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Risk-based approach to maritime safety

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RISK-BASED APPROACH TO MARITIME SAFETY

By

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DECLARATION

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

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

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ABSTRACT

Title of Dissertation: **Risk-based Approach to Maritime Safety**

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This dissertation is a methodological study of the risk-based approach to safety and its application to maritime industry.

The concept of safety and risk is defined and discussed as well as their relationships. The traditional approach to safety is examined including its limitations, the advantages and necessity of the risk-based approach to safety is identified. The general procedure of the risk-based approach is presented, and the major limitation: the uncertainty associated with the risk-based approach is analysed.

Various techniques of risk-based approach are presented and investigated with regard to their advantages and disadvantages, and a comprehensive examination of the characteristics of these techniques is made for the purpose of paving the way for choosing appropriate techniques in the application to maritime safety.

The characteristics of maritime industry are investigated as well as their implications to the application. Two methodological issues in the practical application, adaptation of the general procedure and selection of suitable techniques, are examined. In order to show how the risk-based approach will be applied to maritime safety in depth, a model case of risk assessment of a generic ship is presented, which illustrates how a combination of techniques should be applied in practice. An ideal scheme of application is presented in order to show at macro level how the risk-based approach may be applied to the maritime industry.

The current situation is examined and the future development of the risk-based approach in maritime safety is discussed. Several major recommendations are made concerning the future promotion of the risk-based approach.

KEYWORDS: Maritime, Safety, Risk, Approach, Assessment

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LIST OF ABBREVIATIONS

APJ	Absolute Probability Judgement
CAF	Cost of Averting a Fatality
CBA	Cost Benefit Analysis
CEA	Cost Effectiveness Analysis
COLREG	Convention on the International Regulations for Preventing Collisions at Sea, 1972
CURR	Cost of Unit Risk Reduction
DNV	Det Norske Veritas
DOE	Department of Energy
EPC	Error Producing Conditions
ETA	Event Tree Analysis
FMEA	Failure Mode and Effect Analysis
FMECA	Failure Mode and Effect Criticality Analysis
FSA	Formal Safety Assessment
FTA	Fault Tree Analysis
HAZOP	Hazard and Operability Analysis
HEART	Human Error Assessment and Reduction Technique
HEP	Human Error Probability
HRA	Human Reliability Analysis
HSE	Health Safety Executive
IACS	International Association of Classification Societies
ICAF	Implied Cost of Averting a Fatality
IMO	International Maritime Organization
IMSRS	International Maine Safety Rating System
ISM Code	International Safety Management Code
MORTA	Management Oversight and Risk Tree Analysis
MSC	Maritime Safety Committee
NEA	Nuclear Energy Agency
NHEP	Nominal Error Probability
PC	Paired Comparison
PET	Project Evaluation Tree
PHA	Preliminary Hazard Analysis
PSF	Performance Shaping Factor
RCM	Risk-Centered-Maintenance
SLI	Success Likelihood Index
SLIM-MAUD	Success Likelihood Index Method Using Multi Attribute Utility Decomposition
SMORT	Safety Management Organization Review Technique
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978
THERP	Technique for Human Error Rate Prediction
USCG	United States Coast Guard

CHAPTER 1

Introduction

1.1. Background

Shipping is an old industry and from the very beginning safety has been major concern of this industry. Throughout history people have been continuously exploring new techniques to improving efficiency of shipping industry as well as safety performance in order to meet the intense competition and growing demand for safety from the society. Nowadays a whole set of approaches to safety have been developed through accumulation of hard work of safety practitioners over the years, and such traditional approaches have contributed greatly to maritime safety and marine environmental protection. However drawbacks more easily draw the attention of the society. The traditional approach is blamed as “passive” instead of “active”, and the maritime industry is blamed as “slow to change” to improve its safety performance. The only chance of change seems to be the occurrence of catastrophic accidents. Nevertheless society expects actions to be taken before the occurrence of such accidents and prevent the occurrence of them. Facing such growing pressure for a more effective safety approach, the so-called “risk-based approach” to safety was introduced under intense discussion and debate as a defence against such criticism.

1.2. Purpose and incentive

The risk-based approach originated from the nuclear industry, but later saw wider application in other sectors like chemistry, aviation, offshore and proved to be effective and efficient in enhancing safety performance. The application of the risk-based approach to maritime safety is still at the initial stage of development, to most of the people in the maritime industry except those risk experts and analysts, the knowledge of the risk-based approach is quite new and remote. Some people could not accept the idea of this approach, one reason might be the lack of understanding; some people simply stay away from it and do not go into this area because, they think, this approach is so difficult and complicated a subject that it is only for experts, not for them. Even people, who want to explore this approach, have difficulty in finding suitable materials or guidance to start with, because the information and materials on this approach are scattered in many areas. It is very difficult to find a comprehensive material that systematically introduces and discusses the risk-based approach to maritime safety. Knowledge therefore becomes a major obstacle for the promotion of the application of the risk-based approach to maritime safety. The purpose of this dissertation is to help alleviate this problem by providing a systematic discussion of the risk-based approach from the basic concept, procedure and various techniques, to the application of it to maritime safety. In fact, this dissertation aims to construct a comprehensive framework or picture of the risk-based approach to maritime safety, which is very necessary and important for people to understand, especially at the initial stage of development. Therefore this dissertation can as well serve as a guideline on the risk-based approach to maritime safety at a broad level.

1.3. Objectives

The main objectives of this dissertation are the following:

- Define the concept of safety and risk as well as their relationship
- Identify the necessity of the risk-based approach to safety
- Summarize the general procedure of the risk-based approach and analyse the uncertainty associated with it
- Examine the advantages and disadvantages of various techniques of the risk-based approach
- Identify the characteristics of maritime industry and their implications to the application of the risk-based approach

- Examine the practical procedure of the application and the principles of choosing suitable techniques
- Present a model case of risk assessment of a generic ship, and an ideal scheme of the application of the risk-based approach to the maritime industry at macro level

1.4. Methodology and limitations

Literature research is the major method of research of this dissertation. Various resources are utilized, such as WMU library and its partner libraries, Internet resources, materials collected from IMO, UK Maritime Coast Guard Agency (MCA) during field trips, materials from Lund University, and so on. Resources from non-maritime industries are widely used for the research on the general methodology. As previously mentioned, materials on the risk-based approach is widely scattered, and since the application of the risk-based approach to maritime safety is only at the initial stage, relevant materials, especially those with maritime background, are very difficult to be located, therefore the process of material collection is quite tough and time consuming.

This research is a study focusing on the methodology at a broad level. It is constrained by the nature of the topic and therefore not allowed to go into details of certain specific methods, which is the limitation of this research. Another limitation comes from the author's background, also because the application of the risk-based approach is at the initial stage, only a few experts have certain practical experiences, most of people, including the author, do not have such experiences. The author tries to compensate for this limitation by more extended literature research on practical cases of application and the record of expert discussions.

CHAPTER 2

Risk-based approach to safety

As the basis of this dissertation, this chapter will introduce and discuss the basic concepts of safety and risk as well as their relationship. The traditional approach to safety and the present situation of maritime safety will be examined, and then the risk-based approach will be introduced and examined with the aim of identifying its advantages and necessity to maritime safety.

2.1. Safety and risk

2.1.1. The interpretation of safety

Safety is a popular topic that is deeply concerned by the whole human world. The term safety is discussed widespread under different contexts, from different perspectives; accordingly, it has various interpretations. Therefore, before going further to the relation between safety and risk, it is essential to examine the meaning of the term "safety" and have an accurate understanding of safety.

Typical examples of the general definition of safety are:
"Freedom from danger" (Concise Oxford Dictionary, 20), and
"freedom from unacceptable risks/personal harm" (Kuo, 1998 attributed to Fido and Wood, 1989).

These different definitions share some common grounds, which can be regarded as generally accepted attributes of safety:

1. Safety is always used in contrast with such negative words as danger, harm, hazard, and so on. In other words, safety is expressed by means of these words; it is not possible to discuss safety without mentioning these negative words.
2. There is no complete freedom from danger, which implies that absolute safety is not available and there is always room for improvement.

There are some other definitions that go into certain details and are specific to industrial activities. Mr. Kuo C. (1998) proposed the following definition of safety:

> **Safety is perceived quality that determines to what extent the management, engineering and operation of a system is free of danger to life, property and the environment.**

Kuo (1998) also uses this definition to identify the basic aspects of safety and address the interrelationship between them under the context of industrial activities. Following is a discussion of Kuo's nomenclature reinforced with this author's viewpoint:

- System: safety cannot be discussed without referring to any concrete system. The discussion of safety is always centered on some specific system, such as a ship, a component of a ship, or the process of an operation. For example, ship safety, nuclear safety.
- Quality: quality is an abstract word, here it can be interpreted as attribute, characteristic. To the author's understanding safety is one of the attributes, characteristics of the system subjected to a specified circumstance at a specific time.
- Extent: extent implies the idea that there is no complete safety, 100% safety does not exist.
- Danger to life, property and environment: Under the context of industrial activities life, property and environment are the main victims of negative events happened to the system, for example, fire, explosion; therefore the aim of carrying out safety activities is to protect life, property and environment, and reduce the damage, harm to life, property and environment.

Accordingly the degree of the damage, harm to life, property and environment is taken as the indicator of safety performance.

- Management, engineering, and operation of the system: It is obvious that the safety performance of the system is determined by the internal factors within the system and the external factors from the circumstance where the system is situated. There are many factors within the system that directly or indirectly affect the safety performance of it. According to their specific ways of affecting safety these factors can be grouped into three main categories: management, engineering and operation. Although management, engineering and operation affect the system's safety performance from different perspectives and angles, they are functioning interactively rather than independently. The interaction among them plays an equally important role to the safety performance of the system. It is not difficult to observe the possible performance of an incorrect operation of a carefully designed system, and the difficulty to operate a poorly designed system. Also a high standard performance of operation will never be expected under poor management. It is virtually not possible to improve safety performance to a satisfactory level by solely working on any one of these factors. Therefore, for the purpose of enhancement of safety efforts shall not be directed at management, engineering and operation separately and independently, instead, attention should be paid to the mechanism that management, engineering and operation interact with each other, and a balanced approach should be adopted to improve management, engineering and operation together.
- **Determine**: since the word "quality" in the definition is abstract, it is difficult to grasp its meaning and evaluate it directly. However the abstract "quality" can be reflected and indicated by certain concrete parameters or specifications. In this term of safety, the "quality" is **determined** by the management, engineering and operation of the system and its external circumstance, and **reflected** by the extent to which the system is free from danger. Therefore, in order to avoid confusion and misunderstanding it is better to replace the word "determines" with "is reflected".

- Perceived: “perceived” is a critical word in the definition and it implies the “subjectivity” of the term - safety, which means that safety is the personal perception of the actual situation depending on people’s background, experience, knowledge, skill, personality, and so on. Towards the same situation individuals could have different perception of the safety level of the same system. Now we are facing such questions as: whose perception is the correct reflection of the actual situation? All of them are correct or none of them is correct? What is the real level of safety, or dose the real level of safety exist? If it does exist, is it within the capability of human beings to know that?

To understand these questions and go further on to look for the answers to them, it is necessary to examine the way that human beings interact with the world. By means of “sense organs” like eyes, ears, fingers, human beings interact with the world. For example, when you touch the surface of the table with your fingers, you may have the judgment that “the surface of the table is smooth”. While in fact this judgment is just your personal perception, not necessarily the real situation of the table. To be accurate, you should say, ”I feel that the surface of the table is smooth”. By perceiving the world human beings learn about the outside world and accumulate knowledge about the world. Such information and knowledge about the world perceived by human beings becomes the basis which human beings fully rely on to make decisions and to explore the world. Due to the limitation of human beings there is always a difference to a certain degree between the actual situation and human’s perception of it, therefore it would be better to have everything, every judgment based on the actual situation, however, the problem is that how do human beings know that? To work according to the perception is the only way available for human beings to interact with world although it is not perfect. Fortunately, the human society does not require anything to be perfect, to work according to the perception is able to satisfy the needs of human beings to a considerable degree, and the continuous development of the human society is strong evidence that it is an acceptable and suitable way for human beings.

Safety is a typical example of the human beings' perception of the actual world. Each individual has its own sufficient reasons for his or her perception of safety. What safety practitioners should do is not to judge whose perception is right or wrong, instead, they should take into account the perceptions of all people concerned and consider them holistically. Therefore the purpose of safety activities is to enhance safety to a level that is based on the perception of all people concerned as a whole, and the effort shall be directed at enhancing the perceived safety level accordingly.

Based on the above discussion on the basic aspects of safety, especially about the word "determine", and in order to show the relevance of safety to system, circumstance and time, the author would like to propose the following definition of safety:

Safety is the perceived quality of a system under certain circumstance at a specific time, which is reflected by the extent to which the management, engineering and operation of a system is free of danger to life, property and the environment.

2.1.2. The interpretation of risk

Risk is not a new word to everybody and its meaning seems to be very obvious. While in fact not everybody is able to interpret it in a correct and accurate way, sometimes it is regarded as the synonym of "hazard", sometimes it is interpreted as "chance or probability". In the "Interim Guidelines for the Application of Formal Safety Assessment (FSA) to the IMO Rule-making Process", the International Maritime Organization defines risk as **"the combination of the frequency and the severity of the consequence"**(IMO, 1997). Sir Frederick Warner proposes a similar definition with some further elaboration: **"Risk is a combination of the probability, or frequency, of occurrence of a defined hazard and the magnitude of the consequences of the occurrence"** (Warner, 1992).

These definitions interpret the concept of risk concisely and precisely. In order to have a deep and accurate understanding of risk, it is essential to examine the meaning of those terms which are either contained in the definition of risk or closely related with risk, such as hazard, accident, frequency, consequence and so on. In the “Interim Guidelines for the Application of Formal Safety Assessment (FSA) to the IMO Rule-making Process” the definitions of such terms are provided in the context of the maritime industry: (IMO, 1997)

Hazard - a potential to threaten human life, health, property or the environment.

Accident - an unintended event involving fatality, injury, ship loss or damage, other property loss or damage, or environmental damage.

Consequence - the outcome of an accident.

Frequency - the number of occurrences per unit time (e.g. per year).

Initiating event - the first of a sequence of events leading to a hazardous situation or accident.

In IMO Maritime Safety Committee meeting document “Formal safety assessment: basic glossary of terms”, which was submitted by the International Association of Classification Societies, further definitions are provided:

Hazardous situation - a physical situation with a potential to threaten human life, health, property or the environment.

Incident - an unforeseen or unexpected event which has the potential to become an accident but in which injury to personnel and/or damage to ship or the environment does not materialize; a ”near miss”.

The relation between these terms is critical for the understanding of risk and can be exemplified by an accident taken from the casualty investigation report “Safety Digest” (3/2000) published by Maritime Accident Investigation Branch (MAIB), Great Britain:

> **Another Leak + Heat = Fire**
>
> The Luxembourg registered high-speed craft Diamant suffered an engine room fire while on passage from Ostend to Dover during August 1998. The fire was quickly extinguished using the drencher system. Securing bolts on a main engine high-pressure fuel pump were found to have fractured. This allowed the pump to move, disturbing pipework, and resulting in fuel impinging on a hot surface, most probably an indicator cock.

This is a typical case of engine room fire caused by leaking fuel. In this case the hot surface is a hazard. The hazard is something in the system concerned that has just a potential threat and does not necessarily evolve into accident unless certain conditions are met. The hot surface itself cannot initiate a fire unless it meets fuel and its temperature is high enough. The fracture of securing bolts is the initiating event, which consequently allowed the pump to move, the moving pump disturbed the pipework, and then fuel leakage on the hot surface caused fire. The fire is the accident that is unintended and involves certain damage to the equipment in the engine room. The damage, which is the outcome of the accident, is the consequence. Suppose in the routine check the engineer noticed the fuel leakage, which is a hazardous situation, and took remedial actions in time before the fire developed, this accident would not happen and it would be called an incident, or "near miss". In the sequence starting from the initiating event (fracture of bolts) to the accident (fire), since there is always the chance or probability to prevent the accident, the happening of the accident (fire) would not be 100%. There is a probability for it, which can also be indicated by the frequency. In this case the combination of the frequency of the fire and the severity of the damage caused by the fire is the risk under this specific situation and related with this specific hazard of the "hot surface". If the situation of the system changed, the frequency and the severity of the accident will change, accordingly the risk will change. If under the same situation, another hazard is considered, everything concerned will be different including the nature of the possible accident, frequency and the severity of the accident, accordingly the risk level will be different. Therefore risk has to be considered under the context of a specified situation of the system concerned and with connection to certain hazards (within the system or external to the system), or accidents, for example, "the risk presented by this hazard under the situation …", "the risk of fire on board this ship taking into account all hazards…"

Risk is also subject to human perceptions. Given the same situation, individuals could have different perceptions of the risk level. The product of the frequency and consequence is not the only way to "combine" them; individuals have different ways of "combining" the frequency and consequence, for example, "There is a clear perception in society that a single accident that kills 1,000 people is worse than 1,000 accidents that kill a single person" (IMO, 1997).

2.1.3. Relation between safety and risk

Having examined the meaning of safety and risk, the relation between them would not be difficult to understand. In short, safety concerns the extent to which the system is free of danger to life, property and the environment. The less the danger presented by the system, the more freedom from danger is enjoyed by human beings, which can also be called as "safer". Therefore the extent to which the system presents danger, causes harm and damage to life, property and the environment reflects the level of safety from the reversed direction. Since risk concerns both the frequency and severity of consequence, it is adequate and suitable to represent the extent to which the system presents danger to life, property and the environment, and consequently the level of safety from the reversed direction: higher risk, less safety; lower risk, more safety. So it is reasonable and appropriate to improve safety by controlling and reducing risks. In addition "safety" is an abstract term, while the term risk is more concrete than the term safety and can be qualified and quantified by various means. It is therefore practical to represent safety by means of risk and improve safety by managing risks.

2.2. Traditional ways of dealing with maritime safety

Shipping has always been regarded as a risky business and from the beginning safety has been a very basic issue in the design, construction and operation of ships, because no cargo owners are willing to have their cargoes carried by a ship that is going to sink. Therefore people have been working hard continuously to improve shipping safety throughout history in order to maintain and develop the shipping business. By looking at the history of shipping, from the first ancient wooden canoe to the present VLCC, container ship, cruise ship, it is not difficult to see how much people have achieved by their continuous efforts in ship building and shipping, as well as maritime safety, which is an integral part of the maritime industry. Now let us have a look at how people have been dealing with maritime safety traditionally and what is the present situation of maritime safety.

2.2.1. "Learning from experiences"

"Learning from experiences" is the basic traditional approach that people deal with safety, in fact this is also the basic method that people learn and accumulate knowledge in every area. The core of this approach is "past experience" which constitutes the basis of decision-making. The circles in Figure 2.1, as proposed by this author, illustrate the basic theory of this approach.

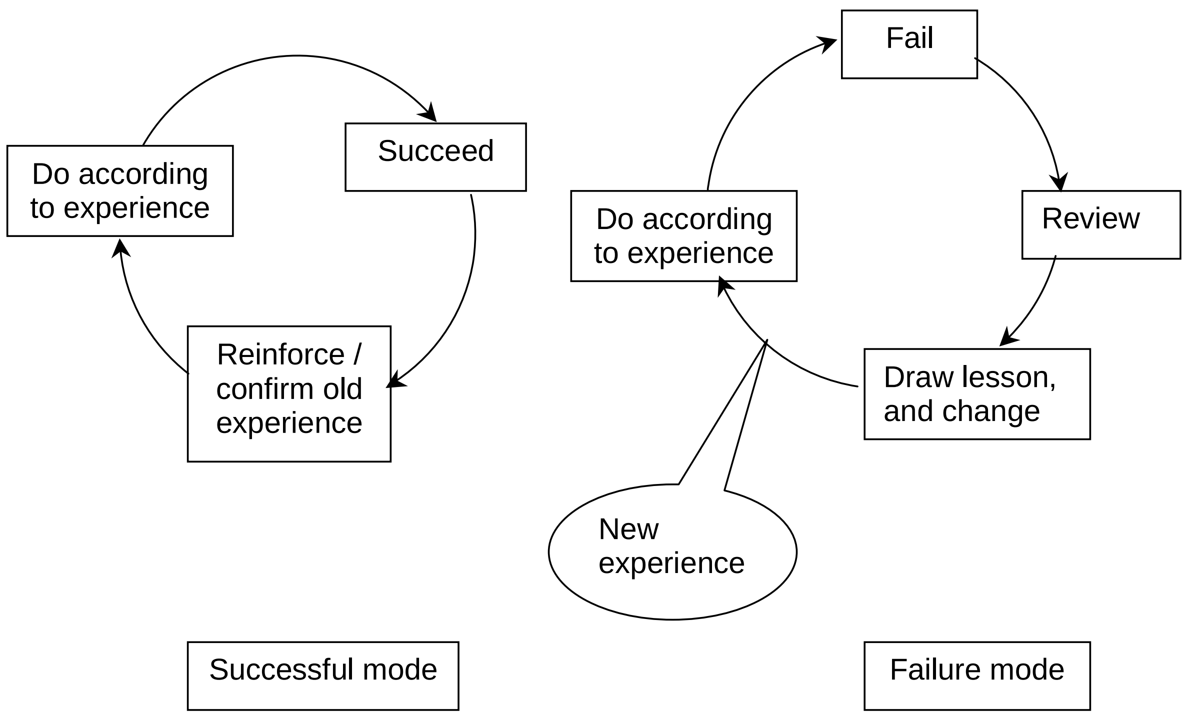


Figure 2.1: The circle of "learning form experiences"

The starting point of the circle is that people take action according to past experiences, the outcome of which could be success or failure. In case of success past experiences will be confirmed and reinforced. In case of failure people will review and investigate the subject matter in order to identify the underlying reasons.

Then people will draw lessons from the failure and make necessary changes, which will become new experiences to guide future actions. A typical example of the failure mode of “learning from experiences” is the Titanic accident: before the Titanic accident, people were only concerned about intact stability, which is the past experience, after the accident people realized the importance of damage stability, which is the new experience. Afterwards the new experience --- damage stability criteria were applied to ships. This approach can be summarized in the following statement: **Keep and follow past experiences until something goes wrong so that improvements have to be made.**

2.2.2. Scientific research and development

The scientific research and development is the other way that people deal with maritime safety. Scientists and experts from various sectors concerned by maritime safety, such as shipyards, classification societies, maritime Administrations, equipment manufactures, technical institutions and so on, have been actively conducting research for the purpose of improving maritime safety. Scientific researches have very wide coverage, from structural strength, engines, navigation equipment, to operations, ship maneuvering, cargo handling, safety management and so on. Some scientific researches and development focus on existing problems and could provide solutions to them, some focus on the training of seafarers and may produce more effective training facilities, and some researches may provide guidance for the more effective and efficient administration and management of maritime safety. In short, the scientific research and development has made a valuable contribution to the improvement of maritime safety.

Although the above approaches are discussed separately, they are in fact closely connected. The approach “learning from experiences” is also the underlying principle of the scientific research and development, and the review and investigation of the failure in “learning from experiences” would inevitably involve scientific researches in order to identify the underlying reasons behind the failure.

2.2.3. The present situation of maritime safety

Nowadays there is a complex maritime safety framework in place internationally and nationally, in which the main players are ship owners/operators, maritime Administrations, classification societies, shipyards. The fundamental basis of the framework is a regulatory regime on maritime safety and environmental protection, which consists of international and national rules and regulations, such as IMO Conventions, national legislations, and class rules. This regulatory regime provides for the responsibilities and obligations of the players in maritime sector, the standards concerning safety, environmental protection and seafarers, and so on. The safety performance of the maritime industry largely depends on the quality of this regulatory regime, and the effective implementation of it by all players. The basic approach of the present regulatory regime is to provide safeguards against identified hazards and remedies for failures. By "learning from experiences" and scientific researches, maritime people have identified considerable hazards and provided necessary safeguards against them and remedies for them, which are reflected in safety rules and regulations. Through years of accumulation this regulatory regime has already become considerably complete. For example, there are technical requirements in IMO Conventions provided against engineering hazards, such as structure failure, fire/explosion; there are STCW Convention against hazards related with operations, ISM Code against hazards related with management, COLREG Convention against hazards external to the ship, and so on. In short, the present regulatory regime has addressed all perceived hazards and provided safeguards and remedies (Smith, 1999).

2.3. Risk-based approach to maritime safety

The risk-based approach is a scientific method that deals with safety by controlling risks in a systematic way. The core of this approach is "risk", such as analysis of risks, quantification of risks, evaluation and reduction of risks, and so on. Developed in recent years, this approach has been widely applied in the nuclear and offshore industry and proved to be a useful, powerful tool to deal with safety issues. Risk management might be an appropriate name for this approach, which is defined by

Warner (1992) as "**The process whereby decisions are made to accept a known or assessed risk and/or the implementation of actions to reduce the consequences or probability of occurrence**." The basis of the risk-based approach is risk assessment, which is "the integrated analysis of the risks inherent in a product, system or plant and their significance in an appropriate context" (Warner, 1992). Generally risk assessment comprises the following steps: (Warner, 1992)

- Hazard identification
- Risk estimation or analysis (quantification of frequency and severity of accidents)
- Risk evaluation (risk criteria, risk acceptability)

Based on the risk level obtained from risk assessment and the result of risk evaluation, risk reduction measures will be considered and the benefit will be evaluated against their cost, which is called cost/benefit assessment, finally based upon the above analysis, decisions will be made to accept the risk and implement risk reduction measures.

According to Hood et al. (1992), the advantages of the risk-based approach are the following:

- It is a systematic process; decisions are made on the basis of scientific analysis and in a rational way.
- It is a proactive approach, which can identify new hazards and excessive risk areas, therefore risk reduction measures could be taken to prevent accidents from happening.
- Quantification of the risk level can help people to understand and be aware of the safety situation more clearly.
- Cost/benefit assessment can keep the balance among all risk areas.

2.4. Necessity of the risk-based approach

Under the traditional approach a complete safety framework and a regulatory regime have been established, and enormous improvements and progresses have been achieved. There are, however, still some problems that have been baffling maritime safety sector for many years, or for which the traditional approach could not provide satisfactory answers. For example, how safe is safe enough? What safety level does the current maritime safety regulatory regime provide? Why is the maritime safety sector so reactive that measures were always taken after major accidents have already happened? In addition, even when measures have been taken after accidents, people still do not know exactly how much the safety level has been improved by such measures. There is also the dilemma that on one hand, there are a lot of complaints from the society that the maritime industry is not safe enough, because there are always serious accidents happening now and then, which make people question the effectiveness of maritime safety regime; on the other hand, there are a lot of complaints from the shipping industry that there are too many safety rules and regulations, and the economic burden of fulfilling safety requirements is so heavy that it is going to kill the industry.

From the discussion about the advantages of the risk-based approach in Section 1.3, we can see that the risk-based approach can provide certain solutions to the problems and questions mentioned above:

- Risk criteria, risk acceptability and cost/benefit assessment can help to understand the problem of "how safe is safe enough?"
- Quantified risk assessment can provide a clear picture of the safety situation; therefore people can see the risk level they are facing, and cost/benefit assessment can make people aware of the additional cost needed to further reduce the risk level. As a result the society will be more willing to accept the risk, and will not complain too much on the safety level of the maritime industry.
- The risk-based approach is a proactive approach, which can identify new hazards and excessive risk areas so that safeguards could be taken before accidents happen, thereby reducing the number of serious accidents, improving maritime safety, and reducing complaints from the society.
- Cost/benefit assessment can keep the **balance** among all risk areas and safety measures, and **rationalize** the regulatory regime, which will help to reduce the risk level, enhance the safety level in a rational, practicable and balanced manner, and obtain more understanding from the maritime industry.

- The risk-based approach can provide more transparency in the decision-making process; therefore it can promote the understanding of the industry on the necessity of safety measures and the willingness to accept them.
- When performance-based regulations are adopted by the Administration, the risk-based approach can provide more flexibility for the industry in achieving the safety standard set by the Administration.
- Quantification of the risk level can illustrate the extent of safety improvement achieved by the new measures implemented after accidents, which helps people to see more clearly the effectiveness of the new measures, thereby achieving more consensuses on them.

To provide a firm foundation for this dissertation, this chapter discussed the very basic issues about safety and risk, the traditional and risk-based approach to safety, and finally identified the advantages and necessity of the risk-based approach. Based upon this, this dissertation will move on to explore in detail the risk-based approach to maritime safety from different perspectives.

CHAPTER 3

The general procedure of risk-based approach to safety

3.1. Introduction

As a systematic process, the procedure is of the first importance to the risk-based approach. This chapter will discuss the general procedure of risk-based approach step by step, and then analyze the uncertainty that exists in risk assessment, which is major limitation to this approach.

As a powerful flexible tool, risk-based approach can be applied to different cases under different contexts, and in different ways to suit different purposes and circumstances. The general procedure, however, is roughly the same for all cases. There is plenty of literature about the procedure of risk-based approach under different contexts, which summarizes the general procedure as follows (Jenner, 1997; IMO, 1997; Warner, 1992):

- Risk assessment
  - Definition and description of the system
  - Identification of hazards
  - Risk analysis (qualitatively or quantitatively)
  - Risk evaluation
- Identification of risk reduction or control measures
- Cost benefit (effectiveness) assessment
- Recommendation for decision-making

This author proposes Figure 3.1 as a simple illustration of the risk-based approach:

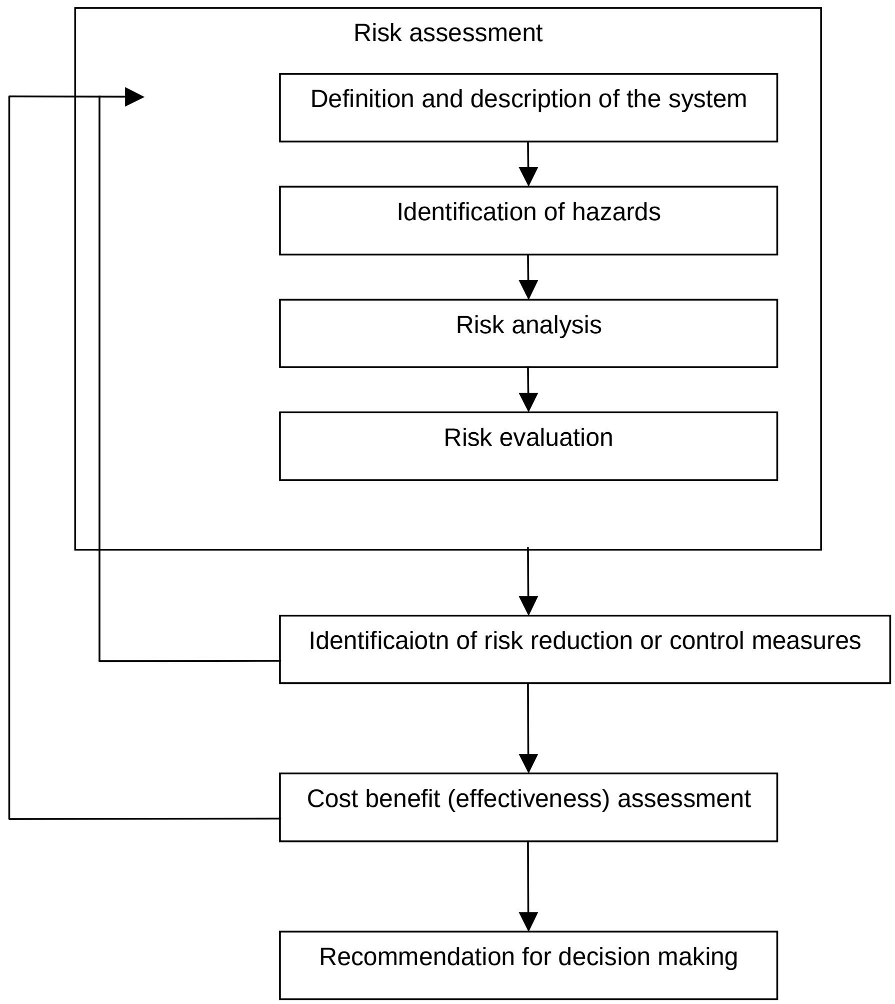


Figure 3.1 General procedure of the risk-based approach

3.2. Risk assessment

3.2.1. Definition and description of the system

Risk assessment is conducted with regard to certain systems for the purpose of solving certain safety problems. The system concerned and its boundaries should therefore be defined clearly, the current situation of the system and the problem existed should be described, and the purpose of the risk assessment should be presented clearly as well. For example, the system could be a ship, a category of ships (oil tankers, bulk carriers), the fleet of a shipping company, certain areas of a ship (engine room, bridge), ship equipment, shipping company, maritime Administrations.

3.2.2. Identification of hazards

This step is to "identify and generate a prioritized list of hazards, specific to the problem under review" (IMO, 1997). The reason for this step is that we need to know firstly what could go wrong in the system before estimating the risk and deciding on the risk reduction action (Kuo, 1998). In this step two layers of objectives should be achieved: (IMO, 2001a)

- The primary objectives are:
  - Completeness Full list of potential hazards
  - Knowledge–based Be aware of past accidents and other work
  - Multi–disciplinary Allow lateral thinking from diverse experiences
- The secondary objectives are:
  - Auditability Possible to track the process, well documented
  - Structure To ensure completeness and quality of documentation
  - Efficiency Focus on immediate problem, useful for other purposes

To ensure the realization of the above-mentioned objectives, certain principles should be followed, Kuo (1998) proposed the following principles for hazard identification:

- Understand the mechanism the system works, the planned path of the system and the associated assumptions.
- Identify the possible deviation from the planned path, the possible cause and effect of the deviation.
- Document all the identified deviation.

To achieve the objectives mentioned above, standard techniques, analytical or creative, should be adopted for hazard identification, such as Brainstorming, What-If analysis, Checklist, the hazard and operability analysis, FMEA, FMECA, and so on.

“The analytical techniques can ensure that previous experience is taken into account properly and systematically; the creative techniques can ensure that the process is proactive, and not confined only to hazards that have materialized in the past” (IMO, 1997). Appropriate techniques should be chosen according to the characteristics of the system under consideration and the types of hazards as well (IMO, 2001b).

Hazards can be grouped into different types according to their characteristics. Kuo (1998) believes that grouping hazards is beneficial in that it allows one to choose the most appropriate identification techniques for that type of hazard, select suitable risk analysis techniques, and facilitate the process of seeking suitable risk reduction measures according to the type.

Various ways of grouping hazards can be employed for different purposes. Considering the discussion on the term safety, the author proposes to group hazards as follows:

- Internal hazards:
  - Management hazards
  - Engineering hazards
  - Operational hazards

- External hazards:
  - Hazards from natural environment
  - Hazards from political environment
  - Hazards from other systems
  - Hazards from commercial environment

The identified hazards will be screened and prioritized according to the significance, which can be undertaken by using historical statistics and professional judgment. This ranking is just a coarse and rough screening and prioritization of hazards. This process helps people to better understand hazards identified, focus on significant hazards and facilitates the procedures followed (IMO, 1997).

The output of hazard identification is a prioritized list of hazards, and a preliminary description of the development of hazards to final outcomes (IMO, 1997).

3.2.3. Risk analysis

This step is to estimate the risk level and identify the distribution of risks among categories and sub-categories of accidents. The analysis could be qualitative or quantitative as required by the actual situation. It involves the systematic analysis of the developing path from hazards to final accidents, the causal chain of accidents, the accident scenario, and so on. In short, the connection between hazards and accidents will be carefully examined and established, this also facilitates the understanding of the operating mechanism of the system. Various techniques are available for risk analysis, such as Event Tree Analysis, Fault Tree Analysis, neural network, fuzzy set, and so on. Since the demand for historical data is very heavy in the risk analysis process, from the very beginning insufficient data has been a major difficulty confronting risk analysts. When historical data are not sufficient and reliable, expert judgement can be employed for the analysis.

There are two fundamental expressions of risks: individual risk and societal risk in terms of human life. Individual risk can be regarded as "the risk of death, injury and ill health to an individual in isolation" (IMO, 1997), such as crews, passengers, and so on. The widely used expression is mortality rate, for example 10^{-3} annually. The mortality rate can also be expressed relative to other measure units, such as passenger-hours, passenger-miles, and so on. Loss of Life Expectancy is used to express individual risk of injury and ill health. Quality Adjusted Life Year (QALY) can be used as an integrated indicator for the risk of death, injury and ill health.

Societal risk can be regarded as "the risk to society of a major accident" (IMO, 1997). Societal risk can be expressed by means of FN curve, a diagram where the frequency (F) of "N or more fatalities" is plotted against the "N or more fatalities" (See Figure 3.2). Using FN curve the frequency of accidents with different consequence magnitude can be illustrated clearly, as well as the risk level

(Grossland, et al. 1993). Another way to express societal risk is Potential Loss of Life (PLL), which represents the number of annual fatalities.

Risk may also be expressed by monetary units, for example 10^5 US$ annually, where the loss of human life, damage to property and environment are represented by monetary units. Theoretically this is a perfect alternative to express risks, however, in practice, it is very hard to have consensus on the value of human life, and even the idea of "value of human life" could not be accepted generally.

3.2.4. Risk evaluation

Once the risk level has been estimated, it will be evaluated against the risk acceptance / tolerance criteria with the purpose of deciding whether measures should be taken to reduce the risk level. There are mandatory risk evaluation criteria established by government as well as voluntary criteria set up by companies for their own safety practices. Generally there are three risk levels: Intolerable, As Low As Reasonably Practicable (ALARP) and Negligible (IMO, 1997).

- Intolerable – The risk is very high and cannot be justified so that measure should be taken to reduce risk level regardless of cost.
- Negligible – The risk is so small that no risk reduction is necessary.
- ALARP –The risk falls between the other two states. It is also called Tolerable level, meaning that the risk is tolerable in this region. Risk reduction measures may or may not be taken depending upon the cost-effectiveness of them. If the risk reduction measure is cost-effective, it should be taken to reduce the risk as low as reasonably practicable. If the cost of the measure outweighs the benefit, then no action needs to be taken to reduce the risk.

The following are some examples of risk evaluation criteria for individual risk (IMO, 2000 attributes Health Safety Executive, 1999):

- Maximum tolerable risk for crew members 10^{-3} annually
- Maximum tolerable risk for passengers 10^{-4} annually

- Maximum tolerable risk for public ashore 10^{-4} annually
- Negligible risk 10^{-6} annually

Risk evaluation criteria for societal risk can be shown by diagrams, Figure 3.2 is an example of the diagram:

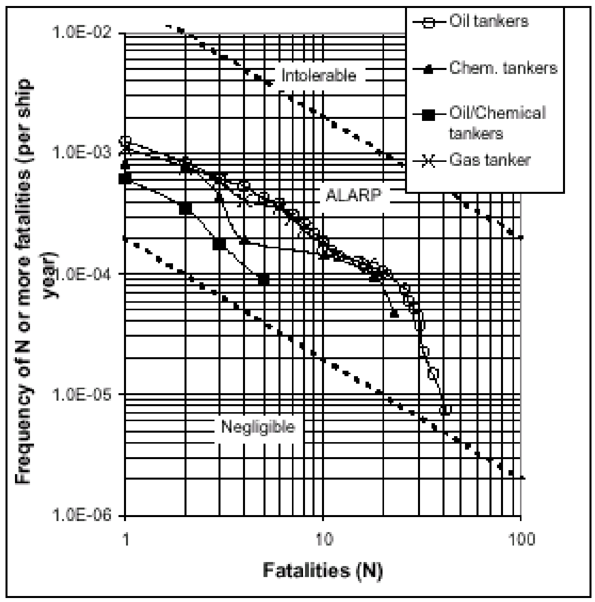


Figure 3.2**:** FN curves for different tankers, shown together with established risk acceptance curves. Data from 1978-1998. (Data source: LMIS)

Source: International Maritime Organization, MSC 72/16, 2000.

3.3. Risk reduction or control measure

According to the evaluation of risk level risk reduction or control measures should be identified. By looking at the developing path of hazards into accidents, risk control measures can be classified into two groups: preventive measures and mitigating measures. Preventive measures aim at reducing the likelihood of failures and accidents, in short, controlling the frequency. Mitigating measures aim at reducing the severity of failures and accidents, in short, controlling the escalation of failures and accidents (IMO, 1997).

As there are hazards internal to the system, like management, engineering and operation, and there are hazards external to the system, risk control measures can be identified at where hazards exist. Therefore risk control measures can be identified aiming at improving management, engineering and operation of the system, and aiming at alleviating the negative environment of the system.

Once risk control measures have been identified, they should be grouped and organized into practical control options, which will be assessed for their cost-effectiveness at the later stage.

3.4. Cost benefit (effectiveness) assessment

Cost benefit assessment is an important feature of the risk-based approach to safety, which would ensure the balance among the risk control options. Safety costs money, if the cost of a risk control option outweighs its benefit: the improved safety or the reduced risk that such "cost" could achieve, then this risk control option is not regarded as cost-effective. There are two ways to conduct such assessment: Cost Benefit Assessment (CBA) and Cost Effectiveness Analysis (CEA).

In Cost Benefit Assessment (CBA) all losses (life, injury, ill health, property, environmental) are converted to monetary units, as well as all benefits. Then the benefit is simply compared with the cost in monetary terms. This approach seems to perfectly match the theoretical idea of such assessment, however, big difficulty arises when it comes to the "value of life". Although many ways are available to estimate the "value of life", there is no general consensus on it.

In Cost Effectiveness Analysis (CEA), a ratio of costs to benefits is presented in order to avoid putting a value to "life". The ratio will then be compared with the criterion determined by decision-makers. Basically the ratio represents the amount of resources needed to reduce per unit risk, i.e. one life annually. Accordingly the criterion on this ratio represents the amount of resources that the society is willing to spend in order to reduce per unit risk, i.e. saving one life annually.

In practice the cost effectiveness is expressed in forms of Implied Cost of Averting a Fatality (ICAF), or Cost of Unit Risk Reduction (CURR) (IMO, 2000).

$$ICAF = \frac{\Delta Cost}{\Delta Risk}$$

$\Delta Cost$ is the marginal (additional) cost of the risk control option, whilst $\Delta Risk$ is the reduced risk in terms of fatalities averted. ICAF is also called as Gross Cost of Averting a Fatality (Gross CAF) (IMO, 2000).

$$CURR = \frac{\Delta Cost - \Delta EconomicBenefits}{\Delta Risk} = ICAF - \frac{\Delta EconomicBenefits}{\Delta Risk}$$

In CURR the economic benefits of risk control options are accounted for, such as risk reduction in property, environment, and so on. CURR is also called as Net Cost of Averting a Fatality (Net CAF) (IMO, 2000).

Table 3.1 below gives some examples of criteria of ICAF.

Table 3.1: Published ICAFs in use as acceptance criteria
Source: International Maritime Organization, MSC 72/16, 2000.

Published ICAFs in use as acceptance criteria		
ORGANISATION	SUBJECT	ICAF
US Federal Highway Administration	Road Transport	\$2.5m (£1.6m)
UK Department of Transport	Road transport	£1.0 m (1998, uprated with GDP per capita)
UK Health & Safety Executive	Industrial safety	As above or higher
Railtrack (UK rail infrastructure controller)	Overground railways	As above to £2.65m
London Underground Ltd	Underground railways	£2m
EU	Road Transport	ECU 1 million (£0.667m)
Norway	All hazards	NOK 10m (£0.8m)

3.5. Recommendation for decision making

In this step the cost-effectiveness of risk control options are compared, based on the comparison recommendations will be given to decision-makers for consideration.

3.6. Uncertainty in risk assessment

Having introduced the general procedure of the risk-based approach to safety, readers may have got deeper understanding about the advantages of this approach. However, nothing in the world is perfect, the limitation of this approach should also be properly identified and addressed to ensure the effective implementation in practice. The main limitation of the risk-based approach is the uncertainty inherent in the process, which attracts heavy criticism from those who are against this approach, and affects people’s confidence in this approach. Nevertheless, it will not affect the advantages if it is properly recognized and treated. In this section, types, sources of the uncertainty, the treatment of and appropriate attitude to that will be discussed.

It is very important to distinguish two types of uncertainties (Bolsover et al., 1998):

- Variability (also called as random uncertainty, inherent uncertainty or Type A uncertainty). This is due to natural randomness, e.g. the variation in wind speed over time. It can be defined more accurately by repeated measurements.
- Epistemic uncertainty (also called as Type B uncertainty). This is due to lack of knowledge and information. It includes uncertainties in modeling and data collection, and can be reduced by gathering more information and increased knowledge.

Generally, according to the source the uncertainty can be grouped into data-related and methodology-related uncertainties.

3.6.1. Data-related uncertainty

Using historical data is a relatively reliable way to quantify risk level compared with others. However data could give rise to some uncertainty due to the applicability of historical data to the current situation, and the completeness of data (White, 2001).

Historical data reflect the previous situation; when historical data are applied to the current situation to estimate the current risk level, there is an assumption that the situation has not changed over this period of time. However, the situation is changing all the time, including the system itself and the external operating environment. Therefore, the uncertainty will arise when historical data are applied to the current situation. Fortunately such change is occurring very slowly, especially in the shipping industry, which has a long history and is considered to be very conservative. In addition, since the life cycle of a ship is normally over 20 years the total “sudden step-change” is very unlikely to occur, instead, it is evolving gradually. Therefore the uncertainty arising from the changing situation is not big.

Since it is extremely impossible for every accident to be reported and recorded, the risk level estimated by historical data will obviously be lower than the risk in reality. Although there are several organizations in the world that are collecting casualty data, complete data are still impossible. However, major accidents were always recorded, so in certain high-risk areas, data may be regarded as sufficient.

3.6.2. Methodology-related uncertainty

The uncertainty may also come from some areas related with methodology and modeling, such as quantification of human element, the use of professional judgement, and the existence of simplifying assumption (White, 2001).

The contribution of human elements to safety has been widely recognized, however, the quantification of it is a very challenging task that involves considerable uncertainty. Although the risk-based approach is considered as an objective process, professional judgement is used everywhere in the process, especially when data are not sufficient (Grossland, et al. 1993). To model the system assumptions have to be made with regard to various situations, which also introduce uncertainties to the process.

3.6.3. Treatment of the uncertainty

It is an unchangeable fact that the uncertainty in the risk-based approach will always exist to a certain degree, there are no ways to avoid it, and the only proper way available is to treat the uncertainty explicitly thereby improving the confidence in the risk-based approach. Some uncertainty are quantifiable, others are less tractable. As recommended by Carr et al., (1995) the best way of treating uncertainty is "best estimate with uncertainty quantified as fully as possible". Therefore the general principle is to quantify uncertainties that are quantifiable; for those that are not quantifiable, qualitative analysis should be made explicitly.

3.6.3.1. Treatment of the uncertainty related with data

To handle this kind of uncertainty proper selection of data and methodology is the key: data should be selected to reflect the actual situation of the system concerned, and the methodology should be able to handle the variance in input data. Various techniques are available for the quantification of the uncertainty, such as Monte Carlo tools, Bayesian analysis, sensitivity analysis, maximum/minimum bound estimates, and so on (Bolsover et al., 1998).

Carr et al. (1995) recommended a practical scheme for the quantitative assessment of the overall uncertainty, which can be implemented by means of Monte Carlo simulation technique. The theory is as follows: The process of the risk-based approach involves data inputs, mathematics analysis and outputs, in the conventional deterministic approach, input parameters are treated as single values as well as output parameters (as presented in Figure 3.2). In the Monte Carlo simulation probalistic approach, input parameters are treated as random variables whose uncertainty is represented by probabilistic distributions, accordingly, output parameters are in the form of probability distributions rather than single values (as presented in Figure 3.3). Therefore the output will not only represent the "most likely value" that can be defined in various way for different purpose, such as mean, median, and so on, but also represent the probability of such "most likely value".

For example, the risk level is 10^{-6} annually, the probability of the risk level being 10^{-6} is 90%. In this way the uncertainty can be clearly and explicitly illustrated.

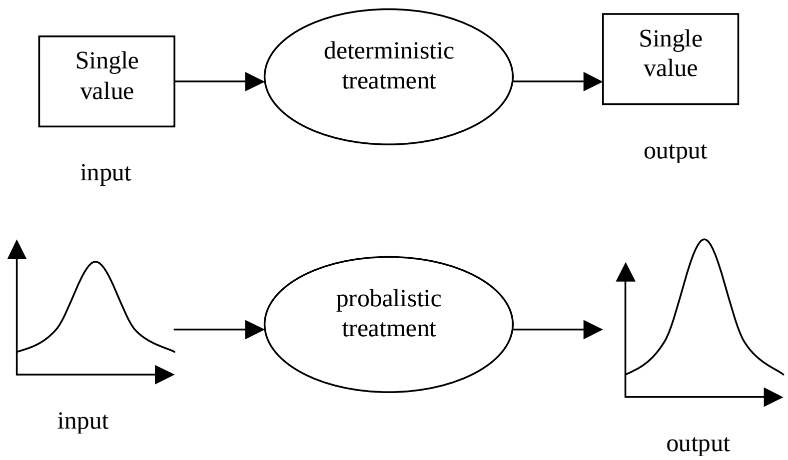


Figure 3.3: Treatment of uncertainty related with data

3.6.3.2. Treatment of the uncertainty related with methodology and modeling

This kind of uncertainty is more difficult to handle than the uncertainty related with data. Bolsover et al. (1998) suggested that using a wide range of modeling approaches could provide some insights to this kind of uncertainty. In addition understanding and recognition of limitations of models will also help for this.

3.6.4. Attitude towards the uncertainty

The existence of uncertainties is not a shame or substantial drawback to the risk-based approach; to avoid discussing uncertainties is of course not an honest and convincing way to serve decision-makers and the public. In addition the human world does not require everything to be perfect, human beings act for certain purposes, not just for the sake of the act itself. In the context of safety, human beings conduct risk assessment for the purpose of mitigating risks and improving safety, therefore, the whole process of risk assessment serves this purpose. In return, this purpose will determine how risk assessment should be carried out, including the degree of accuracy and uncertainty of it. So the realistic goal, as

Grossland (1993) indicated, is that the accuracy should be “adequate in relation to the needs and to enable effective mitigation of risks." It is not necessary to quantify the uncertainty to a fixed degree under all circumstances. Sometimes the actual situation may require the uncertainty to be quantified. Under some circumstances qualitative assessment of uncertainties might satisfy the need. Whatever ways to treat uncertainty, the issue of uncertainty should not be avoided; it should be identified, highlighted, and analyzed explicitly.

This chapter summarized and discussed the general procedure of the risk-based approach, which further illustrated the systematic feature of this approach. The uncertainty issue related with this approach is analyzed, which help to provide a complete recognition of the risk-based approach with regard to advantages and limitations. Under the general framework built up in this chapter, this dissertation will move on to discuss the various scientific techniques to reflect the scientific feature of the risk-based approach.

CHAPTER 4

Techniques of risk-based approach

4.1. Introduction

The application of the risk-based approach needs the proper procedure and suitable techniques. Having discussed the general procedure of the risk-based approach, this Chapter will look at various techniques that are currently employed for the risk-based approach. The techniques nowadays available mostly focus on the risk assessment step of the risk-based approach; therefore they are very often called as risk assessment techniques. In this chapter the most commonly used techniques will be described, and their characteristics discussed to identify their strengths and weaknesses. A final generalization of all the techniques is provided in the end.

4.2. Brainstorming

Brainstorming "involves the generation of ideas over a specified period by a group of people with different interests, expertise and experience" (Kuo, 1998). It is a practical and efficient way of organizing expert judgement for various purposes, such as the identification of hazards in the system, estimation of probabilities.

First a team is formed consisting of people with a range of experience, knowledge, outlook and attitude. A co-ordinator is appointed or selected who is responsible for guiding the process, encouraging members to contribute ideas. A fixed time period and a target number of ideas are agreed in advance. Once the target is reached, the ideas will then be discussed, some maybe grouped together, some maybe discarded if too preposterous. The result should be a comprehensive list of items, for example, a list of hazards in the system (Kuo, 1998). As proposed by Kuo, the advantages of brainstorming are that the team is with a range of background, expertise, experience and knowledge; the approach is flexible and open; and a lot of hazards can be generated if team members have overcome the initial inhibitions about unusual ideas. Its disadvantages are that team members should have right attitude to this open approach; team members have to overcome the initial inhibitions about presenting unusual ideas without worrying about being ridiculed afterwards; and team member sometimes cannot get going and on the same wavelength.

4.3. What-If

What-if analysis is a broad, loosely structured technique, the purpose of which is to identify hazards and ensure proper safeguards are in place. This technique has the following procedure: (USCG, 2001)

- Define the system concerned
- Subdivide the system for analysis
- Generate what-if questions for each element of the system, like “what if the relieve valve fails to open”
- Respond to the what-if questions, such as causes, consequences, safeguards, and so on

As a qualitative technique, What-if can be applied to any kind of system, especially those with simple failure scenarios. It is often used in combination with other more structured methods, such as Checklist analysis. Due to its loose structure of What-if technique, some hazards are likely to be missed, and its thoroughness is difficult to be audited (USCG, 2001).

4.4. Checklist Analysis

According to the US Coast Guard (2001) “Checklist Analysis is a systematic evaluation against pre-established criteria in the form of one or more checklists.”

First a checklist is prepared by careful examination of the system, and then items are checked one by one to see if any one has gone wrong, and the mitigating action is proposed in the checklist record (Hong, 1999).

Checklist analysis is applicable for any kind of system, and often used to guide the inspection of the system concerned. The quality of the evaluation is exclusively relied upon the knowledge and experience of experts who generate checklists, so if the checklist fails to include certain key issue, the analysis is likely to overlook this aspect. The simplicity of this method present value for minimal cost, however, only qualitative assessment can be provided (USCG, 2001).

4.5. Physical inspection

This method is widely used for hazard identification. The advantage is that the safety auditor can see the system himself/herself and does not have to rely on reports from others. The disadvantage is the considerable time invested in the inspection (Hong, 1999).

4.6. Hazard and Operability Analysis (HAZOP)

HAZOP is a qualitative method used to analyse hazards in the system with the aim to eliminate or minimise them (IMO, 1997). Its principle is “to identify hazards by using “guidewords” to study variations from the design objectives of a system and its components” (Kuo, 1998).

The first step in HAZOP procedure is to form a team consisting of designers, practical engineers and safety auditors. The whole system is divided into a number of smaller and manageable sub-systems that will be examined by guidewords, such as “None”, ”More”, ”Less”, and ”other”. The effort is directed at seeking answers to the following questions: (Kuo, 1998)

- The objective of the sub-system concerned
- The deviations from the stated objective (Generated by combining guidewords and properties of the system)

- The causes of these deviations
- The consequences resulting from deviations
- The actions to eliminate or minimise deviations

Dickson (1987) suggested a complete process of HAZOP by a chart as presented in figure 4.1. Sheets with columns for guidewords, deviations, causes, consequences and actions are developed to record the findings of the analysis; table 4.1 is an example of the sheet for a fuel storage and supply sub-system (Dickson, 1987):

Table 4.1: Hazard and Operability Analysis worksheet

Source: (Dickson, 1987)

Guidewords	Deviations	Causes	Consequences	Actions
No	No flow	• Tank empty • Inlet valve V1 is shut • Pump is not working • Hose blocked	• No petrol gets to vehicles • Petrol seeps out of pipes • Hose bursts	• Regular chcking of tank • Vavles to be checked everyday • Regular maintenance of the pump

HAZOP is used primarily for systems with continuous process, especially fluid, air and thermal systems. The advantages of this technique are that It is extensive, major hazard will not be omitted; the team benefits from different expertise, experience and background; and each part of the system can be examined in detail. Its disadvantages are that It requires a well-defined system; investment of time is expensive; in case the system is simplified to facilitate the study, there is the risk that certain aspects maybe omitted; and it focuses only on identifying single failure, it is not able to analyse failure caused by a combination of events.

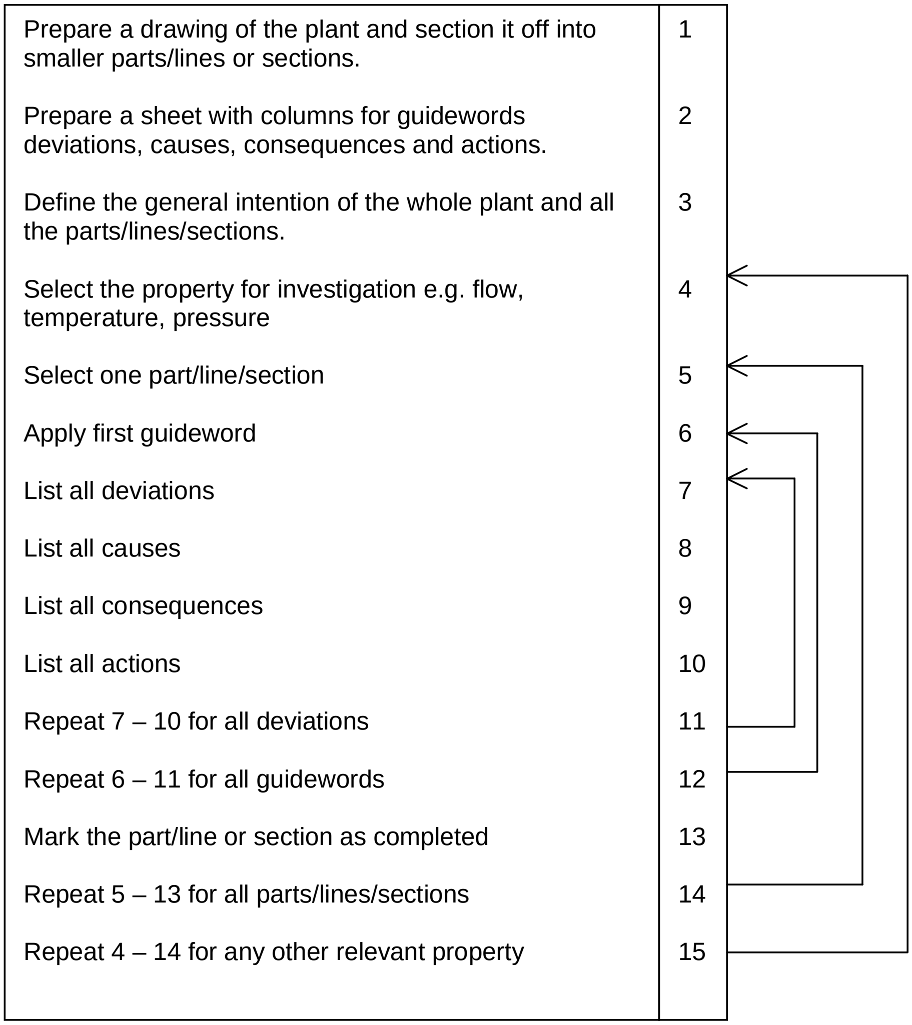


Figure 4.1: Process of Hazard and Operability Analysis

Source: (Dickson, 1987)

4.7. Failure Mode and Effect Analysis (FMEA)

Failure Mode and Effect Analysis (FMEA) is a technique to identify and analyse the potential failure mode of a system and its effects, as well as actions that could eliminate or mitigate the effects of the potential failure (NASA, 2001). When the FMEA is extended by a criticality analysis, the technique is then called failure mode and effects criticality analysis (FMECA). It is considered as state-of-art to perform

FMECA instead of FMEA. Nowadays some sources call FMEA as Fault Hazard Analysis. The theory of FMEA can be illustrated by the following Figure 4.2:

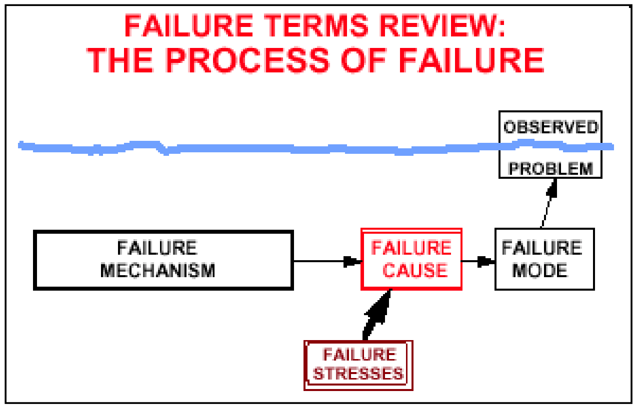


Figure 4.2: Theory of Failure Mode and Effect Analysis

Source: (NASA, 2001)

The following outlines the process of Failure Mode and Effect Criticality Analysis (FMECA):

1. Define the system to be analyzed.
2. Define the function model and reliability model of the system. Break the system down into convenient and logical elements: subsystems, assemblies, subassemblies, components, and piece parts. (See Figure 4.3) System Breakdown can be either Functional, or Geographic/Architectural, or both (i.e., Functional within the Geographic, or *vice versa*).
3. Establish a Coding System to identify system elements.
4. Analyze (FMEA) the elements. Identify the failure modes of elements, detection methods, their causes and effects on the system performance at different level.
5. Determine the criticality of failures and rank them. Criticality is the combination the severity and frequency of the failure mode, which is the risk associated with each failure.

6. Formulate corrective actions for each failure mode. The correction and mitigation action is usually based on the ranking of the criticality of the failure.

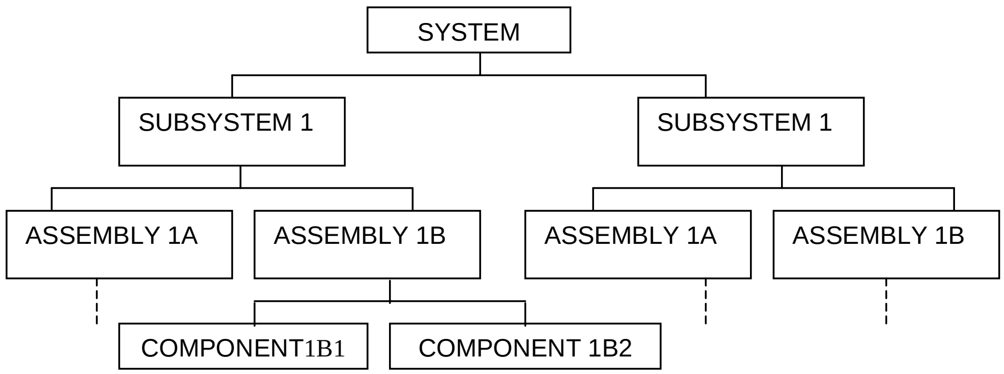


Figure 4.3: Block diagram of system subdivision

Source: (NASA, 2001)

The FMECA Sheet is used to guide and record the analysis, the following is an example of it.

Table 4.2: Failure Mode and Effect Criticality Analysis worksheet

Source: (NASA, 2001)

Description	Function	Failure Mode	Cause of Failure	Effect of Failure (local, upper level)	Corrective Action	Detection method	Criticality Rank

Being a systematic and highly structured technique, FMEA is primarily used in mechanical and electrical systems. It can be used as a basis of optimization of maintenance plan, and provide valuable information for troubleshooting system.

FMEA could be carried out in a quantitative, semi-quantitative or qualitative manner depending on the level of requirement. When the quantitative FMEA is carried out, it requires sufficient information on the statistical distribution of component failures and good understanding of dependency relationships among components of the system under various operational modes. In some situations quantitative, semi-quantitative FMEA can well meet the demand.

FMEA only analyzes the effects of a single component failure; it can identify single failure modes that may cause system failure, however it is not possible to analyze the problems caused by combinations of component failures. In addition FMEA focuses on how equipment failure can occur, those human factors, external influences that do not cause equipment failure are often overlooked although they may present dangers directly to human being or the system as a whole (USCG, 2001).

4.8. Preliminary Hazard Analysis (PHA)

"The Preliminary Hazard Analysis technique is a broad, initial study used in the early stages of system design" (USCG, 2001). By identifying weaknesses at the early stage of a system development, the application of PHA could avoid major redesign at a later stage. This technique focuses on identifying hazards, assessing the severity of possible accidents, and identifying safeguards to reduce risks.

The general procedure of PHA is as follows: (Vinnem, 1993)

- Definition of subsystem and operational modes
- Identification of potential hazards
- Definition of unwanted events
- Evaluation of unwanted events
- Evaluation in the PHA sheet
- Identification of critical and sub-critical events
- Corrective Action Recommendation Forms

The PHA sheet, as presented in table 4.3, is similar with that of FMEA. PHA technique is applicable to any system or activity and commonly used in the early stage of system development, often as a precursor to further risk assessment.

Table 4.3: Preliminary Hazard Analysis worksheet

Source: Adapted from (Vinnem, 1993)

Taxonomy number	Ongoing operation	Unwanted event	Probable causes	Probable conseque n-ces	Preventive actions/ contingen- cies	Probility class	Conseq- -uence class

The focus is largely on the identification and classification of hazards. Since there is no detailed information of the system at the early stage, the quality of the risk assessment is highly dependent on the knowledge and experience of the team. In order to fully assess hazards and potential accidents identified in PHA, further follow-up risk assessment need to be carried out (USCG, 2001).

4.9. Fault Tree Analysis (FTA)

Fault Tree Analysis is a technique that, by means of tree structures, visually models the logical causal relationship between events that singly or in combination cause accidents (IMO, 1997).

FTA is a top-down approach where, starting from the top event, the tree is systematically developed by identifying the causes at lower levels. Logical gates such as "AND ","OR" are used to show the relationship among events at the same level. Logical "AND" gate is used when two or more events need in combination to cause the next higher event; Logical "OR" gate is used when any of two or more events may occur to cause the next higher event (IMO, 1997).

According to the US Coast Guard (2001), the procedure of Fault Tree Analysis (FTA) is as follows:

- Define the system of interest.
- Define the TOP event for analysis.

- Define the treetop structure; specify the events that most directly lead to the TOP events.
- Explore each branch in successive levels.
- Identify the combinations of events contributing to the TOP event.
- Identify important dependent failure potentials and adjust the model appropriately.
- Perform quantitative analysis to predict the risk level.

Figure 4.4 is an example of fault tree:

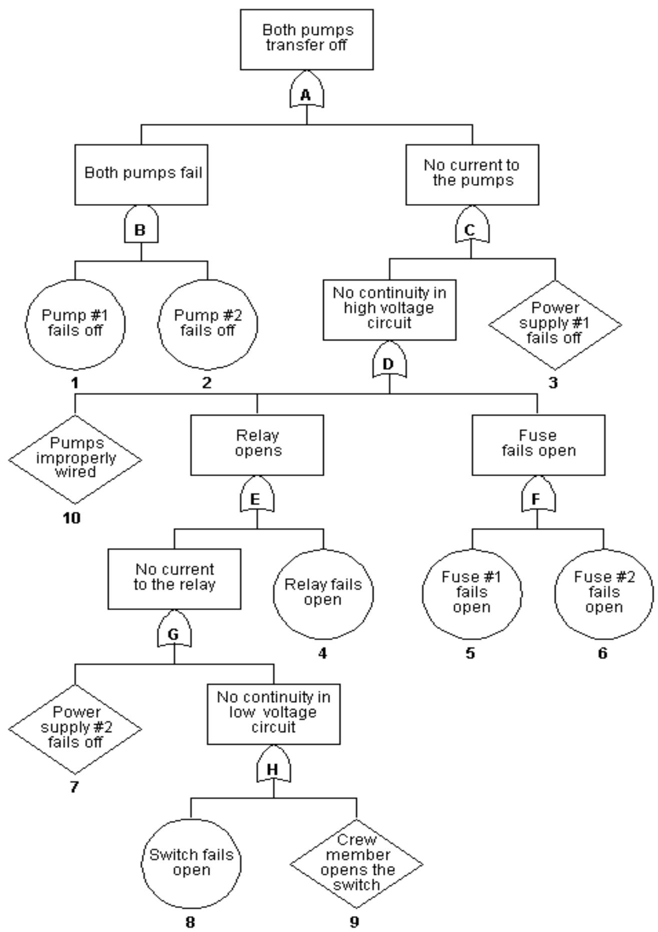


Figure 4.4: fault tree

Source: (USCG, 2001)

FTA can be conducted qualitatively or quantitatively. Qualitatively the relationship among events is illustrated; quantitatively the risk level and the relative importance of various events can be calculated. FTA is able to analyse common cause failures and failures caused by events in combination. It is effective to be used to analyse the root causes of specific accidents with relatively complex combinations of events. As to a complex system FTA can help the better understanding of it.

FTA is a technique with narrow focus; it only examines one specific accident of interest. More fault trees should be developed in order to analyse other types of accidents. The quantification of analysis requires significant expertise and reliable statistical data (USCG, 2001; Kuo, 1998).

4.10. Event Tree Analysis (ETA)

Event Tree Analysis is a technique, which by means of tree structure, visually models the possible outcomes of an initiating event. “The model illustrates how safeguards and external influences, called lines of assurance, affect the path of accident chains” (USCG, 2001). The probability of success or failure of each safeguard action is analyzed along each path; the multiplication of them by the probability of the initiating event gives the probability of each consequence.

According to the US Coast Guard (2001), the procedure of Event Tree Analysis is as follows:

- Define the system of interest
- Identify the initiating event of interest
- Identify lines of assurance—the safeguards that help to mitigate the consequence of the initiating event
- Define accident scenarios and construct the event tree logic
- Analyze accident sequence outcomes—the frequency and consequence of outcomes
- Summarize results in the table or graphic (F-N Curve) for evaluation and decision-making

Figure 4.5 below is an example of event tree:

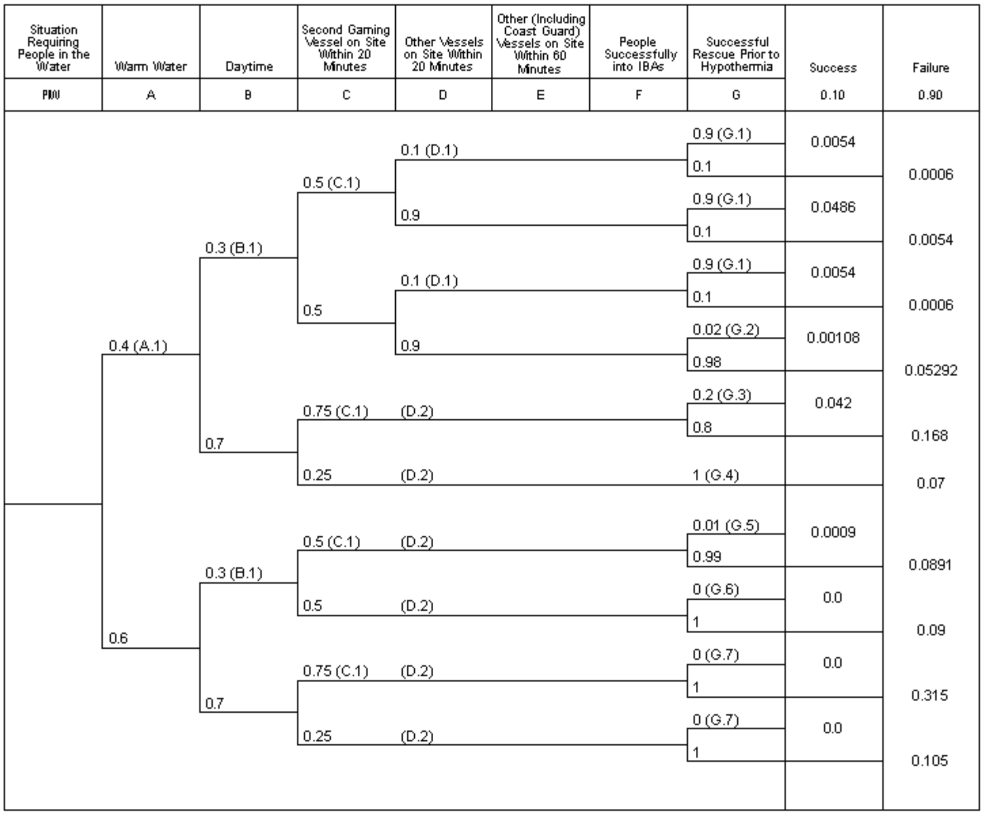


Figure 4.5: event tree

Source: (USCG, 2001)

ETA is applicable for almost any kind of system. It is very effective to model accidents for the system with multiple safeguards and to determine the consequence resulted from various initiating events. It is able to account for timing, dependence, and domino effects among various events. Qualitatively it shows the development path of accidents from the initiating events. Quantitatively it presents the frequency, consequence of various sequence, and the relative importance of various sequence and contributing events.

However the scope of ETA is limited to only one initiating event, it is not effective to be used to identify all causes that can result in accidents. The subtle dependency among various lines of assurance could be easily overlooked, which may present certain uncertainty in the analysis (USCG, 2001).

4.11. Cause-Consequence Analysis

"Cause-Consequence Analysis is a technique to explore time-sequenced system responses to initiating "challenges" and enables probability assessment of success/failure outcomes at staged increments" (Clemens, 1992). It is sometimes called as "expanded" Event Tree Analysis, or a combination of Fault Tree Analysis and Event Tree Analysis.

Cause-consequence Analysis is a two-part technique: cause part that is analysed by Fault Tree Analysis, and consequence part that is evaluated by Event Tree Analysis (Clemens, 1992). Therefore Cause-consequence Analysis has the same advantages as FTA and ETA, and shares the same disadvantages with FTA and ETA, which is that Cause-consequence Analysis focus on only one single "challenge".

The following is an example of the diagram of Cause-consequence Analysis:

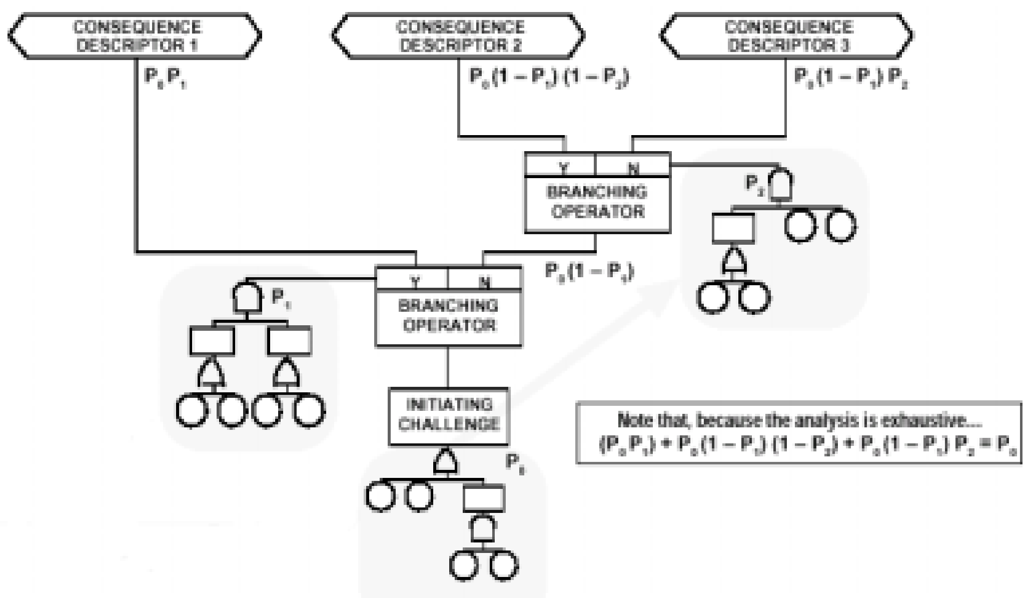


Figure 4.6: Cause-consequence Analysis *Source: (Clemens, 1992)*

4.12. Management Oversight and Risk Tree Analysis (MORTA)

MORTA is a comprehensive analytical tree technique for identifying the potential oversights / omissions and management deficiencies in a project activity. MORTA is based on the theory that losses are from two sources: a) specific job oversight and omissions, b) the management system that controls the job. MORTA can be regarded as a very detailed graphical checklist, where the factors involved in the accident are arranged in a logical tree structure (generic tree) and accompanied by evaluating criteria (generic questions).

The general procedure is to go through the checklist along the defined generic tree structure, answer the generic questions associated with each item in the checklist, evaluate it with factual data and colour-code it accordingly. Four colours are used to represent different significance of the event:

- Red: The event is less than adequate (LTA)
- Green: The event is satisfactory and adequate
- Blue: The event has insufficient evidence or information to evaluate
- Black: The event is not applicable or relevant to the accident

Finally the path of cause and effect can be traced back by going through the events with red colour (Jeffcott, 2001; DOE, 2001) Figure 4.7 below is a MORTA chart displaying the injury, damage, other costs, performance lost, or degraded event:

Among the advantages of MORTA is that it is very systematic, comprehensive, and very effective in the analysis and investigation of accidents and events. It dissects an accident systematically, and can serve as a “road map” to guide the investigator through all possible factors. The scope of MORTA goes beyond the immediate causes of an accident by scrutinizing the management systems closely and human factors. MORTA reflects the multi-factorial nature of accidents and is able to evaluate simultaneously multiple accident causes through the tree structure (DOE, 2001).

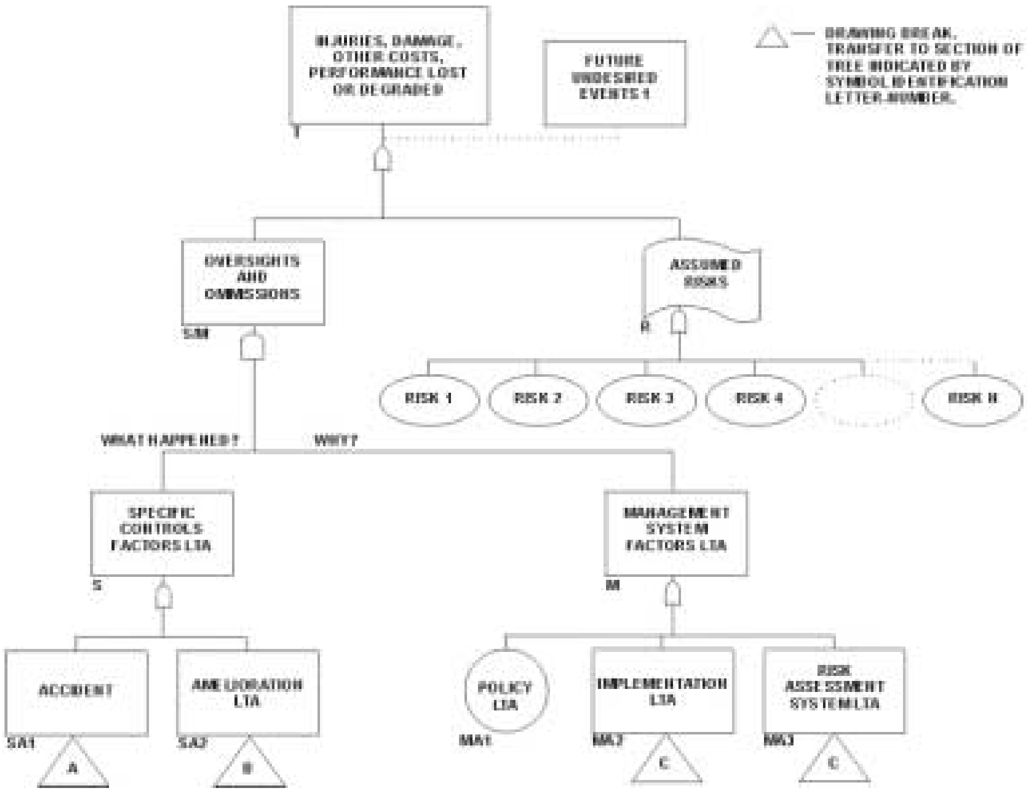


Figure 4.7: MORTA chart displaying the injury, damage, other costs, performance lost, or degraded event.

Source: (DOE, 2001)

Among its main disadvantages is MORTA's complexity. Professional MORTA analysts are needed to conduct MORTA effectively. Also it is not appropriate to analyse relatively simple accidents (Jeffcott, 2001). There are some simplified techniques that apply the principle of MORTA, such as Project Evaluation Tree (PET) Analysis, and Safety management Organization Review Technique (SMORT), which can be used in a simple and convenient manner for simple accidents (DOE, 2001).

4.13. Techniques for analysis of dynamic systems

Dynamic system is the system whose state is evolving over time. Traditional risk assessment techniques are developed to analyse static systems where the time-dependency factor of the system is not considered, so these methods meet difficulty when addressing dynamic scenarios. In a dynamic system, the system evolves dynamically and operators decisions, actions, failures and controls can influence the dynamics; reciprocally, the dynamics of the system affects operators decisions, actions, failures and controls. Therefore there is a dynamic interaction between the system and the operational decisions, actions, control, failures. Methods to analyse dynamic systems are developed, such as Markov modelling, dynamic event logic analytical methodology, dynamic event tree analysis method, digraph/fault graph, GO method, and so on. There are, however, still certain drawbacks related with these dynamic analysing methods, especially the requirement for large amount of computer resources and extensive data collection. With the development of powerful computers and the improvement on methodology, such dynamic analysing methods would be widely applied to overcome problems faced by traditional methods (UMD, 2001).

4.14. Relative Ranking / Risk Indexing / Rating system

"The Relative Ranking / risk indexing technique assesses the attributes of a vessel, shore facility, or operation to calculate index numbers" (USCG, 2001). It provides index numbers for relative risk comparison among various alternatives, systems, so that the priority is established to facilitate decision-making process.

The general procedure of Relative Ranking / Risk Index is the following: (USCG, 2001)

- Define the scope of the study
- Select the ranking tool that will be used
- Collect scoring information
- Calculate ranking indexes

The ranking tool is very important to the quality of evaluation; the development of a ranking tool requires substantial experience and knowledge. The core of such tools is to select suitable factors to assess, and to determine the relevant importance of these factors to system performance (USCG, 2001).

This technique is effective to make relative comparison, however the score or index resulted could not provide information about the absolute risk level. Each ranking tool normally focuses on a specific type of risk or system. To assess the risk or system outside the scope of that tool, new tools have to be developed (USCG, 2001).

4.15. Human Reliability Analysis (HRA)

At the initial stage of development of the risk-based approach, risk analysts have been solely focusing on technical systems --- hardware. Eventually people realized that "the human element is one of the most important contributory aspects to the causation and avoidance of accidents" (IMO, 2001). Therefore efforts were made to incorporate human elements into the process of risk-based approach through the use of human reliability analysis (HRA). This section will describe the general procedure of HRA, introduce and evaluate the most commonly used HRA techniques, and discuss the limitations of HRA at this developing stage.

The general procedure of HRA is the following: (IMO, 1997)

- Identification of key tasks by performing the high-level task analysis, and associated human related hazards
- Detailed task analysis of key tasks to identify critical subtasks and associated human related hazards
- Identification of human error
- Analysis of human error, including causes, error-recovery, consequence
- Quantification of human Error Probabilities (HEPs)

For the purpose of integration, the result of each step of the HRA should be fit into the corresponding step of the risk assessment. If a quantitative risk assessment is required, the quantitative value of HEPs should be fit into the risk assessment procedure. However, considering the complexity of the techniques and availability of data, it is sufficient to conduct a qualitative HRA analysis, especially at the early stage of the risk assessment, since it can provide a clear indication of critical areas that should be chosen for analysis (IMO, 1997).

The HRA techniques that will be discussed in this section are as follows:

- Technique for Human Error Rate Prediction (THERP)
- Absolute Probability Judgement (APJ)
- Human Error Assessment and Reduction Technique (HEART)
- Paired Comparison (PC)
- Success Likelihood Index Method Using Multi Attribute Utility Decomposition (SLIM-MAUD)

4.15.1. Technique for Human Error Rate Prediction (THERP)

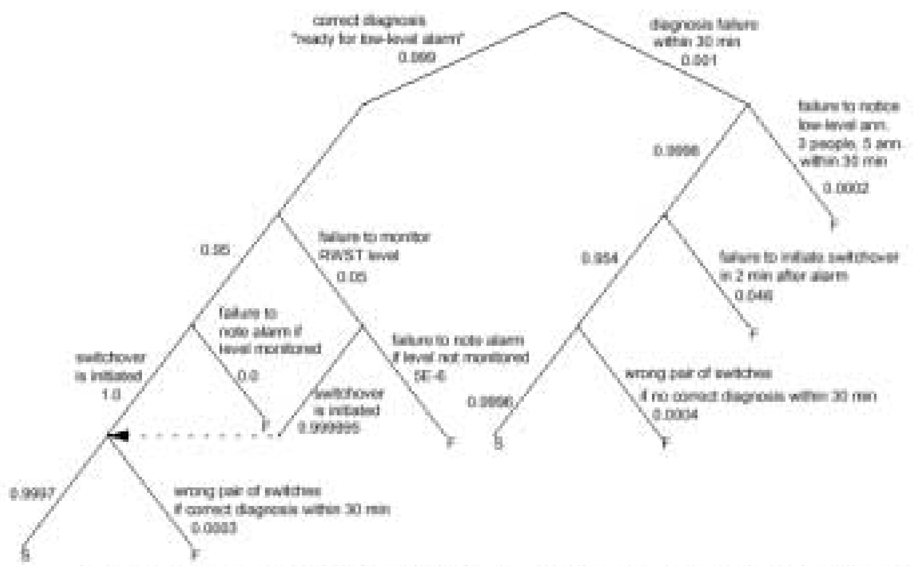
THERP is both a HRA technique and a human error databank. It is "a comprehensive methodology covering task analysis, human error identification, human error modelling and human error quantification" (IMO, 2001). The general procedure of THERP is as follows: (IMO, 2001)

- Identify all the systems that are influenced and affected by human operations;
- Perform task analysis in order to identify all human operations that affect the system;
- Determine the Human Error Probability (HEP) through the database and expert judgement;
- Determine the consequence of human errors by incorporating the human error into the risk modelling procedure.

For the purpose of task decomposition and subsequent error quantification, the "HRA event tree" is established to model the logical and time-dependent correlations between the individual success and failure event. Figure 4.8 below is an example of the "HRA event tree".

The general principle of determining HEPs is that, first the nominal error probability (NHEP) is checked from the database, and then the NHEP is adapted or modified to the actual situation. Sets of Performance Shaping Factors (PSFs) are used in THERP for this adaptation, which have reliability-decreasing or –increasing effect and "include experience, situational stress factors, work environment, individual motivation, and the human-machine interface“ (IMO, 2001). The HEP is calculated through the following formula: (NEA, 1998)

$HEP = NHEP \cdot PSF_1 \cdot PSF_2 ...,$



From ([Swain 83], p. 21-22) with additional explanations reflecting the analysis described by Swain & Guttmann; F: failure, S: success

Figure 4.8: THERP event tree modelling for the failure of the task of changing from feed to circulation mode as soon as the alarm warns of an excessively low water level in the refuelling water storage tank (RWST) during a large loss-of-coolant accident.

Source: (NEA, 1998)

To assess the probability of diagnosis failure, the time-reliability correlation model is used; the probability of diagnosis failure is defined as a function of the time available for diagnosis. The education- and training-related knowledge level is considered here, since “the better the knowledge about the accident to be analysed, the faster a correct diagnosis is to be expected” (NEA, 1998).

4.15.2. Absolute Probability Judgement (APJ)

“APJ refers to a group of techniques that utilises expert judgement to develop human error probabilities (HEPs)” (IMO, 1997). This technique is used in situation where relevant data is not available and direct numerical estimation is the only way possible to obtain the HEPs. Typical techniques are the Delphi technique, the Nominal Group Technique, and so on (IMO, 1997).

4.15.3. Human Error Assessment and Reduction Technique (HEART)

HEART is a relatively simple and quick technique to develop HEPs. This technique is based on a database with nine generic task descriptions and associated human error probabilities (IMO, 1997). The general principle is similar with THERP. Firstly the analyst matches the assessed task to the generic task description and finds the generic HEP, then adapts or modifies the generic HEP according to characteristics of the identified Error Producing Conditions (EPCs), Similar to PSFs in THERP, the EPC multiplier is utilised to increase the order of magnitude of the HEP measurement (Kirwan, 1988).

4.15.4. Paired Comparison (PC)

Paired Comparison can be regarded as “a significant, expert judgement technique” (IMO, 2001) and a method of relative ranking of human errors. Paired Comparison requests experts to make a series of simple judgement between pairs of human error descriptions and decide which error is more probable in each pair. For ‘n’ errors, each expert makes n(n-1)/2 comparisons. Then the relative scaling of error likelihood of all errors can be established based on the combination of the comparisons from all different experts. Finally the HEP is derived by using calibration on condition that there shall be at least two error with known HEPs (Kirwan, 1988).

4.15.5. Success Likelihood Index Method Using Multi Attribute Utility Decomposition (SLIM-MAUD)

SLIM-MAUD is a computerised technique and is a method of relative ranking of human errors. MAUD is an approach to ensure that the expert group conducts the study without being affected by their biases. The basic assumption of SLIM-MAUD is that relative likelihood of human error can be defined as a function of various

Performance Shaping Factors (PSFs). A relative scale, called Success Likelihood Index (SLI), is established by SLIM-MAUD to represent the relative likelihood of human error, then this index can be calibrated to develop the human error probability (Kirwan, 1988).

4.15.6. Evaluation of HRA techniques

The human reliability analysis techniques could be evaluated against the following criteria in table 4.4:

Table 4.4: HRA techniques evaluation criteria

Source: based upon (Humphreys, 1988)

Accuracy	**Validity**	**Usefulness**
• Numerical • Consistency	• Modelling • Theoretical • Perceived • Comparative	• Qualitative • Sensitivity analysis capability • Breadth of applicability • Comprehensiveness
Effective use of resources	**Acceptability**	**Maturity**
• Equipment and personnel • Data requirements • Resource limitations • Degree of decomposition • Training requirements	• To regulatory bodies • To the scientific community • To assessors • Auditability • Expert review	• Current • Development potential

In order to aid the selection of the technique to perform analysis, “The Human Reliability Assessors Guide 1” provides an comparative evaluation of the above mentioned HRA techniques, which is summarized in the table below:

Table 4.5: Summary of evaluations of HRA techniques

Source: (Humphreys, 1988)

	THERP	APJ	HEART	PC	SLIM
Accuracy	Moderate	Moderate	Moderate	Moderate	Moderate
Validity	Moderate	Moderate/ high	Moderate	Moderate	Moderate
Usefulness	Moderate	Moderate/ high	High	Low/ Moderate	High
Effective use of resources	Low/ Moderate	Moderate	High	Low/ Moderate	Low/ Moderate
Acceptability	High	Moderate	(Moderate)	Moderate/ high	Moderate/ high
Maturity	High	High	Low/ Moderate	Moderate	Moderate/ high

4.15.7. The limitation of current HRA techniques

Before proceeding to the discussion of the limitation, it is necessary to understand the two classes of human errors applied in HRA: errors of omission and errors of commission. “Errors of omission refer to the failure to perform an action required in response to a situation (a part of a scenario). Errors of commission consist of the execution of actions inappropriate for the given situation,” which is closely related with decision errors (NEA, 1998). The main limitation of the currently available HRA techniques is that they are not suitable to address errors of commission; comparatively they handle errors of omission better. The current HRA techniques are “not generally based on an empirically supported model of human behaviour, and especially, of the cognitive behaviour of operators“ (NEA, 1998). With such weak basis they failed to consider broadly the cognitive state of the operator and its evolution. Lack of sufficient data on operator performance is one important contributing factor to this deficiency. In addition some other limitations are as follows: (NEA, 1998)

- Significant differences in quantitative results from different analysts (using the same method) or from different methods.
- Weak treatment of dependencies between actions.
- Weak treatment of diagnosis.
- Lack of treatment of dependencies between Performance Shaping Factors (PSFs).

Due to such limitations mentioned above, the research and development is driven in a wide range of areas, such as new HRA methods, data collection and analysis, organizational factors and safety culture, the dynamic approach to treat errors of commission, and so on (NEA, 1998).

4.16. Generalization of the techniques of the risk-based approach

Each technique has various attributes, this section will explore the basic attributes of these techniques, group them according to their attributes, and present a comprehensive map illustrating the relationship among all these techniques.

4.16.1. Deductive – Inductive

Deductive or inductive refers to the logic procedure according to which the technique is conducted. The distinction between deductive and inductive procedures can be clearly illustrated by figure 4.9.

Event Tree Analysis and Fault Tree Analysis are very typical deductive techniques, in that FTA starts from the single top event and goes down to various contributing factors at lower levels; ETA starts from the single initiating event and goes up to various sequences at higher levels. As a combination of ETA and FTA, Cause-Consequence Analysis is also a deductive technique since it starts from the single initiating challenge and goes downwards to contributing factors like FTA, and upwards to various consequences like ETA.

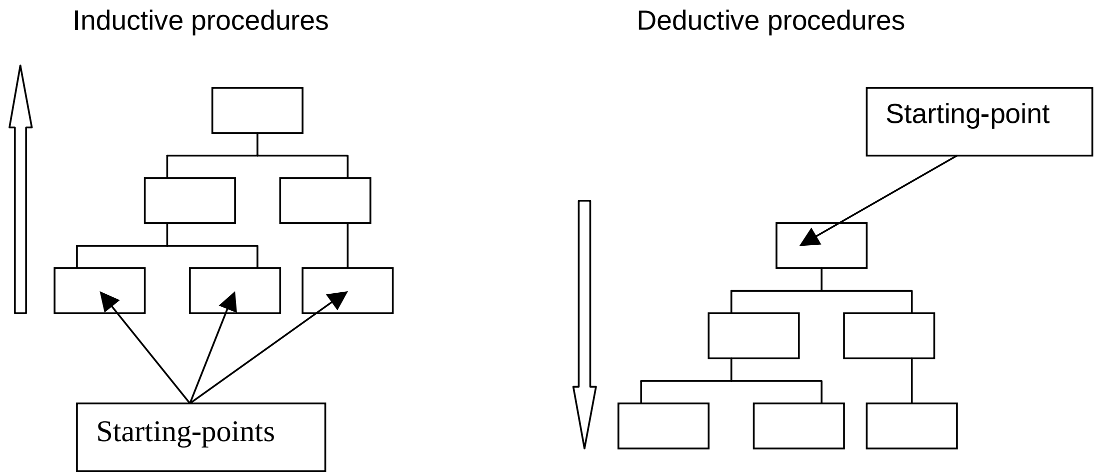


Figure 4.9: Deductive procedure and inductive procedure of risk assessment

FMEA, or FMECA is a typical inductive procedure, in that it starts from determining the failure modes of all components at the lowest level, then goes upwards to determine the effects of the failure modes at higher levels, and identify the failure modes at higher levels. Working in the similar principle PHA, HAZOP are also inductive techniques.

4.16.2. Structure

Structure is an important attribute concerning how the technique is structured. It is not difficult to see that some techniques discussed above are loosely structured like Brainstorming; some are highly structured like FMEA. Generally there are two ways to structure the technique: “system structure” and “tree structure”.

The techniques with “system structure” normally start with the subdivision of the system of interest. The system is subdivided into various subsystems, assemblies, and components, the level of details depends on the actual requirement. The structure can be illustrated by block diagrams, flow charts, and so on. Then by following and going through the system structure, each component, assembly, or subsystem is considered and analysed, therefore the probability of certain subsystem or component being neglected is very low. FMEA, PHA, HAZOP, and What-If (if conducted in a similar manner) can be classified as techniques with “system structure”.

For techniques with “tree structure”, the basis of the analysis is the tree by which the logical relations among various factors are illustrated. Therefore the first task to conduct such techniques is to develop the tree like in FTA, ETA, or Cause-Consequence Analysis, or choose a proper prepared tree like in MORTA. Then the analysis is conducted by going through all the factors in the tree.

Checklist is a structured technique; its structure is fully determined by the developer of the checklist, it could be a “system structure”, or a “tree structure” like MORTA — a graphic checklist.

4.16.3. Scope

The scope of the technique is an issue related with the structure of the technique, and the deductive or inductive nature of the technique. It is obvious that the scope of the inductive techniques with “system structure” is the whole system. For the deductive techniques with “tree structure”, the scope is only the single initiating event, for example an accident.

4.16.4. Focuses of techniques

Although all the techniques discussed above are called techniques of the risk-based approach, not all of them could cover the whole procedure of the risk-based approach, each technique has its specific focus aiming at handling certain part of the whole procedure of the risk-based approach.

Some techniques are more specialized at the part of hazard identification, although different names for “hazard” are used in these techniques, such as HAZOP, PHA, FMEA, What-If, Checklist, physical inspection, and Brainstorming. Although these techniques contain procedures like determining the causes and consequences of hazards, failures or accidents, they don't provide specific technique for those procedures, direct expert judgement is normally utilized.

Some techniques focus on determining the causal factors. Fault Tree Analysis focuses on the identification of the causal factors of the accident, thereby establishing the probability of the accident. MORTA focuses on identifying omission / oversight and management deficiencies, and the causal chain. Techniques like Event Tree Analysis focuses on the identification of the scenario and various possible consequences of the accident, and determining the severity of the consequence. Some techniques directly focus on the estimation of the risk level, such as Criticality Analysis. Relative Ranking / Risk Indexing focuses on the relative estimation of the risk level.

The above discussions on the basic attributes of techniques can be roughly illustrated by the following Figure 4.10. This figure is drawn to reflect the basic particulars of these techniques, it should not be construed as the comprehensive representation of these techniques.

This chapter discussed various scientific techniques that are commonly used in the risk-based approach, and analysed their strengths and limitations. The attributes of these techniques were identified and generalized, thus the relationship among these techniques is established under the framework of the risk-based approach. As the major general methodological issues, the procedure and techniques, as well as their interactions, have been settled down, this dissertation will move on to discuss the risk-based approach under the context of maritime safety.

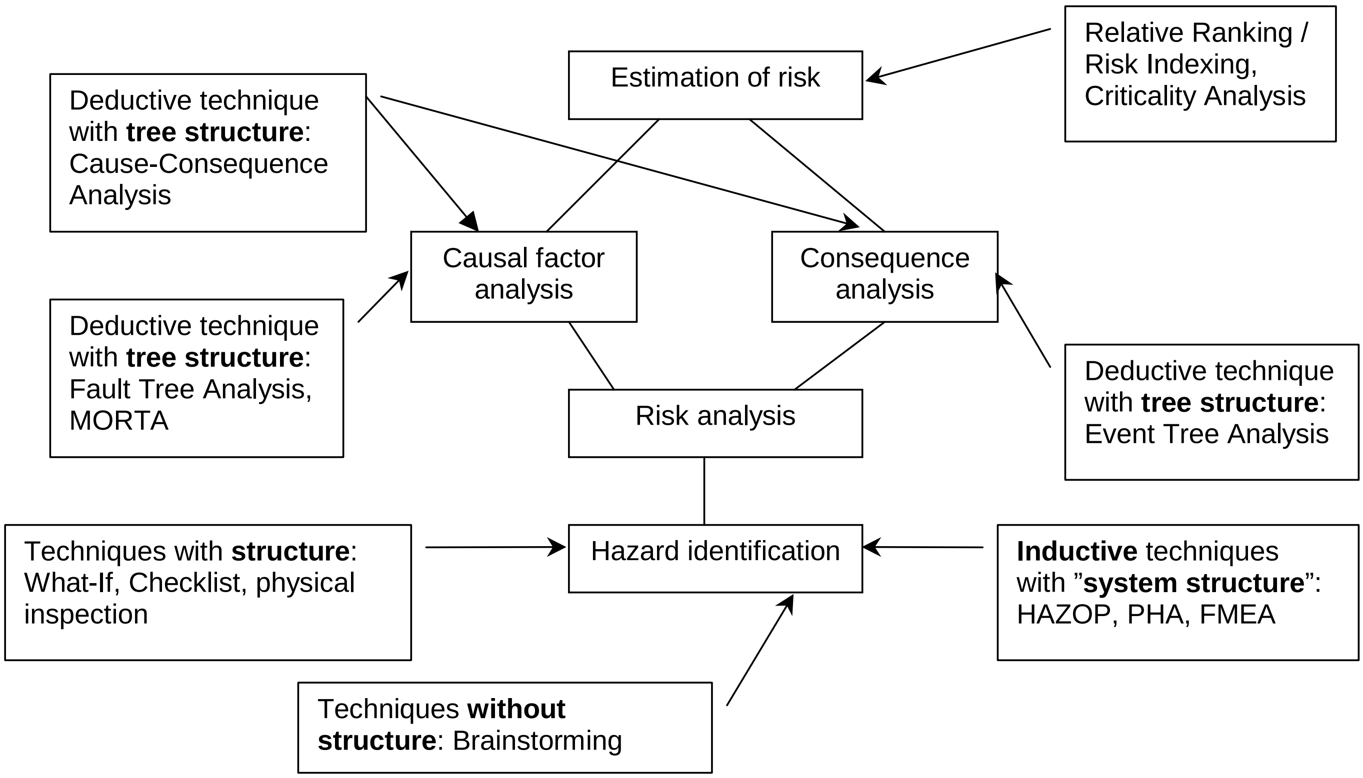


Figure 4.10: General positioning of techniques of risk-based approach

CHAPTER 5

Risk-based approach to maritime safety

5.1. Introduction

In previous chapters, the general processes of the risk-based approach and various techniques have been discussed. This chapter will look at how this approach can be properly applied to maritime safety. The characteristics of maritime industry will be analyzed as well as the implications to the application; two methodological issues, the practical procedure and the selection of techniques, will be discussed. A model case of risk assessment of a generic ship will be presented as an example to show in depth how the risk-based approach can be applied to ships. An ideal application scheme will be provided to show at macro level how the risk-based approach will be applied to the maritime industry.

5.2. Characteristics of maritime safety

The risk-based approach originated from the land-based industries like nuclear industry, chemical plant, which are very different with the maritime industry from various aspects. Therefore the special characteristics of the maritime industry must be carefully considered and taken into account when the risk-based approach is applied. The following identifies several basic characteristics of the maritime industry; it is only for the purpose of illustrating the difference with other land-based industries, not necessarily a comprehensive comparison of it.

The core of the maritime industry is the ship. The basic characteristic of ships is that ships are floating systems; ships therefore have to maintain floatability, watertight integrity and stability (intact and damage), which are the basic requirements for the survival of ships. Ships also have to employ special ways of propulsion, steering and maneuver. Different ways of lifesaving, evacuation, search and rescue have to be introduced considering the fact that an accident could happen to a ship that is floating somewhere in the ocean with violent sea conditions and cold seawater.

The hardware of a ship is a very complex self-sustaining system, which is sometimes compared to a "floating city". The basis of the system is the hull of the ship, which provides floatability and strength for the whole system. Various subsystems serving for different purposes are accommodated in the limited space provided by the hull, such as living quarters for crew, passenger cabins, cargo holds, propulsion, steering, main engines, generators, navigation equipment, cargo handling equipment, fire fighting equipment, and so on. In addition, since so many subsystems are sharing such a limited space, if accidents occur to some subsystems, other subsystems would be very easily affected. For example, fire can spread very quickly in the absence of any control measures.

The maritime industry is highly affected by human factors in different ways. It is because of human beings that the ship has possibility to navigate, and it is also because of human beings that most of the accidents occur. Seafarers operate the ship in a highly interactive way. It is common sense that the navigation of ships requires highly skilled seafarers, because it involves complex decision-making processes, and the execution of decisions. Although ships nowadays are much more automated than before, the key role of human beings in safety is not decreasing. On the contrary, with the increase of hardware reliability, the human factor has become even more significant to maritime safety. Looking at the operational level, human factors involve various aspects, such as fatigue, multi-nationalities of crew, cultural differences, language and associated communication difficulties, influences from the motion of the sea, extended periods of separation from family, boring life with long time at sea, pure "male world" onboard ships, and so on. Looking at management level, however, shipping companies are organized and operated in various flexible ways for the purpose of economy, not for the concern of safety. To the same ship, there might be owners, operators, and various types of charterers, who are scattered around the whole world, and with complex relationships and unclearly defined responsibilities for safety. The master of the ship, which can be regarded as the connection between the land-based management and the shipboard management, is a key feature of shipping that is very different with other land-based industries.

Ships are more heavily affected by external environmental factors than land-based industries. The most typical factors are weather conditions, sea conditions, navigation channels, other ships, and so on. Nowadays ships are becoming larger in size and faster in speed, and the influence of external environmental factors to ships will be more significant.

5.3. The implication of maritime characteristics to the application of the risk-based approach

The characteristics of the maritime industry have to be taken into account when applying the risk-based approach, compared with land-based industries, attention should be given to the following aspects that implied by the maritime characteristics:

- New areas of analysis will arise, and accordingly the hazards specific to maritime industry will arise, which are totally unexpected in land-based industries, such as hazard to hull integrity, hazard from the sea condition, and so on.
- New causes and consequences of accidents specific to maritime industry will arise, for example the consequence to stability, the causes from marine environment.
- Different ways of implementing risk techniques will be adopted to cope with maritime characteristics. For example, maritime safety is very heavily involved with human factors in different ways, implying that not only new hazards will arise, but also different ways of integrating human factors into

the risk assessment have to be carefully considered and established in order to fully reflect maritime characteristics.

5.4. Two methodological issues in the practical application of the risk-based approach

Two aspects should be considered in the application of the risk-based approach, one is the practical procedure of the application; the other is the selection of suitable techniques to apply for the application.

5.4.1. Adaptation of the general procedure of the risk-based approach

The procedure of the risk-based approach discussed in Chapter 3 is generalized result from various typical applications, which reflects the basic principle of the risk-based approach. In the practical application, the actual procedure to be followed will be decided by the actual situation, and under the guidance of the general procedure of the risk-based approach. Since the risk-based approach is a very flexible tool, it can be well adapted to suit various situations and needs in different ways, forms, and be conducted in different procedures. Whatever procedures being adopted, risk assessment is always the basic step that should not be neglected.

Generally, when the risk-based approach is applied for the purpose of seeking safety solutions, the complete procedure will roughly be followed. For example, the shipping company applies Safety Case to look for cost-effective measures for safety improvement, or applies Risk-Centered-Maintenance to seek the optimized maintenance scheme; the Administrations and classification societies apply Formal Safety Assessment to develop rules and regulations. More discussions about Safety Case, Risk-Centered-Maintenance and Formal Safety Assessment can be found in Section 5.6 and the Appendix.

When the risk-based approach is applied for evaluation purposes, maybe only risk assessment step is conducted. For example, the Administrations assess the risk of ships in order to set the inspection priority, the decision is made only upon the risk assessment, although steps like risk control measures and the cost effectiveness assessment are not conducted, they are in fact hiding in the philosophy of the application in that the inspection can be regarded as a risk control measure, and to inspect according to the priority is the cost-effective way to use inspection resources.

5.4.2. The principle of choosing appropriate techniques for the application

Chapter 4 discussed various risk assessment techniques; it is obvious that one technique could not satisfy all of the requirements of an application. It is more advisable to employ a combination of techniques and use the advantages of them. The following are some factors that should be taken into account in choosing suitable techniques for the application: (USCG, 2001)

- Reason for the application: The reason behind the application and the purpose shall be clearly defined and understood.
- Type of result needed: The result that is expected from the application is an important factor since various techniques are capable of producing different results. The result might be a list of ranked items for decision-making, causal factors and mechanism of accidents or failure, quantitative or qualitative risk level, risk control measures, and so on.
- Type of resources available: Since the various techniques have different demands on the resources, the resource available would affect the choosing of techniques. On the other hand the chosen technique would determine further resources needed, in case the current resources are not sufficient.
- Complexity and size of the application: The complexity and size of the application is dependent on the complexity of the system concerned and the level of detail needed. Some techniques are not capable of dealing with complex applications; therefore other techniques with such capability shall be used.
- Type of system, operation or accident: Some techniques are more suitable to analyze certain system than others, therefore the technique that is good at analyzing the system concerned shall be chosen and used. For example, as discussed in Chapter 4, HAZOP is good at analyzing system with certain

"flow", Event Tree Analysis is good at analyzing the consequence development of accidents.

In short, a good understanding of the advantages and disadvantages of various techniques, and a clear understanding of the application, will help to choose the suitable techniques.

5.5. A model case of risk assessment of a generic ship

The core of the maritime industry is the ship, and the risk assessment of ships is the core and base case of the risk-based approach to maritime safety, therefore a reliable risk assessment of ships is very essential and important. This section will present a model case of risk assessment of a generic ship in order to show how a combination of techniques should be applied to ships by taking account into maritime characteristics. This model can be used as a basis for risk assessment of specific ships.

This model is based on the following assumptions:

- The ship is a general cargo ship at the operation stage.
- The purpose of risk assessment is for the preparation of a Safety Case.
- The result needed is a list of prioritized hazards, causal factors and sequence of accidents, and the quantified risk level.
- Resources available are drawings, statistical data on casualty, failure, near miss, and so on.

5.5.1. Definition of ship model

The first step of risk assessment is to define and understand the system to be analyzed. As discussed in chapter 1, safety is determined by engineering, operation, management and the environment. By taking into account this principle and the characteristics of generic ships, this section will present a ship model by using the following figures:

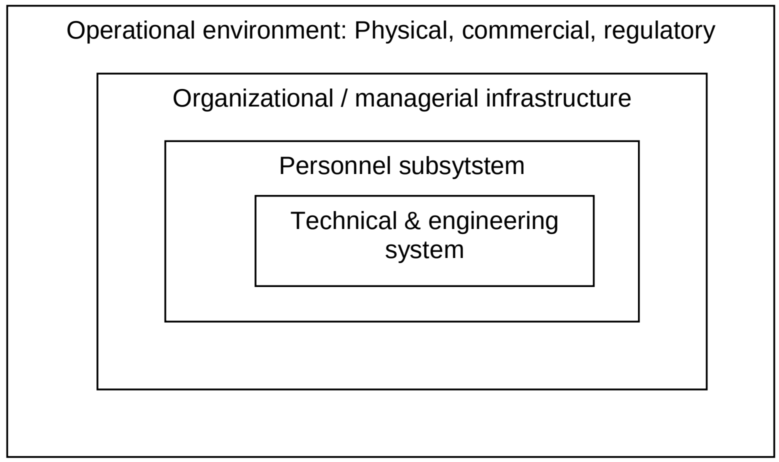


Figure 5.1: The component levels of the generic model of ships

Source: Formal safety assessment of containerships (Wang & Foinikis, 2000)

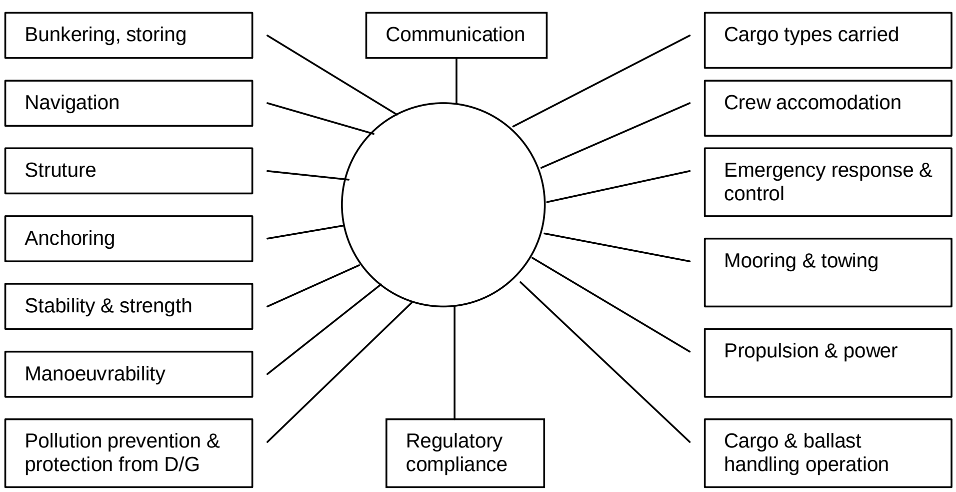


Figure 5.2: The generic engineering and technical system

Source: Formal safety assessment of containerships (Wang & Foinikis, 2000)

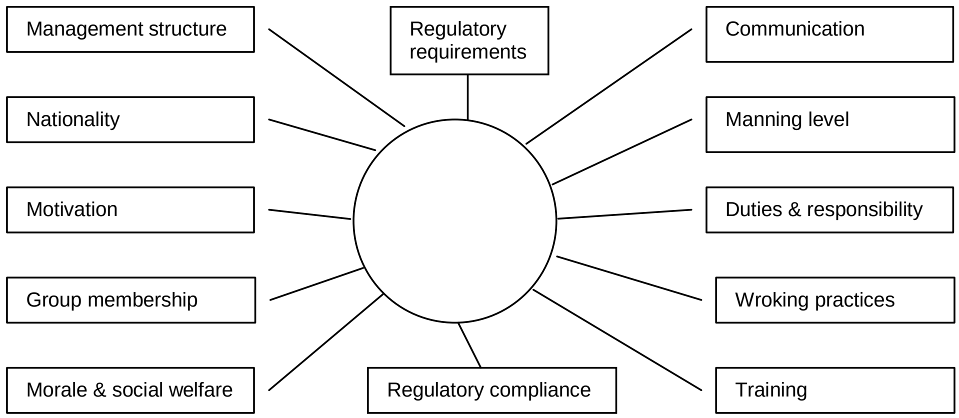


Figure 5.3: Personnel subsystem
Source: Formal safety assessment of containerships (Wang & Foinikis, 2000)

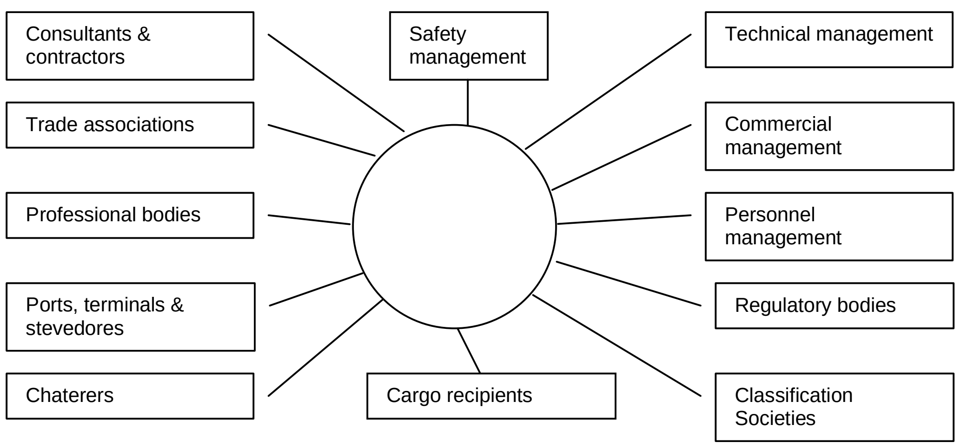


Figure 5.4: Organizational / managerial infrastructure
Source: Formal safety assessment of containerships (Wang & Foinikis, 2000)

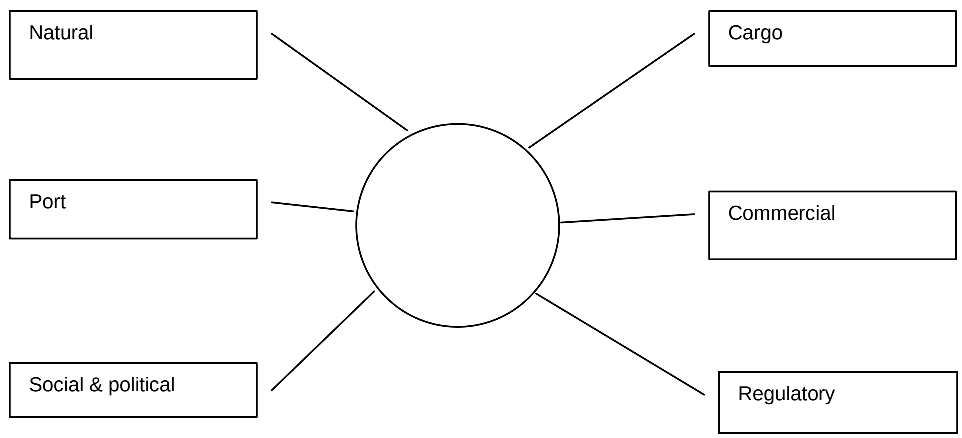


Figure 5.5: The generic environment of operation
Source: Formal safety assessment of containerships (Wang & Foinikis, 2000)

5.5.2. Hazard identification

Various techniques for hazard identification are available, to assure the completeness of the hazard identification, the techniques with "system structure" as discussed in chapter 4 should be considered, such as PHA, HAZOP, FMEA. Since this model ship is at operational stage, HAZOP and FMEA are adopted as the main techniques for this step, of course other techniques will be used as well for certain systems or certain purposes. Since risk assessment is a group work, brainstorming technique is always integrated in the whole procedure as a means of applying other techniques. In hazard identification all operational modes of the ship should be considered: (Wang, 2000)

- Entering and leaving port
- Berthing and unberthing
- Cargo and ballast operations
- Coastal navigation
- Open sea navigation
- Planned maintenance (day-to-day onboard)
- Major maintenance (dry docking)

To ensure the completeness of hazard identification, hazards should be explored in all subsystems: the engineering & technical system, the personnel subsystem, the organizational / managerial infrastructure and the operational environment. The underlying hazards or causal factors existed in the organizational / managerial infrastructure and the operational environment (related with commercial, political) cannot be easily identified, however, they will be explored in the risk analysis step. Therefore this step focuses on the engineering & technical system, the personnel subsystem and the operational environment (related with nature, port, other ships), in short, the hardware, the associated operations of the hardware and the natural environment of ships.

The identification of human related hazards should be conducted at the same time when the hardware is analyzed. For each subsystem in the engineering & technical system, the analysis of hardware and the task analysis of operations associated with that hardware should proceed together, like two parallel lines, the interaction and interface should be examined carefully. This can be illustrated by figure 5.6 as proposed by the author:

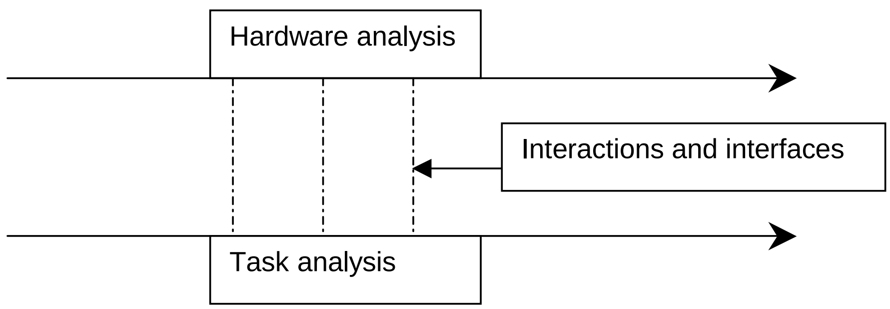


Figure 5.6: The integration of hardware analysis and task analysis (By the author)

Looking at the hardware of the ship, two requirements should be met to assure the completeness of hazard identification:

- All hardware should be analyzed
- All compartments should be analyzed, main compartments onboard ships are as follows (Wang, 2000):
    - Navigation Bridge
    - Cargo Spaces
    - Engine Room
    - Void Spaces

- Tunnels
- Upper Deck Areas
- Crew Accommodation
- Galley
- Provisions' Storage Spaces (including Bonded Stores)

To each subsystem of the hardware of the ship, suitable techniques should be selected according to its characteristics. The following is the suggested technique for different engineering subsystems:

HAZOP: for systems with continuous process, such as hydraulic systems, compressed air systems, fuel supply systems, ballast water systems.
FMEA: for mechanical systems and electrical systems, such as the main engine, generators, motors, electrical equipment.
Structured What-if technique or checklist: for other system not suitable for HAZOP and FMEA, such as hull, structure.

Take compressed air system for starting the ship's main engine as an example, this system is suitable to be analyzed by HAZOP: the objective of the compressed air system is to provide compressed air to start main engine. "Pressure" is an important property of this sub-system. By applying guidewords to the property --- "pressure" of the compress air system, possible deviations are generated, such as "No pressure", "More pressure", "Less pressure", and so on. Then the causes, consequences and mitigating actions will be analyzed for each deviation. Repeat the same procedure to all the properties of the sub-system, the comprehensive list of hazards in the compressed air sub-system and their causes, consequences and mitigating actions will be generated.

To the operations of the hardware, such as ship maneuvering, navigation, cargo handling, hazard identification should start from task analysis, which is the first step of Human Reliability Analysis, and then to each subtask, the following methods can be applied to identify hazards:

- Use guidewords to subtask like HAZOP

- Identify failure of performance like FMEA
- Ask What-if questions
- Checklist

Since the natural environment is not a structured system, the Brainstorming approach is a suitable solution for the hazard identification. Firstly it is necessary to list all natural environment factors by using brainstorming approach, and then to ask What-if questions to each factor, thereby identifying possible hazards associated with it. This can be conducted either separately or along with the hazard identification of hardware and operation. When it is conducted along with the hazard identification of hardware and operation, the same principle applies, firstly, identify the environmental factors that could affect each hardware or operations, such as hull, lifeboat launching, and then What-if questions will be asked to the environmental factors to generate the hazard list.

For each hazard identified, the causes, consequences should be analyzed and a semi-quantitative criticality analysis be conducted for the purpose of prioritization. Risk matrix can be applied for the criticality analysis. Risk matrix is a method to represent frequency, consequence and risk by using indices. The process is to assign indices to frequency and consequence, then the combination of frequency index and consequence index presents the risk index (IMO, 2000). The index can be determined according to table 5.1, 5.2, 5.3. Table 5.4 is an example of the outcome of hazard identification.

Table 5.1: Consequence Index
(*Source: IMO MSC 72/16*)

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

Table 5.2: Frequency Index (*Source: IMO MSC 72/16*)

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

Table 5.3: Risk matrix (*Source: IMO MSC 72/16*)

Risk matrix					
FI	Frequency	Severity			
		1	2	3	4
		Minor	Significant	Severe	Catastrophic
7	Frequent	8	9	10	11
6		7	8	9	10
5	Reasonably probable	6	7	8	9
4		5	6	7	8
3	Remote	4	5	6	7
2		3	4	5	6
1	Extremely remote	2	3	4	5

Table 5.4: Examples of hazard list (*IMO, MSC 74/INF.5/Add.1*)

Hazard	Effect	Cause	Suggested hazard frequency	Worst credible consequence	Suggested screening band
Poor wheelhouse visibility due to general low height of bridge structure	Encountered vessels cannot be observed easily. Potential for deck cargo to create blindspot. Increased collision potential.	Design compromise to allow transit under low bridges	5	1	6
Ability to maneuver limited, especially in close quarters situations at reduced speed.	Increased collision potential during port entry or exit.	Propulsion power to weight ratio of bulk carriers reducing. High windage when light ship.	4	2	6

5.5.3. Risk analysis

According to the prioritization, those hazards of minor significance are discarded from consideration of continuous analysis. Each significant hazard will be examined more deeply and in more detail with regard to the connection and dependency among hazards, causal factors, and the accident scenario. Therefore techniques with "tree structure" like Fault Tree Analysis, Event Tree Analysis, and Cause Consequence Analysis, MORTA are suitable to be applied here in this step.

The hazards generated can be very large in number and scattered; therefore it is meaningful to group them under accident categories according to their relevance, then each accident category will be analyzed by utilizing and structuring the information generated in hazard identification.

The generic accident categories of ships include: (Wang, 2001; IMO, 1997)

- Contact and / or Collision
- Flooding
- Foundered
- Grounding and / or stranding
- Hull damage, loss of hull integrity
- Fire / explosion
- Machinery damage (including electrical equipments)
- Oil spill
- Personal accidents
- Cargo damage

It is not convenient to apply techniques directly to the accident category, before the analysis, it is necessary to subdivide each accident category into subcategories according to certain parameters, for example, locations, operation modes. Then FTA is applied to each sub-category to explore the causal factors, and ETA is applied to develop the sequence of the accident category in order to show the final outcome of the accident. Figure 5.7 below is an example on accident category "fire" illustrating how fire accident category is subdivided, and FTA, ETA are applied to it.

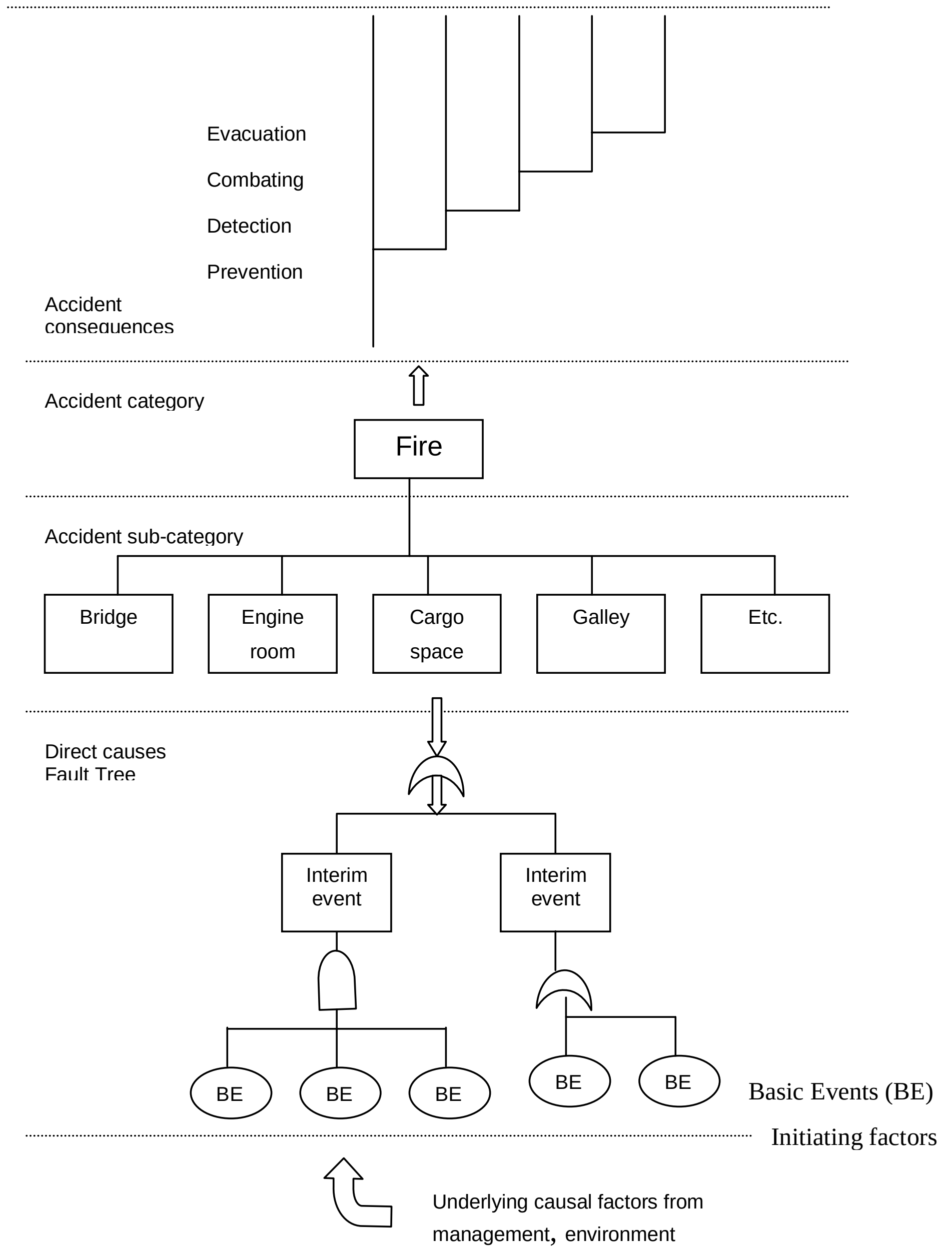


Figure 5.7: Risk Contribution Tree for fire
Source: Formal safety assessment of containerships (Wang & Foinikis, 2000)

As discussed in previous sections, maritime safety is heavily involved with human factors; therefore the human factor is an integral part of the risk assessment, meaning that human error is incorporated in the fault tree and event tree for each accident category. However, each accident category and subcategory is different in the degree of involvement of human factors, some accident categories and subcategories involve very complex operations, such as navigation of ships, especially under the context of the collision accident, it is very difficult to directly incorporate human errors into the fault tree and event tree for the collision accident. Therefore to such complex operations, the Human Reliability Analysis event tree introduced in Chapter 4.15.1 should firstly be developed as a basis for the development of the whole fault tree and event tree for the accident category. The HRA event tree will not only facilitate the understanding of the accident, but also facilitate the quantification of human errors.

This step will continue to explore the underlying hazards or factors in the management / organization infrastructure and the operation environment by using Fault Tree Analysis. For complex matters, MORTA technique can be applied to identify management deficiencies. The identification of underlying factors will help to identify corresponding risk control measures.

FTA produces the frequency of the accident sub-category, and then based on that ETA produces the frequency and consequence of each outcome, the combination of all outcomes produces the final risk level of the accident sub-category. Historical data will be used for the quantification process, expert judgement will be used to areas where data are not sufficient. Techniques could be used to assist the process of expert judgement, such as Delphi technique, the Nominal Group Technique, Brainstorming. Relative ranking technique can also be used to assist expert judgement in that the relative ranking of unknown probabilities can provide a basis for the generation of absolute value. The HRA techniques can be used to generate Human Error Probabilities. Table 5.5 below is an example of the distribution of risk among sub-categories of fire accident:

The sum up of the risk level of all accident categories will produce the final risk level of the ship.

Table 5.5: Cumulative table for fire sub-categories

Source: Formal safety assessment of containerships (Wang & Foinikis, 2000)

ACCIDENT CATEGORY: FIRE			
Compartment (Sub-category)	Potential loss of life (PLL)	Frequency (Per vessel / year)	Severity (max. observed)
Navigation bridge	2.2E-04	1.4E-04	1
Cargo space	6.6E-04	4.3E-04	4
Engine room	7.7E-03	5.3E-03	3
Void spaces	4.4E-04	2.8E-04	3
Tunnels	4.4E-04	2.8E-04	3
Upper deck areas	9.9E-05	6.4E-05	3
Crew accommodation	3.3E-04	2.1E-04	3
Galley	5.5E-04	3.5E-04	2
Provision stores	1.1E-05	7.1E-06	3

5.6. An ideal scheme of application of risk assessment to maritime safety

This Chapter has discussed various aspects of the application of risk-based approach to maritime safety; this section will present an ideal scheme of the application to maritime industry in order to give a comprehensive "picture" at macro level on how various maritime players could apply and benefit from this approach. Before doing that it is necessary to have a look at the main players concerning maritime safety, because they are the potential users of the risk-based approach. For the convenience of discussion, the main players can be roughly classified into the following groups:

- Ship owners, and associated commercial stakeholders, such as ship yards, insurance companies, P & I Clubs, financial organizations, ship brokers, chaterers, and so on
- Classification societies

- Governmental authorities: flag State Administrations, port State Administrations, environmental authorities, search & rescue organizations, port authorities, IMO, regional MOUs, and so on
- Seafarers' education and training establishments, research Institutes

The starting point is the ship design stage, a Safety Case is prepared by the ship owner, "A "Safety Case" is a written document prepared by the operator of an installation, onshore or offshore, to demonstrate that major potential hazards have been reduced to risk levels which are as low as reasonably practicable and that they will be effectively managed and controlled throughout the life cycle of the installation" (Kuo, 1998). This Safety Case is mainly used for:

- Selecting design options, and optimization of safety design
- Seeking approval of design from the classification society, and approval of exemption or equivalent safety arrangement from the classification society or the Administration
- Seeking financing from financing organizations

At operational stage, based on the initial Safety Case, the Safety Case for the operation of the ship is prepared, and mainly used to:

- Maintain and improve the safety management system of the shipping company;
- Instruct crew training in order to better understand the system relevant to their specific positions, improve operation and emergency response skill; and
- Demonstrate the safety level to stakeholders, like P & I Clubs, insurance companies, chaterers, customers, and governmental authorities.

The Risk-centered-maintenance system is developed and maintained by the classification society for the shipping company. Under the theory of Risk-centered-maintenance, maintenance is treated as a risk control measure, and assessed by cost/benefit analysis in order to achieve a balanced maintenance scheme of the whole system. To classification societies the information and data from RCM can also be used to guide the survey of the ship, and for the development of class rules.

Insurance companies, P & I Clubs and charterers will develop evaluation tools to assess the risk of ships, and usually a relative ranking / indexing system is used. The data from such evaluation systems will constitute the basis for them to assess the risk of certain group of ships that they deal with, and to adjust policy.

The rule-making process of the Administrations and classification societies will be assisted by Formal Safety Assessment. Formal Safety Assessment is "a structured and systematic methodology, aiming at enhancing maritime safety, including protection of life, health, the marine environment and property, by using risk and cost / benefit assessment" (IMO, 1997). In the enforcement of rules and regulations, governmental authorities and classification societies apply their evaluation tools to ships, usually a relative ranking system, such as Inspection Targeting System. The data from such evaluation systems will provide input and constitute the basis for the authorities and classification societies to assess the risk of certain group of ships, certain areas where these ships navigate, and to develop or adjust rules, regulations and policy.

In an ideal scheme, all people involved in maritime safety should understand the principle and philosophy of the risk-based approach, and apply it in daily work. The risk-based approach is a very flexible tool and should not be rigidly perceived only as a complicated process with quantitative mathematics calculations like Safety Case or FSA; it can also well be used in a simple, qualitative way, where the principle of the risk-based approach provides a systematic guidance to the logical thinking of people in daily work. In fact there is a close relation and interaction between these two ways of application: take a ship as an example, on one hand, the carefully prepared complicated Safety Case is a basis and provides valuable information to the simple, qualitative application in daily operations; on the other hand, the qualitative application in daily operations can produce and accumulate valuable inputs for the update of the Safety Case.

The ideal scheme is a dynamic scheme aiming at continuous improvement of safety. On one hand, new challenges arise, such as new technology, the changed environment, the established application like Safety Case should be updated to accommodate such changes; on the other hand, new experience and knowledge will improve people's skill in the risk-based approach thereby identifying better risk control measures, thus improve safety performance.

CHAPTER 6

Conclusion and recommendation

6.1 Review

Safety is perceived quality of a system under certain circumstance at a specific time, which is reflected by the extent to which the management, engineering and operation of a system is free of danger to life, property and the environment. Traditional approaches to safety have been successful and have contributed greatly to the improvement of safety throughout history. Plenty of precious experience have been accumulated through hard work by safety practitioners.

Risk is the combination of frequency and the severity of the consequence. Risk-based approach is the systematic process of making decisions on the bases of risk assessment, cost-benefit assessment, and implementation of risk control actions to reduce the risk to the acceptable level. As a proactive approach, the risk-based approach is able to further improve the safety performance in a cost-effective way, thereby justifying the necessity of its application to maritime safety.

The risk-based approach is a systematic process, which generally consists of risk assessment, identification of risk reduction measures, cost benefit (effectiveness) assessment and recommendations for decision-making. The uncertainty is inherent in the process of the risk-based approach, which is a major limitation of this approach and affect people's confidence in this approach. For an honest and convincing application of risk-based approach, the uncertainty should be identified, highlighted, and analyzed explicitly. "Be adequate for the needs" is the general principle to treat and control the uncertainty.

There are numerous techniques available for the risk-based approach, each of which has specific focus, structure, advantages and limitations. In order to use the capability and advantages of these techniques, this dissertation made a comprehensive discussion over the principle, procedure and characteristics of these techniques. The characteristics of each technique should be carefully examined when it is applied for certain purposes and certain areas.

The application of the risk-based approach should take into account the characteristics of the maritime industry. The maritime industry has its specific characteristics, such as hull integrity, stability, and the complex involvement of human factors. To the application of the risk-based approach, such characteristics imply new areas of analysis, new hazards, new causes and new consequences of accidents, and new ways of applying risk techniques. It is obvious that one technique could not satisfy all requirements of the application; a combination of techniques might provide a satisfactory solution, for this purpose, this dissertation presented the principle for the selection of appropriate techniques for the application, and a model case of risk assessment of a generic ship to illustrate how a combination of techniques may be applied to a ship in practice.

The risk-based approach is a powerful and flexible tool, which can be used by many players in the maritime industry to improve safety, such as ship owners, maritime Administrations, classification societies, and so on. This dissertation presented an ideal scheme illustrating how various players will apply and benefit from the risk-based approach.

6.2 The current situation and the future of the risk-based approach to maritime safety

The application of the risk-based approach to maritime industry is only at the initial stage, the wide application is still far away. Everybody knows the word “risk”, and is intuitively analyzing, assessing risks in daily work; however, very few do it in a scientific and systematic way.

Shipping is an industry with great diversity, ships range from small wooden ships to VLCC, navigation areas range from lake, inland water to ocean globally, shipping companies range from “single ship company” to giant companies like MAERSK, ship types range from passenger ships, different cargo ships, to high speed crafts. This diversity implies that flexibility is needed for the application of the risk-based approach. On the other hand, considering the similarity existed among ships, or certain groups of ships, there is the possibility to develop simple tools (model case) as basis for the development of specific Safety Cases, so that shipping companies do not have to start to develop Safety Cases for its ships from the very beginning, thereby reducing cost and enhancing efficiency.

The debate over the prescriptive approach and the risk-based approach to the maritime regulatory regime has been going on for years. In fact both approaches have advantages and disadvantages. Nevertheless, the exclusive use of prescriptive approach or full substitution of it with risk-based approach is not possible and reasonable in the future. The best way should be the combination of both approaches by using the capabilities of both. The combination will undergo the following stages depending on the degree of knowledge, skill, confidence and acceptance of the risk-based approach in the future:

1. Prescriptive rules are applied to ships, the development and amendment of such rules is based on the risk-based approach. The risk-based approach is an input to prescriptive approach at this stage.
2. In some areas risk-based requirements will be developed in order to accommodate more flexible safety arrangements. Such risk-based requirements will increase eventually. There are three possibilities for this:
    a. New risk-based requirements are developed.
    b. Risk-based requirements come as an alternative to certain prescriptive rules, and the choice is left to the users.
    c. Certain prescriptive rules will be replaced by risk-based requirements.
3. Risk-based requirements are applied to the whole ship as an alternative to prescriptive rules, this will happen when people have acquired considerable

confidence in the risk-based approach and it will be applied to restricted groups of ships as follows:

a. Certain ships that need more flexible arrangement and are navigating fully under the jurisdiction of only one Administration.
b. Certain ships that need more flexible arrangement and are navigating under the jurisdiction of several Administrations, on condition that the regional agreement or memorandum is reached among the Administrations concerned.

The importance of reliable data to the risk-based approach is obvious. At present many players in the maritime sector have databases serving for their own interests, however, these kinds of databases could not cope with the demands from wide application of the risk-based approach globally. Therefore a new global database might be established by an international organization like IMO, so as to ensure the availability and reliability of data and the effectiveness of the risk-based approach accordingly.

6.3 Recommendations

Taking into account the current situation and the future development of the risk-based approach to maritime safety, promote its application in the maritime industry, the author would like to proposes the following:

Firstly, the understanding of the basic concept, principle of the risk-based approach of all people involved in maritime safety should be promoted, this is the basis for the wide acceptance and application the risk-based approach. The risk-based approach should not be construed as something only used by scientists or high level decision-makers, the operational people, in fact, need this knowledge most because they are the direct human factors affecting safety, the understanding and utilizing of such knowledge by them will greatly benefit the improvement of safety performance.

Secondly, a unified database structure should be established. As previously mentioned, an international data is the best solution for the application of the risk-based approach to maritime safety, it seems very difficult to be realized in the near future. Considering the fact that many countries have their own database system for casualties and accidents in different structures, a unified database structure could be preferable solution, since a excellent unified database structure will not only benefit the data collection for the Administrations, classification societies, and so on, but also provide the potential for the data sharing in the future.

Thirdly, model tools of the Safety Case should be developed. As previously mentioned, the similarity of ships makes it possible to develop model tools of the Safety Case for ships, Considering the knowledge and expertise required to develop the Safety Case, the model tools will greatly reduce the difficulty and enhance efficiency thereby reducing cost and benefiting the shipping companies, especially small companies.

Lastly, further researches need to be made to improve the skill of risk assessment. As previously mentioned, the current techniques have limitations in addressing certain problems, for example the inability of current HRA techniques in addressing "errors of commission". A ship is a very complex system that involves many different accidents and very complex human factors, and the application of the risk-based approach is at the initial stage, there are many areas that need to be investigated and researched. Therefore not only the risk assessment techniques need to be developed, but also the practical aspects of application be researched.

The application of the risk-based approach to maritime safety is only at the early stage, there are still disputes on the feasibility and effectiveness of the application of this approach to maritime safety. Nevertheless, it does provide a positive direction towards the further improvement of safety. There is still a long way to go, it also needs to be improved in order to be applied appropriately to maritime safety, so that its value could eventually be recognized and it will gain wide acceptance and utility in the future.

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Appendix:

Typical examples of the application of risk-based approaches to maritime safety

1. Safety Case

The Safety Case was introduced to the UK offshore industry by the UK Health & Safety Executive (HSE). “A “Safety Case” is a written document prepared by the operator of an installation, onshore or offshore, to demonstrate that major potential hazards have been reduced to risk levels which are as low as reasonably practicable and that they will be effectively managed and controlled throughout the life cycle of the installation.” (Kuo, 1998) The key elements of the Safety Case are the following: (Kuo, 1998)

- Hazard identification
- Risk assessment
- Risk reduction
- Emergency preparedness
- Safety management system

In principle, the Safety Case approach can be applied to ships, and in fact there are several applications to ships on voluntary basis. Focusing on the individual ship, the Safety Case is a comprehensive assessment of the whole system including the hardware of the ship, crew and management, with regard to the risk to life, property and environment. Therefore the Safety Case can be used by the ship owner to assess, control and demonstrate the safety level of their ships, and the company itself.

2. Formal Safety Assessment (FSA)

Formal Safety Assessment is introduced by IMO to facilitate the rule-making process. “It is a structured and systematic methodology, aiming at enhancing maritime safety, including protection of life, health, the marine environment and property, by using risk and cost / benefit assessment" (IMO, 1997). The focus of FSA is not the individual ship, it is intended to be applied generically to a group of ship, such as a type of ships, all ships, and so on. FSA comprises five steps: (IMO, 1997)

- Identification of hazards
- Risk assessment
- Risk control options (regulatory options)
- Cost benefit assessment
- Recommendation for decision-making.

3. The Green Award System

The Green Award certification scheme is developed by the Rotterdam Municipal Port Management aiming at improving safety and environmental standards on board ships. (Germanischer Lloyd, 1999) This system emphasizes environmental protection more than safety. Based on the audit of the ship, crew and management with respect to the compliance with national and international requirements, the ship is assessed by scoring each item audited. Depending on the total score, the ship will be awarded a certificate, which will bring to that ship certain reduction in the normal port fee as an incentive for safety and environmental protection. The Green Award System is a pure risk indexing system applied to individual ships with respect to the compliance of law.

4. The International Marine Safety Rating System (IMSRS)

The IMSRS was developed by Det Norske Veritas (DNV) for the measurement of the status of a safety management system, it focuses on the control of loss related with life, health, property and environment. Based on management system audit and physical condition checks, the safety management system is assessed and scored, the sum of points shows the "Level of Excellence" of the safety management system, which arranges from level 1 to level 10. This is a Risk Indexing system applied to management system concerning loss control, and can be used by insurance companies, P & I Clubs for the evaluation of shipping companies and ships. (Germanischer Lloyd, 1999)

5. Inspection targeting system

Inspection targeting system is used by the Administrations to set priority of ships to be inspected. The philosophy is that the limited resources should be used to select and inspect the ships with highest risk. Each ship is assessed against a set of targeting factors, the sum of that will give the targeting value of that vessel, then priority can be set according the ranking of targeting values of ships. This is very convenient relative ranking system for ships. (Germanischer Lloyd, 1999)

6. Risk-centered-maintenance (RCM)

Traditionally maintenance is based on the recommendation from the manufacture, which only consider the failure from the technical perspective, not form the perspective of probability of failure and consequence to the whole system concerned. Under the theory of Risk-centered-maintenance, maintenance is treated as a risk control measure, and is assessed by cost/ benefit analysis in order to achieve a balanced maintenance scheme of the whole system. The general procedure of Risk-centered-maintenance is as follows: (Child, 1997)

- Identify failure mode
- Analyze likelihood and consequence of failure mode
- Identify the means of maintenance
- Analyze effectiveness of maintenance
- Cost benefit analysis of maintenance
- Implementation of maintenance, verify the effectiveness and improve if necessary