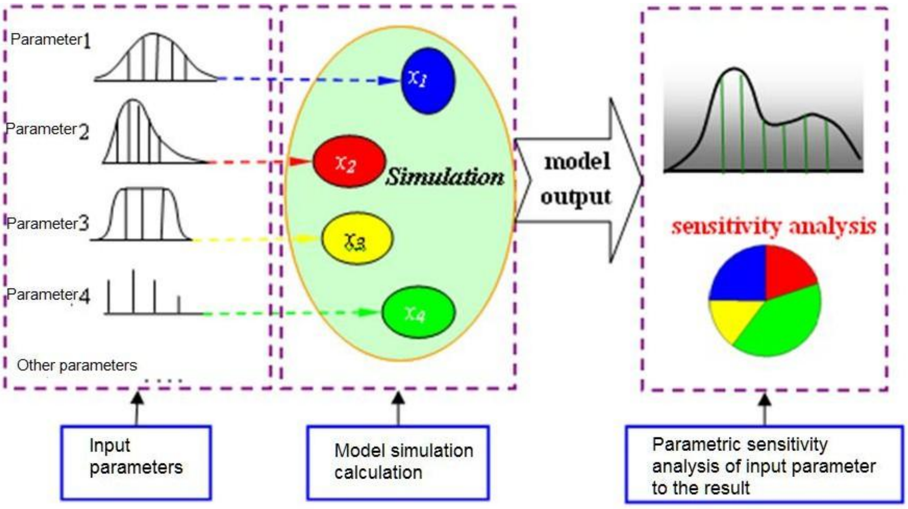


Figure 2.13 Sensitivity Analysis

4 Applicability of risk assessment techniques

During the process of hazard identification and risk analysis of FSA, the applicability of each assessment technique is described as Strongly applicable, Applicable or Not applicable as shown in the table below.

Applicability of Various Assessment Techniques **Table 2.1**

Tools and techniques	Risk assessment process				
	Identification of hazards (step 1)	Risk analysis (step 2)			Risk evaluation
		Consequence	Probability	Risk level	
Brainstorming	Strongly applicable	Applicable	Applicable	Applicable	Applicable
Delphi method	Strongly applicable	Applicable	Applicable	Applicable	Applicable
Checklist method	Strongly applicable	Not applicable	Not applicable	Not applicable	Not applicable
Hazard analysis in advance	Strongly applicable	Not applicable	Not applicable	Not applicable	Not applicable
Failure Mode & Effect Analysis	Strongly applicable	Not applicable	Not applicable	Not applicable	Not applicable
Hazard and Operability Studies	Strongly applicable	Strongly applicable	Not applicable	Not applicable	Strongly applicable
What if analysis	Strongly applicable	Strongly applicable	Strongly applicable	Strongly applicable	Strongly applicable
Risk matrix	Strongly applicable	Strongly applicable	Strongly applicable	Strongly applicable	Applicable
Human reliability analysis	Strongly applicable	Strongly applicable	Strongly applicable	Strongly applicable	Applicable
Fault tree analysis	Not applicable	Applicable	Applicable	Applicable	Applicable
Event tree analysis	Not applicable	Strongly applicable	Strongly applicable	Applicable	Not applicable
FN curve	Applicable	Strongly applicable	Strongly applicable	Applicable	Strongly applicable
Bayesian network	Not applicable	Not applicable	Strongly applicable	Not applicable	Strongly applicable

Appendix3 MEASURESANDACCEPTANCECRITERIAOFRISKS

1 Measures of risks

Basic expression of risk is as follows:

$$R = \sum_i (P_i \times \mathrm{C_i})$$

where: P_i is the probability of individual event; C_i is the expected consequence resulting from the event.

In general, three types of consequences as follows are to be taken into account for risk measurement, i.e. (1) risk to personnel; (2) risk to property; (3) environmental risk.

Different risk types are to be considered for different analysis purposes, and relevant risk measuring units are to be used at the same time. Simultaneous analysis to several kinds of risks may be needed in a study.

1.1 Risk to personnel

Risk to personnel is risk of death, injuries and ill health experienced by an individual and/or a group of people. The notion of risk combines frequency and an identified level of harm. Commonly, the level of harm is narrowed down to the loss of life and risk is an expression of frequency and number of fatalities. In other words, life safety is usually taken to refer to the risk of loss of life, and usually expressed as fatalities per year.

Concerning risk to personnel, the most commonly used expressions are Individual Risk and Societal Risk.

1.1.1 Individual Risk

Individual Risk (IR) means the risk of death, injury and ill health as experienced by an individual at a given location, e.g. a crew member or passenger on board the ship, or belonging to third parties that could be affected by a ship accident. Usually IR is taken to be the risk of death and is determined for the maximally exposed individual. Individual Risk is person and location specific.

$$IR_{\text{for Person Y}} = F_{\text{of undesired Event}} \times P_{\text{for Person Y}} \times E_{\text{of Person Y}}$$

where: F = frequency;

P = resulting casualty probability;

E = fractional exposure to that risk.

The purpose of estimating the Individual Risk is to ensure that individuals, who may be affected by a ship accident, are not exposed to excessive risks. This risk expression is used, when the risk from an accident is to be estimated for a particular individual at a given location. Individual Risk considers not only the frequency of the accident and the consequence (here: fatality or injury), but also the individual's fractional exposure to that risk, i.e. the probability of the individual of being in the given location at the time of the accident. Example: The risk for a person to be killed or injured in a harbor area, due to a tanker explosion is the higher the closer the person is located to the explosion location, and the more likely the person will be in that location at the time of the explosion. Therefore, the Individual Risk for a worker in the vicinity of the explosion will be higher than for an occupant in the neighborhood of the harbor terminal.

1.1.2 Societal Risk

Societal Risk means average risk, in terms of fatalities, experienced by a whole group of people (e.g. crew, port employees, or society at large) exposed to an accident scenario. In fact, people care more about consequences of the accident to the whole society, i.e. total effects of the accident on the whole society, which are required to be measured by Societal Risk. Societal Risk is a kind of risk killing many people, considering not only the probability of unexpected events but also the number of personnel in danger. Societal Risk is not person and location specific. Usually Societal Risk is taken to be the risk of death and is typically expressed as FN-curves or Potential Loss of Life (PLL, person per ship year).

Societal Risk is used to estimate risks of accidents affecting many persons, e.g. catastrophes, and acknowledging risk averse or neutral attitudes. Societal Risk includes the risk to every person, even if a person is only exposed on one brief occasion to that risk. For assessing the risk to a large number of affected people, Societal Risk is desirable because Individual Risk is insufficient in evaluating risks imposed on large numbers of people. Societal Risk expressions can be generated for each type of accident (e.g. collision), or a single overall Societal Risk expression can be obtained, e.g. for a ship type, by combining all accidents together (e.g. collision, grounding, fire).

(1) **FN-curves:** showing explicitly the relationship between the cumulative frequency of an accident and the number of fatalities in a multidimensional diagram. Society in general has a strong aversion to multiple casualty accidents. There is a clear perception that a single accident that kills 1,000 people is worse than 1,000 accidents that kill a single person. Societal Risk expressed by an FN-curve show the relationship between the frequency of an accident and the number of fatalities (see Figure 3.1 below), with the ordinate representing the cumulative frequency distribution of N or more fatalities and the abscissa representing the consequence (N fatalities).

The FN-curve represents the cumulative distribution of multiple fatality events and therefore useful in representing societal risk. The FN-curve is constructed by taking each hazard or accident scenario in turn and estimating the number of fatalities. With the estimated frequency of occurrence of each accident scenario the overall frequency with which a given number of fatalities may be equaled or exceeded can be calculated and plotted in the form of an FN-curve.

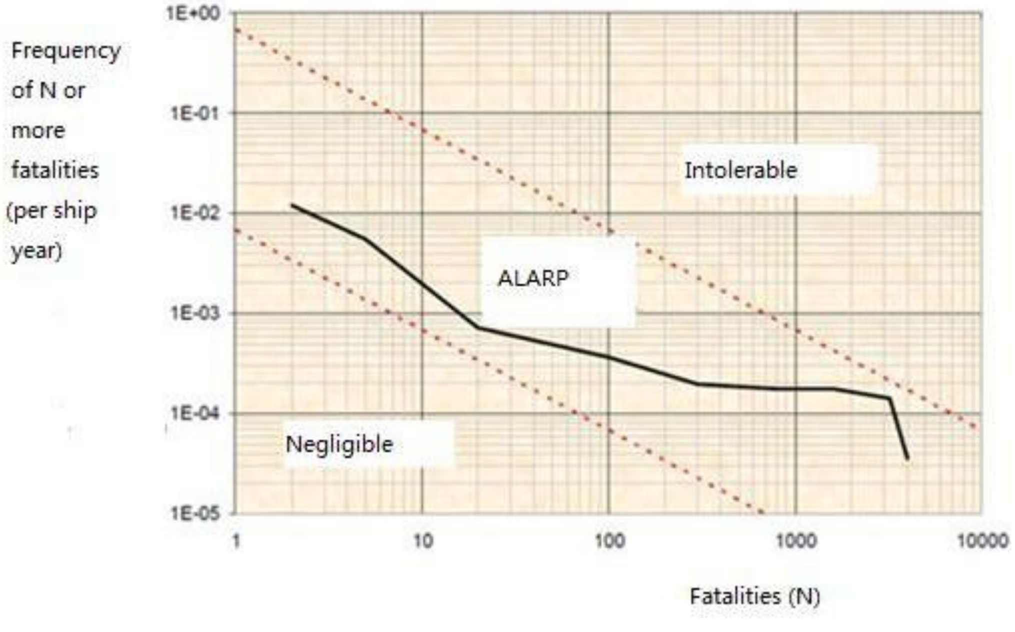


Figure 3.1 FN-curve

(2) **Potential Loss of Life (PLL):** A simple measure of Societal Risk is the PLL which is defined as the expected value of the number of fatalities per year. PLL is a type of risk integral, being a summation of risk as expressed by the product of consequence and frequency. The integral is summed up over all potential undesired events that can occur.

Compared to the FN-curve, the distinction between high frequency/low consequence accidents and low frequency/high consequence accidents is lost: all fatalities are treated as equally important, irrespective of whether they occur in high fatality or low fatality accidents. PLL is a simpler format of Societal Risk than the FN-curve. PLL is typically measured as fatality per ship-year.

1.1.3 Comparing Societal Risk and Individual Risk

Societal Risk expressed in an FN-curve allows a more comprehensive picture of risk than Individual Risk measures. The FN-curve allows the assessment not only of the average number of fatalities but also of the risk of catastrophic accidents killing many people at once.

However, unlike Individual Risk, both FN-curves and PLL values give no indication of the geographical distribution of a particular risk. Societal Risk represents the risk to a (large) group of people. In this group, the risk to individuals may be quite different, depending, e.g. on the different locations of the individuals when the accident occurs. The Societal Risk value therefore represents an average risk. There is a general agreement in society that it is not sufficient to just achieve a minimal average risk. It is also necessary to reduce the risk to the most exposed individual. It is therefore adequate to look at both Societal Risk and Individual Risk to achieve a full risk picture.

Societal Risk is difficult to apply to the task of risk reduction, specifically because it is multidimensional.

1.1.4 Risk equivalence concept

Normally, from a given activity in industry, there tends to be a relationship between fatalities and injuries of different severities resulting from an accident. Furthermore, measures that will reduce the occurrence of fatalities also tend to reduce injuries in proportion. In the literature there exist some studies on the ratio between accidental outcomes, e.g. from Bird and German (1966). In document MSC 68/INF.6, a straightforward approach was introduced, suggesting an equivalence ratio between fatalities, major injuries and minor injuries:

(1) one (1) fatality equals ten (10) severe injuries;

(2) one (1) severe injury equals ten (10) minor injuries.

2 Risk acceptance criteria

Risk acceptance criteria (also known as risk tolerability) mean an acceptable level of total risk within a specified period or at a certain behavioral phase, which provide reference basis for risk analysis and developing risk reduction measures; therefore, they are to be provided prior to risk evaluation. In addition, risk acceptance criteria are to reflect safety objective and behavioral characteristics as far as possible. Risk acceptance criteria are to be proposed with attention to the following:

(1) determining the scope of defined risk evaluation items;

(2) determining measurable parameters for risk comparison;

(3) providing input for performance effectiveness of the system to be evaluated.

Methods for risk measurement include qualitative and quantitative methods, and the expression of risk acceptance criteria is to be corresponding with such methods. Whether it is qualitative or quantitative, the following points are to be included:

(1) Development of risk acceptance criteria is to satisfy the requirements for safety in engineering;
(2) Recognized industrial standard;
(3) Knowledge accumulation of accidental events and their effects;
(4) Experience gained from own activity and relevant accidents.

2.1 Risk matrix

Accident probability and relevant consequences are placed in a matrix, i.e. risk matrix, as shown in Figure 3.2. Risk matrix includes three areas:

(1) unacceptable risk;
(2) acceptable risk;
(3) critical areas between unacceptable risk and acceptable risk. Critical areas are to be subject to risk evaluation to determine whether measures are to be taken to reduce risk or further study is required in advance.

Acceptable risk limit is set by defining acceptable and unacceptable risk areas in the matrix. Risk matrix can be used for qualitative or quantitative risk evaluation. If probability is categorized roughly according to being infrequent or frequent and consequence is categorized according to being minor, moderate and catastrophic, the results of qualitative analysis can be expressed by risk matrix. Categorization standard in qualitative analysis is of great importance.

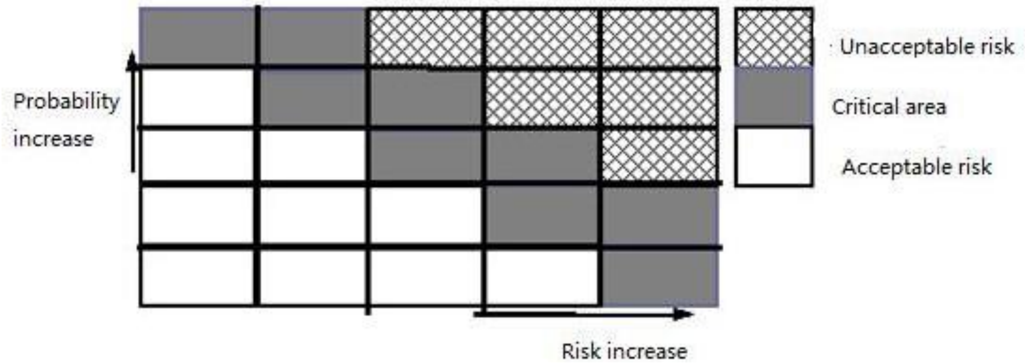


Figure 3.2 Risk Matrix

2.2 FN-curve

An FN-curve shows the relationship between the frequency of an accident and the number of fatalities, with the ordinate representing the cumulative frequency distribution of N or more fatalities and the abscissa representing the consequence (N fatalities).

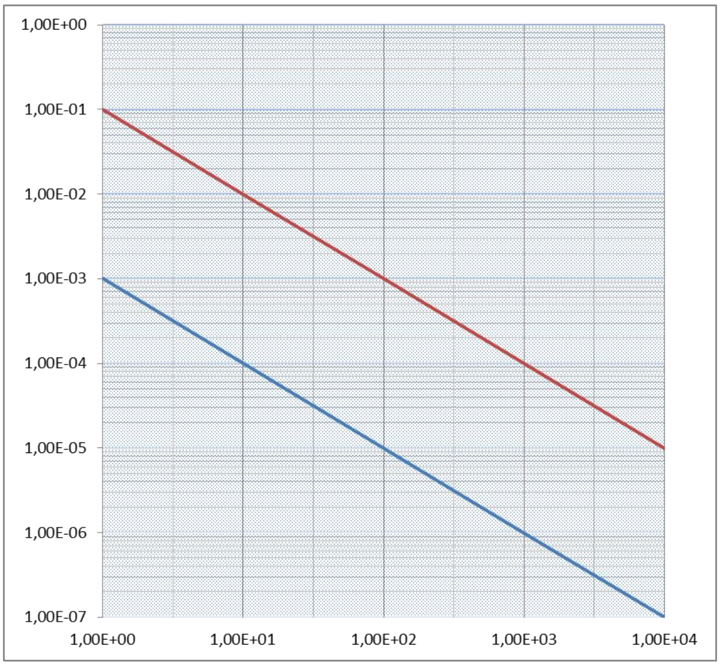


Figure 3.3 Upper and lower bounds of FN-curve

In FN-curve, a slope equal of -1 on a log/log scale of unacceptable lower bound and negligible upper bound reflects the risk aversion, in which unacceptable lower bound is higher than average acceptable risk (reference value) by more than one order of magnitude and negligible upper bound is lower than average acceptable risk (reference value) by more than one order of magnitude. (For details, see 5.2 of Appendix 5 of MSC-MEPC.2/Circ.12).

2.3 ALARP principle

ALARP (As Low As Reasonably Practicable) principle is a principle judging whether risk control measures are needed according to the risk level. For hazards between negligible and intolerable line, risk is to be minimized as far as possible under reasonable and practicable premises. Level of risk within ALARP region is neither negligibly low nor intolerable high. Reasonable and practicable premises mean the use of cost-benefit analysis to identify risk control option with cost-benefit ratio.

ALARP is actually the attribute of a risk, for which further investment of resources for risk reduction is not justifiable. The principle of ALARP is employed for the risk assessment procedure. Risks are to be As Low As Reasonably Practicable. It means that accidental events whose risks fall within this region have to be reduced unless there is a disproportionate cost to the benefits obtained.

By using different forms of risk expressions, risk criteria can be created that meet the requirement of different principles. The commonly accepted principle is known as the ALARP principle. Risk criteria are used to translate a risk level into value judgement.

The purpose of FSA is to reduce the risk to a level that is tolerable. For regulation establishment and revision, spending resources on recommended technical measures whose benefits are grossly disproportionate to their costs will put the technical measures in a less than competitive position. This is realized in the ALARP principle, which is shown in Figure 3.4.

ALARP principle states that there is a risk level that is intolerable above an upper bound. In this region, risk cannot be justified and must be reduced, irrespectively of costs. The principle also states that there is a risk level that is 'broadly acceptable' below a lower bound. In this region risk is negligible and no risk reduction required. If the risk level is in between the two bounds, the

ALARP region, risk is to be reduced to meet economic responsibility: Risk is to be reduced to a level as low as is reasonably practicable. The term reasonable is interpreted to mean cost-effective. Risk reduction measures are to be technically practicable and the associated costs are not to be disproportionate to the benefits gained. This is examined in a cost-effectiveness analysis.

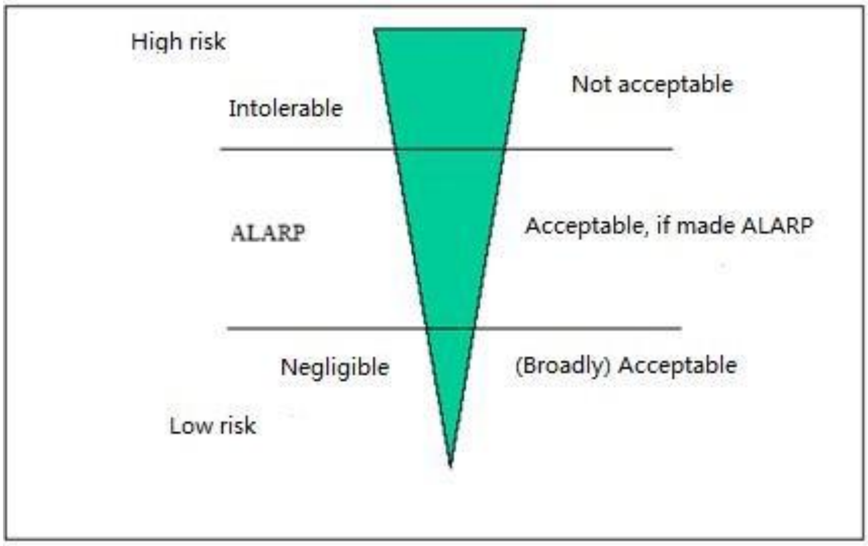


Figure 3.4 ALARP Principle

3 Recommended risk evaluation criteria

3.1 Individual Risk

Individual Risk criteria for hazardous activities are often set using risk levels that have already been accepted from other industrial activities. The level of risk that will be accepted for an individual depends upon two aspects:

(1) if the risk is taken involuntarily or voluntarily;
(2) if the individual has control over the risk or no control.

If a person is voluntarily exposing himself to a risk and/or has some control over it, then the risk level that is accepted is higher as if this person was exposed involuntarily to that risk or had no control over it. For example: A passenger on a cruise ship or an occupant living in the vicinity of a port have little or no control over the risks they are exposed to from the ship and/or the port activity. They are involuntarily exposed to risks. A crew member on a ship, instead, has chosen his work place on a voluntary basis, and due to skills and training has some control over the risks he/she is exposed to at the work place.

An appropriate level for the risk acceptance criteria would be substantially below the total accident risks experienced in daily life, but might be similar to risks that are accepted from other involuntary sources.

The lower and upper bound risk acceptance criteria as listed in Table 3.1 are provided for illustrative purposes only. The specific values selected as appropriate are to be explicitly defined in FSA studies.

3.2 Societal Risk/FN-curve

For a given activity, an average acceptable Potential Loss of Life (PLL) is developed by considering the economic value of the activity and its relation to the gross national product. This can be done for crew/workers, passengers and other third parties. The risk is defined to be intolerable if it exceeds the average acceptable risk by more than one order of magnitude, and it is negligible (broadly acceptable), if it is one order of magnitude below the average acceptable risk. These upper and lower bounds represent the ALARP region, which thus ranges over two orders of magnitude, which is in agreement with other published Societal Risk acceptance criteria.

It is recommended to apply this method to define Societal Risk acceptance criteria on different ship types and/or marine activities, as the method can contribute to transparency in using risk acceptance criteria for Societal Risk. When conducting risk evaluation, societal risk criteria appropriate to the activity being evaluated are to be selected. The selection criteria and methodology for determining the nominal values of the societal risk criteria/F-N curve are to be clearly specified. In document MSC 72/16, Societal Risk criteria developed with this method and expressed in FN-curves are provided for different ship types.

3.3 Examples of risk acceptance criteria

3.3.1 Personnel risk

The following criteria are broadly used in other industries and have been also published in HSE (2001).

The above risk acceptance criteria always refer to the total risk to the individual and/or group of persons. Total risk means the sum of all risks that, e.g. a person on board a ship is exposed to. The total risk therefore would contain risks from hazards such as fire, collision, etc. There is no criterion available to determine the acceptability of specific hazards. Therefore, the above criteria can be used to assess the acceptability of the total risk on being, e.g. on a passenger ship, but not for assessing the specific risk of dying on a passenger ship due to a fire.

Personnel Risk Acceptance Criteria **Table 3.1**

Decision parameter		Acceptance Criteria	
		Lower bound for ALARP region	Upper bound for ALARP region
		Negligible (broadly acceptable) fatality risk per year	Maximum tolerable fatality risk per year
Individual Risk	To crew member	10^{-6}	10^{-3}
	To passenger	10^{-6}	10^{-4}
	To third parties, members of public ashore	10^{-6}	10^{-4}
	Target values for new ships*)	10^{-6}	Above values to be reduced by one order of magnitude
Societal Risk	To groups of above persons	To be derived by using economic parameters as per MSC 72/16	

*) While it is recommended that the maximum tolerable criteria for Individual Risk as listed apply to all ships, it is proposed, in accordance with MSC 72/16, that for comprehensive FAS studies for new ships, a more demanding target is appropriate.

3.3.2 Environmental risk

When environmental risk due to oil spill is required to be taken into account, a general approach to be followed is outlined in this Section.

Cost for compensating oil spills may be obtained from existing oil spill database. Figure 3.5 shows the data of the consolidated oil spill database in terms of specific costs per tonne spilled (Figure 5 of document MEPC 62/INF.24). The submitter of the FSA can amend this database with new oil spill data, however, this amendment are to be properly documented.

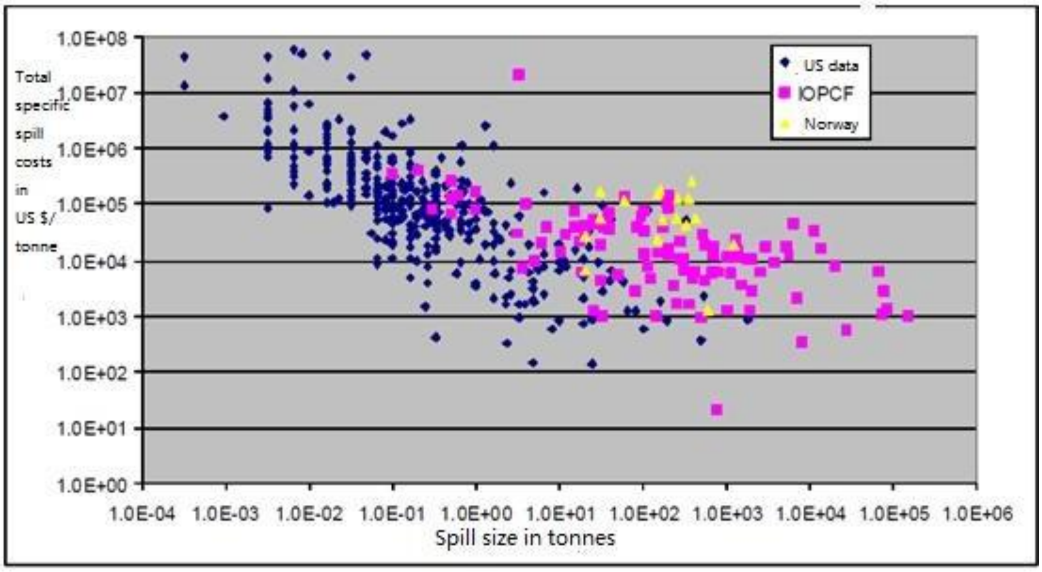


Figure 3.5 All specific oil spill cost data in 2009 USD (spill cost per tonne)

Some regression formulae derived from the consolidated oil spill database are summarized in Table 3.2 in which V is spill size in tonnes.

Regression formulae derived from the consolidated database Table 3.2

Dataset	F(V) = Total Spill Cost（TSC） （2009 US dollars）	Reference
All spills	$62{,}275\ V^{0.5893}$	MEPC 62/INF.24
V > 0.1 tonnes	$42{,}301V^{0.7233}$	MEPC 62/18[6]

FSA analysts are free to use other conversion formulae, so long as these are well documented by the data. For example, if an FSA is considering only small spills, the submitter may filter the data and perform his or her own regression analysis.

It is recommended that the FSA analyst use the following formula to estimate the societal oil spill costs (SC) used in the analysis:

$$SC(V) = F_{Assurance} \times F_{uncertainty} \times f(V)$$

where:

Factor $F_{Assurance}$: allowing for society's willingness to pay to avert accidents, $F_{assurance} \geq 1$;

Factor $F_{Uncertainty}$: allowing for uncertainties in the cost information from occurred spill accidents, $F_{uncertainty} \geq 1$;

Volume-dependent total cost function ($f(V)$): representing the fact that the cost per unit oil

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[6] Updated regression made on the final consolidated dataset.

spilled decreases with the spill size in US$ per tonne oil spilled.

In FSA study report, the values of $F_{Assurance}$ and $F_{Uncertainty}$ are to be detailed. The frequency of oil spill accidents (per ship year) is assigned as , and final oil spill cost (per ship year) is:

$$PSC = \sum_{i} f_i \times SC(V_i)$$

4 Calculation results of existing cases

Example of calculation results of Individual Risk of existing ships:

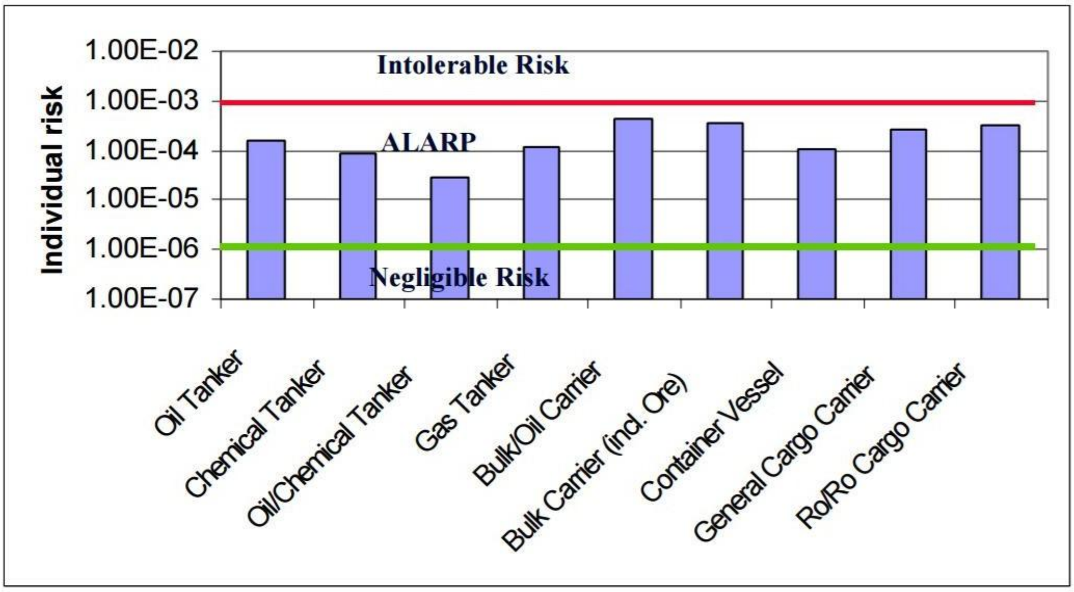


Figure 3.6 Individual Risk of different types of ships (from MSC72/16)

Example of calculation results of Societal Risk of some ships:

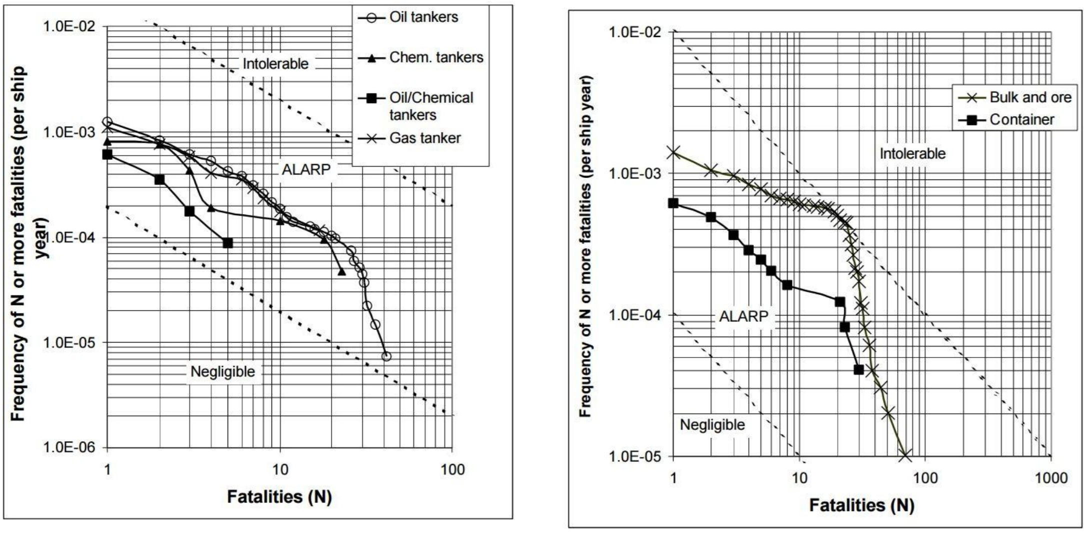


Figure 3.7 Societal Risk of different types of ships (from MSC72/16)

Results of some existing FSA application cases show that the risk of most types of ships are within ALARP region; therefore cost-benefit ratio or cost effectiveness is the basis for judging whether recommendations are to be adopted. For an FSA study of certain type of ship, it is not necessary to analyze all types of accident scenarios, and as a result the total risk of ship may be still unknown. Recommendations for decision-making are based on cost effectiveness of RCO, e.g. ECDIS recommendations are only based on reduction of grounding accident risk. However, risk acceptance criteria use ALARP principle.

Appendix 4 ATTRIBUTES OF RISK CONTROL MEASURES

1 Category A attributes

1.1 **Preventive risk control** is where the risk control measure reduces the probability of the event.

1.2 **Mitigating risk control** is where the risk control measure reduces the severity of the outcome of the event or subsequent events, should they occur.

2 Category B attributes

2.1 **Engineering risk control** involves including safety features (either built in or added on) within a design. Such safety features are safety critical when the absence of the safety feature would result in an unacceptable level of risk.

2.2 **Inherent risk control** is where at the highest conceptual level in the design process, choices are made that restrict the level of potential risk.

2.3 **Procedural risk control** is where the operators are relied upon to control the risk by behaving in accordance with defined procedures.

3 Category C attributes

3.1 **Diverse risk control** is where the control is distributed in different ways across aspects of the system, whereas concentrated risk control is where the risk control is similar across aspects of the system.

3.2 **Redundant risk control** is where the risk control is robust to failure of risk control, whereas single risk control is where the risk control is vulnerable to failure of risk control.

3.3 **Passive risk control** is where there is no action required to deliver the risk control measure, whereas active risk control is where the risk control is provided by the action of safety equipment or operators.

3.4 **Independent risk control** is where the risk control measure has no influence on other elements.

3.5 **Dependent risk control** is where one risk control measure can influence another element of the risk contribution tree.

3.6 **Involved human factors** is where human action is required to control the risk but where failure of the human action will not in itself cause an accident or allow an accident sequence to progress.

3.7 **Critical human factors** is where human action is vital to control the risk either where failure of the human action will directly cause an accident or will allow an accident sequence to progress. Where a critical human factor attribute is assigned, the human action (or critical task) is to be clearly defined in the risk control measure.

3.8 **Auditable** or **Not Auditable** reflects whether the risk control measure can be audited or not.

3.9 **Quantitative** or **Qualitative** reflects whether the risk control measure has been based on a quantitative or qualitative assessment of risk.

3.10 **Established** or **Novel** reflects whether the risk control measure is an extension to existing marine technology or operations, whereas novel is where the measure is new. Different grades are possible, for example the measure may be novel to shipping but established in other industries or it is novel to both shipping and other industries.

3.11 **Developed** or **Non-developed** reflects whether the technology underlying the risk control measure is developed both in its technical effectiveness and its basic cost. Non-developed is either where the technology is not developed but it can be reasonably expected to develop, or its basic cost can be expected to reduce in a given timescale. The purpose of considering this attribute is to attempt to anticipate development and produce forward looking measures and options.

Appendix 5 HUMAN RELIABILITY ANALYSIS

1 General

1.1 Purpose

1.1.1 Human reliability analysis is used to evaluate effects of human elements on system performance (failure), especially when quantitative risk assessment is used to assess the frequency of system failures. On board ships, the human has a greater degree of freedom to disrupt system performance. Therefore, a high-level task analysis needs to be considered at the outset of an FSA.

1.1.2 HRA may be performed on a qualitative or quantitative basis depending on the level of FSA being undertaken. The HRA process usually consists of the following stages:

(1) identification of key tasks;
(2) task analysis of key tasks;
(3) human error identification;
(4) human error analysis; and
(5) human reliability quantification.

1.1.3 Where a fully-quantified FSA approach is required, HRA can be used to develop a set of HEPs for incorporation into probabilistic risk assessment. However, this aspect of HRA can be over-emphasized. Experienced practitioners admit that greater benefit is derived from the early, qualitative stages of task analysis and human error identification. Effort expended in these areas pays dividends because an HRA exercise (like an FSA study) is successful only if the correct areas of concern have been chosen for investigation.

1.1.4 It is also necessary to bear in mind that the data available for the last stage of HRA, human reliability quantification, are currently limited. Although several human error databases have been built up, the data contained in them are only marginally relevant to the maritime industry. In some cases where an FSA requires quantitative results from the HRA, expert judgement may be the most appropriate method for deriving suitable data.

1.2 HRA application scope

1.2.1 HRA guidance should be used wherever an FSA is conducted on a system which involves human action or intervention which affects system performance.

1.2.2 Figure 5.1 shows how the HRA Guidance fits into the FSA process.

1.2.3 As with FSA, HRA can be applied to the design, construction, maintenance and operations of a ship.

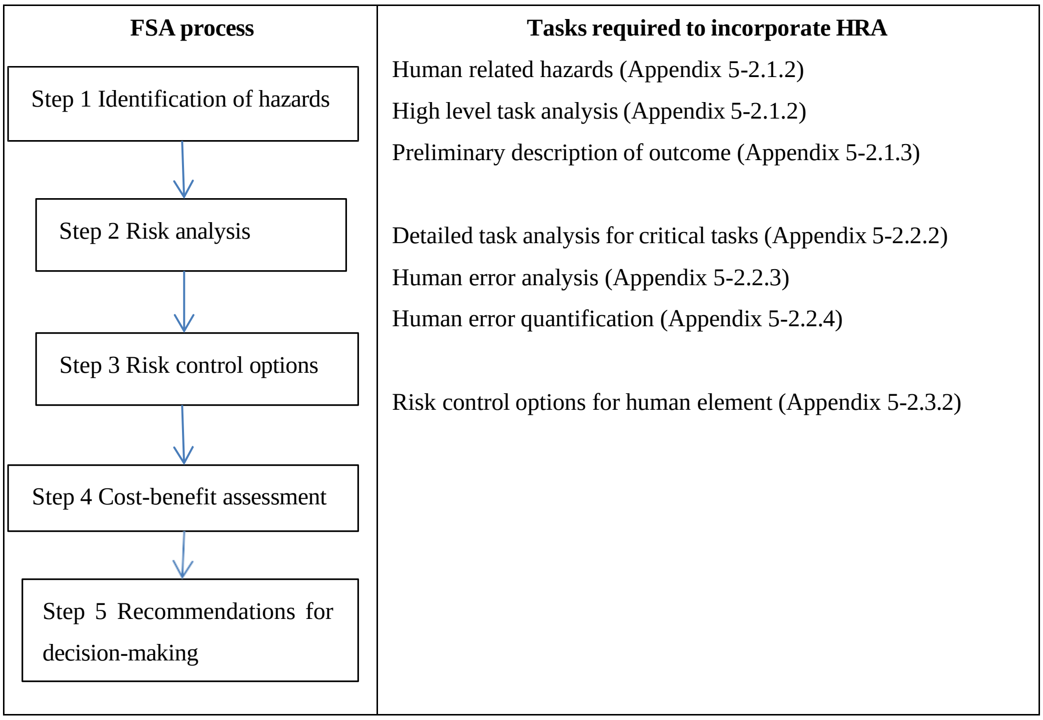


Figure 5.1 Incorporation of HRA into the FSA process

1.3 Basic terminology

Error producing condition: Factors that can have a negative effect on human performance.
Human error: A departure from acceptable or desirable practice on the part an individual or a group of individuals that can result in unacceptable or undesirable results.
Human error recovery: The potential for the error to be recovered, either by the individual or by another person, before the undesired consequences are realized.
Human error consequence: The undesired consequences of human error.

Human error probability: Defined as follows:

$$HEP = \frac{Number\ of\ human\ errors\ that\ have\ occurred}{Number\ of\ opportunities\ for\ human\ error}$$

Human reliability: The probability that a person correctly performs some system-required activity in a required time period (if time is a limiting factor) and performs no extraneous activity that can degrade the system. *Human unreliability* is the opposite of this definition.
Performance shaping factors: Factors that can have a positive or negative effect on human performance.
Task analysis: A collection of techniques used to compare the demands of a system with the capabilities of the operator, usually with a view to improving performance, e.g. by reducing errors.

1.4 Methodology

HRA can be considered to fit into the overall FSA process in the following way:
(1) identification of key human tasks consistent with step 1;
(2) risk assessment, including a detailed task analysis, human error analysis and human reliability quantification consistent with step 2;
(3) risk control options consistent with step 3.

1.5 Problem definition

Additional human element issues which may be considered in the problem definition include:

(1) personal factors, e.g. stress, fatigue;
(2) organizational and leadership factors, e.g. manning level;
(3) task features, e.g. task complexity;
(4) onboard working conditions, e.g. human-machine interface.

2 HRA steps

2.1 Step 1—Identification of hazards

2.1.1 **Scope**

2.1.1.1 The purpose of this step is to identify key potential human interactions which, if not performed correctly, could lead to system failure. This is a broad scoping exercise where the aim is to identify areas of concern (e.g. whole tasks or large sub-tasks) requiring further investigation.

2.1.1.2 Human hazard identification is the process of systematically identifying the ways in which human error can contribute to accidents during normal and emergency operations. HAZOP and FMEA can be, and are, used for this purpose. Additionally, it is strongly advised that a high-level functional task analysis is carried out. This section discusses those techniques and methods which were developed solely to address and identify human hazards.

2.1.2 **Methods for hazard identification**

2.1.2.1 In order to carry out a human hazard analysis, it is first necessary to model the system in order to identify the normal and emergency operating tasks that are carried out by the crew. This is achieved by the use of a high-level task analysis (as described in Section 3 of this Appendix) which identifies the main human tasks in terms of operational goals. Developing a task analysis can utilize a range of data collection techniques, e.g. interviews, observation, critical incident, many of which can be used to directly identify key tasks. Additionally, there are many other sources of information which may be consulted, including design information, past experience, normal and emergency operating procedures, etc.

2.1.2.2 The aim is to identify those key human-human and/or human-machine interactions which require further attention. Therefore, once the main tasks, sub-tasks and their associated goals have been listed, the potential contributors to human error of each task need to be identified together with the potential hazard arising. There are a number of techniques which may be utilized for this purpose, including HAZOP, Hazard Checklists, etc. An example of human-related hazards identifying a number of different potential contributors to sub-standard performance is included in Section 5 of this Appendix.

2.1.2.3 For each task and sub-task identified, the associated hazards and their associated scenarios are to be ranked in order of their criticality in the same manner as discussed in Section 3, Appendix 1 of the Guidelines.

2.1.3 **Results**

The output from step 1 is a set of activities (tasks and sub-tasks) with a ranked list of hazards associated with each activity. This list needs to be coupled with the other lists generated by the FSA process, and is therefore to be produced in a common format. Only the top few hazards for critical tasks are subjected to risk assessment, less critical tasks are not examined further.

2.2 Step 2—Risk analysis

2.2.1 **Scope**

The purpose of step 2 is to identify those areas where the human element poses a high risk to system safety and to evaluate the factors influencing the level of risk.

2.2.2 **Detailed task analysis**

2.2.2.1 At this stage, the key tasks are subjected to a detailed task analysis. Where the tasks involve more decision-making than action, it may be more appropriate to carry out a cognitive task analysis. Section 3 of this Appendix outlines the extended task analysis which was developed for analyzing decision-making tasks.

2.2.2.2 The task analysis is to be developed until all critical sub-tasks have been identified. The level of detail required is that which is appropriate for the criticality of the operation under investigation. A good general rule is that the amount of detail required is to be sufficient to give the same degree of understanding as that provided by the rest of the FSA exercise.

2.2.3 **Human error analysis**

2.2.3.1 The purpose of human error analysis is to produce a list of potential human errors that can lead to the undesired consequence that is of concern. To help with this exercise, some examples of typical human errors are included in Table 5.1.

2.2.3.2 Once all potential errors have been identified, they are typically classified along the following lines. This classification allows the identification of a critical subset of human errors that must be addressed:

(1) the supposed cause of the human error;

(2) the potential for error-recovery, either by the operator or by another person (this includes consideration of whether a single human error can result in undesired consequences);

(3) the potential consequences of the error.

2.2.3.3 Often, a qualitative analysis is to be sufficient. A simple qualitative assessment can be made using a recovery/consequence matrix such as that illustrated in Table 5.2. Where necessary, a more detailed matrix can be developed using a scale for the likely consequences and levels of recovery.

2.2.4 **Human error quantification**

2.2.4.1 This activity is undertaken where a probability of human error (HEP) is required for input into a quantitative FSA. Human error quantification can be conducted in a number of ways.

2.2.4.2 In some cases, because of the difficulties of acquiring reliable human error data for the maritime industry, expert judgement techniques may need to be used for deriving a probability for human error. Expert judgment techniques can be grouped into four categories:

(1) paired comparisons;

(2) ranking and rating procedures;

(3) direct numerical estimation;

(4) indirect numerical estimation.

It is particularly important that experts are provided with a thorough task definition. A poor definition invariably produces poor estimates.

2.2.4.3 Absolute Probability Judgement (APJ) is a good direct method. It can be used in various forms, from the single expert assessor to large groups of individuals whose estimates are mathematically aggregated. Other techniques which focus on judgements from multiple experts include: brainstorming; consensus decision-making; Delphi; and the Nominal Group technique.

2.2.4.4 Alternatives to expert opinion are historic data (where available) and generic error probabilities. Two main methods for HRA which have databases of human error probabilities (mainly for the nuclear industry) are the Technique for Human Error Rate Prediction (THERP) and Human Error Assessment and Reduction Technique (HEART) (see Section 4 of this Appendix).

2.2.4.5 Technique for Human Error Rate Prediction (THERP)

THERP was developed by Swain and Guttmann (1983) of Sandia National Laboratories for the US Nuclear Regulatory Commission, and has become the most widely used human error quantitative prediction technique. THERP is both a human reliability technique and a human error databank. It models human errors using probability trees and models of dependence, but also considers performance shaping factors (PSFs) affecting action. It is critically dependent on its database of human error probabilities. It is considered to be particularly effective in quantifying errors in highly procedural activities.

2.2.4.6 Human Error Assessment and Reduction Technique (HEART)

HEART is a technique developed by Williams (1985) that considers particular ergonomics, tasks and environmental factors that adversely affect performance. The extent to which each factor independently affects performance is quantified and the human error probability is calculated as a function of the product of those factors identified for a particular task.

2.2.4.7 HEART provides specific information on remedial risk control options to combat human error. It focuses on five particular causes and contributions to human error: impaired system knowledge; response time shortage; poor or ambiguous system feedback; significant judgement required of operator; and the level of alertness resulting from duties, ill health or the environment.

2.2.4.8 When applying human error quantification techniques, it is important to consider the following:

(1) Magnitudes of human error are sufficient for most applications. A 'gross' approximation of the human error magnitude is sufficient. The derivation of HEPs may be influenced by modelling and quantitative uncertainties. A final sensitivity analysis is to be presented to show the effect of uncertainties on the estimated risks.

(2) Human error quantification can be very effective when used to produce a comparative analysis rather than an exact quantification. Then human error quantification can be used to support the evaluation of various risk control options.

(3) The detail of quantitative analysis is to be consistent with the level of detail of the FSA model. The HRA is not to be more detailed than the technical elements of the FSA. The level of detail is to be selected based upon the contribution of the activity to the risk, system or operation being analyzed.

(4) The human error quantification tool selected is to fit the needs of the analysis. There are a significant number of human error quantification techniques available. The selection of a technique is to be assessed for consistency, usability, validity of results, usefulness, effective use of resources for the HRA and the maturity of the technique.

2.2.5 **Results**

2.2.5.1 The output from this step comprises:

(1) an analysis of key tasks;

(2) an identification of human errors associated with these tasks;

(3) an assessment of human error probabilities (optional).

These results are then to be considered in conjunction with the high-risk areas identified elsewhere in step 2.

2.3 Step 3—Risk control options

2.3.1 **Scope**

The purpose of step 3 is to consider how the human element is considered within the evaluation of technical, human, work environment, personnel and management related risk control options.

2.3.2 **Application**

2.3.2.1 The control of risks associated with the human interaction with a system can be approached in the same way as for the development of other risk control measures. Measures can be specified in order to:

(1) reduce the frequency of failure;
(2) mitigate the effects of failure;
(3) alleviate the circumstances in which failures occur;
(4) mitigate the consequences of accidents.

2.3.2.2 Proper application of HRA can reveal that technological innovations can also create problems which may be overlooked by FSA study of technical factors only. A typical example of this is the creation of long periods of low workload when a high degree of automation is used. This in turn can lead to an inability to respond correctly when required or even to the introduction of 'risk taking behavior' in order to make the job more interesting.

2.3.2.3 When dealing with risk control concerning human activity, it is important to realize that more than one level of risk control measure may be necessary. This is because human involvement spans a wide range of activities from day-to-day operations through to senior management levels. Secondly, it must also be stressed that a basic focus on good system design utilizing ergonomics and human factor principles is needed in order to achieve enhanced operational safety and performance levels.

2.3.2.4 In line with Figure 2.6.4 of the Guidelines, risk control measures for human interactions can be categorized into four areas as follows:

(1) technical/engineering subsystem;
(2) working environment;
(3) personnel subsystem;
(4) organizational/management subsystem.

2.3.2.5 Once the risk control measures have been initially specified, it is important to reassess human intervention in the system in order to assess whether any new hazards have been introduced. For example, if a decision had been taken to automate a particular task, then the new task would need to be re-evaluated.

2.3.3 **Results**

The output from this step comprises a range of risk control options categorized into 4 areas, easing the integration of human related risk into step 3.

2.4 Step 4—Cost-benefit assessment

No specific HRA guidance for this section is required.

2.5 Step 5—Recommendations for decision-making

Judicious use of the results of the HRA study is to contribute to a set of balanced decisions and recommendations of the whole FSA study.

3 Summary of task analysis types

3.1 High-level task analysis

3.1.1 High-level task analysis here refers to the type of task analysis which allows an analyst to gain a broad, but shallow, overview of the main functions which need to be performed to accomplish a particular task.

3.1.2 High-level task analysis is undertaken in the following way:

(1) describe all operations within the system in terms of the tasks required to achieve a specific

operational goal;

(2) consider goals associated with normal operations, emergency procedures, maintenance and recovery measures.

3.1.3 The analysis is recorded either in a hierarchical format or in tabular form.

3.2 Detailed task analysis

3.2.1 Detailed task analysis is undertaken to identify:

(1) the overall task (or job) that is done;
(2) sub-tasks;
(3) all of the people who contribute to the task and their interactions;
(4) how the work is done, i.e. the working practices in normal and emergency situations;
(5) any controls, displays, tools, etc., which are used;
(6) factors which influence performance.

3.2.2 There are many task analysis techniques – Kirwan and Ainsworth (1992) list more than twenty. They note that the most widely used, hierarchical task analysis (HTA), can be used as a framework for applying other techniques:

(1) data collection techniques, e.g. activity sampling, critical incident, questionnaires;
(2) task description techniques, e.g. charting and network techniques, tabular task analysis;
(3) tasks simulation methods, e.g. computer modelling and simulation;
(4) task behavior assessment methods, e.g. management and oversight risk trees;
(5) task requirement evaluation methods, e.g. ergonomics checklists.

3.3 Extended task analysis (XTA)

3.3.1 Traditional task analysis was designed for investigating manual tasks, and is not so useful for analyzing intellectual tasks, e.g. navigation decisions. Extended task analysis or other cognitive task analyses (see Annett and Stanton, 1998) can be used where the focus is less on what actions are performed and more on understanding the rationale for the decisions that are taken.

3.3.2 XTA is used to map out the logical bases of the decision-making process which underpin the task under examination. The activities which comprise XTA techniques are described in Johnson and Johnson (1987). In summary, they are:

(1) Interview. The interviewer asks about the conditions which enable or disable certain actions to be performed, and how a change in the conditions affects those choices. The interviewer examines the individual's intentions to make sure that all relevant aspects of the situation have been taken into account. This enables the analyst to build up a good understanding of what the individual is doing and why, and how it would change under varying conditions.

(2) Qualitative analysis of data. The interview is tape-recorded, transcribed and subsequently analyzed. Methods for analyzing qualitative data are well-established in social science and more recently utilized in safety engineering. The technique (called Grounded Theory) is described in detail by Pidgeon, et al. (1991).

(3) Representation of the analysis in an appropriate format. The representation scheme used in XTA is called systemic grammar networks – a form of associative network – see Johnson and Johnson (1987).

(4) Validation activities, e.g. observation, hypothesis.

4 Summary of human error analysis techniques

The two main HRA quantitative techniques (HEART and THERP) are outlined below. CORE-DATA provides data on generic probabilities. As the data from all of these sources are based on non-marine industries, they need to be used with caution. A good alternative is to use expert judgement and one technique for doing this is Absolute Probability Judgement.

4.1 Absolute Probability Judgement (APJ)

4.1.1 APJ refers to a group of techniques that utilize expert judgement to develop human error probabilities (HEPs) detailed in Kirwan (1994) and Lees (1996). These techniques are used when no relevant data exist for the situation in question, making some form of direct numerical estimation the only way of developing values for HEPs.

4.1.2 There are a variety of techniques available. This gives the analyst some flexibility in accommodating different types of analysis. Most of the techniques avoid potentially detrimental group influences such as group bias. Typically the techniques used are: the Delphi technique, the Nominal Group Technique and Paired Comparisons. The number and type of experts that are required to participate in the process are similar to that required for Hazard Identification techniques such as HAZOP.

4.1.3 Paired Comparisons is a significant expert judgement technique. Using this technique, an individual makes a series of judgements about pairs of tasks. The results for each individual are analyzed and the relative values for HEPs for the tasks derived. Use of the technique rests upon the ability to include at least two tasks with known HEPs. CORE-DATA and data from other industries may be useful.

4.1.4 The popularity of these techniques has reduced in recent times, probably due to the requirement to get the relevant groups of experts together. However, these techniques may be very appropriate for the maritime industry.

4.2 Technique for Human Error Rate Prediction (THERP)

4.2.1 THERP is one of the best known and most often utilized human reliability analysis techniques. At first sight the technique can be rather daunting due to the volume of information provided. This is because it is a comprehensive methodology covering task analysis, human error identification, human error modelling and human error quantification. However, it is best known for its human error quantification aspects, which includes a series of human error probability (HEP) data tables and data quantifying the effects of various performance shaping factors (PSFs). The data presented is generally of a detailed nature and so not readily transferable to the marine environment.

4.2.2 THERP contains a dependence model which is used to model the dependence relationship between errors. For example, the model could be used to assess the dependence between the helmsman making an error and the bridge officer noticing it. Operational experience does show that there are dependence effects between people and between tasks. Whilst this is the only human error model of its type, it has not been comprehensively validated.

4.2.3 A full THERP analysis can be resource-intensive due to the level of detail required to utilize the technique properly. However, the use of this technique forces the analyst to gain a detailed appreciation of the system and of the human error potential. THERP models humans as any other subsystem in the FSA modelling process. The steps are as follows:

(1) identify all the systems in the operation that are influenced and affected by human operations;

(2) compile a list and analyze all human operations that affect the operations of the system by performing a detailed task analysis;

(3) determine the probabilities of human errors through error frequency data and expert judgements and experiences;

(4) determine the effects of human errors by integrating the human error into the PRA modelling procedure.

4.2.4 THERP includes a set of performance shaping factors (PSFs) that influence the human errors at the operator level. These performance factors include experience, situational stress factors, work environment, individual motivation, and the human-machine interface. The PSFs are used as a basis for estimating nominal values and value ranges for human error.

4.2.5 There are advantages to using THERP. First it is a good tool for relative risk comparisons. It can be used to measure the role of human error in an FSA and to evaluate risk control options not necessarily in terms of a probability or frequency, but in terms of risk magnitude. Also, THERP can be used with the standard event-tree/fault-tree modelling approaches that are sometimes preferred by FSA practitioners. THERP is a transparent technique that provides a systematic, well-documented approach to evaluating the role of human errors in a technical system. The THERP database can be used through systematic analysis or, where available, external human error data can be inserted.

4.3 Human Error Assessment and Reduction Technique (HEART)

4.3.1 HEART is best known as a relatively simple way of arriving at human error probabilities (HEPs). The basis of the technique is a database of nine generic task descriptions and an associated human error probability. The analyst matches the generic task description to the task being assessed and then modifies the generic human error probability according to the presence and strength of the identified error producing conditions (EPCs). EPCs are conditions that increase the order of magnitude of the error frequency or probability measurements, similar in concept to PSFs in THERP. A list of EPCs is supplied as part of the technique, but it is up to the analyst to decide on the strength of effect for the task in question.

4.3.2 Whilst the generic data is mainly derived from the nuclear industry, HEART does appear amenable to application within other industries. It may be possible to tailor the technique to the marine environment by including new EPCs such as weather. However, it needs careful application to avoid ending up with very conservative estimates of HEPs.

4.4 CORE-DATA

4.4.1 CORE-DATA is a database of human error probabilities. Access to the database is available through the University of Birmingham in the United Kingdom. The database has been developed as a result of sponsorship by the UK Health and Safety Executive with support from the nuclear, rail, chemical, aviation and offshore industries and contains up to 300 records as of January 1999.

4.4.2 Each record is a comprehensive presentation of information including, e.g. a task summary, industry origin, country of origin, type of data collection used, a database quality rating, description of the operation, performance shaping factors, sample size and HEP.

4.4.3 As with all data from other industries, care needs to be taken when transferring the data to the maritime industry. Some of the offshore data may be the most useful.

5 Examples of human-related hazards

Human error occurs on board ships when a crew member's ability falls below what is needed to successfully complete a task. Whilst this may be due to a lack of ability, more commonly it is because the existing ability is hampered by adverse conditions. Below are some examples (not complete) of personal factors and unfavorable conditions which constitute hazards to optimum performance. A comprehensive examination of all human-related hazards is to be performed. During the "design stage" it is typical to focus mainly on task features and on board working conditions as potential human-related hazards.

5.1 Personal factors

(1) Reduced ability, e.g. reduced vision or hearing;

(2) Lack of motivation, e.g. because of a lack of incentives to perform well;

(3) Lack of ability, e.g. lack of seamanship, unfamiliarity with vessel, lack of fluency of the language used on board;

(4) Fatigue, e.g. because of lack of sleep or rest, irregular meals;

(5) Stress.

5.2 Organizational and leadership factors

(1) Inadequate vessel management, e.g. inadequate supervision of work, lack of coordination of work, lack of leadership;

(2) Inadequate ship owner management, e.g. inadequate routines and procedures, lack of resources for maintenance, lack of resources for safe operation, inadequate follow-up of vessel organization;

(3) Inadequate manning, e.g. too few crew, untrained crew;

(4) Inadequate routines, e.g. for navigation, engine-room operations, cargo handling, maintenance, emergency preparedness.

5.3 Task features

(1) Task complexity and task load;

(2) Unfamiliarity of the task;

(3) Ambiguity of the task goal;

(4) Different tasks competing for attention.

5.4 Onboard working conditions

(1) Physical stress from, e.g. noise, vibration, sea motion, climate, temperature, toxic substances, extreme environmental loads, night-watch;

(2) Ergonomic conditions, e.g. inadequate tools, inadequate illumination, inadequate or ambiguous information, badly-designed human-machine interface;

(3) Social climate, e.g. inadequate communication, lack of cooperation;

(4) Environmental conditions, e.g. restricted visibility, high traffic density, restricted fairway.

6 Examples of risk control options

6.1 Technical/engineering sub-system

(1) ergonomic design of equipment and work spaces;

(2) good layout of bridge, machinery spaces;

(3) ergonomic design of the man-machine interface/human computer interface;

(4) specification of information requirements for the crew to perform their tasks;

(5) clear labelling and instructions on the operation of ship systems and control/ communications equipment.

6.2 Working environment

(1) ship stability, effect on crew of working under conditions of pitch/roll;

(2) weather effects, including fog, particularly on watch-keeping or external tasks;

(3) ship location, open sea, approach to port, etc.;

(4) appropriate levels of lighting for operations and maintenance tasks and for day and night time operations;

(5) consideration of noise levels (particularly for effect on communications);

(6) consideration of the effects of temperature and humidity on task performance;

(7) consideration of the effects of vibration on task performance.

6.3 Personnel subsystem

(1) development of appropriate training for crew members;
(2) crew levels and make up;
(3) language and cultural issues;
(4) workload assessment (both too much and too little workload can be problematic);
(5) motivational and leadership issues.

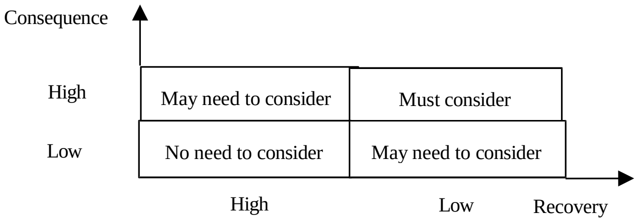
6.4 Organizational/management subsystem

(1) development of organization policies on recruitment, selection, training, crew levels and make up, competency assessment, etc.;
(2) development of operational and emergency procedures (including provisions for tug and salvage services);
(3) use of safety management systems;
(4) provision of weather forecasting/routeing services.

Typical human errors **Table 5.1**

Physical errors	Mental errors
Action omitted	Lack of knowledge of system/situation
Action too much/little	Lack of attention
Action in wrong direction	Failure to remember procedures
Action mistimed	Communication breakdowns
Action on wrong object	Miscalculation

Recovery/consequence matrix **Table 5.2**



Consequence	Recovery High	Recovery Low
High	May need to consider	Must consider
Low	No need to consider	May need to consider

Appendix 6 FSA APPLICATION EXAMPLE—FSA STUDY OF CRUDE OIL TANKERS

1 Summary

Denmark submitted a report on the Formal Safety Assessment (FSA) study on crude oil tanker (MEPC 58/INF.2) at IMO MEPC 58th session in 2008. As a part of EU research project SAFEDOR, the report carried out complete FSA study on crude oil tankers according to IMO FSA Guidelines, including hazard identification, risk analysis, risk control options and cost-benefit analysis. The Guidelines extract the report as an FSA application example.

2 Step 1: hazard identification

2.1 Approach and methodology

2.1.1 Casualty database

In order to carry out risk analysis, a new casualty database POP&C is constructed, which is based on the theories of Event Trees and Fault Trees and obtained by revising LRFP (Lloyds Register Fairplay)(now IHS Fairplay) and LMIU (Lloyds Maritime Intelligent Unit) database. As risk assessment deepens, casualty database POP&C is further developed by NTUA-SDL with the aim to extract more detailed information (mainly accident conditions and consequences) useful for the risk assessment. Latest version of NTUA-SDL casualty database is used in statistical analysis of historical data.

2.1.2 Applied risk assessment methodology

Methodologies such as Event Trees are used to analyze event cause and consequences. In order to determine event frequency, different methodologies are used, e.g. Fault Trees, analysis investigation based on historical data, estimation and simulation, comparison analysis analogy of similar ship type and expert opinions.

2.1.3 Boundaries

First of all, hazard identification is to be carried out for risk assessment of oil tankers to determine hazards that potentially lead to Loss Of Watertight Integrity (LOWI), namely:

(1) Collision: striking or being struck by another ship, regardless of whether under way, anchored or moored;

(2) Contact: striking any fixed or floating objects other than those included under collision or Grounding;

(3) Grounding: being aground or hitting/touching shore or sea bottom or underwater objects (wrecks, etc.);

(4) Fire: incidents where fire is the initial event;

(5) Explosion: incidents where explosion is the initial event;

(6) Non-accidental structural failure: when the hull presents cracks and fractures, affecting ship's seaworthiness.

Scenarios due to failure of hull fittings or machinery failure as well as incidents associated with piracy or war losses are not considered in the study.

FSA to large oil tankers covers oil tankers in the range of deadweight greater than 60,000 tonnes. Therefore, objects of the study involve double hull ships such as PANAMAX, AFRAMAX, SUEZMAX, VLCC and ULCC. When analyzing and studying historical data, single hull large oil tankers are also within the scope of consideration.

The main concern of the study is environmental impact and casualties due to an accident. For personnel, effects on crew health and casualty risk are considered. When collision risk assessment is carried out, casualty of the ship being struck is taken into account rather than casualty of crew and passenger on board the striking ship. Meanwhile, if damage to hull structure does not lead to casualty, loss of property due to structural damage may not be considered.

The study does not consider risk containing terrorist attacks or the ship being struck by missiles, and occupational hazards in special circumstances even causing the death of individual crew members are also not within the purpose of consideration. The study is limited to the risk at the operational phase of an oil tanker's life cycle, and risks associated with the vessel being in shipyards are also considered out of the scope.

The characteristics of different seaways and port environments are considered essential for the chain of Event Tree Analysis. Therefore the environment of the ship must be considered when establishing the event tree model.

The study defines four different operational states associated with four different operational speed ranges respectively. One more operational state is considered, namely Shipyards & Drydocks. Different operational states are further related to different type of sea areas with different conditions for rescue efforts and environmental pollution, namely:

(1) Terminal areas (port, anchorage, port approach and at berth). The ship lies at berth/ port or is operating at low speed because of port or berth approaching or anchorage operations. The low sped generally reduces the severity of the consequences;

(2) Congested waters (coastal (<12 miles off) or restricted waters). Areas within congested waters are characterized by high density traffic;

(3) En route at sea (open sea (≥12 miles off) & archipelagos). Ship has her full operational speed;

(4) Operation in limited waters (rivers, canals and inland waters);

(5) Shipyards & drydocks.

In order to calculate the probability of hull breaching, if the database does not clearly indicate whether watertightness is lost or not, the study makes some assumption to judge whether watertightness is lost or not.

2.1.4 General assumption

Four representative large oil tankers, i.e. PANAMAX, AFRAMAX, SUEZMAX, VLCC and ULCC, are selected to serve as reference ships. At the same time, aiming at each ship type, ships with typical scale parameter are to be selected for analysis.

2.2 Hazard identification

2.2.1 Hazard identification process

Hazard identification process comprises two stages, namely an analysis of statistical data aimed to identify the main hazardous processes/operations from historical experience followed by hazard identification expert sessions in which hazards relating to the mentioned processes/operations are identified and prioritized. The expert sessions are performed by means of Failure Modes, Effects and Criticality Analysis (FMECA). The following four processes/operations are investigated:

(1) Loading/unloading operations, including tank cleaning and crude oil washing(COW);

(2) Ship-to-ship transfer (STS) at open sea;

(3) Operations in coastal and restricted waters, including navigation under pilotage;

(4) Maintenance tasks.

It mainly identifies hazards which may lead to casualty and environmental damage, and analyze hazard cause and consequence severity. The analysis results are given by frequency of occurrence and severity of consequence. Here, severity was ranked separately for human life and environmental damage. In order to ensure that experts make their judgements on a common scale, frequency index (FI) and severity index (SI) are defined:

Definition and classification of frequency index FI **Table 6.1**

FI	Definition	Frequency (per ship year)
8	Occur once or twice per week on one ship	100
7	Occur once per month on one ship	10
6	Occur once per year on one ship	1
5	Occur once per year in a fleet of 10 ships	0.1
4	Occur once per year in a fleet of 100 ships	0.01
3	Occur once per year in a fleet of 1000 ships	0.001
2	Occur once per year in a fleet of 10000 ships	0.0001
1	Occur once in the lifetime (20 years) of a fleet of 5000 ships	0.00001

Definition and classification of severity index SI **Table 6.2**

SI	Personnel safety	Environmental damage	Property loss($)	Fatality
1	Single injury	Negligible leakage, without pollution or serious effect on environment or public health	30000	0.01
2	Multiple severe injuries	Minor leakage, perceptible environmental damage	300000	0.1
3	Single fatality or multiple severe injuries	Major leakage, ecosystem damaged in short term	3M	1
4	Multiple fatalities	Severe pollution, ecosystem damaged within certain period	30M	10
5	Many fatalities	Uncontrollable pollution, ecosystem damaged in long term	300M	100

2.2.2 Outcome of hazard identification

The experts define 81 hazards according to operational phases of oil tankers, i.e. 36 in navigation scenario, 30 in loading/unloading scenario, 8 in ship-to-ship transfer scenario and 7 in maintenance scenario.

Values of FI and SI of each hazard are given according to pre-defined frequency index FI and severity index SI to determine risk index RI (maximum 8). At the same time, a hazard is considered to be serious if the risk index RI⩾6 and/or the severity index SI⩾4.

The top-ranked hazards with respect to human life are:

(1) Explosion during loading/unloading in harbor;

(2) Fire/explosion after collision due to communications problem during navigation;

(3) Fire/explosion after breach of manifolds/pipelines caused by drift of vessel during SP mooring;

(4) Fire/explosion during loading/unloading due to failure/absence of vapor emission control system;

(5) Fire/explosion during weld repairs due to insufficient cleaning of pipes.

The top-ranked hazards with respect to environmental damage are:

(1) Explosion during loading/unloading in harbor;

(2) Loss of cargo after high-energy impact due to human communications problem leading to a collision;

(3) Loss of cargo after high-energy impact due to technical communications problem leading to a Collision;

(4) Breach of cargo tank due to stuck pressure valve during ballasting;

(5) Damaged bunker tanks due to collision during preparation of STS.

2.2.3 General accident scenarios

Based on outcome of hazard identification and in combination with casualty data of oil tankers over 60,000 tonnes DWT in the period 1980-2007, it is determined that accidents to be considered include collision, contact, grounding, fire, explosion and non-accidental structural failure.

2.3 Accident occurrence frequency

This study only carries out research on accidents causing loss of structural watertightness.

2.3.1 Historical data analysis

It is to analyze and determine frequency of different types of accidents in combination with historical accident data of large oil tankers. In the period 1980-2007, 2033 oil tanker accidents occurred, and distribution and frequency of different types of accidents are analyzed. In the period 1980-2007, total ship year N = 38211.20 is obtained by counting double hull oil tankers and non-double-hull oil tankers over 60,000 tonnes DWT. Casualty of each type of accident can be obtained in combination with historical data, and calculated accident frequency is shown as follows:

Casualty by accident category, covered period 1980-2007 Table 6.3

Accident	Frequency (per ship year)		Injured		Fatalities/missing	
	All accidents	Accidents with environmental pollution	Number of persons	Number of accidents	Number of persons	Number of accidents
Collision	1.59 E-02	1.02 E-03	2	3	55	7
Contact	7.04 E-03	6.80 E-04	0	0	0	0
Grounding	1.11 E-02	1.05 E-03	0	0	1	1
Fire	5.89 E-03	1.05 E-04	100	16	61	19
Explosion	3.01 E-03	1.57 E-04	30	10	119	31
Structural failure	1.03E-02	1.33 E-03	0	0	8	2
Total			132		244	

2.3.2 Accident occurrence frequency

A downward trend of frequencies is noted, especially significant reduction of accident occurrence in the post-90 period. Therefore, average accident frequency in the period 1990-2007 is taken as the accident frequency of each type of accident.

2.3.3 Input frequencies for the Event Tree models

Frequencies of 6 types of accidents are required to be inputted respectively for establishment of Event Tree model. When determining frequency of accidents such as collision, grounding, contact, fire and explosion, oil tanker type (single hull or double hull) need not be considered. However, when determining frequency of structural failure accidents, because hull type is highly related to the internal structure of oil tanker, additional account is to be taken for structural failure frequency of double hull oil tankers.

Frequency of different type of accidents can be determined in combination with analysis of big historical accident data. 845 accidents of oil tankers occurred in the period 1990-2007. Input frequencies for the Event Tree models corresponding to 6 types of accidents can be determined through analysis, as shown in the following table.

Frequency by accident category, covered period 1990-2007 Table 6.4

Fleet at risk of all ships =25780.22 ship years (Na)
Fleet at risk of double hull ships =10377.87 ship years (Nd)

Accident	Frequency	Event Tree input frequency (per ship year)	Frequency of accident occurrence of double hull ship (per ship year)
Collision	265	1.03E-02	-
Contact with a floating object or a fixed installation	96	3.72E-03	-
Grounding	193	7.49E-03	-
Fire	94	3.65E-03	-
Explosion	49	1.90E-03	-
Non-accidental structural failure	148	5.74E-03	1.93E-03
Total	845	3.28E-02	1.93E-03

2.4 Consequence assessment

The total risk of oil tankers is the sum of the risk contributions from the six (6) selected accident scenarios, and the risk contributions from all other scenarios are negligible.

2.4.1 Consequences on crew's life

The expected number of fatalities for each identified scenario is presented as the Potential Loss of Life, PLL, per ship year. The related estimation of PLL is derived from historical data on the basis of a typical crew number of 30 persons.

2.4.2 Environmental impact

The consequences to the environment for each identified scenario are presented as the expected cargo oil tonnes released to the sea. According to individual tank loading capacity and typical size parameter (based on the assumption of 98% fully loaded) of 4 types of oil tankers, oil spill quantity is 10726 tonnes and 152191 tonnes respectively for the scenario that the inner hull is breached without ship sinking and the scenario that the ship is loaded and the accident results to ship's total loss. Two oil spill values are inputted in Event Tree model to determine accident consequences.

2.4.3 Economic impact

Economic impact is calculated in terms of oil tanker property in cases of expected loss according to typical value of oil tanker and oil cargo as shown in following table.

Oil tanker and oil cargo typical values Table 6.5

Ship	Oil tanker value ($) (assumed ship age of 5 years)	Oil cargo value ($/tonne) (as of March 2008)
PANAMAX	50,000,000	923
AFRAMAX	65,000,000	
SUEZMAX	85,000,000	
VLCC	130,000,000	
Average value	82,500,000	

3 Step 2: risk analysis

3.1 Establishing Event Tree model

Different channel conditions and harbor environment conditions will lead to different order of subsequent events following initial events. When establishing Event Tree model, operational state or water environment of the oil tanker must be taken into account, which corresponds to four different speed ranges of oil tankers. In addition, the condition that the oil tanker is in shipyard or drydock is also taken into account.

When the oil tanker is under different loading conditions, the accident consequences are different. If oil leakage occurs, expected oil spill is of great difference. Therefore, loading conditions of the oil tanker must be considered for Event Tree model.

The collision accident includes an oil tanker striking or being struck by another ship, but accident consequences are different, which requires respective consideration for Event Tree model.

For the purpose of fire, there may be different fire sources. For the purpose of explosion, there may be different consequence due to different explosion position.

3.2 Risk model—collision

Collision events consist of scenarios where two vessels accidentally come into contact with each other. The scenarios contain collisions when the tanker vessel is striking or being struck by another ship. A collision involves at least two ships and in statistics each collision event is registered as two casualties – one for each involved vessel. Because not all collisions took place between two tankers, in the determination of the risk for tankers, it is necessary to consider only one incident as tanker accident. However, if the frequency of collisions involving tankers needs to be determined, the number of collisions between tankers has to be divided by a certain number, reflecting the probability of the tanker to be striking or being struck by another tanker vessel.

Collision scenarios present 32% of all registered initial causes in the setup databases involving tanker ships during the period 1990-2007. In total, 265 recorded accidents were registered as collisions. Concerning the degree of event's severity as coded in LRFP/LMIU databases, in 64 cases the event characterized by serious degree of severity, in 191 cases there were of non-serious degree of severity and in 10 cases there was no relevant registration. In 8 accidents, there were 2 non-serious injuries and 55 fatalities (39 missing persons and 16 deaths). Furthermore, in 27 collision accidents, oil spill occurred because of the accident, resulting to 126,532 tonnes of oil spill. In 11 cases out of the 265 recorded accidents, fire was occurred because of the accident.

3.2.1 Qualitative analysis

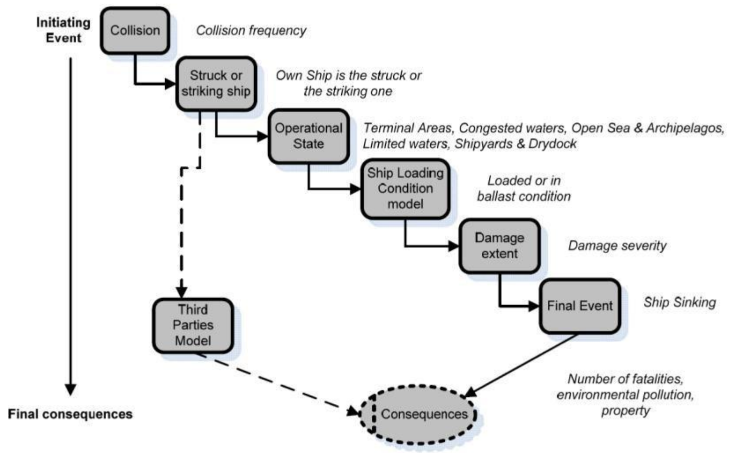


Figure 6.1 Event sequence in collision risk model of an oil tanker

According to the statistics, most collisions take place within congested waters with dense ship traffic, crossing routes and areas with large ship speed variations. A typical collision scenario involving a tanker ship starts with the event occurrence. It can be derived from collision scenarios that the Event Tree has many branches, e.g. the tanker vessel might be struck by another vessel or it might be the striking one, loading condition and water environment of the oil tanker, whether the inner hull of oil tanker is breached, whether fire and explosion occur due to breach. Event sequence in collision risk model is shown in Figure 6.1.

3.2.2 Quantitative analysis

3.2.2.1 Frequency of collision scenarios

For the risk analysis of oil tankers, the frequency of collision events is calculated in terms of oil tankers involved in the particular casualties (265 incidents). Estimated frequency of collision occurrence in terms of ships involved in collisions per ship year is 1.03E-02. There are 24 cases (out of 265 incidents) for which both ships involved in collisions are registered in separate records. That is to say, if only the number of collisions is taken into account, there are a total of 241 incidents. Based on this, the estimated frequency of collision occurrence in terms of collisions per ship year is 9.35E-03.

3.2.2.2 Struck or striking vessel

The calculated probability of a struck ship to be in collision with a tanker (striking ship type probability) is 0.252. It is more likely a particular ship to meet ships of the same type since they travel the same routes. Given the fact that the tanker ship has relatively low operational speed, it is expected that it is related to a higher probability that a tanker is the struck ship than to be the striking one. According to expert discussion, the probability of a tanker to be the struck ship or be the striking one in a collision event is assumed as 80%(struck)-20%(striking). Concerning events where the tanker ship is the striking vessel, the probability of receiving a critical damage is assumed to be negligible.

3.2.2.3 Operational state or water environment

Assumed probabilities of different operational states are based on historical data.

Collision probability of different operational state **Table 6.6**

Operational state	Collision probability
Terminal areas	0.30
Operation in congested waters	0.37
En route at open sea	0.26
Operation in limited waters	0.07
Shipyards & drydocks	0.00

3.2.2.4 Ship loading condition

By comprehensive analysis of LRFP database information and considering better maneuverability of ship in ballast condition, the experts propose that in the Event Tree, probability of ship in loading condition is 0.60 and probability of ship in ballast condition is 0.40.

3.2.2.5 Hull breaching

The probability of hull breaching is estimated from historical data and is calculated on the basis of each given operational state in case of a collision event.

Probability of hull breaching **Table 6.7**

Operational state	Breaching probability
Terminal areas	0.46
Operation in congested waters	0.36
En route at open sea	0.46
Operation in limited waters	0.42

3.2.2.6 Damage penetration

According to study on damage extent modelling concerning oil tankers and based on relevance of damage size and penetration depth, the probability of penetrating the inner hull structure is 0.22.

3.2.2.7 Damage severity

The probability of ship’s damage to be severe or not severe is calculated as a conditional probability of having or not LOWI occurrence in a given operational state in case of collision according to LRFP/LMIU coding.

Probability of LOWI occurrence in operational states **Table 6.8**

Operational state	Fire/explosion and having LOWI occurrence after collision	Fire/explosion and no LOWI occurrence after collision
Terminal areas	0.03	0.00
Operation in congested waters	0.06	0.00
En route at open sea	0.23	0.03
Operation in limited waters	0.00	0.00

3.2.2.8 Final event

For the struck ship, two final outcomes were identified: The struck ship remains afloat and continues to sail by her own means or towed away and total loss of the struck ship.

For personnel safety, the expected number of fatalities is calculated from the historical data and is summarized below:

Fatalities due to collision accidents **Table 6.9**

Crew number = 30 persons	
Collision scenarios	Expected number of fatalities (% of crew number)
Existence of fire and ship total loss	44%
Existence of fire with ship’s severe damage	14%
No fire and ship’s severe damage	7%
Non-severe damage	0
No LOWI occurrence	0

The environmental consequences of the risk modelling consider the release of oil cargo from the damaged tanker. Oil spill under three accident scenarios are as follows: 10726 tonnes when the ship is assumed loaded, the inner hull is breached without ship sinking, 152191 tonnes when the ship is assumed loaded and the accident results to ship's total loss, 184.6 tonnes for non-serious accidents.

For economic loss caused by the accident, if the oil tanker is of total loss, the economic loss is the oil tanker value, with average value of 82500000$; When the oil tanker is subject to serious accident but without total loss, it is assumed that the economic loss is 5% of the oil tanker value, i.e. 4125000$.

3.2.3 Event Tree model

It can be obtained from qualitative analysis of sequence of collision accidents and quantitative analysis of frequency corresponding to each branch that:

For crew member: $PLL_{\text{Collision-Crew}}$ = 4.91E-03 persons per ship year

For environment: $PLC_{\text{Collision-Environment}}$ =1.30E+01 tonnes per ship year

The event tree is graphically presented in the Appendix.

In a similar way, risk models are established for accident contact, grounding, fire, explosion, non-accidental structural failure (NASF) and casualties in shipyards & drydocks.

3.3 Risk summation

Based on the risk modelling, total risk of the oil tanker is shown in Table 6.10.

Total risk of oil tanker **Table 6.10**

Event	Frequency per ship year	PLL persons per ship year	PLC tonnes per ship year
Collision-struck ship	8.24 E-03	4.91 E-03	1.30 E+01
Collision-striking ship	2.06 E-03		
Contact with fixed installation	2.43 E-03		1.09 E+00
Contact with floating object	1.19 E-03		3.17E-01
Powered grounding	6.22 E-03	1.32 E-04	1.86 E+01
Drift grounding	1.27 E-03		6.16E+00
Fire due to internal source	2.86 E-03	2.34 E-03	2.35 E+01
Fire due to external source	3.65 E-05		
Fire by lightning	7.29 E-05		
Fire internal source--shipyards	6.43 E-04		
Explosion—operational phase	1.48 E-03	5.07 E-03	1.23 E+01
Explosion--shipyards	4.18 E-04		
NASF	1.93E-03	1.94 E-04	1.44 E+00
Totals		1.26E-02	7.63 E+01

Based on above risk analysis, it is determined that risk areas or scenarios that may cause heavy casualties are: (1) collision; (2) fire due to internal source; (3) explosion; and risk areas or scenarios that may cause serious oil spill are (1) collision; (2) powered grounding; (3) fire due to internal source; (4) explosion.

4 Step 3: risk control options

Potential risk control options are determined through brainstorming, and measures to reduce accident frequency and mitigate accident consequence are selected respectively to form a list containing all control measures. Then risk control measures are screened to determine certain amount of applicable risk control measures.

In this study, there are 79 control measures for oil tankers, and according to IMO criteria, measures of which cost-effectiveness ratio cannot meet the requirements are determined and removed (initial evaluation), then more comprehensive analysis is carried out to relatively small amount of measures for simplifying measures by the project team. Effective sequencing for screening control measures is mainly based on following principles: (1) Preventive options have priority before mitigating options; (2) Design options have priority before operative measures; (3) Passive systems have higher priority than active systems.

Finally, 9 control measures are determined by screening, as shown in Table 6.11.

Recommended risk control options **Table 6.11**

	Control options
RCO3	Active Steering Gear Redundancy
RCO4	Electronic Chart Display and Information System (ECDIS)
RCO5	Terminal Proximity and Speed Sensors (Docking Aid)
RCO6	Navigational Sonar
RCO7	Design modifications to reduce collision, contact, grounding and oil pollution risks
RCO8	Better implementation of Hot Work Procedures
RCO9	Double Sheathed Fuel oil pipes within the engine room
RCO11	Engine control room additional emergency exit
RCO12	Hull stress and fatigue monitoring system

5 Step 4: Cost benefit assessment

5.1 Risk reduction

An individual analysis is carried out to each risk control options to determine risk reduction.

(1) Active steering gear redundancy

This RCO relates to the automatic changeover of the steering gear pump/motor within the steering gear system in the event of failure to reduce the risk of collision/grounding. Upon discussion with experts in the field of ship control systems, it has been identified that there would normally be one steering gear pump/motor in use at open waters. In narrow waters and when docking, two (both) steering gear pumps/motors are in operation. In event of a pump/motor or electrical failure in narrow waters and in terminal areas, the second pump would already be operating and would be sufficient to control the ship steering gear.

In the event of failure of the running pump or electrical supply in open waters, the navigator is alerted by an audio and visual alarm and will start the second pump manually if not already running. This would suggest that the benefit gained through introduction of this RCO is the reduction in reaction time and the reduced possibility of human error. From the above statement it is clear that any introduction of an automatic changeover facility will only provide risk reduction benefit at open sea.

Through a workshop by means of the Delphi technique using experts, it was agreed that a risk reduction of 10% with regards to fatalities from powered groundings can be expected from this active steering gear redundancy in open waters, taking into account that not all powered groundings are caused by loss of steering. It is clear that there is no perceived risk of fatality when striking, as such no risk reduction could be applied. Aiming at grounding, it is to use the Grounding Event Tree to recalculate risk value.

It can be found by analyzing Event Tree that there are 2 scenarios with fatality: (1) powered grounding in congested waters; (2) powered grounding in open waters. Measures are mainly taken to powered grounding in open waters, that is to say, there is no change for fatality due to powered grounding in congested waters. With regard to grounding, fatality under most serious condition is 1, if risk is reduced by 10%, fatality due to powered grounding in open waters in Event Tree is 0.9. Calculation process is shown in the following table.

Proposed risk control measures **Table 6.12**

Average value (per tonne)	Prior to taking measures (person per ship year)	After taking measures (person per ship year)	Reduced risk (person per ship year)	Sum of reduced risk value (person per ship year)	Reduced risk (25 years)
Powered grounding in congested waters	8.41E-05	8.41E-05	0	4.76E-06	1.19E-04
Powered grounding in open waters	4.76E-05	4.28E-05	4.76E-06		

It can be found by analyzing Grounding Event Tree that there are relatively more oil spill scenarios, but active steering gear redundancy in open waters mainly reduces oil spill scenarios of powered grounding in open waters, and the corresponding calculation is as follows:

Oil spill risk prior to taking measures: 6.233E+00 tonne per ship year;

Oil spill risk after taking measures: 5.609E+00 tonne per ship year;

Reduced risk value: 6.233E-01 tonne per ship year;

Total risk reduced within 25 years: 1.558E+01 tonne per ship year.

(2) Electronic Chart Display and Information System (ECDIS)

The experts have previously identified that a risk reduction of 36% for powered grounding can be expected from the implementation of ECDIS. Using the grounding Event Tree, calculations indicate that 4.7E-05 lives per ship year or 1.2E-03 over the 25 year lifetime of a tanker will be saved. In terms of potential loss of cargo, calculations suggest that 6.7E+00 tonnes of oil per ship year and 1.7E+02 over the 25 year ship lifetime may be prevented from being spilled.

(3) Terminal proximity and speed sensors (docking aid)

When considering docking aid systems, there are three main categories which includes Doppler, ship/land based GPS, and shore based laser/radar. It is clear that there is no perceived risk of fatality in relation to the ship in terminal areas. As such, there is no perceived reduction in the risk of fatality. In terms of potential loss of cargo, calculations suggest that 1.4E-01 tonnes of oil per ship year and 4E+00 over the 25 year ship lifetime may be prevented from being spilled.

(4) Navigational sonar

Navigational Sonar systems have been in use for some time, largely for cruise and smaller ships. The extra consideration with larger ships, such as a VLCC, is the reaction capability after identification of a grounding hazard.

Through a workshop by means of the Delphi technique using experts, it was agreed that a risk reduction of 15% with regards to fatalities from powered grounding accidents can be expected from the introduction of navigational sonar. Using the grounding Event Tree, calculations indicate that 2.0E-05 lives per ship year or 4.9E-04 over the 25 year lifetime of a tanker will be saved. In terms of potential loss of cargo, calculations suggest that 2.8E+00 tonnes of oil per ship year and 7.0E+01 over the 25 year ship lifetime may be prevented from being spilled.

(5) Ship design modifications

This RCO investigates the effectiveness of three potential hull design modifications, namely:

① RCO 7.1: Enhanced cargo tank subdivision: The current cargo tank configurations of the four representative tankers are a 6 × 2 configuration for the Panamax, Aframax and Suezmax (an arrangement with 6 transverse bulkheads and a longitudinal bulkhead on the centreline, resulting in a 12 cargo tank arrangement) and a 5 × 3 configuration for the VLCC (an arrangement with 5 transverse bulkheads and two longitudinal bulkheads, resulting in a 15 cargo tank arrangement). On the alternatives considered, an additional longitudinal bulkhead was considered for the Panamax, Aframax and Suezmax and an additional transverse bulkhead was considered for the VLCC, resulting in all cases in a 6 × 3 cargo tank arrangement.

② RCO 7.2: Increased double bottom height: The four representative tankers feature double bottoms of heights 2.04 m, 2.30 m, 2.80 m and 3.00 m (Panamax, Aframax, Suezmax and VLCC, respectively) in way of the cargo area. Parameter studies are performed considering double bottom height increases of 0.50 m and 1.00 m for the 6 × 2 cargo tank configuration for the Panamax, Aframax and Suezmax and the 5 × 3 cargo tank configuration for the VLCC, by considering a corresponding increase in the ships' depth. Potential risk reduction is calculated for grounding incidents.

③ RCO 7.3: Increased side tanks width: The four representative tankers feature side tanks of widths 2.075 m, 2.18 m, 2.50 m and 3.38 m (Panamax, Aframax, Suezmax and VLCC, respectively) in way of the cargo area. Parameter studies are performed considering side tank width increases of 0.40 m and 0.8 m for the 6 × 2 cargo tank configuration for the Panamax, Aframax and Suezmax and the 5 × 3 cargo tank configuration for the VLCC, by considering a corresponding increase in the ships' breadth. Potential risk reduction is calculated for collision and contact incidents.

The potential offered by these RCOs on reducing oil pollution risks due to collision, contact and grounding incidents, and their corresponding cost-effectiveness, are investigated. The potential for oil outflow risk reduction is calculated for all cases using the Event Tree models for collision, contact and grounding. The potential offered by these RCOs on reducing risks to life is negligible, hence not investigated.

① RCO7.1 Enhanced cargo tank subdivision

The Event Trees for collision, contact and grounding have been used to calculate the oil outflow risk for the four representative ships. Compared to the characteristics of the four representative ships, the only difference is the average size of the cargo tanks, which is now reduced due to the introduction of additional subdivision. When recalculation is carried out by using Event Tree, once the oil tanker is subject to inner hull breaching without total loss of the tanker in loaded condition, expect oil outflow will change.

ΔPLC prior to and after RCO7.1 (tonne per ship year) Table 6.13

PANAMAX	AFRAMAX	SUEZMAX	VLCC
[6×2→6×3]	[6×2→6×3]	[6×2→6×3]	[6×2→6×3]
1.41	2.32	2.49	1.17

Table 6.13 values indicate a PLC reduction of 16%, 17%, 17% and 7% on oil pollution risk from collisions, contacts and groundings over the PLC of the current configurations for the Panamax, Aframax, Suezmax and VLCC, respectively.

② RCO 7.2 Increased double bottom height

The grounding Event Trees has been used to calculate the oil outflow risk for the increased double bottom heights of 0.5 m and 1.0 m for the four representative tanker ships, by correspondingly increasing the ships' depth. In all cases, it is noted that the increase in draught due to the additional steel and outfit weight is of negligible magnitude. The cargo tank configurations are considered as of the current configurations for the representative tankers (6 × 2 for the Panamax, Aframax and Suezmax and 5 × 3 for the VLCC).

When the double bottom height changes, the probability of penetrating the inner shell will change. That is to say, both the probability of penetrating inner hull and the probability of non-penetrating in the Event Trees will change. Based on new probability value, new risk value can be obtained so as to determine reduced risk.Final calculation indicates the following PLC reductions on oil pollution risk from groundings over the PLC of the basis configurations:

Panamax: 4.9% for 0.50 m double bottom increase; 9% for 1.0 m double bottom increase.

Aframax: 4.6% for 0.5 m double bottom increase; 8.9% for 1.0 m double bottom increase.

Suezmax: 4.2% for 0.5 m double bottom increase; 8.2% for 1.0 m double bottom increase.

VLCC: 2.4% for 0.5 m double bottom increase; 5% for 1.0 m double bottom increase.

③ RCO 7.3 Increased side tanks width

The cargo tank configurations are considered as of the current configurations for the representative tankers (6 × 2 for the Panamax, Aframax and Suezmax and 5 × 3 for the VLCC). The Event Trees for collision and contact have been used to calculate the oil outflow risk for the increased side tank widths of 0.4 m and 0.8 m for the four representative tanker ships, by correspondingly increasing the ships' breadth. After the increase in width, both the probability values for breaching the inner hull and non-breaching the inner hull will change.

Calculation indicates the following PLC reductions on oil pollution risk from collisions and contacts over the PLC of the basis configurations:

Side tanks width increased by 0.4 m: 11.6%, 10.1%, 8.6% and 5.7% PLC reduction for the Panamax, Aframax, Suezmax and VLCC, respectively.

Side tanks width increased by 0.8 m: 20.2%, 18.4%, 15.9% and 10.5% PLC reduction for the Panamax, Aframax, Suezmax and VLCC, respectively.

(6) Hot works procedures training

The study indicates that hot works procedures training is to be carried out twice a year, which is one of the requirements for risk control measures. Experts were consulted during Delphi sessions which suggests that a risk reduction of 43% with regards to fatalities due to fire and explosion accidents caused by hot works only can be expected from hot works procedures training if applied to suitably qualified and experienced personnel.

Risk is recalculated by using the Fire and Explosion Event Trees. The results indicate that 7.8E-04 lives per shipyear or 1.9E-02 over the lifetime of a tanker will be saved by implementing this RCO. Ship lifetime is assumed to be 25 years. Moreover, calculations suggest that 7.1E-01 tonnes of oil per shipyear or 1.8E+01 over the lifetime of the ship will be prevented from being spilled.

(7) Double sheathed low pressure fuel pipes in engine room

Experts suggest that although all hot surfaces are to be insulated, in reality approximately 75% are adequately covered. This is typically due to maintenance being carried out on equipment and insulated coverings not being properly refitted or being damaged over time. The risk reduction can be gained from installing double sheathed low pressure fuel pipes. Experts find that 56% of engine room fires are caused by fuel coming into contact with hot surfaces. Opinion from Delphi meeting sessions involving experts suggests that double sheathed low pressure fuel pipes may reduce the residual risk of fire in the engine room due to oil leakage onto hot surfaces by 55%.

Risk is recalculated by using Event Tree. The results indicate an engine room fire risk reduction of 5.7E-04 lives per shipyear, or 1.4E-02 lives per ship lifetime. Ship lifetime is assumed to be 25 years. Moreover, calculations suggest that 6.2E+00 tonnes of oil per shipyear and 1.5E+02 over the 25 year ship lifetime will be prevented from being spilled.

(8) Engine control room additional emergency exit

RCO of installing an additional emergency exit linking the engine control room to the superstructure but independent of the engine room itself is considered. Expert judgement gained from Delphi sessions suggests that a risk reduction of 21% with regards to fatality of personnel in the engine control room during an emergency situation can be expected with respect to this RCO. It is assumed that one crew member will be present in the engine control room for 30% of the time; this is based on average safe manning certificate numbers and normal unmanned machinery spaces working procedures. During a crisis event, several members of the crew may be sent to the engine control room to attempt to take control of the situation; if evacuation is required in these circumstances, the additional emergency exit will have a greater effect on Potential Loss of Life (PLL) due to the fact that a greater number of crew will use the exit.

Risk is recalculated by using Fire Event Tree. The results indicate 1.7E-04 lives per shipyear or 4.4E-03 lives per ship lifetime. Ship lifetime is assumed to be 25 years.

(9) Hull stress and fatigue monitoring system

Fatigue build-up in vessels leads to local cracks in the hull, which if left unrepaired, eventually endanger the structural integrity of the ship. In this respect, the RCO hull stress and fatigue monitoring system (HMS) is proposed. HMS will have a positive effect on risk in the two following scenarios: 1) Structural damage due to overloading of hull girder due to heavy weather; 2) Structural damage due to fatigue (local and global). Delphi meeting sessions involving experts estimate that the risk associated with structural failure will be reduced by 11% by using a HMS.

Using the Non-accidental Structural Failure (NASF) Event Tree, the total risk of fatality in incidents involving double hull (DH) tankers is calculated. The results indicate 2.1E-05 lives per shipyear and 5.3E-04 lives over the 25 year lifetime of a tanker. With respect to potential loss of cargo, calculations following the same methodology undertaken for PLL indicate that 1.6E-01 tonnes of oil per shipyear and 4.0E+00 tonnes of oil per ship lifetime will be prevented from spillage.

5.2 Cost of implementing RCOs

(1) Active steering gear redundancy

The cost associated with introducing the active steering gear redundancy will be negligible as this would only be a slight addition to the existing system layout during the design phase. For calculation purposes, an initial purchase price of $2,000 and an annual spares/repairs cost of $200 are considered. Over 25 years, this provides a Net Present Value of $4,800.

$$\mathrm{NPV} = 2000 + \sum_{t=1}^{25} \frac{200}{(1+5\%)^{t}} = \$4819$$

(2) Electronic chart display and information system (ECDIS)

A net present value (NPV) of ECDIS is $75,000, which consists of an initial purchase and installation cost of $32,000, back-up arrangements at $20,000, annual maintenance of $150, initial training of $6,000 and an annual training cost of $750.

$$\mathrm{NPV} = \mathrm{A} + \frac{X}{(1+\mathrm{r})} + \frac{X}{(1+\mathrm{r})^{2}} + \frac{X}{(1+\mathrm{r})^{3}} + \cdots + \frac{X}{(1+\mathrm{r})^{T}} = \mathrm{A} + \sum_{t=1}^{T} \frac{X}{(1+\mathrm{r})^{t}}$$

where: A=32000+20000+6000; X=750+150

(3) Terminal proximity and speed sensors (docking aid)

The cost of implementing a Doppler type docking system is largely associated with the initial purchase price which is considered to be $70,000. Other perceived costs include an outlay of $4,000 every five years for maintenance during dry docking periods, and an annual figure of $400 for general spares and repairs. Over 25 years, this provides a Net Present Value of $85,840.

$$\mathrm{NPV} = 70000 + \sum_{t=1}^{25} \frac{400}{(1+5\%)^{t}} + \frac{4000}{(1+5\%)^{5}} + \frac{4000}{(1+5\%)^{10}} + \frac{4000}{(1+5\%)^{15}} + \frac{4000}{(1+5\%)^{20}} + \frac{4000}{(1+5\%)^{25}} = \$85840$$

(4) Navigational sonar

A 0.5 NM system would cost approximately $150,000 for the initial purchase. It is also considered that there would be a maintenance cost of $10,000 every five years during dry docking periods, and an annual figure of $1,500 for spares/repairs. Over 25 years, this provides a Net Present Value of $196,650.

(5) Ship design modifications

The implementation cost of the various RCOs being examined refers to the construction cost (additional steel and outfit work), maintenance and increased fuel consumption (due to the heavier structure). A life time of 25 years and an interest rate of 5% are assumed in the calculations.

RCO7.1 Enhanced cargo tank subdivision

The increase in steel weight is the result of the introduction of one additional longitudinal bulkhead running the full length of the cargo holds for the Panamax, Aframax and Suezmax ships. For the case of the VLCC, the introduction of one additional transverse bulkhead is considered. The weight for the additional longitudinal bulkhead is 500 tonnes, 600 tonnes and 950 tonnes for the cases of a Panamax, Aframax and Suezmax, respectively and that the weight of the transverse bulkhead for the case of the VLCC is 350 tonnes. Current pricing at Chinese shipyards indicates a cost of $2.2 per kilogram of steel, which includes labor cost but excludes staging or coating. On the basis of this price, the additional cost for construction is $1.1 million for the Panamax, $1.3 million for the Aframax, $2.1 million for the Suezmax and $0.77 million for the VLCC. As maintenance costs, 1% of construction cost is considered per annum.

At the same time, operational cost is increased, as well as oil consumption in full load and partial load conditions. The additional steel weight would result in an estimated increase in draught, and this is a negligible increase in draught which could be compensated in a great variety of ways in the full load condition. It is assumed that the ships will be operating approximately 340 days in a year. A Panamax ship consumes 45 tonnes per day of heavy fuel at full load and 35 tonnes per day at partial load, an Aframax 60 tonnes and 45 tonnes per day, a Suezmax 75 tonnes and 58 tonnes and a VLCC 85 tonnes and 65 tonnes, respectively. Fuel price is taken as $500 per tonne.

The increased cost $\triangle C$ of Panamax, Aframax and Suezmax and VLCC is 1472602, 1723185, 2731930 and 956843 ($) respectively.

RCO7.2 Increased double bottom height

Based on calculation, the increased cost is shown in Table 6.14.

RCO7.2—△C **Table 6.14**

Ship type	Size	Cost ($)	Ship type	Size	Cost ($)
PANAMAX	2.54×20.3	273928	SUEZMAX	3.30×23.6	357999
	3.04×20.8	547856		3.80×24.1	717984
AFRAMAX	2.80×21.5	293938	VLCC	3.50×31.75	451087
	3.30×22.0	587862		4.00×32.25	902160

RCO7.3 Increased side tanks width

Based on calculation, the increased cost is shown in Table 6.15.

RCO7.3—△C **Table 6.15**

Ship type	Size	Cost ($)	Ship type	Size	Cost ($)
PANAMAX	2.475×33.0	235646	SUEZMAX	2.90×48.8	309310
	2.875×33.8	471277		3.30×49.6	618606
AFRAMAX	2.58×43.8	250283	VLCC	3.78×58.8	393668
	2.98×44.6	500566		4.18×59.6	787337

(6) Hot works procedures training

The cost of undertaking one day hot works procedures training onboard is estimated at $1,000/ship. Hot works training is to be conducted twice a year, giving a total yearly cost of $2,000/ship. Travel and subsistence costs are not considered as training takes place on the ship. Therefore, total costs over the lifetime of the tanker taking into account NPV are approximately $28,000.

(7) Double sheathed low pressure fuel pipes in engine room

The cost of double sheathed low pressure fuel pipes is estimated at $420/m for 350mm (d) and $350/m for 250mm (d) including materials and labor. For the purposes of RCO, it is assumed that 30m of the heavy fuel pipe requires 350mm sheathing and 10m requires 250mm; this translates to a total one-off cost of $16,100; in addition, $40,000 maintenance costs will be incurred over the 25 year lifetime of a tanker, which translates to approximately $23,000 when NPV is taken into account. Taken together calculations suggest that the total cost of implementation of this RCO over the lifetime of a ship will be approximately $39,000.

(8) Engine control room additional emergency exit

The installation of an additional emergency exit from the engine control room independent of the engine room itself at new build stage includes material costs associated with steel, A60 insulation and miscellaneous items such as the door and ladder, as well as the actual labor. Indicative costs following reference suggest the total cost of installing this RCO will be $13,280 and $14,400, with mean value of $13,840.

(9) Hull stress and fatigue monitoring system

The system includes 12 sensors and installation is approximately $117,000; the cost of maintenance over a typical 25 year tanker lifetime is estimated to be $20,000, which when taking into account NPV is approximately $11,000, giving a grand total of $128,000.

5.3 Economic benefit of implementing RCOs

5.3.1 Example of active steering gear redundancy

The economic benefit of introducing an active steering gear redundancy is the reduction in groundings leading to fatal accidents, oil spills and property damage. When considering the risk reduction benefits with regards to reduced oil spill per ship year ($378,000) and property damage to the ship ($392), this provides a benefit NPV of $530,000.

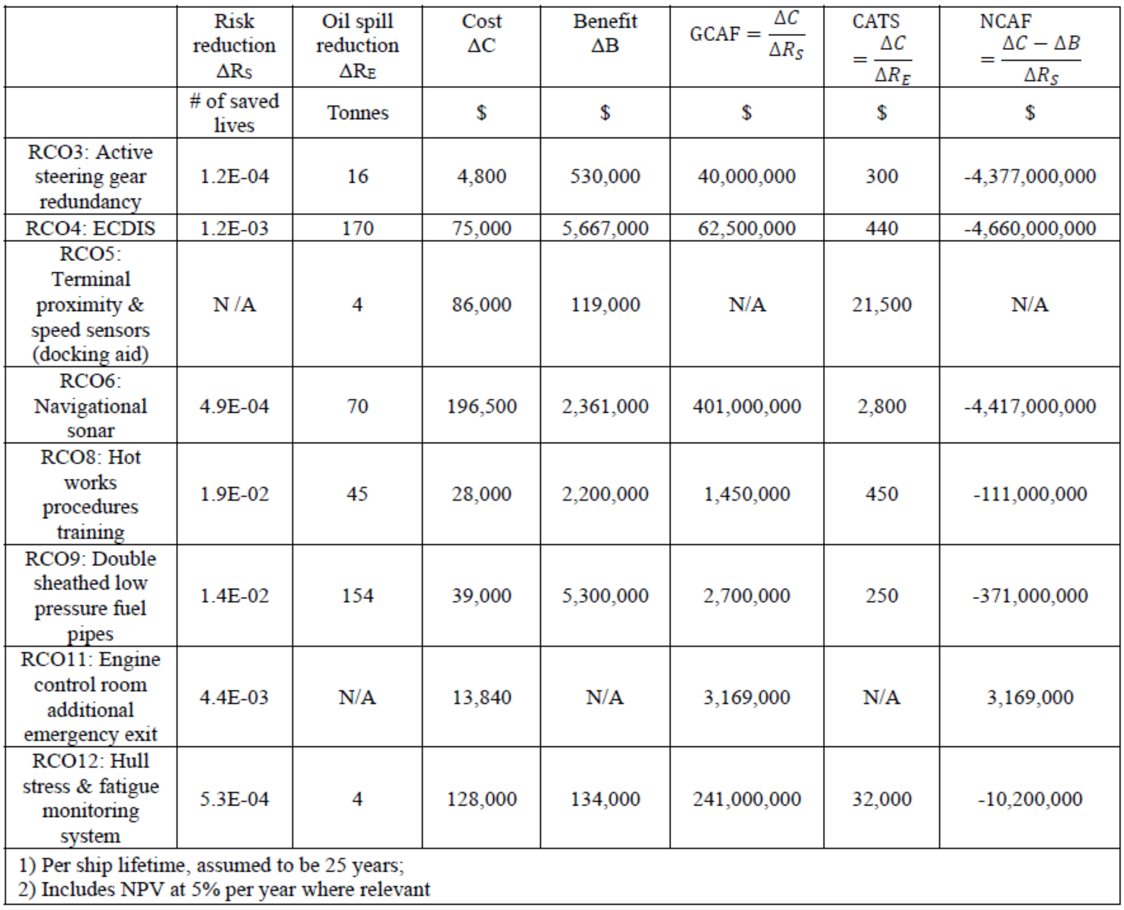
$$\text{GCAF} = \frac{\Delta C}{\Delta R_S} = \frac{4819}{1.19\text{E} - 04} = \$40495798$$

$$\text{NCAF} = \frac{\Delta C - \Delta B}{\Delta R_S} = \frac{4819 - 530000}{1.19\text{E} - 04} = -\ \$4413285714$$

5.4 Cost benefit evaluation

GCAF, NCAF and CATS corresponding to each RCO are calculated as follows:

Results of cost benefit evaluation of each RCO **Table 6.16**



	Risk reduction ΔR_S	Oil spill reduction ΔR_E	Cost ΔC	Benefit ΔB	$\text{GCAF} = \frac{\Delta C}{\Delta R_S}$	CATS $= \frac{\Delta C}{\Delta R_E}$	NCAF $= \frac{\Delta C - \Delta B}{\Delta R_S}$
	# of saved lives	Tonnes	$	$	$	$	$
RCO3: Active steering gear redundancy	1.2E-04	16	4,800	530,000	40,000,000	300	-4,377,000,000
RCO4: ECDIS	1.2E-03	170	75,000	5,667,000	62,500,000	440	-4,660,000,000
RCO5: Terminal proximity & speed sensors (docking aid)	N /A	4	86,000	119,000	N/A	21,500	N/A
RCO6: Navigational sonar	4.9E-04	70	196,500	2,361,000	401,000,000	2,800	-4,417,000,000
RCO8: Hot works procedures training	1.9E-02	45	28,000	2,200,000	1,450,000	450	-111,000,000
RCO9: Double sheathed low pressure fuel pipes	1.4E-02	154	39,000	5,300,000	2,700,000	250	-371,000,000
RCO11: Engine control room additional emergency exit	4.4E-03	N/A	13,840	N/A	3,169,000	N/A	3,169,000
RCO12: Hull stress & fatigue monitoring system	5.3E-04	4	128,000	134,000	241,000,000	32,000	-10,200,000
1) Per ship lifetime, assumed to be 25 years; 2) Includes NPV at 5% per year where relevant							

The results in Table 6.16 show that RCO 8, RCO 9 and RCO 11 have relatively low GCAF values compared to RCO 3, RCO 4 and RCO 6. A GCAF value of less than $3 million implies that an RCO is to be implemented. However, in order to assess the global benefit of each RCO, the NCAF values incorporating the economic benefit of reduced PLC and PLP must be considered. With this in mind, it is clear that the NCAF values of RCOs 3, 4, 6, 8, 9 and 12 are negative indicating that these RCOs are economically beneficial in themselves.

6 Step 5: Recommendations for decision-making

According to IMO FSA Guidelines, an RCO is considered cost effective if the GCAF is less than $3 million. An RCO is also cost effective if the NCAF is either less than $3 million or negative. A negative NCAF indicates that the benefits in monetary units are higher than the costs associated with the RCO. From a PLC point of view, an RCO is considered cost effective if the CATS (Cost of Averting a Tonne of Oil Spilled) is less than $60,000. It is noted that of the RCOs considered, all have a CATS satisfying requirements except certain outcomes in RCO 7. Recommendations for decision-making can be provided through analysis.

With respect to RCO 8, GCAF=$1.45M<$3M but NCAF<0, RCO 8 is recommended RCO, which is the best.

With respect to RCO 3, RCO 4 and RCO 6, the analysis is as follows.

RCO recommendations **Table 6.17**

	GCAF（$）	CATS（$）	NCAF（$）	Analysis
RCO3: Active steering gear redundancy	40,000,000	300	-4,377,000,000	GCAF>$3M, but CATS<60000, and NCAF<0
RCO4: Electronic chart display and information system	62,500,000	440	-4,660,000,000	GCAF>$3M, but CATS<60000, and NCAF<0
RCO6: Navigational sonar	401,000,000	2,800	-4,417,000,000	GCAF>$3M, but CATS<60000, and NCAF<0

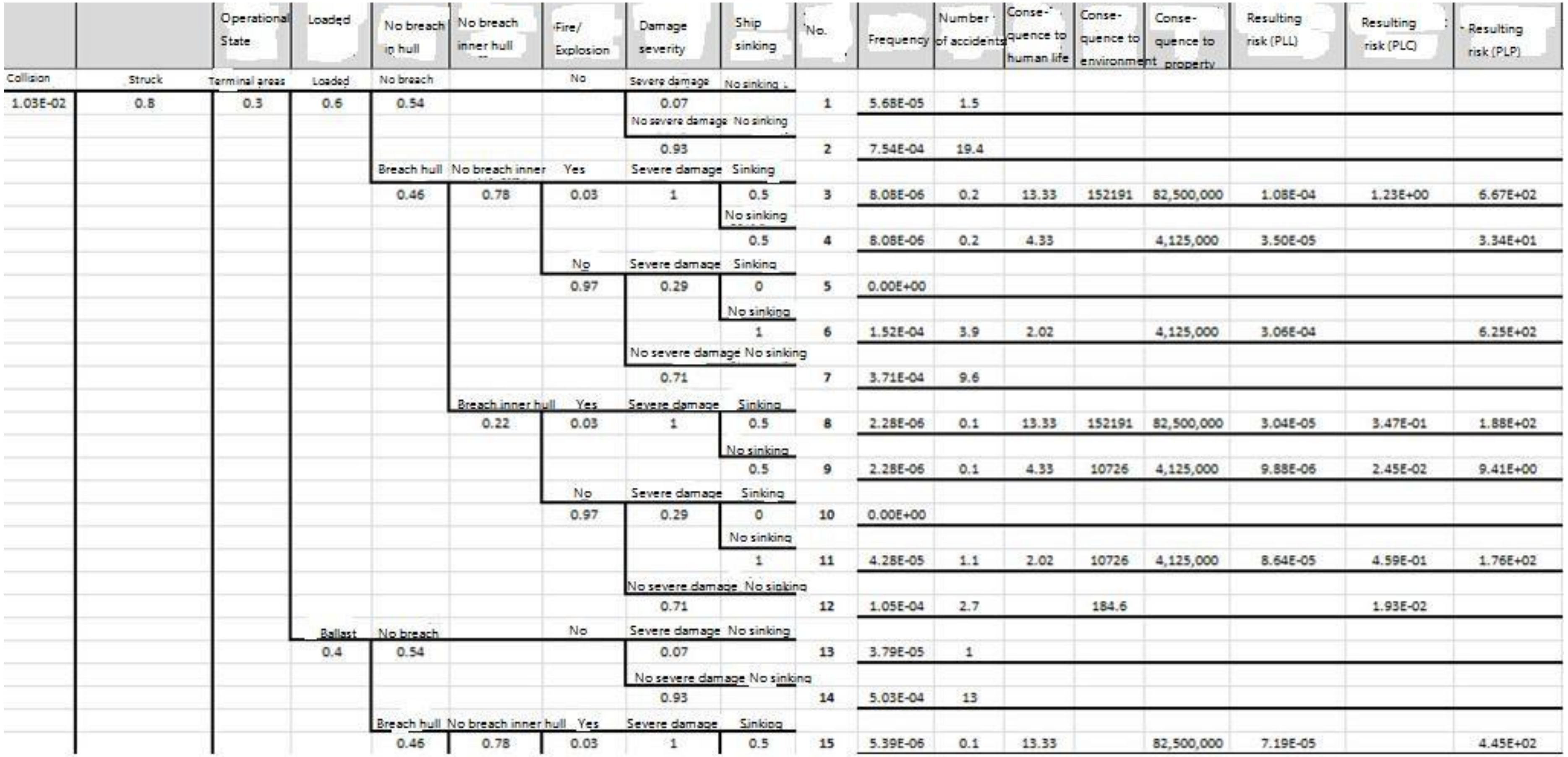
With respect to RCO 3, RCO 4 and RCO 6, all GCAF are much more than $3M, but NCAF and CATS satisfy requirements. These three RCOs are recommended because PLC and PLP risks are reduced when calculating reduced risk, and PLL is reduced relatively small, i.e. 1.2E-04, 1.2E-03 and 4.9E-04 respectively.

With respect to RCO 9, GCAF=$2700000=$2.7M<$3M, GCAF is a little bit less than 3M, but CATS<60000 and GCAF<0, though GCAF is not more than 3M, but it is relatively big. At the same time, PLL is reduced by1.4E-02, which is relatively big, so it is recommended.

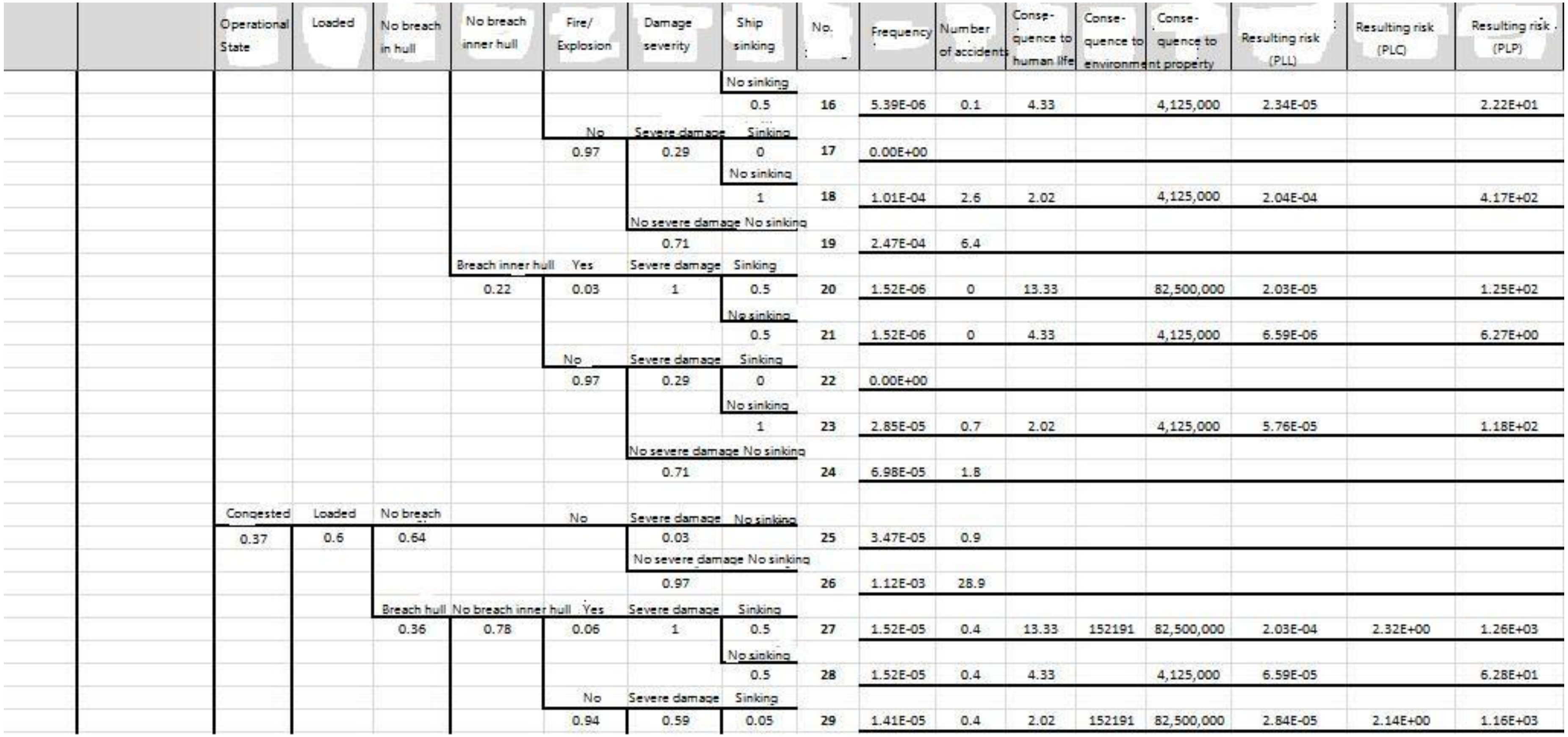
With respect to RCO 11, GCAF=$3169000>＄3M, and GCAF is a little bit more than 3M, which cannot meet the requirements of the criteria. However, because initial cost is low and there is no maintenance cost or serious incompliance of GCAF, this RCO is deemed acceptable.

RCO5 and RCO12 are not recommended. Though the values of CATS are less than 60000, and cost benefit ratio is too small, i.e. the cost of implementation of RCO 5 is 72% of the economic benefit and RCO 12 is 96%.

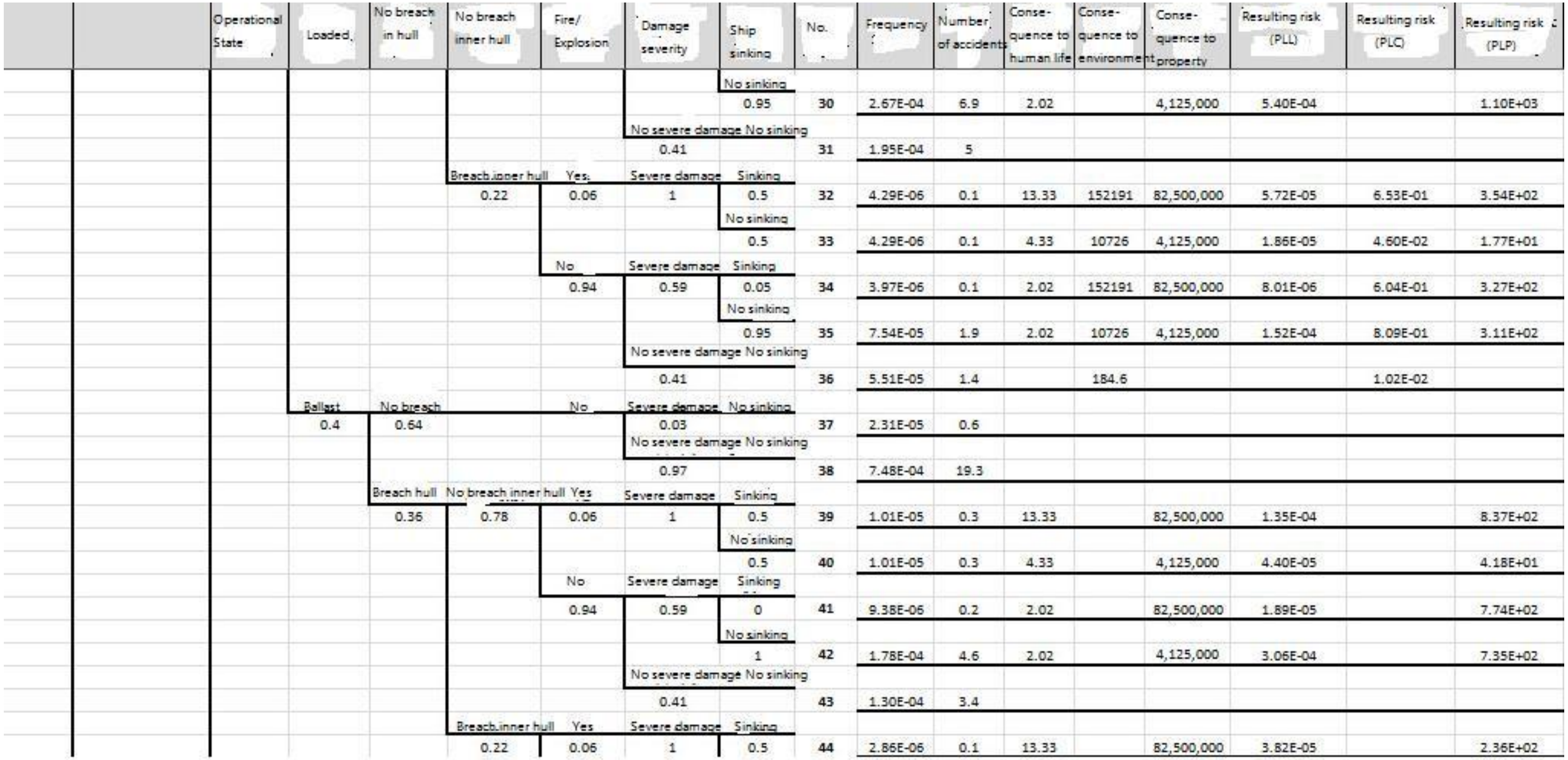
Figure 6.2 Collision Event Tree



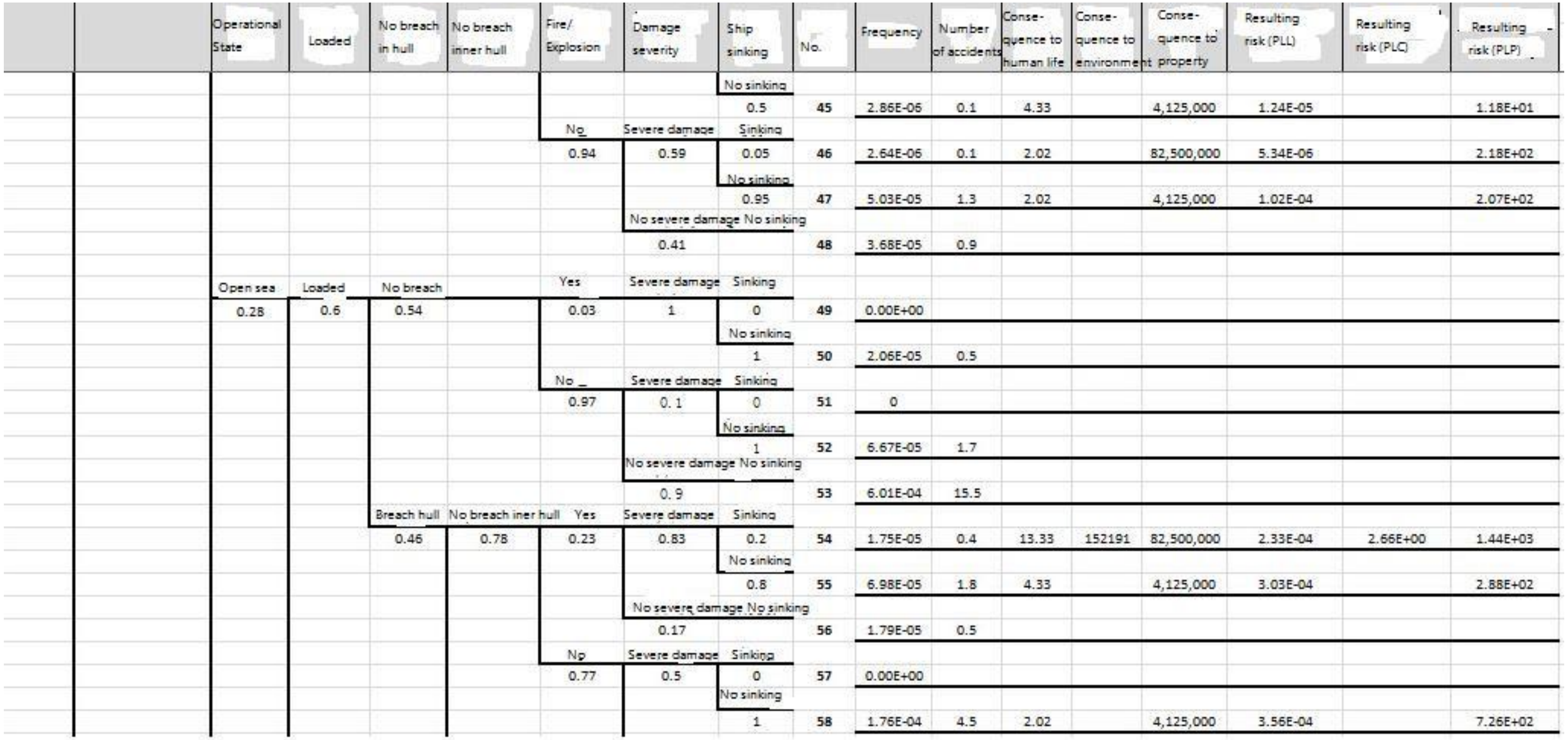
		Operational State	Loaded	No breach in hull	No breach inner hull	Fire/ Explosion	Damage severity	Ship sinking	No.	Frequency	Number of accidents	Consequence to human life	Consequence to environment	Consequence to property	Resulting risk (PLL)	Resulting risk (PLC)	Resulting risk (PLP)
Collision	Struck	Terminal areas	Loaded	No breach		No	Severe damage	No sinking									
1.03E-02	0.8	0.3	0.6	0.54			0.07		1	5.68E-05	1.5						
							No severe damage	No sinking									
							0.93		2	7.54E-04	19.4						
				Breach hull	No breach inner	Yes	Severe damage	Sinking									
				0.46	0.78	0.03	1	0.5	3	8.08E-06	0.2	13.33	152191	82,500,000	1.08E-04	1.23E+00	6.67E+02
								No sinking									
								0.5	4	8.08E-06	0.2	4.33		4,125,000	3.50E-05		3.34E+01
						No	Severe damage	Sinking									
						0.97	0.29	0	5	0.00E+00							
								No sinking									
								1	6	1.52E-04	3.9	2.02		4,125,000	3.06E-04		6.25E+02
							No severe damage	No sinking									
							0.71		7	3.71E-04	9.6						
					Breach inner hull	Yes	Severe damage	Sinking									
					0.22	0.03	1	0.5	8	2.28E-06	0.1	13.33	152191	82,500,000	3.04E-05	3.47E-01	1.88E+02
								No sinking									
								0.5	9	2.28E-06	0.1	4.33	10726	4,125,000	9.88E-06	2.45E-02	9.41E+00
						No	Severe damage	Sinking									
						0.97	0.29	0	10	0.00E+00							
								No sinking									
								1	11	4.28E-05	1.1	2.02	10726	4,125,000	8.64E-05	4.59E-01	1.76E+02
							No severe damage	No sinking									
							0.71		12	1.05E-04	2.7		184.6			1.93E-02	
			Ballast	No breach		No	Severe damage	No sinking									
			0.4	0.54			0.07		13	3.79E-05	1						
							No severe damage	No sinking									
							0.93		14	5.03E-04	13						
				Breach hull	No breach inner hull	Yes	Severe damage	Sinking									
				0.46	0.78	0.03	1	0.5	15	5.39E-06	0.1	13.33		82,500,000	7.19E-05		4.45E+02



Operational State	Loaded	No breach in hull	No breach inner hull	Fire/ Explosion	Damage severity	Ship sinking	No.	Frequency	Number of accidents	Conse-quence to human life	Conse-quence to environment	Conse-quence to property	Resulting risk (PLL)	Resulting risk (PLC)	Resulting risk (PLP)
						No sinking									
						0.5	16	5.39E-06	0.1	4.33		4,125,000	2.34E-05		2.22E+01
				No	Severe damage	Sinking									
				0.97	0.29	0	17	0.00E+00							
						No sinking									
						1	18	1.01E-04	2.6	2.02		4,125,000	2.04E-04		4.17E+02
					No severe damage	No sinking									
					0.71		19	2.47E-04	6.4						
			Breach inner hull	Yes	Severe damage	Sinking									
			0.22	0.03	1	0.5	20	1.52E-06	0	13.33		82,500,000	2.03E-05		1.25E+02
						No sinking									
						0.5	21	1.52E-06	0	4.33		4,125,000	6.59E-06		6.27E+00
				No	Severe damage	Sinking									
				0.97	0.29	0	22	0.00E+00							
						No sinking									
						1	23	2.85E-05	0.7	2.02		4,125,000	5.76E-05		1.18E+02
					No severe damage	No sinking									
					0.71		24	6.98E-05	1.8						
Congested	Loaded	No breach		No	Severe damage	No sinking									
0.37	0.6	0.64			0.03		25	3.47E-05	0.9						
					No severe damage	No sinking									
					0.97		26	1.12E-03	28.9						
		Breach hull	No breach inner hull	Yes	Severe damage	Sinking									
		0.36	0.78	0.06	1	0.5	27	1.52E-05	0.4	13.33	152191	82,500,000	2.03E-04	2.32E+00	1.26E+03
						No sinking									
						0.5	28	1.52E-05	0.4	4.33		4,125,000	6.59E-05		6.28E+01
				No	Severe damage	Sinking									
				0.94	0.59	0.05	29	1.41E-05	0.4	2.02	152191	82,500,000	2.84E-05	2.14E+00	1.16E+03

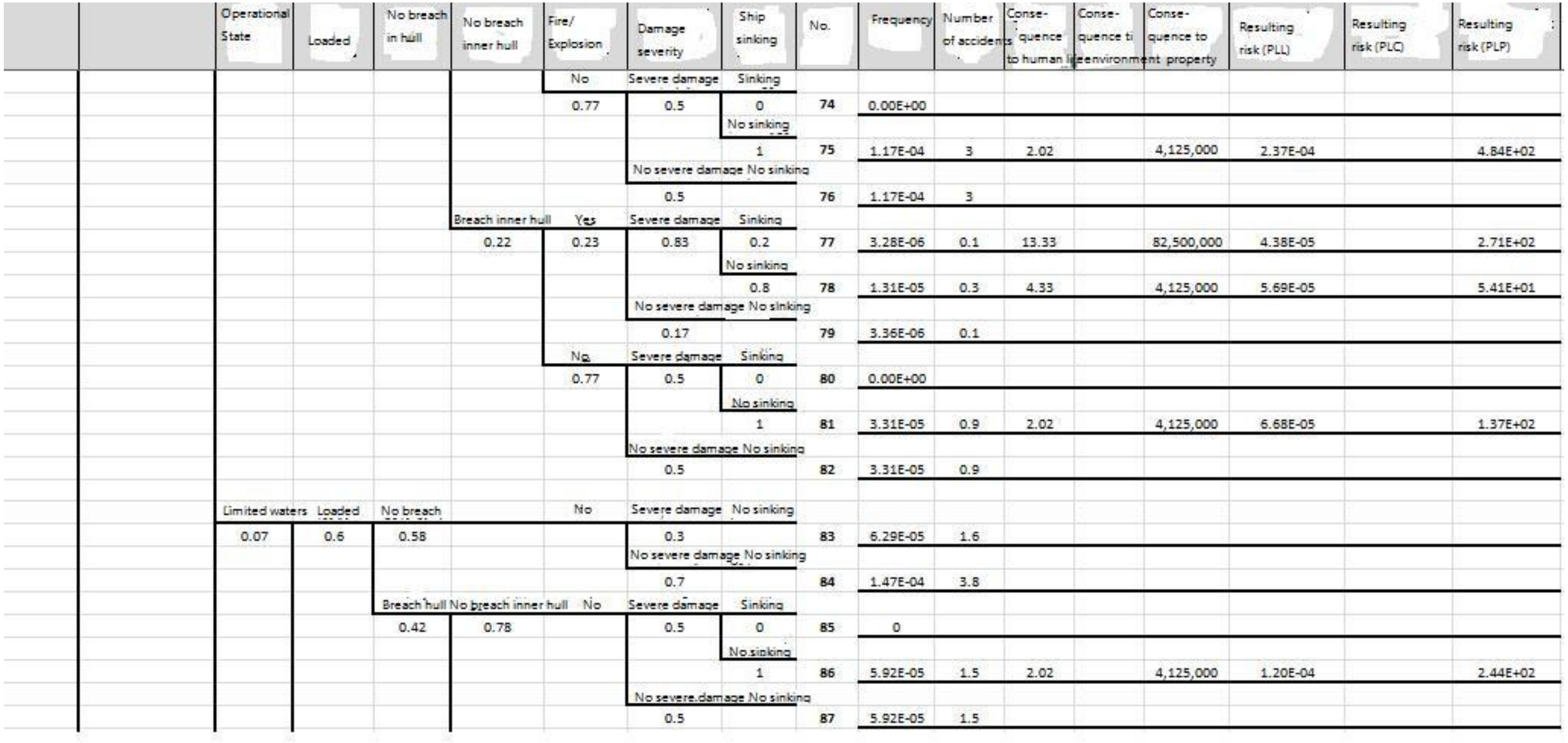


Operational State	Loaded	No breach in hull	No breach inner hull	Fire/ Explosion	Damage severity	Ship sinking	No.	Frequency	Number of accidents	Conse-quence to human life	Conse-quence to environment	Conse-quence to property	Resulting risk (PLL)	Resulting risk (PLC)	Resulting risk (PLP)
						No sinking									
						0.95	30	2.67E-04	6.9	2.02		4,125,000	5.40E-04		1.10E+03
					No severe damage	No sinking									
					0.41		31	1.95E-04	5						
			Breach inner hull	Yes	Severe damage	Sinking									
			0.22	0.06	1	0.5	32	4.29E-06	0.1	13.33	152191	82,500,000	5.72E-05	6.53E-01	3.54E+02
						No sinking									
						0.5	33	4.29E-06	0.1	4.33	10726	4,125,000	1.86E-05	4.60E-02	1.77E+01
				No	Severe damage	Sinking									
				0.94	0.59	0.05	34	3.97E-06	0.1	2.02	152191	82,500,000	8.01E-06	6.04E-01	3.27E+02
						No sinking									
						0.95	35	7.54E-05	1.9	2.02	10726	4,125,000	1.52E-04	8.09E-01	3.11E+02
					No severe damage	No sinking									
					0.41		36	5.51E-05	1.4		184.6			1.02E-02	
	Ballast	No breach		No	Severe damage	No sinking									
	0.4	0.64			0.03		37	2.31E-05	0.6						
					No severe damage	No sinking									
					0.97		38	7.48E-04	19.3						
		Breach hull	No breach inner hull	Yes	Severe damage	Sinking									
		0.36	0.78	0.06	1	0.5	39	1.01E-05	0.3	13.33		82,500,000	1.35E-04		8.37E+02
						No sinking									
						0.5	40	1.01E-05	0.3	4.33		4,125,000	4.40E-05		4.18E+01
				No	Severe damage	Sinking									
				0.94	0.59	0	41	9.38E-06	0.2	2.02		82,500,000	1.89E-05		7.74E+02
						No sinking									
						1	42	1.78E-04	4.6	2.02		4,125,000	3.06E-04		7.35E+02
					No severe damage	No sinking									
					0.41		43	1.30E-04	3.4						
			Breach inner hull	Yes	Severe damage	Sinking									
			0.22	0.06	1	0.5	44	2.86E-06	0.1	13.33		82,500,000	3.82E-05		2.36E+02

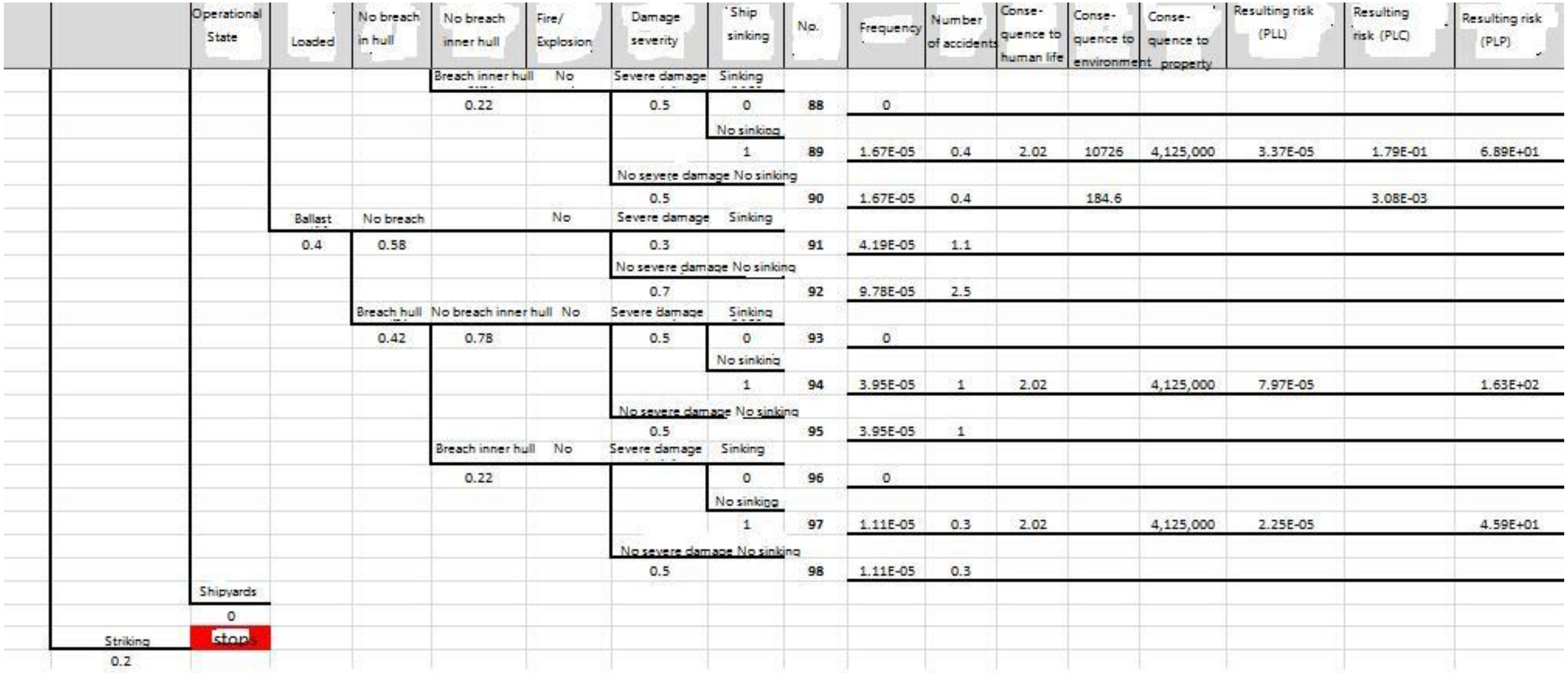


		Operational State	Loaded	No breach in hull	No breach inner hull	Fire/ Explosion	Damage severity	Ship sinking	No.	Frequency	Number of accidents	Conse-quence to human life	Conse-quence to environment	Conse-quence to property	Resulting risk (PLL)	Resulting risk (PLC)	Resulting risk (PLP)
								No sinking									
								0.5	45	2.86E-06	0.1	4.33		4,125,000	1.24E-05		1.18E+01
						No	Severe damage	Sinking									
						0.94	0.59	0.05	46	2.64E-06	0.1	2.02		82,500,000	5.34E-06		2.18E+02
								No sinking									
								0.95	47	5.03E-05	1.3	2.02		4,125,000	1.02E-04		2.07E+02
							No severe damage	No sinking									
							0.41		48	3.68E-05	0.9						
		Open sea	Loaded	No breach		Yes	Severe damage	Sinking									
		0.28	0.6	0.54		0.03	1	0	49	0.00E+00							
								No sinking									
								1	50	2.06E-05	0.5						
						No	Severe damage	Sinking									
						0.97	0. 1	0	51	0							
								No sinking									
								1	52	6.67E-05	1.7						
							No severe damage	No sinking									
							0. 9		53	6.01E-04	15.5						
				Breach hull	No breach iner hull	Yes	Severe damage	Sinking									
				0.46	0.78	0.23	0.83	0.2	54	1.75E-05	0.4	13.33	152191	82,500,000	2.33E-04	2.66E+00	1.44E+03
								No sinking									
								0.8	55	6.98E-05	1.8	4.33		4,125,000	3.03E-04		2.88E+02
							No severe damage	No sinking									
							0.17		56	1.79E-05	0.5						
						No	Severe damage	Sinking									
						0.77	0.5	0	57	0.00E+00							
								No sinking									
								1	58	1.76E-04	4.5	2.02		4,125,000	3.56E-04		7.26E+02

Operational State	Loaded	No breach in hull	No breach inner hull	Fire/ Explosion	Damage severity	Ship sinking	No.	Frequency	Number of accidents	Conse-quence to human life	Conse-quence to environment	Conse-quence to property	Resulting risk (PLL)	Resulting risk (PLC)	Resulting risk (PLP)
					No severe damage	No sinking									
					0.5		59	1.76E-04	4.5						
			Breach inner hull	Yes	Severe damage	Sinking									
			0.22	0.23	0.83	0.2	60	4.92E-06	0.1	13.33	152191	82,500,000	6.56E-05	7.49E-01	4.06E+02
						No sinking									
						0.8	61	1.97E-05	0.5	4.33	10726	4,125,000	8.53E-05	2.11E-01	8.12E+01
					No severe damage	No sinking									
					0.17		62	5.04E-06	0.1		184.6			9.31E-04	
				No	Severe damage	Sinking									
				0.77	0.5	0	63	0.00E+00							
						No sinking									
						1	64	4.96E-05	1.3	2.02	10726	4,125,000	1.00E-04	5.32E-01	2.05E+02
					No severe damage	No.sinking									
					0.5		65	4.96E-05	1.3		184.6			9.17E-03	
	Ballast	No breach		Yes	Severe damage	Sinking									
	0.4	0.54		0.03	1	0	66	0.00E+00							
						No sinking									
						1	67	1.38E-05	0.4						
				No	Severe damage	Sinking									
				0.97	0.1	0	68	0.00E+00							
						No sinking									
						1	69	4.45E-05	1.1						
					No severe damage	No sinking									
					0.9		70	4.00E-04	10.3						
		Breach hull	No breach inner hull	Yes	Severe damage	Sinking									
		0.46	0.78	0.23	0.83	0.2	71	1.16E-05	0.3	13.33		82,500,000	1.55E-04		9.60E+02
						No sinking									
						0.8	72	4.65E-05	1.2	4.33		4,125,000	2.02E-04		1.92E+02
					No severe damage	No sinking									
					0.17		73	1.19E-05	0.3						



Operational State	Loaded	No breach in hull	No breach inner hull	Fire/ Explosion	Damage severity	Ship sinking	No.	Frequency	Number of accidents	Conse-quence to human li	Conse-quence ti eenvironment	Conse-quence to property	Resulting risk (PLL)	Resulting risk (PLC)	Resulting risk (PLP)
				No	Severe damage	Sinking									
				0.77	0.5	0	74	0.00E+00							
						No sinking									
						1	75	1.17E-04	3	2.02		4,125,000	2.37E-04		4.84E+02
					No severe damage	No sinking									
					0.5		76	1.17E-04	3						
			Breach inner hull	Yes	Severe damage	Sinking									
			0.22	0.23	0.83	0.2	77	3.28E-06	0.1	13.33		82,500,000	4.38E-05		2.71E+02
						No sinking									
						0.8	78	1.31E-05	0.3	4.33		4,125,000	5.69E-05		5.41E+01
					No severe damage	No sinking									
					0.17		79	3.36E-06	0.1						
				No	Severe damage	Sinking									
				0.77	0.5	0	80	0.00E+00							
						No sinking									
						1	81	3.31E-05	0.9	2.02		4,125,000	6.68E-05		1.37E+02
					No severe damage	No sinking									
					0.5		82	3.31E-05	0.9						
Limited waters	Loaded	No breach		No	Severe damage	No sinking									
0.07	0.6	0.58			0.3		83	6.29E-05	1.6						
					No severe damage	No sinking									
					0.7		84	1.47E-04	3.8						
		Breach hull	No breach inner hull	No	Severe damage	Sinking									
		0.42	0.78		0.5	0	85	0							
						No sinking									
						1	86	5.92E-05	1.5	2.02		4,125,000	1.20E-04		2.44E+02
					No severe.damage	No sinking									
					0.5		87	5.92E-05	1.5						



		Operational State	Loaded	No breach in hull	No breach inner hull	Fire/ Explosion	Damage severity	Ship sinking	No.	Frequency	Number of accidents	Conse-quence to human life	Conse-quence to environment	Conse-quence to property	Resulting risk (PLL)	Resulting risk (PLC)	Resulting risk (PLP)
					Breach inner hull	No	Severe damage	Sinking									
					0.22		0.5	0	**88**	0							
								No sinking									
								1	**89**	1.67E-05	0.4	2.02	10726	4,125,000	3.37E-05	1.79E-01	6.89E+01
							No severe damage	No sinking									
							0.5		**90**	1.67E-05	0.4		184.6			3.08E-03	
			Ballast	No breach		No	Severe damage	Sinking									
			0.4	0.58			0.3		**91**	4.19E-05	1.1						
							No severe damage	No sinking									
							0.7		**92**	9.78E-05	2.5						
				Breach hull	No breach inner hull	No	Severe damage	Sinking									
				0.42	0.78		0.5	0	**93**	0							
								No sinking									
								1	**94**	3.95E-05	1	2.02		4,125,000	7.97E-05		1.63E+02
							No severe damage	No sinking									
							0.5		**95**	3.95E-05	1						
					Breach inner hull	No	Severe damage	Sinking									
					0.22			0	**96**	0							
								No sinking									
								1	**97**	1.11E-05	0.3	2.02		4,125,000	2.25E-05		4.59E+01
							No severe damage	No sinking									
							0.5		**98**	1.11E-05	0.3						
		Shipyards															
		0															
	Striking	stops															
	0.2																

Appendix 7　BASIC GLOSSARY OF TERMS OF FSA

1　General

The glossary of terms gives basic terms related to FSA, which facilitates the understanding of basic issues of FSA by professionals. Users may further consult relevant literatures and treatises.

2　Terms

(1) **Accident**: an unintended event involving fatality, injury, ship loss or damage, other property loss or damage, or environmental damage.

(2) **Accident category**: a designation of accidents according to their nature, e.g. fire, collision, grounding, etc.

Collision: striking or being struck by another ship, regardless of whether under way, anchored or moored (this category does not include striking underwater wrecks).

Grounding: being aground or hitting/touching shore or sea bottom or underwater objects (wrecks, etc.).

Contact: striking any fixed or floating object other than those included under "Collision" or "Grounding".

Fire/explosion: accidents where fire or explosion is the initial event.

Loss: ship whose fate is undetermined with no information having being received of conditions and whereabouts after a reasonable period of time.

Machinery: Accident due to mechanical failure.

Loss of structural integrity: structural failure that can result in the ingress of water and/or loss of strength and/or stability.

Flooding: the ingress of water that can result in foundering or sinking of the ship.

Foundering: sinking as a result of heavy weather, springing of leaks, breaking into two, etc.)

Other conditions: accidents not included in the above conditions.

(3) **ALARP** (As Low As Reasonably Practicable) region: a risk region between the negligible line and intolerable line, within which the risk should be reduced by applying reasonably practicable approaches insofar as practicable. The cost benefit analysis may be generally used to judge the rationality of risk control options.

(4) **Availability**: capability of an item to complete the required function in an instant or during a period of time as required.

(5) **Brainstorming**: human thinking is motivated through discussion or debate in order to draw upon all useful opinions. It is used to identify possible solutions to problems and potential opportunities for improvement. Brainstorming is a technique for tapping the creative thinking of a team to generate and clarify a list of ideas, problems and issues. In applying brainstorming, two phases are involved:

① the generation phase (diverging phase)
the facilitator reviews the guidelines for brainstorming and the purpose of the brainstorming session, then the team members generate the list of ideas. The objective is to generate as many ideas as possible.

② the clarification phase (converging phase)
the team reviews the list of ideas to make sure that everyone understands all ideas. The

evaluation of ideas will occur when the brainstorming session is completed.
Guidelines for brainstorming include:
the facilitator is identifiable;
the purpose of the brainstorming is clearly defined;
each team member put forward ideas in turn;
team members should consider ideas of other people if possible;
each idea is not commented nor discussed at this phase;
the process is continued until no more ideas are generated; and
all ideas should be reviewed for clarification purpose.

(6) **Casualty**: damage to the life of person, health or environment.

(7) **Checklist Analysis**: a systematic assessment of possible hazards by using one or several checklists.

(8) **Consequence**: the outcome of an accident.

An example showing the degree of safety qualitatively is the International Code of Safety for High-Speed Craft (HSC Code).

Minor: caused by a failure, an event, or an error, which can be readily compensated for by the operating crew.

Significant: a consequence which produces:

a significant increase in the operational duties of the crew or in their difficulty in performing their duties which by itself shall not be outside the capability of a competent crew provided that another major effect does not occur at the same time; or

significant degradation in handling characteristics; or

significant modification of the permissible operating conditions, but will not remove the capability to complete a safe journey without demanding more than normal skill on the part of the operating crew.

Severe: a consequence which produces:

a dangerous increase in the operational duties of the crew or in their difficulty in performing their duties of such magnitude that they cannot reasonably be expected to cope with them and will probably require outside assistance; or

dangerous degradation of handling characteristics; or

dangerous degradation of the strength of the craft; or

marginal conditions for, or injury to, occupants; or

an essential need for outside rescue operations.

Catastrophic: a consequence which results in the loss of the craft and/or in fatalities.

An example of qualitative analysis result is as follows:

In terms of safety (an example):
Minor: single or minor injuries;
Significant: multiple injuries;
Severe: single or a small amount of fatalities, e.g. less than 10;
Catastrophic: multiple fatalities at the same time, e.g. more than 10.

In terms of environmental pollution (an example):
Minor: discharge of domestic wastes, e.g. food or untreated sewage, or leakage of a small amount of oil or oily mixture;
Significant: leakage of oil, oily mixture or chemicals midway;
Severe: leakage of a large amount of oil, oily mixture or chemicals, e.g. partial discharge of an oil

tank of large volume leads to damage over a long period;

Catastrophic: leakage of most oil, oily mixture or chemicals, e.g. total discharge of an oil tank of large volume leads to significant damage over a long period.

In terms of business loss (an example):

Minor: minor damage with loss of 100,000 RMB or less;

Significant: damage requiring shore support or repair, with loss of approximately 1 million RMB;

Severe: damage requiring towing assistance or dry docking or a long period of repair, with loss of approximately 10 million RMB;

Catastrophic: loss of all property, e.g. loss of ship including structural damage or damage equaling to approximately 100 million RMB or more.

(9) **Cost Benefit Analysis**: rational and systematic framework for evaluating, in a directly comparable monetary unit of measurement, advantages and disadvantages of alternative risk control options (RCOs).

(10) **Error**: a departure from acceptable or desirable operation (for example of a component or system) that can result in unacceptable or undesirable consequence.

(11) **Event Tree Analysis (ETA)**: A method of exploring the development or escalation of an accident, a failure or an unwanted event using a diagram which, commencing with the initiating event, branches at each point of influence of a controlling or mitigating measure until the final outcomes are identified. The probability (or frequency) of success of these measures is indicated allowing for the evaluation of the likelihood of each consequence.

(12) **Failure**: an occurrence in which a part, or parts of a system ceases to perform the required function.

(13) **Failure Mode & Effect Analysis (FMEA)**: a process for hazard identification where all conceivable failure modes of components or features of a system are considered in turn and undesired outcomes are noted.

(14) **Failure Mode Effect and Criticality Analysis (FMECA)**: an FMEA where additionally the criticality of a failure mode or failure cause is assessed by estimating the severity and probability of the failure. Severity and probability are each expressed as ranking indices. Criticality is the combination of ranking indices (their output results and sum depend on the mode).

(15) **Fault Tree Analysis (FTA)**: Fault Tree Analysis (FTA) is a logic diagram showing the causal relationships between events, which singly or in combination result in the occurrence of a higher-level event. It is used to determine the frequency of a “top event” which may be a type of accident or an unintended hazardous outcome.

(16) **Formal Safety Assessment (FSA)**: a formal, structured and systematic methodology, currently developed to assist and rationalize rule-making processes and to facilitate proactive risk control.

(17) **FSA application personnel**: professionals with certain qualification and relevant experience, whose field of expertise and experience should be commensurate with the range and nature related to the problem being analyzed when FSA is applied. Such professionals can be rules or engineering technical personnel, ship or engineering design personnel, management personnel or surveyors.

(18) **Frequency**: the number of occurrences per unit time (e.g. per year).

The International Code of Safety for High-Speed Craft – example of ranking of frequency in the HSC Code:

Frequent is one which is likely to occur often during the operational life of a particular craft.

Reasonably probable is one which is unlikely to occur often but which may occur several times during the total operational life of a particular craft.

Remote is one which is unlikely to occur to every craft but may occur to a few craft of a type over the total operational life of a number of craft of the same type.

Extremely remote is one which is unlikely to occur when considering the total operational life of a number of craft of the type, but nevertheless shall be considered as being possible.

Extremely improbable is one which is so extremely remote that it shall not be considered as possible to occur.

(19) **Function**: an aspect of the intended purpose/task of a system.

(20) **Generalized Functional Model**: a description of the overall system including human elements same to the project under consideration and explanation of common features, characters and properties of the problem under consideration, e.g. all ships of certain type engaged in international trade or all system affected by a specific hazard etc.

(21) **Hazard**: a potential to threaten human life, health, property or the environment.

(22) **Hazardous situation**: a situation with a potential to threaten human life, health, property or the environment.

(23) **Hazard and Operability Study (HAZOP)**: A study performed by application of guidewords to identify the deviations from the intended functions of a system which have undesirable causes and effects for safety and operability.

(24) **Hazard Identification (HAZID)**: a process of identifying, confirming and describing hazards.

(25) **Human Error**: a departure from acceptable or desirable practice on the part of the individual or group of individuals that can result in unacceptable or undesirable risks.

(26) **Human Element**: human element involves reasonable relationship between human and organizational factors while the latter will affect the safety and design, construction, maintenance and operation of navigational system.

(27) **Human Factor**: this discipline includes human science and industrial engineering, which also involves techniques optimizing the relationship between people and their working behavior and environment.

(28) **Human Reliability Assessment (HRA)**: such assessment involves qualitative and/or quantitative methods which are used to determine the likelihood and potential consequence of mistakes made by special operating personnel when they perform special tasks.

An example of applying HRA technique is as follows:

Task analysis: a term related to various special techniques for collection of task information which is applied globally. Judgement and design decision can be made through organization and utilization.

Human error and human reliability assessment: a qualitative and quantitative assessment of risks contributed by human elements. Qualitative study includes identification of potential human error and its consequence as well as other human factors (e.g. simulation of human behaviors in emergency and providing input for escape, evacuation and rescue analysis). The quantification of the likelihood of human errors is achieved by making use of relevant human reliability data (if any) and applying comprehensive HRA technique.

(29) **Incident**: an unforeseen or unexpected event which may have the potential to become an accident but in which injury to personnel and/or damage to ship or to the environment does not materialize or remained minor.

(30) **Initiating event**: the first of a sequence of events leading to a hazardous situation or accident.

(31) **Potential Loss of Life (PLL)**: a simple measure of Societal Risk is the PLL which is defined as the expected value of the number of fatalities per year, having taking into consideration the overall risk of all potential accidents.

(32) **Probability (Objective/frequentistic)**: the relative frequency that an event will occur, as expressed by the ratio of the number of occurrences to the total number of possible occurrences.

(33) **Probability (Subjective/Bayesian)**: the degree of confidence in the occurrence of an event, measured on a scale from zero to one. An event with a probability of zero means that it is believed to be impossible; an event with the probability of 1 means that it is believed it will certainly occur.

(34) **Risk**: the combination of the frequency and the severity of the consequence. (This can be either a quantitative or qualitative measure.)

(35) **Risk contribution tree**: the combination of all fault trees and event trees that constitute the risk model, which may be used as a mechanism for displaying diagrammatically the distribution of risk amongst different accident categories and sub-categories.

(36) **Risk Control Measure (RCM)**: a means of controlling a single element or risk; typically, risk control is achieved by reducing either the consequences or the frequencies; sometimes it could be a combination of the two.

(37) **Risk Control Option (RCO)**: an appropriate combination of risk control measures.

(38) **Risk evaluation criteria**: criteria used to evaluate the acceptability/tolerability of risk.

(39) **Risk Matrix**: a matrix formed by the probability and corresponding consequence of all hazards, which is used to rank hazards.

(40) **Risk Tolerance**: the overall risk level which is tolerable within a specified period or at a certain behavioral phase, which provides basis for risk analysis and development of risk control measures.

(41) **Sensitivity Analysis**: study of how the uncertainty in the output of a model (numerical or otherwise) can be apportioned to different sources of uncertainty in the model input. This analysis aims to identify the variables whose uncertainty significantly influences the uncertainty of the result.

(42) **Uncertainty analysis**: investigation of the uncertainty(ies) of variables that are used in decision-making problems in which observations and models represent the knowledge base. In other words, uncertainty analysis aims to make a technical contribution to decision-making through the quantification of uncertainties in the relevant variables and results.

(43) **What-if Analysis**: an approach in which a group of experts identify hazards and their consequences, safeguards and possible risk reduction measures related to a function or system based on answering questions that begin with "What if...".