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# Risk Management System – Risk Assessment Frameworks and Techniques

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# RISK MANAGEMENT SYSTEM – RISK ASSESSMENT FRAMEWORKS AND TECHNIQUES

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# ABBREVIATIONS

| | |
|---|---|
| ACS | – American Chemical Society |
| AEA | – Action Error Analysis |
| AHP | – Analytical Hierarchy Process |
| ALARA | – As Low As Reasonably Applicable |
| ALARP | – As Low As Reasonably Practicable |
| BATNEEC | – Best Available Technology Not Entailing Excessive Costs |
| BDD | – Binary Decision Diagram |
| CARAT | – Chemical Accident Risk Assessment Thesaurus |
| CBA | – Cost Benefit Analysis |
| CCPS | – Center for Chemical Process Safety, American Institute of Chemical Engineers |
| CEA | – Cost Efficient Analysis |
| CEN | – Comite Europeen de Normalisation – Committee for Standardisation |
| CERCLA | – U.S. Comprehensive Environment Response Compensation and Liability Act |
| ChA | – Change Analysis |
| CIA | – Chemical Industries Association |
| CMPT | – Centre for Maritime and Petroleum Technology |
| CRTD | – Convention on Civil Liability for Damage Cause during Carriage of Dangerous Goods by Road, Rail and Inland Navigation Vessels |
| CRN | – Comprehensive Risk Analysis and Management Network |
| CTU | – Cargo Transport Units |
| DCDEP | – Directorate for Civil Defense and Emergency Planning, Norway |
| DETRA | – Department of the Environment, Transport and the Regions, UK |
| DFT | – Dynamic Fault Free |
| DG | – Dangerous Goods |
| DGSM | – Australian Dangerous Goods Safety Management Act |
| DMI | – Danish Maritime Institute |
| DNV | – Det Norske Veritas |
| EC | – European Commission |
| ECFCh | – Event and Causal Factor Charting |
| EMAS | – EC Eco-Management and Audit Scheme |
| EMS | – Environmental Management Systems |
| ETA | – Event Tree Analysis |
| EU | – European Union |

| | |
|---|---|
| FMEA | – Failure Modes and Effects Analysis |
| FSA | – Formal Safety Assessment |
| FTA | – Fault Tree Analysis |
| GCAF | – Gross Cost of Averting a Fatality |
| HAZOP | – Hazard and Operability |
| HCl | – Hazard Checklists |
| HNS | – International Convention on Carriage of Hazardous and Noxious Substances by Sea |
| HR | – Hazard Review |
| HRA | – Human Reliability Analysis |
| HSC | – Health and Safety Commission, UK |
| HSE | – Health and Safety Executive, UK |
| ICAH | – Implied Cost to Avert the Hazard |
| IEC | – International Electrotechnical Commission |
| ILO | – International Labour Organisation |
| IMDG Code | – International Maritime Dangerous Goods Code |
| IMO | – International Maritime Organization |
| IMSRS | – International Maritime Safety Rating System |
| IOMC | – Inter-Organisation Programme for the Sound Management of Chemicals |
| ISO | – International Organisation for Standardizations |
| LNG | – Liquefied Natural Gas |
| LPG | – Liquefied Petroleum Gas |
| LRS | – Lloyd's Register of Shipping |
| MAIB | – Maritime Accident Investigation Branch |
| MARCS | – Marine Accident Risk Calculation System |
| MAUA | – Multi-Attribute Utility Analysis |
| MCA | – Multi-Criteria Analysis |
| MEPC | – IMO's Marine Environment Protection Committee |
| MORT | – Management Oversight and Risk Tree |
| MSC | – IMO's Maritime Safety Committee |
| NCAF | – Net Cost of Averting a Fatality |
| NN | – Neural Network |
| OECD | – Organisation for Economic Co-operation and Development |
| OSHA | – USA Occupation, Safety and Health Administration |
| PA | – Pareto Analysis |
| PARI | – Port Activity Risk Index |
| PDG | – Packaged Dangerous Goods |
| PRA | – Probabilistic Risk Assessment |
| PrHA | – Preliminary Hazard Analysis |

| | |
|---|---|
| PrRA | – Preliminary Risk Analysis |
| PSC | – Port State Control |
| PWRA | – Port and Waterway Risk Assessment Guides |
| QRA | – Quantitative Risk Assessment |
| RBCA | – Risk Based Corrective Action |
| RBDM | – USCG Risk-Based Decision-Making Guidelines |
| REM | – Risk-Effect Model |
| RI | – Relative Ranking/Risk Indexing |
| RMSI | – Risk Management Specific Interest Group |
| RSA | – Swedish Rescue Services Agency |
| RSSG | – Royal Society Study Group, UK |
| SAFECO | – Safety of Shipping in Coastal Waters – EU Project |
| SC | – Safety Case |
| SDR | – Special Drawing Rights |
| SMA | – Swedish Maritime Administration |
| SMS | – Safety Management System |
| SRA | – Society for Risk Analysis |
| SOLAS 74 | – International Convention for the Safety of Life at Sea, 1974 |
| TSE | – Turku School of Economics, Logistics, Turku, Finland |
| UKOOA | – UK Offshore Operators Association |
| USDOT | – U.S. Department of Transportation |
| UN | – United Nations |
| UNEP | – United Nations Environment Programme |
| UNIDROIT | – International Institute for the Unification of Private Law |
| UNIDO | – United Nations Industrial Development Organization |
| UNITAR | – United Nations Institute for Training and Research |
| USCG | – U.S. Coast Guard |
| USEPA | – U.S. Environmental Protection Agency |
| VRI | – Vessel Risk Index |
| WSA | – Work Safety Analysis |
| WET | – Waterway Evaluation Tool |
| WHO | – World Health Organisation |

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# 1 INTRODUCTION

## 1.1 Background

This report deals with the risk management system and risk analysis frameworks and techniques. The report is part of the Safe and Reliable Transport Chains of Dangerous Goods in the Baltic Sea Region (DaGoB) project[1] and the author's[2] own research. The main aims of the DaGoB project include: a) improve co-operation at various levels among parties involved in the transport of dangerous goods in the BSR; b) provide up-to-date information on cargo flows, supply chain efficiency and risks related to the transport of dangerous goods; and c) disseminate and transfer the knowledge gained from the project on local, national, regional and international levels (TSE 2006). The project involves numbers of partners from countries of the Baltic Sea Region (BSR), such as Finland, Sweden, Germany and the Baltic States. The leading partner is Turku School of Economics, Logistics, Turku, Finland.

The author's research work concerns the development of a risk analysis framework for readily application in the maritime transport system of PDG (Packaged Dangerous Goods) as well as the demonstration and validation of the framework in practice. One of the main parts of the thesis is the "Frame of Reference", which provides relevant definitions, concepts and theoretical models in the essential interrelated research areas, such as: a) the maritime transport system of PDG; b) risks of dangerous goods accidents/incidents; and c) *the risk management system* (see Figure 1). The "Frame of Reference"[3] serves as a theoretical platform for the development of the risk analysis framework. The framework development involves exploration of many relevant concepts and their relationships. It is based on the review of a wide range of risk assessment frameworks and techniques and some of the world's best practices in the field. This report deals with one of the research areas, namely: the *risk management system* (see the *highlighted areas* in Figure 1).

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[1] The DaGoB project is partly financed by the European Union (European Regional Development Fund) within the BSR INTERREG III B Neighborhood Programme.

[2] The author of this report is a PhD student at Lund University, Institute of Technology, Department of Industrial Management and Engineering Logistics, Sweden. Lund University is one of the partners in the DaGoB project.

[3] The "Frame of Reference", which is Chapter 3 of the author's thesis, is a summary version of this and another report (see Mullai 2006).

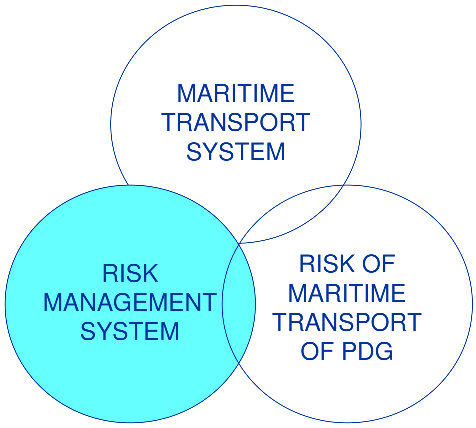


**Figure 1**: The Frame of Reference – key research areas

## 1.2 Purpose

In the context of the DaGoB project objectives, the purpose of this report is to provide unified understanding of the field of risk management. This report is aimed primarily at risk analysts, risk managers as well as other people who are interested in risk issues, risk analysis and management. Based on the review and study of many risk assessment frameworks and techniques employed in shipping and other industries and sectors, this report explores some of the best practices in the field. The main stages and steps of the risk analysis process are also explored, and are further developed for readily application in risk analysis of the maritime transport system of PDG (see Mullai 2004).

## 1.3 Methods and materials

The report is based on the understanding gained through an extensive literature review and personal research work (see Mullai and Paulsson 2002; Mullai 2004). Detailed information about the methods and materials used in this report is provided in the author's PhD thesis.

## 1.4 Report outline

The rest of the report consists of two interrelated Chapters (as shown in the highlighted areas in Figure 1). In Chapter 2, efforts have been made to provide unified understanding of the field of risk management. Chapter 2 presents a conceptual model of the risk management system, based on which this Chapter is largely organised (see Figure 3), consisting of a number of interrelated phases, stages, steps and sub-steps. Each constituent element is explored in some detail. In Chapter 3, which is structured according to Figure 2, many risk assessment frameworks and techniques available as well as some of the related best practices in shipping and other industries and sectors have been reviewed. In this Chapter, the merits of risk analysis techniques and factors affecting their choices are also explored. At the end of Chapter, the main generic stages, steps and sub-steps explored through the review are presented. For the purpose of illustration or demonstration, the report provides several illustrative examples – see boxes with the highlighted text. The report concludes (Chapter 4) with concluding remarks concerning topics and issues raised in this report. Based on inferences and understanding gained in this study, in this chapter some research areas and questions for future studies and recommendations of improving safety and health and environment protection in the BSR are provided. The Attachment contains relevant information related to the contents of the report.

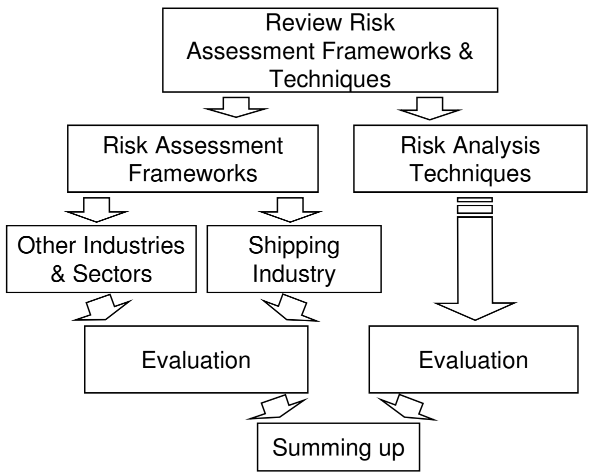


**Figure 2:** The structure of Chapter 3

# 2 RISK MANAGEMENT SYSTEM (RMS)

*In this Chapter attempts have been made to provide unified understanding of the field of risk management. The Chapter begins with a few of many definitions of the central concepts, namely risk analysis, assessment and management. Then, the definition of a unified concept of the risk management system is provided. Based on the understanding gained in this research, a conceptual model of the risk management system has been presented. The Chapter explores in some detail the main phases and stages of the risk management process (see Figure 3).*

## 2.1 Terms, definitions and concepts

Despite of the significant progress being made across many countries, industries and sectors, there are still misconceptions, misuses and ambiguities in the field of risk management. Based on the understanding gained through the extensive literature review, library study and research work experience, in this Chapter attempts have been made to provide a unified understanding of the field. Table 1 provides a few of many definitions available.

The field of risk management is faced with difficulties in defining and agreeing on principles. Risks are dealt with differently across different countries, industries and sectors (DCDEP 2000). Terms, definitions and interpretations are as varied as the number of sources providing them. There are no agreed unified definitions of risk analysis, assessment and management. There are often misconceptions. Different terms, for example “risk analysis” and “risk assessment”, are often used interchangeably. Further, a single term may be used in different ways, meanings or contexts. For example, although the term “analysis” may be narrower than the term “management”, the Society for Risk Analysis (SRA 2004) has chosen to broadly define the term “risk analysis” as the process that includes risk assessment, risk characterisation, risk communication, risk management, and policy making. The EC Health and Consumer Protection Directorate (EC 2000a) defines the term “risk analysis” as the encompassing term used to describe three major sub-fields of the discipline, namely: risk assessment, risk management and risk communication. Further, the Comprehensive Risk Analysis and Management Network (CRN 2004), which is a Swiss-Swedish workshop network initiative for international cooperation among governments, academics and industries and sectors, employs a similar definition of “risk analysis” as those stated above.

**Table 1**: Terms and definitions - risk analysis, assessment and management

| Terms | Definitions and Sources |
|---|---|
| *Risk Analysis* | • The development of a quantitative estimate of risk based on engineering evaluation and mathematical techniques for combining estimates of incident consequences and frequencies (USEPA and CEPPO, from CARAT[4] 2001).<br>• The use of available information to estimate the risk to individuals or populations, property or the environment from hazards. Risk analysis generally contains the following steps: scope definition, hazard identification, and risk estimation (NOVA Chemicals Corporation Canada, from CARAT 2001).<br>• The process in which the risks of a certain activity are evaluated in quantitative terms (RIVM, the Netherlands, from CARAT 2001). |
| *Risk Assessment* | • The process of risk analysis and risk evaluation (NOVA Chemicals Corporation, Canada, from CARAT 2001).<br>• The process in which analysed risk is judged for its acceptability (RIVM the Netherlands, from CARAT 2001). |
| *Risk management* | • Risk management is the process of weighing policy alternatives and selecting the most appropriate regulatory action, integrating the results of risk assessment with additional data on social, economic and political concerns to reach a decision implying the following approach: identification of chemicals for consideration, risk assessment, risk evaluation, and risk mitigation or reduction (EC 1997a).<br>• Risk management is a formal process for managing risks. The process consists of system definition, hazard identification, identification of accident scenarios, quantification of probabilities and consequences, assessment of risk, identification of risk control options, decision on implementation, identification and management of residual risk (EC 1999).<br>• Risk management includes a range of management and policy-making activities, such as agenda setting, risk reduction decision-making, programme implementation, and outcome evaluation (ACS 1998).<br>• Risk (safety) management is the on-going process of controlling risk as part of the management of ship operation. It encompasses tasks such as commissioning risk assessments, making decisions about the recommendations emerging from studies, and implementing and monitoring the chosen solutions (DNV 1996). |

[4] CARAT stands for Chemical Accident Risk Assessment Thesaurus. This is a database of laws, regulations, guidance standards and definitions of terms related to risk assessment. CARAT contains information from various international, national and regional agencies, organisations, and chemical companies, including the European Union and individual countries, the USA, Canada and other OECD countries.

Variations arising in terminology, definitions, concepts, as well as methodologies and practices are the result of a wide range of different factors, including: a) different perceptions, attitudes and values regarding risks in different socio–economic-political contexts; and b) different needs and specifications of diverse industrial sectors and risks specifications in various regions and countries. There are difficulties in agreeing on the principles in the field, because each country has its own priorities, local communities, central authorities and different kinds of legislation (DCDEP 2000). The variations in the shipping industry, for example, may arise from the need to accommodate specifications of the systems and risks involved. The roots of differences in the field may also be the result of the diversity in languages and interpretations and the national social-cultural environment contexts.

## 2.2 A unified concept of the risk management system

As mentioned above, people have often chosen to adopt various views in the field of risk management. In recent years, although some sources may have a narrow view, the term "risk management system" may be used to represent the broadest concept, in particular in the field of human safety and health, the environment and property protection, and in the chemical and shipping industries. A few of many similar terminologies in use include: "Safety Management System" (SMS) (Demichela et al. 2004) (Basso et al. 2004), "Integrated Safety Management System" (Trbojevic and Carr 2000), "Risk-Based Decision Making" (USCG 2001) (EC 2000b), "Risk Policy-Making System", "Social Governance of Risks" (TRUSTNET 2002)[5] "Integrated Socio-Economic Risk Management" (OECD 2000), "Risk Management" (IEC 1995) "Sound Risk Management", "Total Risk Management System" and "Safety, Health and Environmental Management System." In the following Section, attempts have been made to provide a unified understanding of the central concepts related to the risk management system.

The *risk management system* is the overall integrated process consisting of two essential interrelated and overlapping, but conceptually distinct components – *risk assessment* and *risk management*. In recent years,

[5] The term is defined by TRUSTNET (2002), which is a pluralistic and interdisciplinary European network involved in the field of Risk Governance. Its steering committee consists of representatives of major organisations dealing with risk governance, including European national regulatory bodies and representatives of the European Commission.

however, risk communication has become an important integrated component of the risk management system. Risk assessment, which is identical to safety assessment, is an element of the system that consists of *risk analysis* and *risk evaluation* (RSSG 1992) (Emslie 2001) (IEC 1995). However, in many cases, the terms “risk analysis” and “risk assessment” are used interchangeably. *Risk analysis* is a scientific process in which, by applying a wide range of methods, techniques and tools, risks are identified, estimated and presented in qualitative and/or quantitative terms (DNV 1995). *Risk evaluation* is the process of comparing estimated risks with established risk evaluation criteria (e.g. criteria based on the best available technology, legal requirements, practices, processes, or achievements) in order to determine the level or significance of risks and provide recommendations for the decision-makers at various levels (EC 1999). *Risk assessment* combines both risk analysis and risk evaluation, providing practically useful and logically structured inputs and perspectives about risks to the decision-making process, development of policies, strategies and measures for managing risks. Although risk assessment provides basic inputs for helping decision makers to make better, more logical and informed decisions, it may not necessarily provide answers to many questions, for example, questions concerning the level of risks, trade-offs in risk control, costs and benefits. A wide range of factors, such as the society’s values, priorities and perceptions, influences the issues mentioned. Dealing with these issues also requires consideration of factors other than technical and scientific ones.

## 2.3 Main components of the risk management system

The following Section is based on the review and study of some of the world’s best risk management practices, frameworks and techniques in shipping and other industries, sectors and activities. They include the works of the following: a) institutions or organisations: the OECD (OECD 1994, 1996, 2000); the U.S. Coast Guard (USCG 2001); the U.S. Environment Protection Agency (USEPA 1989, 2000); the UK Health and Safety Executive and Commission (HSC 1991; HSE 1992, 1995, 1997, 1999, 2001, 2002); the International Maritime Organisation (IMO 1997, 2002, 2004, 2006); the European Commission (EC 1993, 1997, 1999, 2000); the German Lloyd’s and Det Norske Veritas (DNV 1995, 1996); the ISO and IEC (ISO 1999) (IEC 1995); and others (CCPS 1989, 1992; ACS 1998; DETRA 1999; RSSG 1992; CMPT 1999); b) individual researchers (Vincent et al. 1993; Weigkricht and

Fedra 1993; Saccomanno and Cassidy 1993; Rasmussen 1995; Nicolet-Monnier and Gheorghe 1996; Frewer 2004) and many other works quoted elsewhere in this report.

The risk management system is defined and described prior to the review and evaluation of risk assessment frameworks and techniques, which are presented in Chapter 3. The risk assessment frameworks and techniques are the constituent elements of the overall risk management system.

The model (Figure 3) shows the generic constituent components of the risk management system. As mentioned above, the risk management system is a stepwise process consisting of the following interrelated but distinct phases: *risk assessment* (analysis and evaluation) and *risk management*. Each phase consists of a number of stages, steps and sub-steps that, in principle, are sequential. However, in many situations, this may not necessarily be so. Researches in the field of risk management are, in many cases, carried out on the ad-hoc basis. Initiation of the process is triggered by combinations of different factors at any given time, including the seriousness of accidents, threats, issues or concerns, the availability of resources, the availability of additional and/or new data, and improvements and/or developments of more advanced methods and tools. The process may start at any point and involve any individual component of the system. The literature study shows that each component of the system may be considered a specific field or branch of science in its own right.

The wheel form of the risk management model (see Figure 3) represents a dynamic model. The overall risk management process has a hierarchical structure form consisting of different levels, in which the highest levels are further broken down into stages, steps and sub-steps. The processes are interactive, where changes, re-evaluations and refinements may often take place. Although shown in a sequential and seamless order – i.e. risk analysis, risk evaluation and risk management – some stages and steps may be carried out and accomplished simultaneously. Skipping processes and returning to the earlier processes are also possible. This is due to a variety of factors, including the availability and accessibility of additional and/or new risk-related data and information, the breadth and depth of the analysis, results of the study, re-evaluations and redefinitions, and decision-making alternatives.

In many situations, it may be considered unnecessary to go through all the phases and stages shown in the model (see Figure 3). The process may be suspended at any given phase/stage and time. For example, the risk analysis process can be suspended, that is suspended from going through into a more detailed analysis, if risks are found to be at a low or negligible level and further study may be deemed unnecessary and cost inefficient.

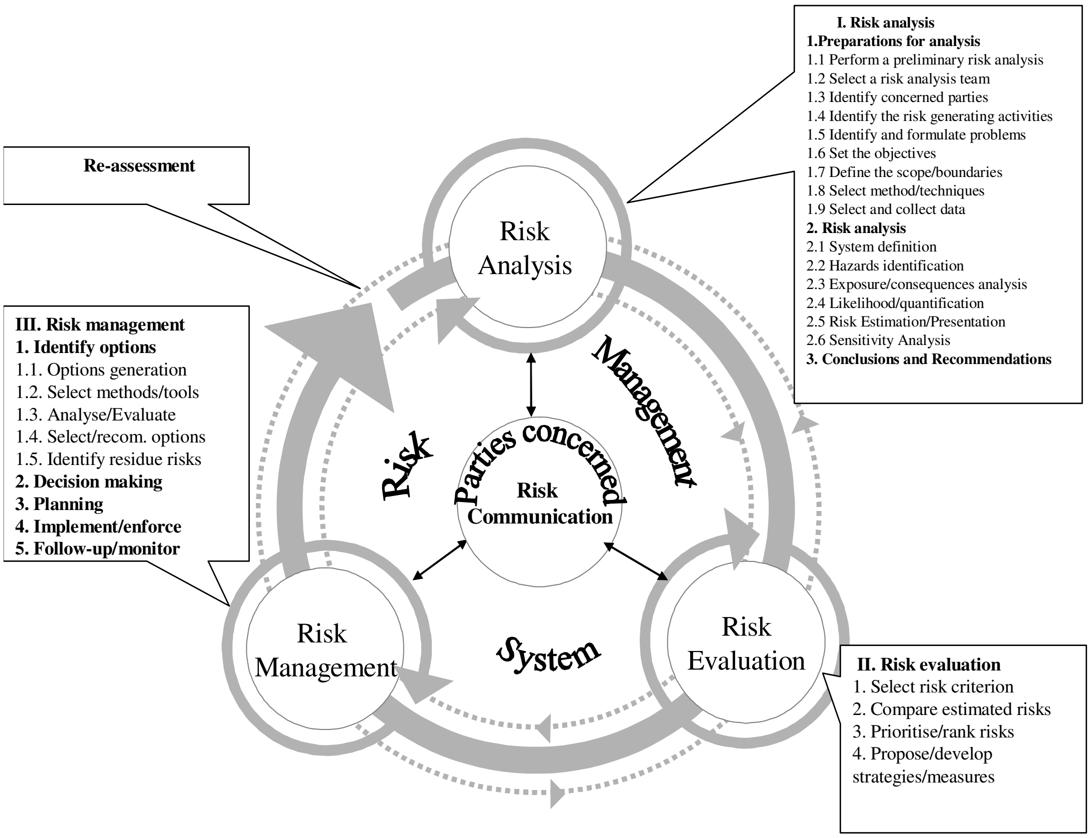


**Figure 3**: Main phases, stages and steps of the risk management system

The following Section describes in some detail the key elements of the risk management system.

### 2.3.1 Phase 1: Risk analysis

Risk analysis is the process in which risks are examined in various degrees of detail – qualifying and quantifying – to determine the extent of risks, how risk components are related to each other, and which ones are the most important to deal with. This may not necessarily involve any consideration of the significance of risks (DNV 1996). The main stages of risk analysis are: 1) *preparations for analysis*, 2) *risk analysis process* and 3) *conclusions and recommendations*. These main stages consist of a number of steps and sub-steps or tasks, which are identified and further developed based on the combination of empirical data and the literature review, including these sources (HSC 1991) (Ertugrul 1995) (Weigkricht and Fedra 1993) (DNV

Technica 1995) (UK DETRA 1999) (OECD 2000) (IEC 1995) (ISO 1999) (CARAT 2001) (Saccomanno and Fedra 1993) (Vincent and Milley 1993). This phase is further developed for readily application in analysis of risks of the maritime transport of PDG. A detailed discussion about this phase is provided in Mullai 2004.

### Stage 1: Preparations for the risk analysis

Preparations for risk analysis consist of the following key steps:

- *Background:* Establish the particular context based on which risks of the maritime transport of dangerous goods will be analysed and evaluated and decisions will be taken. Without the context, without knowing how the risks of dangerous goods can be compared to other risks, it is hard to put these risks into perspectives.
- *Perform a preliminary or screening risk analysis*: For example, perform a preliminary risk analysis in terms of types of marine accidents, ships, dangerous goods, vessel traffic, activities, and geographical locations.
- *Determine who should conduct risk analysis:* Set up a team of risk analysts, whose members are familiar with the maritime transport system of PDG, risks and risk analysis methods and techniques, including other knowledgeable persons with a variety of relevant expertise in the field.
- *Identify interested parties*: Identify parties that are concerned with risks issues and affected by decisions, such as decision or policy makers, shipowners, cargo interests, employees, and many other parties interested in the maritime transport of PDG.
- *Identify risk generating activities*: Identify risk generating activities, such as packing, handling, stowage, loading and unloading, and transport of PDG.
- *Identify and formulate problems:* Some generic issues include human safety and health, marine environment pollution, property damage, security and economic aspects.
- *Set the objective(s) of risk analysis:* A principle objective of every risk study is to provide decisions makers with information and tools.
- *Define boundaries*: Define the system or physical and analytical boundaries of the study.
- *Select appropriate methods and techniques*: Based on the amount, type and quality of data, the time and resources available, and the legal requirements, if any, select the appropriate methods and techniques.

- *Collect relevant risk-related data and information:* Identify the data sources and collect the risk-related data and information sets.

## Stage 2: Risk analysis

Risks analysis varies from simple to very complex and detailed. A preliminary analysis may be conducted prior to detailed risk analysis. The stage of risk analysis consists of the following key steps and sub-steps:

### *Step 1: System definition*

- *Maritime transport system*: define and describe the system and related activities whose risks are to be analysed and managed – the maritime transport system and related activities of PDG.
- *Regulatory system*: review and evaluate the current state-of-the-art regulatory system governing the maritime transport system of PDG.

Based on risk-related data and information and risk analysis techniques, analyse risk attributes including:

### *Step 2: Hazards identification*

- *Define top events*, including the wide rage of breaches and failures of packages.
- *Explore transport/distribution hazards*, including their cause and contributing factors and sequences of events that have or can lead to loss of containment and/or involvement of dangerous goods.

### *Step 3: Exposure and consequences analysis*

- *Dangerous goods and their hazards*: Explore the list/inventory of PDG and their hazards that have or are likely to cause consequences to the risks receptors.
- *Dangerous goods release-dispersion-concentration*: Explore sequences of events following the release, dispersion, concentration and/or involvement of dangerous goods that can lead to consequences for the risk receptors.
- *Modes of contact - the routes of exposure*: Explore the ways and routes through which dangerous substances and/or hazards come into contact and affect the risk receptors.
- *Dose-effect assessment*: Explore and assess dose-effect relationships.

- *Risk receptors exposure*: Explore categories of risk receptors and estimate the size of the risk receptors exposed to dangerous goods hazards.
- *Consequences analysis*: Explore the nature of actual consequences of dangerous goods hazards for the risk receptors.

***Step 4: Likelihood estimation - quantification***

Quantify the risk and system elements, including:

- *Quantify risk elements:* including top events, hazards, and causes and contributing factors.
- *Exposure estimation*: Estimate the size/extent of risk receptors exposed to dangerous goods hazards, along with the magnitude, duration, and spatial extent of the exposure.
- *Consequence estimation*: Estimate the magnitude of the actual consequences of dangerous goods hazards to the risk receptors, including the influencing factors and conditions.

***Step 5: Risk estimation and presentation***

- *Risk estimation*: Estimate risks by combining: a) the likelihood and consequences; b) the consequences and exposures to dangerous goods hazards.
- *Risk presentation*: Present estimated risks based on risk presentation formats, including these formats: a single number index (e.g.1/100,000), tables (e.g. sizes or bands of fatalities are 1-10, 11-100 and 101-1000), graphs or diagrams (e.g. Frequency-Number (F-N) curve), and maps (e.g. risk contour plot).

***Sensitivity analysis***

The Management Index (Risk Index x Sensitivity) provides further ranking for those risks that have equivalent Risk Indexes. Given its scope, this analysis may not necessarily constitute an integrated step of risk analysis.

## Stage 3: Conclusions and recommendations

This stage consists of the following key steps:

- ***Step 1*: *Conclusions***: Synthesize information about the main risk elements, including hazards and their causes and contributing factors, frequency/probability, consequences due to PDG hazards, and estimated risks.

- ***Step 2*: *Recommendations***: Develop a list of recommendations for improving risk management in the maritime transport of PDG. Suggest relevant research areas and questions for future research.

### 2.3.2 Phase 2: Risk evaluation

Risk evaluation may include the following steps:

- ***Step 1: Select risk evaluation criteria***: In many countries and industries, there is a wide range of established qualitative and quantitative risk criteria or standards for evaluation of various types of dangerous goods risks, including human safety and health risks (individual, public or societal risks), environmental risks and property risks. It may become an important task to identify and select the relevant specific risk criteria for specific estimated risks in a specific country and/or industry. Selection of risk criteria may also depend on the results of the risks analysis and how risks are estimated. Further, in cases when aggregated risks (i.e. compounded risks combining human, environmental, property and other risks) are analysed and estimated, select the right risk criteria for the evaluation of this type of risks. Not all types of risk criteria available may serve the evaluation of aggregated risks.

- ***Step 2: Compare estimated risks against the risk criteria***: In order to determine the significance or the level of estimated risks, at this phase estimated risks are compared against the selected risk evaluation criteria available for the transport of dangerous goods. Risk evaluation also takes into account a wide range of additional factors and procedures other than scientific and technical ones. Risk evaluation may involve different parties concerned and/or affected by risks of dangerous goods, including decision or policy makers at high levels.

- ***Step 3: Prioritize/rank risks***: In cases involving various types of risks, the results of risk evaluation may show that risks (e.g. human, environmental and property risks) may have various degrees of significance or lie on various risk regions or levels (see Figure 5). Further, an important task in quantitative risk analysis is to relate risks to various system elements (e.g. types of ships, types of dangerous goods-related activities such as loading and discharging, classes of dangerous goods, location of accidents etc) and risk receptors (e.g. crew, passengers, stevedores etc). In order to prioritize risk management strategies and measures and subsequently resources and efforts, risks are ranked according to their significances.

- ***Step 4:*** **Propose risk management strategies and measures**: Certain risk criteria contain principal risk management strategies and measures (see Figure 5). At this phase, a more detailed list of strategies and measures to deal with the present level of risks can also be developed and proposed for further scrutiny, including further detailed risk analysis and cost-benefit analysis.

The following Sections discuss in some detail two important risk elements that are and directly related to risk evaluation – *risk evaluation criteria* and *risk perception*.

### 2.3.2.1 Risk evaluation criteria

In order to evaluate the significance or levels of the estimated risks, in many countries and industries and sectors, benchmarking standards, known as "risk evaluation criteria", have been developed and employed. Spouge (1997) defines risk criteria as yardsticks providing answers to the question: "How safe is safe enough?" They are standards that represent views, usually of a regulator, of how much risk is acceptable or tolerable (Spouge 1997a) (HSE 1995). Risk evaluation criteria are used to translate a risk level into a value judgement (IMO 2004). Based on the results of risk analysis, risk criteria may also determine principal risk management strategies. Terms such as "risk", "safety", "quality", "tolerable" or "acceptance" criteria generally share similar meanings.

Responsible regulatory bodies or authorities usually set risk criteria. In many countries, a wide range of interests may have a say in shaping risk criteria. Risk criteria reflect to a large extent the broad acceptance of the society (HSE 1992). However, risks may be acceptable to the majority of the public, while a minority may still find risks unacceptable (HSE 1992).

Certain principles are employed as a guide for designing risk criteria, which may be applied differently in different countries, industries or sectors. Thus, the threshold values for tolerable and non-tolerable risks (i.e. lower and upper boundaries of the ALARP region) are usually determined at high levels of decision-making. For example, the Austrian Commission for Tunnel Safety has determined the following principles (Knoflacher and Pfaffenbichlern 2004):

- The basis for the threshold value of non-tolerable risk is that the level of risk in tunnels must not exceed that on the open road.
- The threshold value of tolerable risk should be about the same magnitude as the fatalities due to natural phenomena, for example, lightning or similar disasters.
- Each fatality is valued equally, which means that the tolerated frequency for an accident causing ten fatalities is one tenth that of an accident causing one fatality. This principle defines the slope of the FN-curve.

The U.K. Health and Safety Executive (HSE 2001) has set three principal norms for designing risk criteria. According to the HSE (2001), the regulators in the U.K. have used these criteria as building blocks for creating new risk evaluation criteria and managing risks. Further, risk criteria also can be classified according to these principal criteria, which are summarised as follows (HSE 2001, pp 40-41):

- *An equity-based criterion*: All individuals have unconditional rights to certain levels of protection. This criterion establishes limits, including the limit to represent the maximum level of risk above which no individual can be exposed. The risk above the maximum level is considered to be unacceptable regardless of the benefits.
- *A utility-based criterion*: This criterion applies to the comparison between the incremental benefits and costs of the measures to prevent the risk. Thus, benefits (e.g. statistical lives saved or life-years extended) obtained by the adoption of a particular risk prevention measure are compared in monetary terms with the net cost of introducing it. It is required that a particular balance should be achieved between the two.
- *A technology-based criterion*: This criterion reflects the idea that a satisfactory level of risk prevention is attained when “state of the art” control measures (technological, managerial, and organisational) are employed to control risks whatever the circumstances.

In the shipping industry, certain principles concerning risks related to ship operations are also established, including (Spouge 1997) (IMO 2004):

- Activities should not impose any risk that can reasonably be avoided;
- Risks should not be disproportionate to the benefits;
- Risks should not be unduly concentrated on particular individuals, locations and territories;

- Individuals who may be affected by a ship accident must not be exposed to excessive risks;
- It is not sufficient to merely achieve a minimal average risk; it is also necessary to reduce risks to the most exposed individuals.

In some countries (e.g. the UK, Netherlands, Norway and Australia) (see Table 3), risk criteria are established and employed for risk evaluation in several industries, such as nuclear power plants, petrochemical and offshore industries. In many countries, risk criteria may be nonexistent.

The literature review shows that there is a wide range of risk criteria. They vary in type and scope based on a number of interrelated attributes, including: a) the scope of application (e.g. national or international criteria); b) type of industry or system (e.g. IMO's risk criteria for the shipping industry); c) type of risks (e.g. human risks – individual and societal risks, environmental risk criteria, or individual and compound risk criteria); d) categories and sub-categories of risk receptors, consequences and severity (e.g. fatality and injury risk criteria) (see Tables 3, 4 and 5). Compound risk criteria (see e.g. ISO risk criteria in Figure 4) are criteria designed for evaluation of aggregated risks, which may combine two or more of the following types of risks – human (fatality, injury and others), environmental, property and other risks (see Table 6 and Figure 4). Risk criteria also take various forms, such as in the form of legal requirements, company or industry standards, conventions, and scientific and technical standards. They may represent "undisturbed" values (e.g. environmental quality criteria for air, land and water) and international benchmarking and best practices (e.g. human and technological risks criteria) in industry, for example, GBS (Goal-Based Standards) (IMO 2006) and BATNEEC ("Best Available Technology Not Entailing Excessive Costs").

Risk criteria may be facts-based criteria, performance-based criteria and prescriptive criteria (Vanem and Skjong 2006). Facts-based criteria are generally developed based on the results of the analysis of empirical data. Prescriptive criteria should be, in principal, in accordance with performance requirements of the system to which they apply (Vanem and Skjong 2006).

Risk criteria are also divided into quantitative and qualitative or semi-qualitative criteria. Quantitative risk criteria are in the form of numeric expressions (see Tables 3, 4 and 5), which are represented in the form of diagrams, curves (e.g. FN curves), contours or plots (e.g. risk maps). They are employed in evaluation of risks estimated quantitatively. In order to evaluate the results of qualitative or semi-quantitative risk analysis, qualitative risk criteria (see Figure 4) are employed. They are typically in the form of risk matrices showing in qualitative terms the combinations of the magnitude of the severity of consequences and the likelihood (frequency/ probability) of consequences (see Figure 4).

**Table 2**: Examples of type and scope of risk criteria

| | **Examples of type and scope of risk criteria** | | | | | |
|---|---|---|---|---|---|---|
| | | **Scope of application** | **Industry/ System** | **Type of risk** | **Category and sub-categories of risk receptors, consequences and severity** | |
| **<Compound risk criteria >** | Individual risk criteria > | • Local<br>• National/ Federal<br>• Regional<br>• International | • Shipping industry<br>• Maritime transport system<br>• Organisation<br>• Type of ships<br>• Classes of dangerous goods<br>• Activity | *Human risks*<br>• Individual risk<br>• Societal risk | *Human consequences*<br>• Safety and health<br>- Fatality<br>- Injury<br>- Others<br>• Other human effects | • Crew members<br>• Passengers<br>• Third parties |
| | | | | | | |
| | > | | | *Environmental risks* | *Environment/ ecosystem consequences*: Water, air, land | Marine/ water environment:<br>• Biota:<br>- Flora: plant lives<br>- Fauna: animal lives<br>• Abiotic environment<br>- Sediments/ sea or waterbodies bottom/ floor<br>- Water column<br>• Others |
| | | | | | | |
| | > | | | *Property risks* | *Property consequences* | • Ship<br>• Cargo<br>• Other properties |
| | | | | | | |
| | > | | | *Other risks* | *Other consequences* | • Disruptions<br>• Socio-economic consequences<br>• Others |
| | | Individual risk criteria > | > | > | > | > |
| | **< Compound risk criteria >** | | | | | |

The following Sections discuss *human and environmental risk criteria* in some detail. These criteria are better developed and widely employed in many industries and sectors, including the shipping industry, than other types of risk criteria.

**Human risk criteria**

There are different risk criteria which are used in evaluation of human safety and health risks in various industries and activities, such as aviation, road, rail and sea transport, nuclear power industry, and health and safety sectors (IMO 2006). Risk criteria for the transport of dangerous goods are also developed in a number of countries. For example, the Advisory Committee on Dangerous Substances (ACDS), on behalf of the UK's Health and Safety Commission/Executive, (HSC 1991) has developed risk criteria for nuclear, petrochemical and offshore industries that are adapted for the transport of dangerous goods. Risk criteria are also proposed for evaluation of risks related to ship operations (see Table 5). The most commonly used human risk expressions are individual risk and societal risk (IMO 2004). The literature review shows that risk studies largely focus on the analysis of human safety and health (fatality and injury) risks. The following Section discusses individual and societal risks and respective risk criteria.

*Individual risk and risk criteria*: Individual risk is the frequency at which an individual may be expected to sustain a given level of harm from realization of specified hazards (Vrijling et al. 2004). According to the IMO (2004, p 2), individual risk (IR) is the risk of death, injury and ill health as experienced by an individual at a given location, such as for example a crewmember, a passenger on board the ship, or a person belonging to third parties that could be affected by a ship accident. Individual risk is usually determined for the maximally exposed individual (IMO 2004, p 2). The individual risk criteria applied, for example, in the U.K., specify that "broadly acceptable" risk level is $10^{-6}$ (i.e. 1/1,000,000 – one fatality in a million inhabitants exposed) per year (HSC 1991) (HSE 1999). According to the OECD (2000), in some countries the level of individual risks above $10^{-4}$ per year are considered "unacceptable" for "voluntary" risks (i.e. risks to workers or workplace risks), which include risks associated with the workplace, such as loading, unloading and handing of dangerous goods. Risks above $10^{-5}$ per year are "unacceptable" for "involuntary" risks, which may involve members of the general public living adjacent to ports, terminals or waterways (OECD 2000). The IMO's individual risk criteria are provided in Table 5

*Societal risk and risk criteria:* Societal risk is the risk of the occurrence of multiple fatalities in a single event (HSE 2001) (Vrijling et al. 2004). According to the IMO (2004), societal risk (SR) is defined as average risk, in terms of fatalities, experienced by a whole group of people, such as for example crew, port employees or society at large, exposed to hazards. Societal risk is determined for everyone exposed, even if only once a year, and it is usually presented as FN diagrams or Potential Loss of Life (PLL) (IMO 2004). Societal risk criteria are generally based on individual risk criteria. They usually express a balance between costs and benefits (Spoung 1997). Standards for costs and benefits, risk estimation and evaluation vary among countries, industries, sectors or activities. Therefore, risk criteria for other systems or activities may not be directly employed to the transport of dangerous goods. The IMO's societal risk criteria are provided in Table 5.

**Table 3**: Individual Risk Criteria in Use (Annual Fatality Risk) (IMO 2006 from HSE 1999; Bottelberghs 1995; DUAP 1997; EPA 1998)

| Authority | Description | Criterion (fatality per year) |
|---|---|---|
| U.K. HSE (1999) | Maximum tolerable risk to workers | $1.10^{-3}$ |
| | Maximum tolerable risk to the public | $1.10^{-4}$ |
| | Negligible risk | $1.10^{-6}$ |
| Netherlands Bottelberghs (1995) | Maximum tolerable for existing situations | $1.10^{-5}$ |
| | Maximum tolerable risk for new situations | $1.10^{-6}$ |
| New South Wales, Australia DUAP (1997) | Sensitive developments (hospitals, schools, etc.) | $5.10^{-7}$ |
| | Residential, hotels, motels, tourist resorts, etc. | $1.10^{-6}$ |
| | Commercial, retail, offices, etc | $1.10^{-5}$ |
| | Sporting complexes, active open space | $1.10^{-5}$ |
| | Industrial | $5.10^{-5}$ |
| Western Australia EPA (1998) | Sensitive developments (hospitals, schools, etc.) | $5.10^{-7}$ |
| | Residential zones | $1.10^{-6}$ |
| | Non-industrial (commercial, sporting, etc.) | $1.10^{-5}$ |
| | Industrial | $5.10^{-5}$ |

Table 4 shows human risk criteria applied for evaluation of fatality risk to the members of the public living close to hazardous facilities. These hazardous facilities also may include ports and terminals, channels and rivers where large amounts of many different classes of dangerous goods are handled, stored, transferred or carried through. Table 4 shows that the boundaries of acceptable risk vary among countries. Risks about $10^{-5}$ per year are broadly "unacceptable" for the members of the general public living close to hazardous facilities in the countries shown in Table 4.

**Table 4**: Risks criteria for residents close to hazardous facilities (OECD 2002)

| Countries | Limit of unacceptability | Limit of acceptability | Criteria applied between the upper and lower boundaries |
|---|---|---|---|
| Hong Kong | 1 in 100,000 | 1 in 100,000 | N/A[6] |
| Netherlands | 1 in 1 million | 1 in 100 million | ALARA |
| UK | 1 in 100,000 | 0.3 in a million | ALARP |
| Australia[7] | Not given | 1 in 1 million | N/A |

**The concept of "scrutiny level"**

Balancing costs and benefits is fundamental to the decision making process. Judgments about risks change as dangerous goods related activities and their benefits, tolerance and perceptions also change. An indication of justifiable social risk may be obtained by employing a "scrutiny level." The concept of the "scrutiny level" has been adopted by the U.K. Health and Safety Commission/Executive (HSC 1991) for vessel traffic and handling of bulk dangerous cargoes only. The concept has been applied for both local or port and national risks, where risk levels are scaled in accordance to the annual tonnage of dangerous cargoes shipped through the U.K. ports and national territorial waters. The "scrutiny level" scaled according to the national total tonnage of dangerous cargoes produces a "national scrutiny line." Risks above this line are considered "possibly unjustified." The "scrutiny level" may also be adapted for PDG vessel traffic based on the following indicators: annual tonnage, numbers of packages, types of dangerous goods handled and carried through territorial waters.

[6] Not Available
[7] For some states of Australia

### IMO's risk criteria

The IMO (2004) has proposed individual and societal risk acceptance criteria for the shipping industry (see Table 5) based on risk criteria of the U.K. HSE (1999) and others (see Table 3). The risk criteria, which determine threshold values for tolerability and non-tolerability of risks, concern fatality risks to individuals (e.g. crew, passengers, and the third party such as port employees), groups of people or society. The total risk consists of the sum of all risks. According to the U.K. HSE data (for the period 1987–1991), which are also supported by other studies, the level of the individual risk for the crew in the sea transport was $2.9\times10^{-4}$ per year (Vrijling et al. 2004). The IMO's risk criteria are proposed for use in evaluating the total fatality risk of being onboard the ship, but not for specific risks from specific hazards (e.g. fire) (IMO 2004). Despite extensive search and literature review, no specific risk criteria for the maritime transport of PDG have been found.

**Table 5**: Quantitative risk acceptance criteria – upper and lower bounds (IMO 2004 from HSE 1999)

| **Decision parameter** | | **Risk Acceptance Criteria** | |
|---|---|---|---|
| | | *Lower bound for ALARP region* | *Upper bound for ALARP region* |
| | | *Negligible (broadly acceptable) fatality risk per year* | *Maximum tolerable fatality risk per year* |
| *Individual Risk* | To crew member | $10^{-6}$ | $10^{-3}$ |
| | To passenger | $10^{-6}$ | $10^{-4}$ |
| | To third parties ashore | $10^{-6}$ | $10^{-4}$ |
| | Target value for new ships[8] | $10^{-6}$ | *The above values to be reduced to one order of magnitude* |
| *Societal Risk* | To groups of above people | To be derived by using economic parameters[9] | |

### Environmental quality criteria

Assessing environmental impacts and significance of benefits in risk control may be difficult. When dealing with human health and safety, the level of

[8] More demanding upper bound ALARP region targets for new ships
[9] Economic parameters as specified in the IMO document MSC 72/16

risks may be more obvious and universally applicable across different geographical areas, industries and sectors. Human safety and health concerns have in the past driven most major chemical risk policies (OECD 2000). As a result, there has been a greater emphasis on the development of the human safety and health risks criteria than environmental risks criteria. A few years ago, environmental quality criteria, known also as environmental risk or pollution criteria, were still in their infancy (Smith 1995). The IMO's risk criteria are specially designed for evaluating individual and societal human risks (death and injuries) only. The IMO encourages that similar criteria need to be developed for risks to the marine environment and property in the future (IMO 2004).

In some countries, however, efforts have been made to develop various risk criteria, including environmental risk criteria for marine pollutants. The U.K. Department of the Environment (DE 1991), for example, has used the *costs of cleaning-up and "repair"*, which is an established concept in environmental economics, as criteria for the evaluation of damage to the environment due to spills or contaminations. It is, however, irreversible damage to the environment that presents problems for the evaluation of environmental damage in term of costs (Weigkricht and Fedra 1993).

The perceived "*value*" and "*vulnerability*" of the environment are also some other criteria suggested to evaluate the significance of damage to the environment (Weigkricht and Fedra 1993). Major environmental damage may be defined in terms of the area affected, the likely duration of damage, and the value of the site affected. For example, an accident resulting in damage (contamination) to 10 km of river or 2 hectares of the estuary is considered "a major accident to the environment" (Nicolet-Monnier and Gheorghe 1996).

In response to the environmental concerns, in a number of countries, in particular in European countries and North America, efforts have been made to develop environmental quality criteria for water, land and air. For example, the guidelines for water quality have been in place for some time in the U.S.A., in which many states have used them to derive water quality standards for their water bodies (Russo 2002). However, efforts have been recently directed towards the development of technical guidance based on the concept of bio-assessment and bio-criteria programmes (Russo 2002). Quality criteria for the marine environment include the physical, chemical and biological quality of the water, sediment and biota. Criteria provide benchmarking standards for evaluating the quality of the environment and setting quality objectives. *Water Quality Criteria* (USEPA 2000) for water quality, including fresh and salt water life and human health, for 157 pollutants and Air Quality Criteria (USEPA 2000a) are both examples of environmental quality criteria designed by the USEPA.

**Box 1: Swedish Environment Quality Criteria (EQC)**

In 1998, the Swedish Environmental Protection Agency (SEPA) in co-operation with a number of academic institutions developed criteria for environmental quality assessments (EQC - Environmental Quality Criteria) (SEPA 1998). The EQC is a system of classification facilitating the comparison and interpretation of environmental data. The system is used to determine whether measured values are low or high in relation to reference values.

The Swedish EQC (SEPA 1998) covers the following six areas: ground water, lakes and watercourses, coasts and seas, forest landscapes, agricultural landscapes, and contaminated sites. The environmental quality criteria for coasts and seas are designed to assess the impacts of three main categories of threats to the marine environment: a) eutrophication[10]; b) toxic organic pollutants and metals; and c) physical disturbance (SEPA 1998).

The criteria consist of reference values providing the basis for assessment of environmental disturbances due to human activities. The assessment is based on comparisons between reference values and measured values of the existing state of the environment at the moment of measurement. The reference values represent either the values of the "original undisturbed state" of the environment or values determined (i.e. threshold value) scientifically or by the responsible authorities. The difference between the existing state and reference values determines the deviation values indicating the degree of disturbances due to human activities.

Values are numerically (i.e. quantitative criteria) and qualitatively or descriptively (i.e. narrative criteria) expressed. The measured values and deviations are classified on a four or five-point scale. Conditions that have the greatest consequences for the environment and human health, or

[10] Eutrophication is the process by which pollution from such sources as sewage effluent or leachate from fertilized fields causes a lake, pond, or fen to become overrich in organic and mineral nutrients, so that algae grow rapidly and deplete the oxygen supply. This is the most significant change.

**Box 1: Swedish Environment Quality Criteria (EQC)**

exhibit the greatest deviation, are placed in class 5.

Comparisons are based on indicators, such as chemical properties of pollutants including toxic and non-toxic (e.g. organoleptic effects such as taste and odour) effects, contaminant levels, biological diversity and how it is affected by human activities. In many cases, the deviation is expressed as the ratio between a measured value and its reference value, known as the Ecological Quality Ratio (EQR).

The following is an example from the Swedish EQC for Coasts and Seas - the Organic Toxins in Coastal and Marine Environments where reference, existing state and deviation values cover some selected organic environmental toxins in sediments and certain fish species (SEPA 1998):

- *Reference and existing state values* are measured for: a) sediments and b) fish species such as perch, herring, and eelpout.
- *Levels of concentration*: The level of concentration is measured in µg/kg dry or wet weight livers, muscles or fatty tissues. The deviation levels are classified as class 1 (null), class 2 (low level), class 3 (moderate level), class 4 (high level) and class 5 (very high level).
- *Substances*: Organic environmental toxins measured include: Phenanthrene, Anthracene, Fluoranthene, Pyren, Benzanthracene, Chrysen, Bens (b) fluoranten, Bens(k) fluoranten, Bens(a)pyrene, Bens(ghi)perylene, Indeno (cd) pyrene; PCB: PAH, HCB, PCB 28, PCB 52, PCB 101, PCB 118, PCB 153, PCB 138, PCB 180; HCH: Alfa -HCH, Beta-HCH, Gamma-HCH; Chlordane: Gamma chlordane, Alfa -chlordane, Trans-nonaklor; DDT: p.p'-DDT, p.p'-DDE, p.p'-DDD; EOCl, EOBR, EPOCL, EPOBR.

The aforementioned environmental quality criteria for toxic organic pollutants and metals may also be employed in evaluation of environmental risks of marine accidents and incidents involving PDG.

### Risk criteria for aggregated risks

Evaluation of compound or aggregated risks (which combine two or more of the following: human safety and health risks, environmental risks, property risks and other risks) requires compound risk criteria. Combining one set of criteria with another is a very complex and difficult task. In recent years, attempts have been made to deal with this problem. For example, the IMO Guidelines on the FSA (IMO 2002) contains a risk matrix that has been proposed for evaluation and ranking of aggregated risks, which include both human (fatality and injury) and property (i.e. the ship) risks related to ship operations. The IMO's risk matrix is a 7x4 matrix containing 7 and 4 scales (grades) for frequencies and consequences respectively. Table 6 shows the severity index (SI) of consequences of the human safety and the ship with respective descriptions. Table 7 shows the frequency index (FI) with respective definitions.

**Table 6**: Severity Index (SI) of consequences (IMO 2002)

| SI | Severity | Effects on human safety | Effects on ships | S (Fatality) |
|---|---|---|---|---|
| 1 | Minor | Single or minor injuries | Local equipment | 0.01 |
| 2 | Significant | Multiple or severe injuries | Non-severe ship damage | 0.1 |
| 3 | Severe | Single fatality or multiple severe injuries | Severe casualty | 1 |
| 4 | Catastrophic | Multiple fatalities | Total loss | 10 |

**Table 7**: Frequency Index (FI) (IMO 2002)

| FI | Frequency | Definition | Frequency (Per ship per year) |
|---|---|---|---|
| 7 | Frequency | 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 several times during a ship's life | 0.1 |
| 3 | Remote | Likely to occur once per year in a fleet of 1000 ships, i.e. 10% chance of occurring in the life of 4 similar ships | $10^{-3}$ |
| 1 | Extremely remote | Likely to occur once in 100 years in a fleet of 1000 ships, i.e. 1% chance of occurring in the life of 40 similar ships | $10^{-5}$ |

Table 8 is a risk matrix that combines the SI and the FI. Risk index (RI) is obtained by combining the frequency index (FI) with the severity index (SI) of consequences. For example, an event with a frequency index 4 and severity index 2 has a risk index (RI) of 6. The risk index is used to rank risks and hazards, and prioritize risk measures.

**Table 8**: Risk matrix (IMO 2002)

| **FI** | **Frequency** | **Severity (SI)** | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 |
| | | Minor | Moderate | Serious | Catastrophic |
| 7 | Frequency | 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 |

**ISO risk criteria**

The ISO (1999) 17776 risk matrix (see Figure 4) is a detailed matrix that has been designed for ranking and evaluation of aggregated risks in petroleum and natural gas industries including offshore production installations. It reflects the practices in the industries and organisations in integrating human safety and environmental risks in the total risk decision-making process. The ISO risk matrix is a 5x5 matrix combining various categories of consequences and likelihood. The consequences are divided into four categories: people, assets, environment and reputation. The inclusion of asset and reputation risks is intended for use by any category of corporate businesses including the shipping industry. The matrix can be used as a combined risk criterion for ranking and evaluation of aggregated risks (see Figure 4).

| CONSEQUENCE | | | | | PROBABILITY/FREQUENCY | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | A | B | C | D | E |
| Severity Rating | People | Assets | Environ ment | Reputation | Rarely occurred in industry | Happened several times per year in industry | Has occurred in operating company | Happened several times per year in operating company | Happened several times per year in location |
| 0 | Zero injury | Zero damage | Zero effect | Zero impact | | | | | |
| 1 | Slight injury | Slight damage | Slight effect | Slight impact | Manage for continue improvement | | | | |
| 2 | Minor injury | Minor damage | Minor effect | Limited impact | | | | | |
| 3 | Major injury | Local damage | Local effect | Considerable impact | | | | | |
| 4 | Single fatality | Major damage | Major effect | Major national impact | | | | | |
| 5 | Multiple fatalities | Extensive damage | Massive effect | Major international impact | Incorporate risk reducing measures | | | Intolerable | |

**Figure 4**: ISO Risk Matrix (ISO 1999)

## Some issues related to risk criteria

Based on the understanding gained through the review of several risks criteria, the following provides some issues related to risk criteria.

- Although reflecting the latest scientific knowledge, environmental risk criteria are only for a limited set of pollutants. For example, USEPA's water quality criteria have been developed for a limited number of pollutants – 157 pollutants only. A large number of chemicals have not been included in the criteria. New chemicals may be produced faster than their environmental risks can be assessed and criteria can be developed. Some chemicals, which may result in long-term effects on marine organisms such as those disrupting animal hormone systems, may yet be poorly understood.
- Risk criteria are generally applicable to local conditions. Because of differences among coastal and marine environments, it is difficult, if not impossible, to develop, adopt or apply universal criteria. For example, seawater, sediments and organisms contain natural levels of metals, which may vary according to local factors such as bedrock and sediment

type, oxygen supply, currents, salinity and temperature. In many areas, there are substantial differences even among different parts of a country.

- In many countries and industries, risk criteria only provide guidance to the parties concerned. They may not necessarily be regulations imposing legal binding requirements.
- Risk criteria, including both human and environmental risk criteria, are generally facts or risk-based criteria. In many instances, however, communities affected by risks of chemicals are not satisfied with only fact-based risk analysis and evaluation based on fact-based criteria. In addition to fact-based criteria, risks may also be evaluated against value-based criteria. However, this is not a common practice. Value-based criteria are employed to characterise multiple dimensions of risks involved, which take into account other factors, such as persistency, reversibility (i.e. possibility to restore the situation), and delayed effects (Kilnke and Renn 1999).
- Human risk criteria are designed to measure the level of immediate and apparent consequences. Long term and “minor” disabilities, injuries or ill health, and other human consequences are often not considered.

### 2.3.2.2 Risk perception

Risk perception is an important element that considerably affects the entire risk management process, including risk analysis and risk evaluation, and attitudes towards risks. Risk analysis, which is, in principal, a "pure" scientific and technical process, may not necessarily take into consideration socio-political and other related factors. Risk evaluation, on the other hand, in particular evaluation at high levels of decision-making, takes into consideration the wide range of interrelated factors, including public risk tolerance, costs/benefits trade-offs, socio- political and ethical factors.

The level of risks is generally determined the basis of scientific estimations and judgments, and by observations of what society at the present tolerates. Whether risks are considered tolerable or not may often be judged by the decision-makers at higher levels. Their judgments will depend on whether they believe that there is extra public sensitivity about risks (HSC 1991). In many cases, risk evaluation may be a socio-political rather than a scientific matter (Kunreuther and Slovic 1996).

It is often difficult to judge precisely what may be acceptable and unacceptable in a particular country, industry, or sector of society. This is because of the wide range of various interrelated factors. Judgments about the tolerability or acceptability of risks vary across countries, regions, industries, sectors, individuals, and societies, as do types of risks and experiences. Judgments also alter with time – what was acceptable yesterday may not be acceptable today and tomorrow. People's views on risks and their value judgements are not static, but change according to circumstances (HSE 2001). Studies on risk perception have led to a theory which considers that it may be simplistic to believe that it will be possible to derive a quantifiable physical reality that most people will agree represents the 'true' risk from a hazard (HSE 2001). This theory maintains that the concept of risk is strongly shaped by human minds and cultures (HSE 2001).

The public risk tolerance is a function of different factors including risk perception, judgments, aversion, willingness and benefits. For example, a survey (ACS 1998) has shown that a sizable gap exists between risk experts and non-technical citizens or the general public over how to define, measure and evaluate risks. Risk experts and technical officials tend to focus on the standard concept of risk as the possibility of damage (ACS 1998). By contrast, the general public tends to expand the concept of risk to include other "non-damage" attributes (ACS 1998). They reflect societal values and the role of aversions and fears that hazards can cause. In the Netherlands, for example, attempts have been made to express risk aversion mathematically in the form of a risk aversion index, and to integrate it in the overall risk evaluation (Vrijling et al. 2004).

The following presents the results of several studies concerning attributes affecting risk perception, evaluation and attitudes towards risks, including risks of dangerous goods (Sprent 1988; FACN 1995):

- *Voluntary/involuntary risks*: Risks voluntarily assumed are ranked differently from those imposed by others. Involuntary risks, which may include risks of toxic fumes, spills, contaminations and fires/explosions, are regarded as worse than voluntary risks, such as risks of climbing, diving and driving.
- *Uncontrollable*: The inability to personally make a difference may decrease the acceptability level of risk.
- *Immoral*: Pollution is often viewed as a consummate evil; statements such as "hazards are too low to worry about" can cause suspicions.
- *Familiarity/unfamiliarity*: Generally, more familiar risks are regarded as more acceptable.
- *Dreadful*: Risks that cause highly feared or dreaded consequences are viewed as more dangerous.

- *Uncertain*: Scientific uncertainty about the effects, severity, or prevalence of a hazard tends to escalate unease.
- *Catastrophic*: Large-scale disasters weigh more seriously in the public's mind than small-scale individual events. Society generally has a strong aversion to multiple casualty accidents (IMO 2004). A single accident that kills 1,000 people is perceived worse than 1,000 accidents that kill a single person (IMO 2004).
- *Memorable*: Risks embedded in remarkable events have greater impact than risks that arise in less prominent circumstances.
- *Unfair*: Substantial outrage is a more likely result if people feel they are being wrongfully exposed.
- *Untrustworthy*: The level of outrage is higher if the source of the risk is not trusted.
- *Concentrated risks*: Concentrated risks, in which dangerous goods risks may fall, are regarded as worse than diffused risks, such as for example risks of ordinary traffic accidents.
- *Benefits, voluntary/involuntary risks*: The public aversion is greater for involuntary risks involving activities with no immediate or little benefits than voluntary risks involving activities with immediate and large benefits. For example, risks to people living near roads, railroads, coastal zones, storages, terminals, ports and other facilities handling dangerous goods, with no or few direct benefits from the activities, are regarded as worse than risks to beneficiaries, such as employees (e.g. workers, stevedores and carriers) who are directly involved and benefit, for example, from the transport of dangerous goods and related activities. According to Starr (1969), public tolerance may be as many as 1000 times higher for voluntary risks than for involuntary risks with the same benefits of activities (Vrijling et al. 2004).
- *Immediate risks/consequences*: People are generally more averse to risks with immediate consequences than to those with long delayed effects.

Risk perception also depends on types of risks to which people are exposed. For example, natural and technical or man-made risks may be perceived differently. Thus, natural risks, such as risks of earthquakes and flooding disasters, are generally considered as inevitable because people think that they have little, if any, control over these events and, therefore, they may consider such natural risks as "acceptable" risks. However, technical or man-made risks, in which risks of dangerous goods fall, may not be perceived and accepted in the same way as natural risks.

In summary, risk perception is an important multidimensional and dynamic factor that should be taken into account in understanding and dealing with risk issues, risk evaluation and risk management.

### 2.3.3 Phase 3: Risk management

Risk management attempts to provide answers to the questions on how best to deal with risks, such as (USCG 2001): What can be done? What options are available and what are their associated tradeoffs? What are the effects of current decisions on future options? This process, which is distinct from risk assessment, involves the key stages and steps shown below (Weigkricht and Fedra 1993) (Vincent1 et al. 1993) (USCG 2001). Although a large part of this process concerns the decision of policy makers, risk assessors provide useful information and propositions for dealing with risks in a most effective and efficient manner.

The key stages and steps of risk management are:

***Stage 1: Identify, analyse and select decision making alternatives***, including:

- *Identify key interests*: Identify and solicit involvement from key interests who will be involved in the decision-making and affected by actions resulting from it.
- *Risk management strategies*: Identify and determine which risks are important to deal with and what key strategic decisions must be made to avoid/eliminate, reduce, transfer or retain risks. For more information about the principles of risk management strategies, see Section 2.4.1.
- *Risk management measures - options generation*: Identify choices available to the decision makers. Identify also the factors that will influence the decisions and risk factors, as decisions are rarely based on one single factor alone. For more information about the principles of risk management measures, see Section 2.4.2.
- *Select methods and tools*: Select the appropriate methods and tools for the analysis of alternative options. Some relevant cost-benefit analysis methods and techniques are presented in Section 3.3.18.
- *Option analysis and evaluation*: In the light of the results of risk assessment and other relevant evaluation, conduct specific analyses including cost-benefit analysis and appraise/ weigh/ compare available

options. For more information about cost-benefit analysis, see Section 2.5.
- *Option selection*: Select and recommend appropriate alternative approaches for implementation of risk management strategies and measures.
- *Residual risks and recommendations*: Identify residual risks and provide recommendations for managing them.

***Stage 2: Decision-making***: This concerns decisions on implementation of selected risk management strategies and measures. In consultations with all interested parties, weighed alternatives are selected and decisions are made for their implementation. The decision may involve implementation of measures to reduce or eliminate unacceptable risks. When appropriate, risks are eliminated, reduced or transferred in the most cost effective manner. When they are justified, risks are retained or accepted. For more information about principles of risk management strategies and measures, see Section 2.4.

***Stage 3: Planning***: Prepare and communicate action plans to deal with risks, including:
- Documentation of strategies, actions, goals, and schedule dates;
- Emergency response and contingency planning;
- Transport planning;
- Providing supporting information needed to implement risk management strategies and measures.

***Stage 4: Implementation and enforcement***: The implementation or execution of risk management strategies and measures, including:
- Implementation of risk management measures for different risks and systems components;
- Emergency response procedures and means;
- Education and training of all persons involved;
- Supervision, inspection and monitoring to verify compliance with regulations;
- Measures to compel compliance;
- Safety management audit.

***Stage 5: Follow-up and monitoring actions***: Follow-up and monitor the effectiveness of planned actions and the continuous update of all assessments as they change due to the implementation of actions and changes in the transport system and surrounding environment with the passage of time.

The decision-making process is a central element of risk management. It is a discipline in its own right and involves identification and assessment of alternative actions for risk management, taking into account costs of actions, the likelihood of future uncertain actions that may occur if the action is taken, and the rewards or costs estimated to result (RMSI Group 2001).

In the shipping industry, decision-makers at all levels are continually faced with difficult decisions. A wide range of complex factors and conditions contribute to difficulties in the decision-making process. For managing risks of dangerous goods, the process involves not only consideration of technical factors, but also political, social, economic, and many other factors (for more information, see Section 2.3.2.2). Further, the process may be complicated by the variety and complexity of the choices and the environment in which they are made, multiple and often conflicting objectives, different perspectives of those who are involved and affected by risks, sensitivity of decisions and uncertainty of various variables in the decision-making process. It is, therefore, important to provide decision makers with valid, reliable and sufficient information to ensure that they have taken a decision to their best knowledge.

The following Section discusses risk communication and re-assessment. Risk communication does not constitute a phase on its own, but it is rather an essential integrated element of the system. In each phase and stage of the process, communications among the concerned parties are essential important. Risk-related information generated at each stage is communicated to the concerned parties. The stage of re-assessment indicates that this is a continuous and cyclic process. Although presented at the “end” of the cycle, the re-assessment or re-analysis can take place at any given phase or stage and at any moment.

### 2.3.4 Risk communication

Risk communication has become an important element of the risk management system. Risk communication and its role in attitudes towards risks, risk analysis, risk evaluation and risk management have been explored in several risk communication studies (see Bickerstaff and Walker 1999; HSE 2001; Reid 1999; Zimmerman et al. 2001; Bender et al. 1997; Frewer 2004;

Leiss 2004; OECD 2002). For example, according to Kasperson et al. (1988), risks that are minor in quantitative terms at times produce massive reactions, while major risks may often be ignored (HSE 2001). This is partly attributed to the risk communication approaches. The public responses to risks can be amplified or reduced depending on how the reporting of the risk interacts with psychological, social, cultural, and institutional processes (HSE 2001).

Risk communication may be considered a specific field of science in its own right. It is an interactive process of the exchange of information and opinions among risk assessors and managers and other concerned parties, including various individuals, groups and institutions interested in risk issues and methodologies. The interface among interested parties is a critical element for ensuring that the results of risk assessment can be used to support the decision-making processes at all levels. The risk communication process covers a wide range of activities directed at increasing the knowledge about risk issues and participation in risk management. The process also includes discussions about the nature of risks, risk levels and risk management strategies and measures. Further, people express concerns, opinions and reactions to risks to legal and institutional bodies responsible for risk management. The public prefers clear information regarding risks and associated uncertainties, including the nature and extent of disagreements among different experts in the field (Frewer 2004).

Effective risk communication practices are among the most important responsibilities of industries and governments (Leiss 2004). According to Leiss (2004), the fundamental requirements of good risk communication practices are a) undertaking “science translation”, b) addressing uncertainties, and c) dealing with science and policy interfaces. The OECD (2002) has also been working to identify practical ways to make risk communication an integral and effective part of the chemical risk management process. For the transport of dangerous goods, risk communication encompasses a wide range of specific activities, including:

- Disseminating/sharing risk-related issues, best practices and experiences;
- Disseminating/sharing relevant risk-related data and information;
- Dissemination/sharing research results concerning risks issues and methodologies;
- Holding public hearings on risks and risk management issues;
- Providing warnings about dangerous goods hazards;
- Developing publicly accessible databases concerning dangerous goods risks.

Public information about risks of dangerous goods has become a norm in many countries and industries. Risk assessment processes and outcomes are required to be opened to greater participation and scrutiny by all parties concerned and/or affected. This, in turn, has required the need to help the public understand risk information and to help decision makers to understand public's risk perceptions and responses. Perceptions and responses are complex, multidimensional and diverse, as "the public" consists of many publics, including individuals and groups of people, which have different values and interests in risk issues and risk management. Understanding of public concerns must be the basis for an effective risk management strategy (Frewer 2004). For more information about risk perception, see Section 2.3.2.2.

**Box 2: OECD Risk Communication Guidelines**

The OECD (2002) Guidance Document on Risk Communication for Chemical Risk Management, Section 2 (pp 19-26), contains General Guidance on Design and Implementation of a Risk Communication Programme. The following is a summarised list of the guidelines (OECD 2002):

***1. Designing the strategy for a risk communication programme***

- Find a common denominator between the risk communicator and the audience(s);
- Understand the socio-political and cultural context of the communication programme;
- Consider the likely costs and resource requirements when designing a communication programme;
- Make sure that the same risk communication programme is implemented throughout the organisation and has the support of senior management;
- Ensure that the selection of approaches to planning is well integrated and each complements the others;
- Do what you believe in and avoid approaches that are not convincing;
- Take sufficient time and financial resources to rehearse and practice the organisation performance in a variety of approaches, and learn from others who have become adept at them;
- Evaluate the risk communication programme.

***2. Designing an effective risk communication message***

- Be clear about intentions, and make them the central message of

**Box 2: OECD Risk Communication Guidelines**

communication efforts;

- Simplify your message as much as you can without being inaccurate;
- Place simple messages (general information) at the beginning of a text and gradually add the complex issues (specifics);
- Never assume technical knowledge about the issue unless the audience is clearly a technical community;
- Anticipate the interests of the target audiences and design the communication programme to match their needs.

***3. Rules addressing specific risk issues***

- Place risk in a social context and report numerical probabilities only in conjunction with verbal equivalents;
- Be cautious about using risk comparisons in the message;
- Risk comparisons should be used only for those risks that are perceived as being comparable by the public;
- Relate risk information to the real world of the audience;
- Address the qualitative characteristics that people associate with risk in information sent out;
- Point out the importance of exposure and dose when communicating about risks;
- Avoid linking the risk communication effort to a non-health-related interest;
- Be sure to include all the relevant information in the risk communication portfolio.

***4. Communication in crisis situations***

- Be well prepared for crisis situations and ensure that all necessary resources to communicate effectively in a crisis are at hand;
- Anticipate potential crisis situations and have contingency plans and materials ready before the crisis occurs;
- All communication must either protect people or reduce risks. Priority must be given to this over the needs of the observers to be well informed;
- Do not give premature explanations or statements that you cannot substantiate. Rather, report all measures undertaken to cope with the crisis;
- Always be available to brief the media, provide a climate of confidence and competence, and make sure that the organisation speaks with one voice during a crisis;

**Box 2: OECD Risk Communication Guidelines**

- Avoid bureaucratic or legal language, and show empathy and compassion for the potential victims. Be aware, however, of any legal implications of your statements;
- Advise the risk manager to respond in an expeditious and comprehensive manner;
- Learn from past crisis situations: review all procedures and materials and redesign the approach in light of the experiences of the past crisis.

### 2.3.5 Re-assessment – a continuous and cyclic process

In many cases, risk assessment is carried out on an ad-hoc basis. However, the system and risks associated with it require re-assessment of new situations. A proactive management is to be viewed as a continuous and cyclic process, because of the wide range of interrelated influential factors and situations, such as:

- The systems and environments in which they operate, and many other influential factors and conditions that are dynamic and constantly changing;
- More and better risk-related data and information may become available and accessible;
- Introduction or development of more advanced and better risk analysis/ assessment and management methods, techniques or tools;
- Increasing demands for more frequent and thorough studies of risky activities, technologies or substances.

Changes in the maritime transport system of PDG and the surrounding environment require continuous attention to identification, estimation and evaluation of new and/or additional risks. The system is dynamic and its constituent elements are constantly changing. Some of these changes include changes in the system elements, such as the regulatory system, ships, dangerous goods, dangerous goods traffic, packaging, handling, storing, caring and documentation of dangerous goods. With the implementation of new risk management strategies and measures, one or several system elements may also change. Re-assessment provides feedback on the effects and effectiveness of risk management strategies and measures. Further, re-assessment of risks also informs decision makers about changes in risks, who then determine where future efforts should be directed.

## 2.4 Risk management strategies and measures

There is a large array of approaches for dealing with risks. Although the choices may be endless, there are generally a few principal management strategies, namely *avoidance/elimination, reduction, transfer and acceptance* (USCG 2001) (Knight 1999). The goals of risk management can be achieved by employing various strategies, which, in turn, use different ways and means that vary widely for different situations and systems. The term "risk management measure" is the most generic term representing the wide range of methods, techniques, approaches, or tools for managing risks at a more operational or tactic level. A few of the many different current terms in use are risks control measures, preventive, reduction, and mitigation measures, safety measures, countermeasures, alternatives, actions and options. Each term may have a specific meaning in a specific context. Risk management does not only involve risk control measures as described in the IMO's FSA methodology (see IMO 2002). It encompasses a wide range of strategies and measures. For example, risk transfer and acceptance or retention, which may not necessarily involve any risk control measure at all, are also important risk management strategies.

As mentioned earlier (see Section 2.3.2), risk evaluation involves determination of the level or significance of estimated risks, which may fall into one of the risk regions as shown in Figure 5. For each risk region, generic risk management strategies and measures are designed to deal with risks, such as these (IMO 2004; HSC 1991; HSE 1999; ISO 1998) (see Figure 5):

- *Intolerable/Unacceptable Region*: Risks in this region are considered unacceptable or intolerable and cannot be justified, except in extraordinary circumstances. Immediate measures should be taken to eliminate or reduce risks at the acceptable/tolerable level irrespective of costs.
- *The "As Low As is Reasonably Practicable" (ALARP) or Tolerability Region*: Risks in this region may be considered undesirable, in particular those that lie in the upper boundary (see Figure 5), but acceptable if they meet ALARP. Undesirable risks may only be acceptable /tolerable if the risk reduction strategies and measures are impracticable or if the costs are disproportionate to improvements gained.
- *Broadly Accepted Region*: Risks in this region are considered negligible and broadly accepted. There may be no need for detailed work to demonstrate ALARP. However, it is necessary to insure that risks remain at this level.

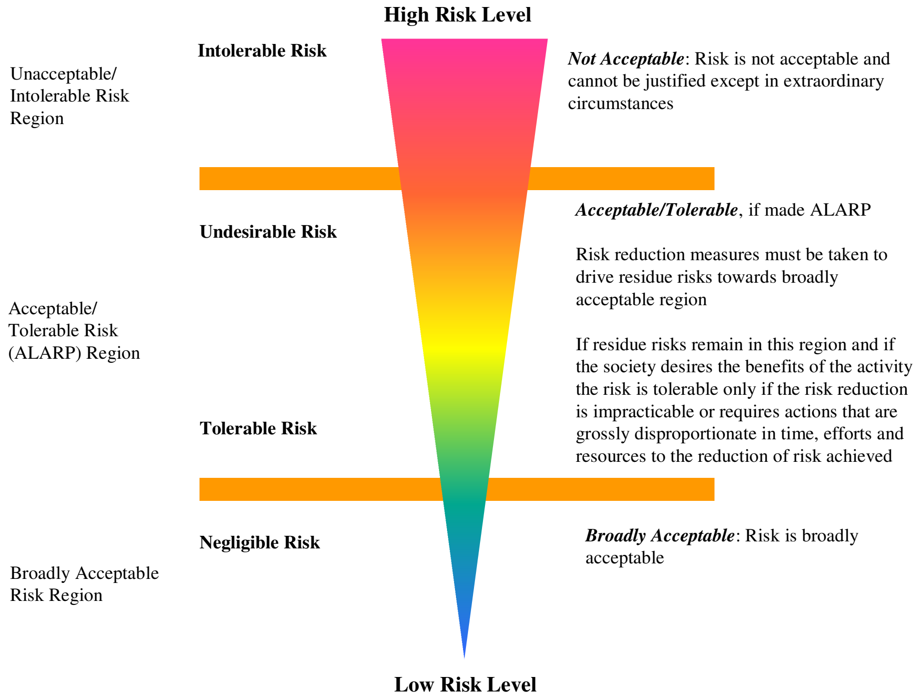


**Figure 5**: Risk regions/levels and principles of risk tolerability/ acceptability and risk management strategies and measures (adapted from IMO 2004; HSE 1999; ISO 1998)

With respect to dangerous goods risks, the results of risk evaluation may lead to the following decision-making scenarios:

a) Dangerous goods risks are found to be negligible and broadly acceptable (i.e. risks that lie in the Broadly Acceptable Risk Region), and no further information may be needed; or
b) Dangerous goods risks are found to be of some concern or undesirable risks (i.e. risks that lie in the ALARP Risk Region), and further information is needed; or
c) Dangerous goods risks are found to be of great concern or intolerable risks (i.e. risks that lie in the Unacceptable/Intolerable Risk Region), and further information and immediate preventive, reduction or mitigation measures are needed.

In the latter two cases (i.e. scenarios b and c), detailed risk analysis is needed.

The following Sections deal in some detail with the principles of risk management strategies and measures.

Risk management strategies and measures can be categories in different ways. However, drawing a clearly defined line between categories becomes a difficult task. Based on the literature review, risk studies and accident investigation reports, taxonomy of risk management strategies and measures is presented in Table 9.

**Table 9**: Taxonomy of risk management strategies and measures

| | **Risk management strategies** | | **Categories of measures** | |
|---|---|---|---|---|
| | | | Regulatory - Command/ control | Non-regulatory - Voluntary |
| **A** | *Avoid* | - Eliminate | • Technological<br>• Operational<br>• Managerial<br>• Training/education<br>• Knowledge/ information<br>• Methodological<br>• Financial<br>• Legal<br>• Others | |
| **R** | *Reduce* | - Reduce the frequency of causes (prevention)<br>- Reduce the frequency of consequences<br>- Reduce or minimise consequences (mitigation) | | |
| **T** | *Transfer* | - Transfer by contract<br>- Transfer by insurance<br>- Physical transfer<br>- Risk sharing | | |
| **A** | *Accept* | - Retain | | |

The model (see Figure 6), which is largely based on the examination of empirical data, is a graphic description of the risk components and the cause-effect chain, which is how marine accidents involving PDG are generated and developed. It may serve as a tool for a better understanding of the principles of risk management strategies and measures. As mentioned above, strategies and measures can take many forms and be enacted throughout the life cycle of the maritime transport system of PDG and the risk components. They can be employed at any point of the cause-effect chain that gives rise to risks from dangerous goods – from “latent” or “root” factors through “final” impacts. In essence, however, they can affect one or both key risk attributes, i.e. frequency and/or consequences. Measures can be seen as interruptions in the growth of events, placing barriers between stages. From the model (see Figure 6), it can also be seen that the measures enacted early in the error chain (for example measures to prevent error causes vs. minimizing consequences) to interrupt accidents can be more effective and efficient in risk reduction.

Risk management strategies and measures are identified, developed and employed in different ways. However, they depend very much on the issues concerning the system. For example, if the risk level is high due to a high frequency, then measures could be enacted to prevent dangerous goods release events from occurring in the first place. Maritime transport hazards, causes and contributing factors leading to release events are first identified by tracing them back through the error chain, and then appropriate measures are implemented to prevent release events. For example, measures could be taken to improve packing, stowage, cargo securing of PDG and/or reducing marine accidents, such as collision, grounding, machinery and hull/watertight failure accidents. Further, factors contributing most to risks and that can be readily managed can also be identified. When the risk level is high due to the severity or magnitude of consequences, then measures could be designed and employed to minimize or mitigate their severity.

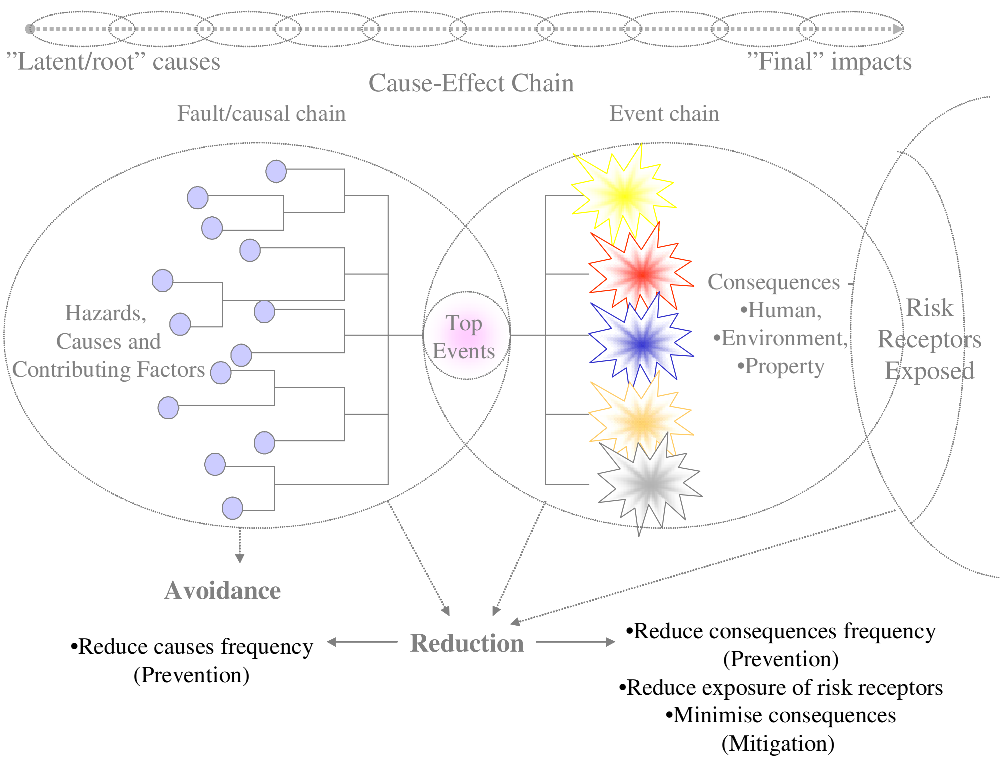


**Figure 6**: Avoidance/elimination, prevention, reduction and mitigation strategies

### 2.4.1 Risk management strategies

As shown earlier (see Table 9), the principal risk management strategies are *avoidance/elimination, reduction, transfer, and retention* (USCG 2001) (Knight 1999). The following Section discusses the mentioned strategies in some detail and provides some illustrative examples.

#### 2.4.1.1 Risk avoidance/elimination

The strategy of risk avoidance or elimination involves elimination of risks at the source. This strategy may, for example, include the elimination of a) chemical-related activities (e.g. banning production and transport of chemicals), b) transport/distribution hazards and their effects (e.g. designing and manufacturing stronger and more secure packages for the carriage of materials and substances of class 7 – radioactive materials and wastes), and c) causes and contributing factors accidents/ incidents involving dangerous goods releases and, subsequently, their consequences. This strategy also includes elimination of the maritime transport of certain chemicals, for example, persistent organic pollutants. Risks are also eliminated by invention, production and use of alternative non-dangerous products – "green products."

Box 3 presents an illustrative example of the risk elimination strategy.

**Box 3: Risk elimination**

**Stockholm Convention (2001) on Persistent Organic Pollutants (POPs)**

The Stockholm Convention (2001) on Persistent Organic Pollutants (POPs) is a global treaty that became legally binding on May 2004, after being ratified by 50 states worldwide. The main objective of the Convention is to protect human health and the environment from persistent organic pollutants. The parties to the Convention are required to take measures to reduce or eliminate releases from intentional production and use, or unintentional production and stockpiles and wastes of the following persistent organic pollutants: Aldrin, Chlordane, Dieldrin, Endrin, Heptachlor, Hexachlorobenzene (HCB), Mirex, Toxaphene, Polychlorinated Biphenyls (PCB), DDT (1,1,1-trichloro-2,2-bis (4-chlorophenyl) ethane) Polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/PCDF). The first nine persistent organic pollutants should be eliminated or banned for production and use.

Risks of the maritime transport of persistent organic pollutants are eliminated by banning production and use of these chemicals.

#### 2.4.1.2 Risk reduction

The strategy of risk reduction involves reduction, but not a complete elimination, of the frequency of occurrence of undesirable events and/or the severity of their consequences. There are many risks that cannot be eliminated in a technology-based society including production, transport, storage, handling and usage of many chemicals. At present, and in the near future, complete elimination of most risks in the transport of dangerous goods may not be possible, as this may be very costly, practically difficult or not feasible. Further, contemporary society relies very heavily on the use of a wide range of dangerous goods and, subsequently, it desires the benefits of activities related to dangerous goods. With respect to the benefits of chemicals, the EU White Paper on the Strategy for the Future Chemicals Policy in the European Community states (EC 2001, p 4):

> *Chemicals[11] bring about benefits on which modern society is entirely dependent, for example, in food production, medicines, textiles, cars etc. They also make a vital contribution to the economic and social wellbeing of citizens in terms of trade and employment. The chemical industry is Europe's third largest manufacturing industry. It employs 1.7 million people directly and up to 3 million jobs are dependent on it.*

Given the benefits of chemicals, in many countries and industries, efforts have been made to reduce dangerous goods risks to an "acceptable" level.

Risk reduction can be achieved by reducing the frequency of occurrences of dangerous goods release events and/or the severity of their consequences should they occur. These comprise two fundamental approaches to risk reduction, which are:

- *Prevention*: that means to hinder or keep from happening (CED 1992), especially by taking precautionary measures. Preventive risk control occurs when risk control measures reduce the probability of the undesirable events (IMO 2002).

[11] Substances and preparations as defined in Directive 67/548/EEC

- *Mitigation*: that means to make or become less severe or harsh, or moderate (CED 1992). Mitigating risk control occurs when risk control measures reduce the severity of outcomes of the events or subsequent events, should they occur (IMO 2002).

Because of the large number of complexly interrelated elements of the systems and the large amounts of different types of dangerous goods carried by water, an "absolute prevention", which is hindering all dangerous goods release events, is not possible. Reducing the frequency of consequences once dangerous goods have been released also reduces risks. For example, in order to reduce risks onboard ships, measures can be taken to contain flammable or toxic spills and prevent fires/explosions. The risks can also be reduced by timely responses in evacuation of people (passengers and ship personnel) that are likely to be exposed to dangerous goods hazards. The approach of reducing the frequency of occurrence, such as causes, contributing factors, hazard release events and exposure, constitutes prevention, also known as loss or accident prevention. Whereas minimisation of the severity of consequences, once the release or involvement of dangerous goods has happened and the risk receptors are exposed to dangerous goods hazards, is generally known as mitigation.

In summary, both prevention and mitigation are risk management strategies enacted to reduce undesirable events and minimise their consequences.

Box 4 presents an illustrative example of risk reduction strategy/ measure.

**Box 4: Risk reduction**

**EU Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) Legislation**

On 13th February, 2001, the European Commission (EC 2001) adopted the White Paper on the new "Strategy for a Future Chemicals Policy" in the European Community. The main objective of the strategy is to ensure a high level of protection for human health and the environment, while ensuring the efficient functioning of the internal market and stimulating innovation and competitiveness in the chemical industry (EC 2001). The EC's White Paper is based on the established preventive principles for risk management, whereby chemicals are considered to be unacceptably hazardous until proven otherwise, and the substitution of dangerous substances by less dangerous ones is encouraged, wherever possible (Combes et al. 2003). The White Paper proposed the establishment of a

**Box 4: Risk reduction**

new system of Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), also known as the REACH-legislation (EC 2001).

On 29 October 2003, the European Commission (EC 2003) adopted the proposal for the new EU regulatory framework for chemicals (i.e. REACH Legislation). Under the proposed new system, enterprises that manufacture or import more than one tonne of a chemical substance per year would be required to register that in a central database (EC 2003). The REACH proposal imposes greater responsibility on the industry to properly manage risks from chemicals and provide safety information on substances. Manufacturers and importers of chemicals should provide lists of chemicals produced and used as well as list any possible risks. They have to demonstrate that products placed in the market are safe. One of the challenges facing manufacturers is that they have to come up with plans for replacing some of the most hazardous chemicals.

According to this legislation, each chemical registration submission will consist of a Technical Dossier and, for substances above 10 tonnes, a Chemical Safety Report (CSR) (EC 2006). Failure to register will mean that the substance cannot be manufactured or imported. The REACH legislation will affect both “new” and “existing” substances.

The European Parliament and EU governments have recently (2006) agreed on the REACH legislation to control the production and use of toxic chemicals. The EU draft law, which is due to come into force in 2007 and still requires EU assembly approval, is designed to make firms prove the chemicals they use are safe. A new European Chemicals Agency, which is required to be fully operational 12 months after entry into force of the legislation, will run databases, coordinate and oversee the way the industries assess chemicals they produce and use.

After the legislation comes into force in 2007, approximately 30,000 existing substances will need to be registered into the database by 2018. The purpose of the REACH legislation is to ensure that the gaps in existing information on the hazardous properties of some 30,000 chemicals are eliminated and that necessary information on the safe use of substances is disseminated throughout the entire chemical supply chain, facilitating prevention and reduction of risks for workers, consumers and the environment (EC 2006). The REACH legislation will reverse the burden of proof to industry, both producers and importers of substances, rather than to the public authorities (EC 2006).

In summary, in response to concerns of risks posed by the large amounts of the wide range of chemicals produced, handled, transported (imported and exported) and used in the European Community, the main

**Box 4: Risk reduction**

objective of the EC’s new strategy (“Strategy for a Future Chemicals Policy”) is to ensure a high level of protection for human safety and health and for the environment.

#### 2.4.1.3 Risk transfer

Risk transfer is carried out in different ways, including risk transfer by insurance and contract, risk sharing and physical transfer. Organisations may transfer insurable risks to a third party under a legal contract. These risks are known as contractually transferred risks.

**Transfer by insurance**

Risk transfer can take many forms, but the most common of these is the purchase of insurance and re-insurance. In recent years, more risks have become commercially insured. In some industries or businesses, insurance is one of the most developed areas of risk management. Risk transfer is mainly based on cost-benefit considerations. The costs of insured risks consist of insurance premiums, fees, commissions, and other administrative costs. In the shipping industry, the risks are insured by the risk carriers such as insurance companies. Approximately 90% of the world's merchant fleet (by tonnage) is bound into a mutual, non-profit-making structure, which is made up of the Protection and Indemnity (P&I) Clubs into which shipowners pool their third-party liabilities (Bennett 2001). Such liabilities include those arising from the ship, cargo and other property losses and damages, personnel injuries, and pollution liabilities (UK P&I Club 1998). The P&I Clubs contrast with commercial “hull and machinery” underwriters, such as the Lloyd's of London syndicates. Shipowners generally purchase insurance from profit-making companies (Bennett 2001).

Although it has become an important part of risk management, and in many cases it is necessary, risk transfer by insurance has its shortcomings. Even when a risk is "fully" insurable, the claims payment may, sometimes, be only a fraction of the total costs. Experiences have shown that for many types of risks, the hidden costs, in particular for accidents involving dangerous goods, may have been much higher than the amount of money paid by insurers. Hidden costs are medium and long term costs encountered by the organisation, including management time, administration, customer satisfaction, effect on morale, public perception and image, loss of market values and shares. For example, the insurance pays for repairing or rebuilding ships and replacing cargo damaged or lost, but it cannot cover for lost markets and customers, or bring back lives of people and marine environment fauna and flora.

### Risk sharing

In many countries and industries, there are various risk pooling arrangements providing for organisations the possibility to co-operate in reducing and sharing risk costs. In addition to the actual sharing of claims and the pooling of premiums, the essence of the pooling is also sharing of the services provided by the scheme management.

### Transfer by contract

In the shipping industry, for example, the charter parties, bill of lading and other contracts (e.g. sale and purchase of goods) stipulate rights and liabilities arising in cases of marine accidents and damages and losses of goods, including dangerous goods.

### Physical transfer

Risk transfer by contract or insurance concerns transfer of risk costs and responsibilities, but it may not necessarily concern physical transfer of human, environmental or property risks. Physical transfer of risks takes many different forms, including the transport mode or activity, whose purpose is to reduce the frequency of dangerous goods releases and/or the severity of consequences. Modal transfer, for example, involves transfer of risks from air to other transport modes, such as maritime, road or rail transport. The carriage of many dangerous goods is prohibited by air, but permitted by other modes. Risks are also physically transferred, for example by diverting the route of transport means (i.e. ships) with dangerous goods from high to less sensitive and dense residential areas.

Box 5 presents illustrative examples of risk transfer, risk prevention and mitigation concerning dangerous goods risks.

**Box 5: Risk transfer - compensation, insurance, liability limitation**

**International Convention on Carriage of Hazardous and Noxious Substances by Sea (HNS Convention 1996)**

The purpose of the HNS Convention (1996) is to provide compensation for loss or damage to persons, property and the environment arising from the carriage of hazardous and noxious substances by sea. Under the HNS Convention (1996), the shipowner is liable for loss or damage up to a certain amount (i.e. the limitation of liability), which is covered by insurance. This is the 1st tier of insurance, and it is compulsory insurance. The shipowner is required to take out insurance, or maintain other acceptable financial security to cover his liability under the HNS Convention (1996), and provide evidence of insurance coverage. The shipowner is strictly liable to pay compensation following an accident involving HNS Convention. However, the shipowner is normally entitled to limit his liability, where the aggregate amount of the liability does not exceed 100 million SDR.[12] A compensation fund, known as the HNS Fund, is a form of risk sharing providing additional compensation when the victims do not obtain full compensation from the shipowner or his insurer (i.e. the 2nd tier). The maximum amount payable by the HNS Fund, in respect of any single incident, is 250 million SDR. The HNS Fund (HNS 1996) is financed by contributions levied on persons that have received, in a calendar year, contributing cargoes after the sea transport.

**U.S. Comprehensive Environment Response Compensation and Liability Act (CERCLA 1980)**

In the late 1970's, massive contaminations from toxic wastes disposed during the 1940's and 50's at Love Canal located in upper New York State in the U.S.A. were discovered. The first discoveries were followed by discoveries of many other sites. In 1976, in response to massive contaminations and sensitised by media attention and public outrage, the U.S. government passed the Toxic Substances Control Act (USEPA 1989). In 1980, the U.S. Congress passed the Comprehensive Environmental Response Compensation and Liability Act (CERCLA 1980). The CERCLA (1980) allowed the U.S. government to tax chemical production, use and

[12] The Special Drawing Rights is a monetary unit established by the International Monetary Fund (IMF); as at 31 December 2001, 1 SDR = £ 0.86558 or U.S.$1.25976.

other related activities. The government used those funds for the restoration of hazardous waste sites across the U.S.A. territory. Because of the huge reserves of money accumulated (30 billion U.S. $) within this fund, it was called “Superfund.” Through the superfund, the government also paid large amounts of money for education, experimentation, technology development, implementation and assessment of risks of hazardous materials.

**Convention on Civil Liability for Damage Caused during Carriage of Dangerous Goods by Road, Rail and Inland Navigation Vessels (CRTD 1989)**

In 1989, because of the continuous increase in the carriage of dangerous goods and given the quality of existing technical standards at national and international levels, it was decided to establish uniform rules ensuring adequate and speedy compensation for damage caused during carriage of dangerous goods by road, rail and inland navigation vessels. The CRTD Convention was prepared by the International Institute for the Unification of Private Law (UNIDROIT) and adopted by the Inland Transport Committee of the Economic Commission for Europe at its fifty-first session, held in Geneva from 2 to 10 October 1989. The CRTD was opened for signature on 1 February 1990. Because of the limit of liability and compulsory insurance, the Convention has not yet entered into force. Only Germany and Morocco have signed the Convention. The Convention comprises seven provisions and 31 articles, including definitions, the scope of application, liability provisions, the limitation of liability, the compulsory insurance, claims and actions, and final provisions.

#### 2.4.1.4 Risk retention

There are various reasons why certain risks are to be retained. In some situations, risks, however undesirable they could be, cannot be avoided, reduced or transferred, as this can be economically or practically impossible. The decision makers may have no other alternative than to retain these risks. In certain circumstances, no active response may be a solution. Further, after reduced risks at a given level, some risks may still remain, known as residual risks. These types of risks may be considered as insignificant or negligible, and further reduction may be very expensive and counterproductive.

Risk retention does not necessarily mean doing nothing. “Doing nothing” means taking some kind of risk (HSE 2001). Although risks may be at the "negligible" level, where no actions for changes or improvements may be needed, the decision makers still need to commit considerable time, resources and efforts to maintain these risks at the current level.

"Self risk", which is known in the insurance industry as deductibles, is a form of risk retention. Another form of risk retention is "self-funding" or "self-insurance", in which certain organisations may fund insurance claims from the organisation's own reserves. This means that claims arising, for example from serious accidents, may be paid from the reserves of the organisation. In some industries and sectors, self-insurance has been used for many years as a means to take control of insurance. Many organisations continue to reduce their dependency on the external insurance market and buy only coverage for catastrophic events.

### 2.4.2 Risk management measures

The list of possible measures to deal with risks of dangerous goods is also endless. However, based on the understanding gained through the literature review and the examination of empirical data, risk management measures (see Table 9) are categorised based on the purpose of enactment, legal aspects and their nature.

***Purpose or strategy of enactment***: Risk management measures can be preventive (e.g. measures to reduce the frequency of accidents) or mitigating. Examples of preventive measures are technical and operational measures to eliminate or reduce releases of dangerous goods. Rescue services and contingency planning are examples of mitigating measures.

***Legal aspects***: From a legal point of view, measures can be divided into a) regulatory (command and control) or non-voluntary, and b) non-regulatory or voluntary measures. Command and control measures include all categories of legally binding measures, for example, technical or operational. The transport of dangerous goods is highly regulated and numbers of responsible authorities are assigned to enforce compliance with regulations. On the other hand, product stewardship and environmentally friendly product design, employee health and safety programmes, information and education programmes to modify people's behaviours and promote marine pollution prevention are voluntary initiatives developed with the purpose of reducing risks from chemicals. For example, the chemical industry's code of practice "Chemical Industries Responsible Care Programme" is a voluntary initiative. For another example, the European Commission (EC 1996a) has published recommendations on the development and implementation of Environmental Agreements with the aim of enhancing the effectiveness of voluntary agreements.

***Types of measures***: The following are some examples of risk management measures by type:

- *Information/knowledge*: for example:
  - Risk communication programmes;
  - Information tools, such as the classification and labelling system;
  - Dissemination/sharing of risk-related data and information;
  - Dissemination/sharing of risk assessment results;
  - Public hearings.
- *Financial*: for example financial instruments including:
  - Market-based economic incentive tools, such as charges, levies on importers and distributors;
  - Trade restrictions or permits systems;
  - Quotas on imports/exports;
  - Subsidies to substitute dangerous with non-dangerous products. The purpose of these measures is to prompt desired changes in decision-makings, and to shift behaviours of people, including producers, carriers and users.
- *Technological*: the use of the best technology available including:
  - Hardware - e.g. ships and packagings;
  - Software - e.g. risk analysis/ assessment software tools;
  - Information Technology and Communication (ITC) solutions.
- *Operational*: for example:
  - Packing
  - Storage
  - Stowage
  - Loading/discharging
  - Caring
  - Transport
  - Documentation
  - Securing of PDG.
- *Training and education*: for example:
  - Programmes for training and education of people involved in dangerous goods activities.
- *Methodological*: for example:
  - Risks assessment and management methods, techniques and tools
  - Marine accident data and databases;

- Marine accident reporting systems;
- Marine accident investigation procedures.

A single measure can be enacted to affect one or several combinations of risk or system elements. On the other hand, multiple measures can be designed to affect a single element. Often, there is no single solution to guarantee a high degree of safety and health, environmental and property protection. As one single measure may be not sufficient, several measures are often combined to achieve the risk management strategies. For example, this may be combining the mandatory technology and procedure with levy or subsidy measures.

Box 6 presents an example of legal measures concerning dangerous goods risk management.

**Box 6: Legal measures**

**Australian Dangerous Goods Safety Management (DGSM) Act, Regulations and Guidelines**

In recent years, in a number of countries dangerous goods safety management acts and regulations are becoming initiatives designed to protect people, the environment and property. The guidelines are produced for the occupiers of dangerous goods facilities, locations, and storage workplaces as references to the requirements of laws. Figure 7 shows the Australian Dangerous Goods Safety Management (2001) legislative framework. The key requirements concern (Australia DGSM Act 2001): a systematic risk assessment; emergency plans and procedures; a safety management system; a programme of induction, information, education, supervision and training for all persons at the facility; information to, and opportunities for, consultation with the neighbouring community; and a safety report.

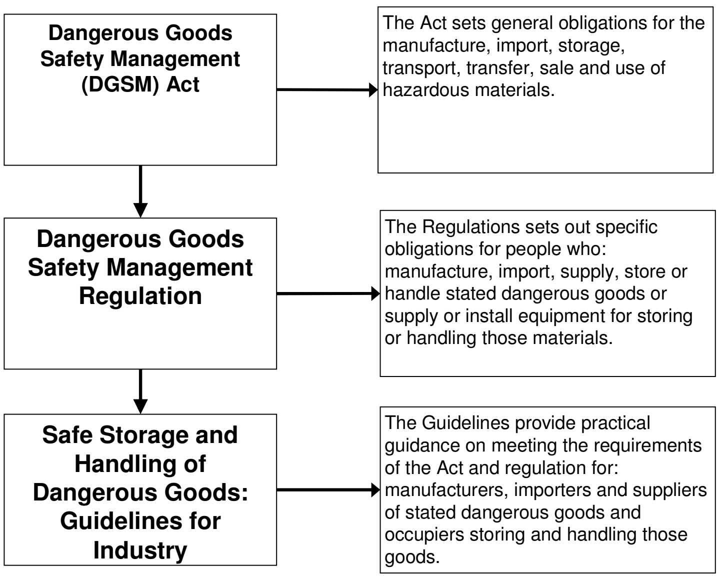


**Figure 7**: An example of the legislative framework (Australia DGSM Act 2001)

The example illustrates a number of points. Because of risks involved, dangerous goods-related activities are highly regulated by the law. The dangerous goods risk or safety management is also regulated. The legislative framework consists of three hierarchically related elements, namely: act, regulation and guidelines, each with a distinct legal status. The framework is a legally binding risk management instrument, which in itself consists of operational, technical and managerial measures concerning specific activities.

Similarly, the U.K. Management of Health and Safety at Work Regulations (MHSWR) 1999 require employers and self-employed people to assess the risks in their undertakings and identify the measures taken to comply with the requirements of the health and safety law (HSE 2001).

### 2.4.3 Evaluation criteria for risk management strategy and measure

Due to the wide range of effects, risk management strategies and measures are often difficult to compare and evaluate. The best decision is the one that yields the greatest expected value. For example, the USCG (2001) has designed three general criteria (Table 10) for evaluation of risk management strategies and measures.

**Table 10**: Evaluation criteria (USCG 2001)

| Criterion | Description |
|---|---|
| *Efficacy* | The degree to which the risk will either be eliminated or minimized by the proposed action. |
| *Feasibility* | The acceptability of implementing the proposed preventative action (economic, legal, physical, political, social, technical, etc.) |
| *Efficiency* | The cost-effectiveness of the proposed action in terms of potential dollars lost if no action is taken versus the cost of the action. |

## 2.5 Costs-benefit trade-off

The aim of risk management is to take measures for managing risks of concern and make sure that they do not give rise to any new or additional risks. However, this may not be possible in all cases and all the time. At some point in time, decision makers will need to balance increases in one type of risk against decreases in another type of risk. This may require comparisons and costs/benefits trade-offs. For example, they need to consider between the following: the human safety and health risks versus the environment risks; individual risks versus collective or societal risks; risk receptors versus risk receptors, chemicals versus chemicals, activities versus activities, and many more.

An important task of risk management is to combine overall perceived risks with overall perceived benefits into an overall evaluation. For a long time, both consciously and unconsciously, individuals, groups of people and the entire society have been exploiting and enjoying benefits attached to chemicals. Benefits and costs of risks are often inseparable.

Almost all risk management strategies and measures, in particular large and sensitive decisions, involve costs. It may be nearly always possible to take measures that would reduce risks further, but the costs would outweigh the expected benefits. In many cases, in decision making, a balance between the benefits of safety and costs of achieving them is needed. In economists' terminology, this means that risks should be reduced until the "marginal cost equals the marginal benefit." These principles are applied to many different kinds of decision-making. For example, ALARP ("As Low As is Reasonably Practicable") and BATNEEC ("Best Available Technology Not Entailing Excessive Costs"), which imply a balance between costs and benefits, are adopted in risk management of dangerous goods-related activities. However, in many cases, large amounts of resources may be invested for "little gains."

An explicit evaluation of the costs and benefits requires a common unit. The common unit of measurement is suggested to be the monetary value. This is considered as the best alternative for facilitating decision-making that is consistent over different areas (Mooney 1977) (Martin 1986). In the absence of explicit cost-benefit assessment, different decisions may imply very different amounts spent to make changes at the margin. Monetary evaluation of risk reduction measures involves putting a monetary value, for example, on saving human life and environmental pollution prevention and compensation. How much is a human life worth? This varies widely among countries. Many do not agree on “putting a price on human life” arguing that a human life is priceless and it is not treated as something special. Purely objective risk assessments, which may involve monetary evaluation of risks and risk reduction measures, have been criticized (Slovic 1992). The ground for criticisms is that these assessments depend upon the measurement of economic losses ignoring other essential factors, such as the long-term environmental effects, fears, shocks and other intangible effects that cannot precisely be measured, in particular in monetary terms. Some others, however, argue that people who know that they are at higher risks still do drive cars or smoke.

The cost/benefit of risk reduction measures can be expressed as follows (Monioudis and Mavromatakis 1997, p 3):

Cost/Benefit = Averted loss (monetary unit/year)/ costs of implemented risk reduction (monetary unit)

Where the averted cost is:

Averted loss (monetary unit/year) = Cost of accident (monetary unit) x Frequency of accident (events/year).

One measure of cost effectiveness is the implied cost of risk reduction related to a specific hazard. Thus, the implied cost to avert the hazard (ICAH) is (Monioudis and Mavromatakis 1997, p 3):

$$ICAH = \frac{CostOfSafetyMeasures}{\Delta r}$$

Where, Δr is risk reduction as the result of safety measures. The equation shows that a low ICAH is an indication that the measure is cost effective, whereas a high ICAH indicates that costs are in disproportion with the benefits.

In order to estimate the cost effectiveness of risk reduction measures in shipping, the IMO (2004) has proposed criteria of Gross Cost of Averting a Fatality (GCAF) and Net Cost of Averting a Fatality (NCAF). These criteria have derived from these approaches: a) observation of the Willingness-To-Pay (WTP) to avert a fatality; b) observation of past decisions and the costs involved with them; and c) consideration of societal indicators (IMO 2004, p 10). The IMO defines GCAF and NCAF as follows (IMO 2004, p 3):

- *GCAF (Gross Cost of Averting a Fatality)*: A cost effectiveness measure in terms of ratio of marginal (additional) cost of the risk control option to the reduction in risk to personnel in terms of the fatalities averted:

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

- *NCAF (Net Cost of Averting a Fatality)*: A cost effectiveness measure in terms of ratio of marginal (additional) cost, accounting for the economic benefits of the risk control option to the reduction in risk to personnel in terms of the fatalities averted:

$$NCAF = \frac{\Delta Cost - \Delta EconomicBenefit}{\Delta Risk} = GCAF - \frac{\Delta EconomicBenefit}{\Delta Risk}$$

The proposed values for NCAF and GCAF criteria, which are derived by considering societal indicators (IMO 2004 with refer to MSC 72/16; UNDP 1990; Lind 1996), are respectively U.S. $ 3 million for risk of fatality, injuries and ill health combined and U.S. $ 1.5 million for risk of fatality, injuries and ill health individually (IMO 2004, p 10).

The U.K. HSE (2001) employs a benchmark value of about £1,000,000 (2001 prices) for the Value of Preventing a Fatality (VPF)[13] when carrying out a costs-benefits analysis (CBA). The VPF has been adopted by the U.K. Department of Transport, local governments and regions for assessment of road safety measures (HSE 2001). The VPF vary depending on country, industry and hazardous situations.

## 2.6 Summary

Despite the progress being made, there are still variations, misuses and misconceptions in the field of risk management. Even some large prominent scientific communities share common misconceptions. Variations arising in terminology, concepts, methodology and practices, are due to combinations of many different factors including differences in perceptions, needs, specifications, and even differences in languages. Based on the understanding gained in this research, through an extensive literature study and examination and analysis of the empirical date, attempts have been made to provide a unified understanding of the field of risk management. Therefore, a generic model has been presented (see Figure 3). The model

[13] This is what people are prepared to pay to secure a certain averaged risk reduction (HSE 2001).

represents graphically the risk management system, which is the broadest concept in the field. The *risk management system* has been defined as the overall integrated process consisting of two interrelated, but distinct, components (phases/stages) – *risk assessment* (or safety assessment) and *risk management*. According to numbers of sources, risk assessment is further subdivided into risk analysis and risk evaluation. The model presents the main phases of the overall process, namely: *phase 1: risk analysis*, *phase 2: risk evaluation*, and *phase 3: risk management*, each of which is further broken down into a number of stages, steps and sub-steps. *Risk communication* has become an important element of the system that involves the exchange of information and opinion among the parties concerned. All these essential concepts and their relationships are accordingly defined and described in some detail. Phase 1: risk analysis is further expanded and further developed for the purpose of readily application in risk analysis of the maritime transport system of PDG (see Mullai 2004).

# 3 RISK ASSESSMENT FRAMEWORKS AND TECHNIQUES

*This Chapter reviews and evaluates risk analysis/assessment frameworks and techniques in shipping and other industries and sectors across different countries, mainly in some OECD countries, such as European countries and North America. They are relevant to the field of human safety and health and environmental protection. The merits of risk analysis techniques and factors affecting their choices are also explored.*

This Chapter is structured according to Figure 8.

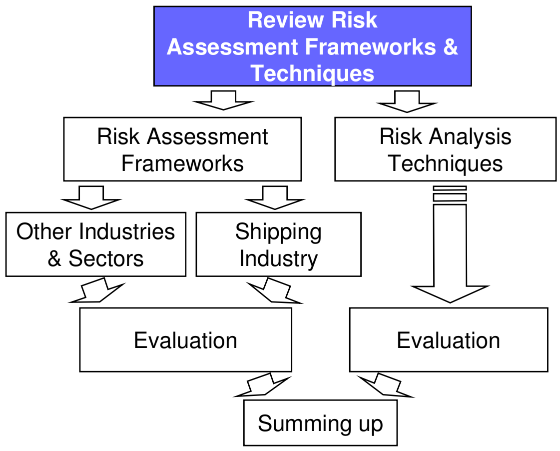


**Figure 8**: Risk assessment frameworks and techniques

## 3.1 Introduction

### Definition of "framework" and "technique"

There is no generally agreed definition of what may constitute "framework" and "technique". Often, other similar terms are used, for example, "standards", "guidelines", "procedures" and "approaches". They may encompass a wide range of activities for preparing and performing risk analysis/assessment and presenting and documenting the results. Sometimes it is difficult to tell them apart. However, from their contents and purposes of applications, some differences can be observed. The term "framework" has a broader scope than the term "technique." They vary in the degree of details – from very detailed and specific to general guidelines. In addition, some frameworks consist of guidelines that may be beyond the risk analysis or assessment processes. For example, they may include activities concerning the decision-making, planning and implementation of risk management strategies and measures.

As mentioned earlier (see Chapter 2), the term “risk management system” represents the broadest concept in the field. However, the term “risk assessment framework” and other similar terms mentioned above are often used interchangeably. Risk analysis techniques (see Section 3.3) are employed as analytical tools for analysis of risk-related data and information. Some techniques focus on analysis of a particular risk element (e.g. hazard identification), whilst some others are best suited for the analysis of several system or risk elements. In some cases, techniques are used as supplements or integrated elements of the risk assessment frameworks. A detailed discussion about risk analysis techniques is provided in Section 3.3.

**The “uniqueness” of the maritime transport of PDG**

Before reviewing risk assessment frameworks and techniques, it is important to discuss differences and similarities in terms of the system and risks associated with it. The discussion focuses on differences and similarities between the maritime transport system of PDG, on the one hand, and other sectors of the shipping industry and other industries, sectors, activities or aspects, on the other hand. This discussion is important for the external validity of the research results and research contributions.[14]

Although sharing similarities with the maritime transport of dangerous bulk cargoes, other modes of transport, industries and sectors, the maritime transport system of PDG and risks associated with it are, to some extent, unique. Table 11 provides some illustrative examples of similarities and differences. All dangerous goods-related activities and aspects share in common, among other things, risks that dangerous goods pose to human safety and health, the environment and properties. Further, regardless of the type of system or activity, the principal elements of risks are the same, namely causes and contributing factors, frequency, consequences and exposures.

[14] See author’s thesis, Mullai 2007.

**Table 11**: Examples of similarities and differences between the maritime transport of PDG and other industries, sectors and activities

| **Industries, sectors or aspects** | **Maritime transport of PDG** | |
|---|---|---|
| | *Similarities* | *Differences* |
| *Shipping industry* | • Maritime transport | • Packaged dangerous goods |
| *Maritime transport of dangerous cargoes in bulk: oil, oil products and other chemicals* | • Maritime transport<br>• Dangerous goods/cargo | • Packaging/cargo transport units (CTU) |
| *Offshore industry* | • Maritime industry/activity<br>• Marine environment<br>• Safety/health and environmental protection | • Maritime transport of PDG |
| *Ports/terminals* | • Maritime transport: shore side activities, e.g. loading or discharging | • Maritime transport – en route/ voyage |
| *Other modes of transport: road, rail, and air* | • Transport<br>• Transport of dangerous goods<br>• Packaging/CTUs | • Maritime transport |
| *Other supply chain activities – chemical life-cycle* | • Chemicals/dangerous goods<br>• Human safety and health and environment | • Maritime transport of PDG<br>• Maritime environment |
| *Occupation, Safety and Health* | • Safety and health protection<br>• Chemicals/dangerous goods | • Maritime transport of PDG |
| *Environmental protection: water, air and land* | • Environmental protection<br>• Chemicals/dangerous goods | • Maritime transport of PDG<br>• Seafarers and local community safety and health<br>• Maritime environment |

The following highlights some specific aspects of the maritime transport system of PDG and risks associated with it.

- *Ports/terminals*: Ships spend time in ports in loading and unloading of their cargoes, but they spend much time at sea, where own and other ship's crews and passengers are exposed to the hazards of dangerous goods. Ships are also exposed to a wide range of weather and sea hazards.
- *Offshore industry*: Ships carry dangerous goods through densely populated areas and very sensitive waters and coastlines. The people ashore are exposed to the wide range of hazardous properties of dangerous goods carried in packaged form, including explosions, fires and toxic fumes, when ships are in ports or passing through residential areas.
- *Other modes of transport*: Ships carry larger amounts of different types of dangerous goods. Ships and packages are exposed to a wider range of weather and transport hazards. Further, dangerous goods pose risks to the marine environment. However, PDG are, in most cases, carried onboard ships in similar packages and CTUs (e.g. containers, vehicles or wagons) as in road and rail transport.
- *Maritime transport of dangerous bulk cargoes*: The maritime transport system of PDG differs from the carriage of dangerous bulk cargoes because of specifications and diversities in a number of things (see Table 11). These include: types of ships (e.g. ro-ro ships, container ships, ferry ships, general cargo ships etc.), types of dangerous goods, packages, transport-related activities (e.g. loading and unloading, stowing, packing, cargo securing and documentation etc), the regulatory system and transport hazards. Today, purpose-built ships, such as container ships and ro-ro ships and their cargo spaces, are intended for the carriage of dangerous goods in freight containers and portable tanks and tank containers. The carriage of containerised cargoes and container ships differ, in many respects, from the carriage of bulk cargoes and bulk carriers and tanker ships (Wang and Foinikis 2001). SOLAS 1974 contains special requirements for ships carrying PDG. However, both sectors share the maritime transport and dangerous cargoes in common.

Given the specifications of the maritime transport system and risks of PDG and the lack of a specific framework, it is important to further develop a risk analysis framework for readily application in the maritime transport system of PDG. On the other hand, given the similarities, it is important to review and gain insights on risk management practices in other sectors of the shipping industry, and other industries, sectors and activities.

## 3.2 Risk assessment frameworks

In the following Section, numerous risk assessment frameworks and some of the related best practices in shipping and some other industries, sectors and activities have been reviewed and evaluated (see the highlighted area in Figure 9). The review begins with frameworks and practices in other industries and sectors (see the highlighted area in Figure 10).

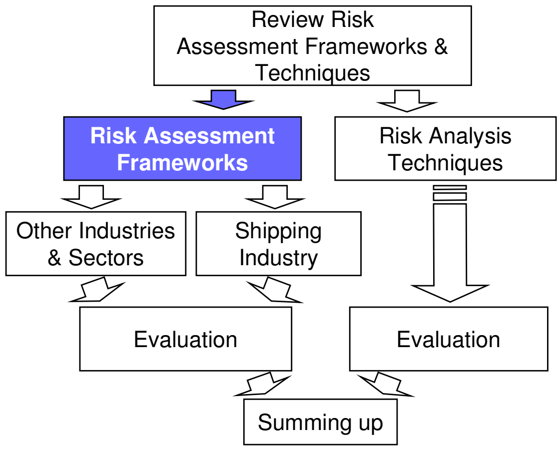


**Figure 9**: Risk assessment frameworks and practices

### 3.2.1 Other industries and sectors

In recent years, a large amount of work has been done by a number of organisations, including Organisation for Economic Co-operation and Development (OECD 2001), Committee for Standardisation (CEN 2001), International Organisation for Standardisation (ISO 2001), United Nations Environment Programme (UNEP 2001), International Maritime Organisation (IMO 1996, 2002), USA Environmental Protection Agency (USEPA 2001) and many other organisations in developing standards for managing risks in a wide range of areas of human activities and technological systems, and human safety and health and environmental protection in particular. They provide reference frameworks for undertaking risk assessment and formulation of policies and strategies. Some examples are the International Organization for Standardization (ISO) Quality Management (ISO 9000 series) and Environmental Management (ISO 14000 series) and Chemical Industry Association guidelines on Safety, Health and Environmental Management Systems. The following Section presents risk assessment frameworks and best practices in some industries and sectors (see the highlighted area in Figure 10), namely:

- Civil protection and rescue service
- Offshore industry
- ILO Guidelines on Occupational Safety and Health Management Systems
- Superfund and risk assessment frameworks (USA)
- USA Environmental Protection Agency (USEPA) Risk Assessment Guidelines
- USA Occupation, Safety and Health Administration Rules
- Chemical industry
- OECD Working Group Chemical Accident System
- ISO 9000 and ISO 14000 Standards
- International Standard IEC 300-3-9

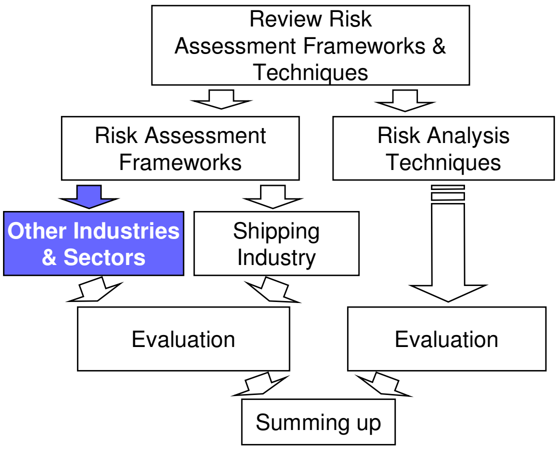


**Figure 10**: Risk assessment frameworks and practices in some other industries and sectors

#### 3.2.1.1 Civil protection and rescue service

In 1998, a study, which was based on a questionnaire, was carried out in civil protection and the rescue services in the EU area, focusing in particular on Denmark, Finland, Germany, the Netherlands and Sweden (DCDEP 2000). The study focused especially on the use of risk assessment procedures. The ways in which risk assessment is performed in the field varied considerably across Europe, reflecting the different administrational systems in these countries. The survey pointed out that the risk assessment procedures are not harmonised in accordance with relevant legal frameworks, such as the Seveso I directive and other EU legal requirements. The Swedish Rescue Services Agency (RSA)[15] planned (1998) to develop an application for risk mapping called Risk-Era, which was intended to complement the Risk Handbook (RSA 1989). The handbook provides guidelines for risk assessment. The application allows the local risk managers to follow a continuous safety improvement process. In addition, in recent years, the agency has also published 20-30 reports and training materials per year dealing with prevention of various types of accidents including fires, explosions, and chemical spills in the chemical industry, transport and other activities.

#### 3.2.1.2 Offshore industry

The UK Offshore Operators Association (UKOOA) and the Health and Safety Executive (HSE) (UKOOA 1999) have produced guidelines for the offshore industry entitled “A Framework for Risk Related Decision Support.” The framework is designed for a wide range of applications under various conditions, providing tools for assessing codes and standards, good practice, engineering judgments, risk analysis, cost benefit analysis, company and social values when making a decision. The framework is also used in combination with other formal decision-making aids such as multi-attribute utility analysis (MAUA) and the analytical hierarchy process (AHP).

[15] In Swedish Räddningsverket

### 3.2.1.3 ILO Guidelines on Occupational Safety and Health Management Systems

According to the International Labour Organisation (ILO 2001), the number of occupational accidents and diseases is increasing, in particular in developing countries. It has been estimated that every year over 1.2 million workers are killed due to work-related accidents and diseases, and 250 million occupational accidents and 160 million work-related diseases are occurring. The economic loss related to these accidents and diseases are estimated to amount to 4% of the world gross national product. In response to these issues, the ILO has developed guidelines on Occupational Safety and Health Management Systems, known as ILO-OSH (2001). The guidelines were adopted at a meeting of experts in April 2001 and published in December 2001.

ILO-OSH Guidelines provide an international model that is compatible with other management system standards and guidelines (ILO 2001). They are not legally binding and do not replace national laws, regulations and accepted standards. The guidelines are in line with the relevant ILO international standards, including the Occupational Safety and Health Convention (ILO, 1981) and the Occupational Health Services Convention (ILO 1985). Their applications do not require certification, but they do not exclude certification as a means of recognition of good practice.

The ILO-OSH Guidelines (ILO 2001) states that OSH should be an integral part of other management systems. Guidelines provide guidance for implementation on two levels – the national level (Chapter 2) and the organizational level (Chapter 3). The OSH management system for the organizational level has five main sections containing a number of elements. The system follows the internationally well-known Deming cycle of Plan-Do-Check-Act. The five main sections and elements of the ILO Guidelines (ILO 2001) are:

- *Policy* (elements: policy and worker participation);
- *Organizing* (elements: responsibility and accountability, competence and training, documentation and communication);
- *Planning and implementation* (elements: initial review, system planning, development and implementation, objectives and hazard prevention);
- *Evaluation* (elements: performance monitoring and measurement, investigation of work related injuries, ill-health, diseases and incidents, audit and management review);

- *Action for improvement* (elements: preventive and corrective action and continual improvement).

The guidelines emphasize the need for continual improvement of performance through the constant development of policies, systems and techniques to prevent and control work-related injuries, ill health, diseases and incidents.

#### 3.2.1.4 Superfund and risk assessment frameworks

In response to massive contaminations (discovered in the late 1970's) from toxic wastes disposed during the 1940's and 50's at Love Canal located in upper New York State in the U.S.A., which was followed by discoveries of many other sites, and sensitised by the media attention and public outrage, the U.S. government passed the Toxic Substances Control Act in 1976 (USEPA, 1989). In 1980, the U.S. Congress passed the Comprehensive Environmental Response Compensation and Liability Act (CERCLA 1980). CERCLA (1980) allowed the U.S. government to tax specific chemicals and use those funds for the restoration of hazardous waste sites across the U.S.A. Because of the huge reserves of money accumulated (30 billion U.S. $) within this fund, it was called "Superfund." The superfund has also paid large amounts of money for education, experimentation, technology development, implementation and assessment. On behalf of the "Superfund", many different organisations and individuals from the scientific community have worked on developing new advanced risk assessment and management guidelines, approaches and tools. In order to set up clean-up goals based on risk and determine necessary remedial efforts, a new approach called Risk Based Corrective Action (RBCA – ReBeCA) was developed. The approach provided U.S. regulators greater flexibility, and its utilisation yielded considerable savings over conventional approaches, without endangering human health or the environment (USEPA 1989). In this respect, numbers of organisations working in human safety and health and environmental protection have benefited from the fund, including the U.S. Environmental Protection Agency (USEPA) and U.S. Coast Guard (USCG).

#### 3.2.1.5 USEPA risk assessment guidelines

The risk assessment guidelines of the U.S. Environmental Protection Agency (USEPA), which are based on a wide range of sources, including issue papers and case studies developed by USEPA Risk Assessment Guidelines, consist of four generic steps (USEPA 1989, 1998):

- Hazard identification
- Dose response assessment
- Exposure assessment
- Risk characterisation

The main purpose of guidelines is to improve the quality and consistency of ecological risk assessments. Guidelines describe how each step should be carried out. The section of problem formulation discusses the role of interested parties in determining the scope and boundaries of the assessment, selecting ecological entities, and ensuring that the information and perspectives of the assessment will support environmental decision-making. The risk characterization section discusses estimating, interpreting, and reporting risks. The interaction among risk assessors, risk managers, and interested parties from the beginning to the end of the process is emphasised as a very important element.

#### 3.2.1.6 USA Occupation, Safety and Health Administration Rules

The OSHA's Process Safety Management Rules (OSHA PSM 1910.119) contain requirements for the management of hazards associated with processes using highly hazardous chemicals. The rules establish procedures for process safety management for safeguarding employees by preventing or minimizing the consequences of chemical accidents involving highly hazardous chemicals. This concerns the employees' exposure to the hazards of toxicity, fires, and explosions from releases of highly hazardous chemicals in their workplaces. The OSHA document addresses a number of elements, including employee involvement in the process, safety information, hazard analysis, operating procedures and practices, training, start-up safety, organisational integrity, managing change, investigation of incidents, emergency preparedness and compliance audits. The following parts of the rules (Standards - 29 CFR) are related to the maritime sector:

- *Part 1915*: Occupation Safety and Health Standards for Shipping yard Employment;
- *Part 1917*: Maritime Terminals;
- *Part 1918*: Safety and Health Regulations for Long shoring.

#### 3.2.1.7 Chemical industry

In 1995, an Inter-Organisation Programme for the Sound Management of Chemicals (IOMC) was established by a number of prominent organisations such as the UNEP, ILO, FAO, WHO, UNIDO, UNITAR and OECD. The purpose was to promote coordination of the policies and activities to achieve sound management of chemicals in relation to human safety and health and environment protection.

Risk assessment practices concerning risks associated with the chemical's life cycle including transportation vary among different countries. In many countries, they may be lacking altogether. A few years ago, a study was undertaken for the European Commission (OECD 1996) and UK Department of Environment (RPA 1996) involving a survey in 19 countries. The study included EU Member States, the U.S.A., Australia, Canada, and Japan. According to the study, regulatory assessment practices, in general, vary considerably among different countries (OECD 1996). Many countries make use of a wide range of assessment approaches, including (OECD 1996):

- Compliance Cost Assessments (CCA)
- Cost Benefits Analysis (CBA)
- Cost Efficient Analysis (CEA)
- Multi-Criteria Analysis (MCA)
- Checklists
- Simple scoring and weighting techniques

Numerous countries have strict requirements for the use of economic appraisal, resulting in highly developed systems for co-ordinating appraisal activities (OECD 1996). However, in some other countries, risk assessments are carried out on a more ad-hoc basis, with little formal co-ordination.

### 3.2.1.8 OECD Working Group Chemical Accident System

The Chemical Accident Risk Assessment Thesaurus (CARAT) (OECD 2001) is a database system developed by the OECD Working Group Chemical Accident with the purpose to facilitate understanding of risk assessment of accidental releases of chemicals from fixed installations. The system contains four classes of information: concepts and definitions associated with risk assessment; laws and regulations concerning risk assessment of hazardous facilities; guidelines, policies or codes related to risk assessment; and specific risk assessment studies that have been conducted on particular cases. Information is provided by various national and regional agencies, international organizations, chemical companies, and other interested parties, including the European Union, individual European countries, the U.S.A., Canada, and other OECD member countries. The system contains four generic elements representing four stages of the risk assessment process, which are (OECD 2001):

- Hazard identification
- Hazard release and exposure scenarios
- Source and subject interaction
- Expression of the risk

Each generic element consists of numbers of sub-elements, which are steps that encompass one phase of the generic element in the risk assessment process. Each sub-element is further broken into categories.

### 3.2.1.9 ISO 9000 and ISO 14000 Standards

The ISO 9000 and ISO 14000 families are among ISO's most widely known and applicable standards (ISO 2004). They have become international references for management systems. Many ISO standards are specific to a particular product, material, or process. The ISO 9000 and ISO 14000 standards have been implemented (as of 2004) by some 634 000 organizations in 152 countries worldwide (ISO 2004). The ISO 9000 family is mainly concerned with quality management, including the requirements that organisations have to fulfil in connection with the customer's quality requirements, customer satisfaction and application of relevant regulations. The ISO 14000 family is concerned with environmental management. The primary purpose of ISO 14000 is to enable organizations to meet relevant environment requirements in minimizing harmful effects on the environment caused by their activities, achieve continual improvements of their environmental performance and meet their environmental challenges in the future.

**Environmental Management Systems (EMSs)**

As environmental issues have increasingly become important for many industries and sectors in many countries, tools have been developed to help organisations to manage their risks. Some of these tools are known as Environmental Management Systems (EMSs). EMSs are developed to systematically assess and manage environmental risks, including risks of accidents involving chemicals. These systems incorporated standard probability risk assessment techniques into environmental hazard analysis procedures. There are various EMSs available, but the most recognised systems are accredited, such as ISO 14001 and EC Eco-Management and Audit Scheme (EMAS), and non-accredited systems, such as the Chemical Industries Association (CIA) Responsible Care Programme. All these systems require a commitment to continual improvements in environmental performance.

The ISO series is a set of individual but related international standards for quality management and quality assurance. They are adjusted to particular products or processes. These standards are used by manufacturing, design and service industries as well. The ISO 14001, which was launched in October 1996, is an accredited EMS. It is an internationally recognised standard and applicable to any type of organisation. Many organisations around the world have obtained the ISO 14001 certificate, seeing it as a competitive advantage for markets where environmental standards are high. The ISO 14001 defines continual improvements in terms of enhancing environmental management systems to achieve improvements in the overall environmental performance.

The EMAS is a Europe-wide scheme that requires a commitment from the participating organisations in the form of an environmental statement. It has been applicable to certain industries and sectors, such as manufacturing, power plants and waste disposal sectors.

The Chemical Industries Association (CIA) Responsible Care Programme is a non-accredited system representing the chemical industry's commitment to continuous improvements in all aspects of the human safety and health and the environmental protection. The Responsible Care, which originated in Canada in 1984 as a "voluntary programme of action", has been disseminated in many organisations throughout the world.

All EMSs share a number of steps in common, which organisations have to undertake, including:

- Agree on an environmental policy;
- Conduct an environmental review;
- Agree on an organisational structure and individuals with environmental responsibilities;
- Develop a register of environmental effects;
- Set up a register of relevant legislation;
- Set objectives and targets; prepare a management manual;
- Implement operational control procedures;
- Train employees;
- Carry out environment auditing;
- Have an external audit;
- Gain registration.

#### 3.2.1.10 International Standard IEC 300-3-9

International Standard IEC 300-3-9, which has the form of recommendations for international application, concerns processes of risk management. The Technical Committee of the International Electro-technical Commission (IEC) has developed the standard. The IEC is a worldwide organisation for standardizations in electrical and electronic fields that cooperates closely with the ISO. The IEC standard (IEC 300-3-9) defines the processes of risk management, which is graphically portrayed in Figure 11, as follows (IEC 1995):

> *The process of risk management incorporates many different elements from the initial identification and analysis of risk to evaluation of its tolerability and identification of potential risk reduction options, through to the selection, implementation and monitoring of appropriate control and reduction measures.*
>
> *Risk analysis is a structured process that identifies both the likelihood and extent of adverse consequences from a given activity, facility or system. Within the context of this standard (IEC 300-3-9), the adverse consequences of concern are physical harm to people, property or the environment. Risk analysis attempts to answer three fundamental questions: What can go wrong? How likely is this to happen? What are the consequences?*

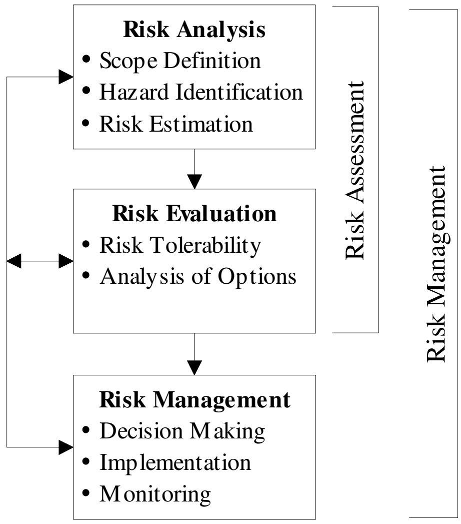


**Figure 11**: The IEC's risk management/assessment model (IEC 1995)

Part 3, Section 9 of the IEC standard (IEC 300-3-9) provides guidance for selecting and implementing risk analysis techniques, mainly employed for technological systems, such as electrical and electronic systems. The main objective of this standard is to ensure quality and consistency in the planning and execution of the risk analysis process and presentation of results (IEC 1995). The standard (IEC 300-3-9) is of a general nature intending to provide guidelines across many industries and systems, in which the following is stated (IEC 1995):

> *This standard does not provide specific criteria for identifying the need for risk analysis, or specify the type of risk analysis method that is required for a given situation. Nor does it offer detailed guidelines for specific hazards or include insurance, actuarial*16*, legal or financial interests.*

## EU directives and regulations

The following are examples of relevant EU directives and regulations concerning risk assessment and management:

- Technical Guidance Document in Support of Commission, Directive 93/67/EEC on Risk Assessment of New Notified Substances lays down common principles for assessing and evaluating risks to human health and the environment posed by new substances;

[16] Actuarial is a statistician, especially one employed by insurance companies to calculate risks, policy premiums and dividends, and annuity rates (CED, 1992).

- European Commission Regulation (EC 1994) No. 1488/94 on Risk Assessment of Existing Substances lays down similar principles for the risks posed by existing substances. EU Directive 76/769/EEC is also directly relevant for risk management.

**Box 7: Swedish Seveso Legislation**

The Swedish Seveso legislation is based on the EC directive and the Convention on the Transboundary effects of Industrial Accidents (OECD 2001). An important part of the implementation of the directive is found within the Work Environment Legislation (e.g. in AFS 1999:5) and other rules such as the Rescue Services Act (SFS 1986:1102), the Act on Flammables and Explosions (SFS 1988:868) and the Environmental Code (SFS 1998:808). In addition to the demand of identification of risks, the Swedish Seveso legislation also covers the following aspects:

- Risk (or safety) management system;
- Information to the public;
- Emergency plans.

The Environmental Code implies that risks be identified, described and managed properly. Reporting after an accident is regulated in paragraphs 70 and 70a in the Rescue Services Ordinance (SFS 1986:1107), as well as in paragraph 2 of the Work Environment Ordinance (SFS 1977:1166).

### 3.2.2 Risk assessment frameworks in shipping

In recent years, facing several challenges and increasing public concern about safety and health, the marine environment and property protection, numerous quantitative and qualitative risk assessment frameworks and techniques have been developed in the shipping industry. The purpose of this Section is to review state-of-the-art risk assessment frameworks and related practices in the shipping industry (see the highlighted area in Figure 12), namely:

- Formal Safety Assessment (FSA)
- Safety Case (SC)
- Quantitative Risk Assessment (QRA)
- Marine Accident Risk Calculation System (MARCS)
- USCG Risk-Based Decision-making (RBDM) Guidelines
- QRA and Risk-Effect Model (REM)
- Risk Assessment Framework for Maritime Safety Management System

- Other frameworks
- Marine accident/risk analysis procedures in the EU
- Example: SMA marine accident/risk analysis procedures

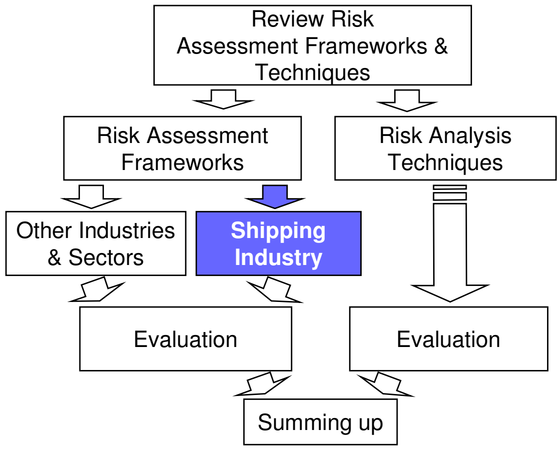


**Figure 12**: Risk assessment frameworks and practices in the shipping industry

### 3.2.2.1 Formal Safety Assessment (FSA)

The Formal Safety Assessment (FSA) is described as a structured and systematic methodology for assessing the risks related to maritime safety and the marine environment protection and for evaluating the costs and benefits of IMO's options for reducing these risks (IMO 1993, 2002). The FSA was introduced to the IMO by the UK's representatives for the first time in 1993. A joint Working Group of the Maritime Safety Committee (MSC) and the Marine Environment Protection Committee (MEPC) further developed the FSA. Since then, the FSA has been discussed and reviewed several times. In 2001, the IMO's main committees (MSC and MEPC) approved the Guidelines for the FSA for use in the IMO rule-making process. The following is a summary of the FSA (IMO 2002).

***Purpose***: The purpose of the FSA (IMO 2002) is to:

- Enhance maritime safety including life, heath, the marine environment and property protection;
- Help in evaluation of new regulations;
- Provide a basis for making decisions in accordance with objectives of the IMO;

- Enable appreciation of the effects of proposed regulatory changes in terms of benefits and related costs incurred for the industry;
- Facilitate the development of regulatory changes equitable to the various parties.

***Scope***: The guidelines are intended to outline the FSA methodology as a tool that may be used in the IMO rule-making process.

***Application***: The FSA methodology can be applied by an IMO Member Government, an organisation in consultative status with IMO or an IMO' committee in the following cases (IMO 2002): a) when proposing amendments to maritime safety, pollution prevention and response-related IMO instruments; b) to provide a balanced view of framework of regulations. According to the guidelines, the FSA is not intended for application in all circumstances (IMO 2002). Its application is particularly relevant to proposals that may have far-reaching implications in terms of either costs or legislative and administrative burdens.

***Steps***: The FSA methodology is a stepwise approach comprising the following five interrelated steps (IMO 2002):

- *Step 1 – Hazard identification*
- *Step 2 – Risk analysis*
- *Step 3 – Risk control options*
- *Step 4 – Cost-benefits assessment*
- *Step 5 – Recommendations for decision-making*

Figure 13 shows the flow chart of the IMO's FSA methodology.

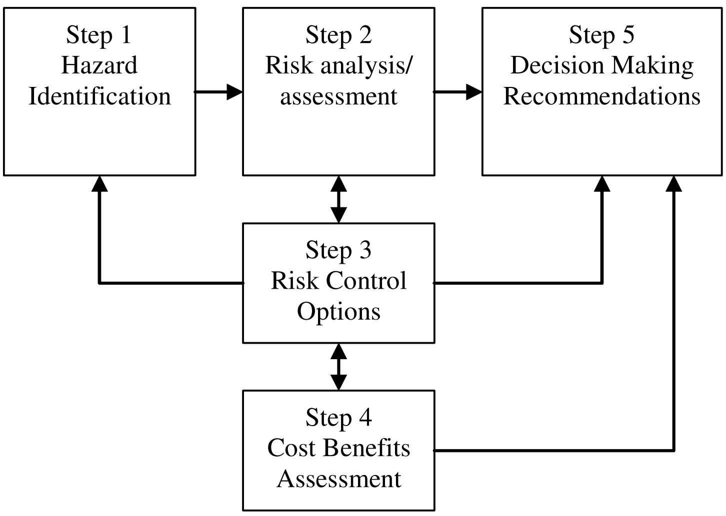


**Figure 13**: Flow chart of the IMO's FSA methodology (IMO 2002)

The FSA recognizes that there are several different interests involved in shipping, such as ship owners, cargo owners, third parties, passengers, crews, flag states, port states, insurers, class societies, associations and many more. Their attitudes and actions are significant influential factors in safety and marine environment protection. The FSA, therefore, includes the identification of shipping interests and consideration of the impact of regulatory options for the relevant shipping interests. At each step of the FSA, numerous techniques are employed to facilitate the process. For example, these techniques include structured group reviews (brainstorming), analysis of historical accident data and task analysis for hazard identification in step 1, fault and event tree analyses for the determination of the risks in step 2 and costs-benefits analysis (CBA) in step 4 (see Figure 13).

Many elements of the FSA are established in other industries and sectors. However, they are adapted for application in the shipping industry covering the risks to people, the marine environment and property resulting from ship operations and other related activities. The FSA has been developed to serve many users, including the IMO's committees and maritime administrations in the member states. The literature review shows that numerous maritime-related risks studies (including: Rao and Raghavan 1996; Lee et al. 2001; Lois et al. 2002; Trbojevic and Carr 2000) are based on the application of the FSA. However, the FSA is a highly generic framework that is not intended for application in all circumstances (IMO 2002). A thorough review of the IMO's guidelines (IMO 2002) also shows that the FSA is not readily applicable for risk analysis in the maritime transport of dangerous goods, including packaged dangerous goods. The FSA lacks the essential concepts or variables for representing and measuring the maritime transport system of dangerous goods and risks associated with it. Thus, the FSA does not contain a single term describing essential concepts related to risks of dangerous goods, such as "dangerous goods, substances, chemicals or hazardous materials", "toxic", "spill", "dose", "exposure" and many more.

#### 3.2.2.2 Safety Case

The UK Health and Safety Executive (HSE 1992) has introduced the Safety Case to the UK offshore industry. The safety case was a key recommendation of the Piper Alpha accident investigation report. Since 1992, this has been a legal requirement in offshore operations - "The Offshore Installations (Safety Case) Regulations 1992 (SCR)."  The safety case has also been adapted and used for assessing the risks in shipping. The safety case constitutes a demonstration to the shipping and public interests that risks arising from the operation of the ship are adequately understood and controlled. The main purpose is to ensure an adequate level of ship safety. A safety case includes a description of the ship and its operation and the environment in which it operates. Risk analysis is performed by making use of techniques such as FMEA and HAZOP for hazard identification, and fault and event tree analyses (FTA and ETA) for determination of the risks. The application of the safety case in shipping is voluntary. There are no requirements to impose a safety case regime on shipowners. However, some national maritime administrations have considered introduction of the approach for domestic shipping. Shipping companies, in particular tankers, liners, high-speed catamaran ferries, have also adapted the safety case approach.

The safety case approach requires the shipowner to take responsibility for assessing the risks associated with his ship, and for documenting how his safety management system limits those risks to an acceptable level. Risks are quantified to the extent deemed appropriate, and risk criteria are set usually in accordance with the ALARP principle. The safety management system is then developed from established good management principles, and becomes an integral part of the company’s overall management strategy. The safety management system includes these elements (HSE 1992):

- Setting policy;
- Organising, planning and implementing actions and monitoring;
- Review and feedback to assess performance against the policy.

The effectiveness and efficiency of the safety management system is monitored and verified by means of regular audits, and compliance with the requirements of the safety case checked by means of inspections. One limitation of the safety case approach for shipping is the burden of work required to undertake the complex analyses and compile extensive documentation for each and every ship.

### 3.2.2.3 Quantitative Risk Assessment (QRA) technique

A risk assessment framework has been developed by the DNV Technica Ltd. UK as part of a major risk study for the transport of bulk dangerous substances in British waters for the Heath and Safety Commission (HSC), known as the Quantitative Risk Assessment (QRA) technique (HSC 1991). The key steps of the approach are (HSC 1991):

- Port and hazardous trade definition
- Hazard identification
- Frequency estimation
- Consequence estimation
- Risk presentation

This systematic approach was employed for the first time to assess risks of the maritime transport of dangerous goods in British waters and ports. The study, subsequently the framework, was confined to the risks of major accidents affecting people ashore from bulk shipment of dangerous cargoes including crude oil, flammable and toxic liquefied gases, flammable liquid petroleum products, flammable liquid chemicals and ammonium nitrate (i.e. dry bulk cargo). The study did not consider the risks of the maritime transport of large amounts of different types of dangerous goods carried in packaged form, injury and other health risks, or the marine environment risks. This work has inspired individuals and authorities to develop or refine frameworks, for example, for assessing the risks from dangerous cargoes in port areas (Saccommanno 1993).

#### 3.2.2.4 Marine Accident Risk Calculation System (MARCS)

Marine Accident Risk Calculation System (MARCS) is a framework (see Figure 14) developed and used for the performance of maritime risk calculation (Fowler and Sorgård 2000). The framework has been developed in a project named SAFECO (Safety of Shipping in Coastal Waters) that was carried out by a consortium contracted by the Commission of European Community (CEC) through the 4th Framework Programme, Waterborne Transport and represented a number of prominent shipping interests. These interests included Det Norske Veritas (DNV), Danish Maritime Institute (DMI), Kelvin Hughes, Rotterdam Port Authority (RPA) and National Technical University of Athens (NTUA). The main project objective was to increase the safety of shipping in coastal waters by analysing factors that contribute to the accident risk level. The risk model uses statistical data to calculate frequency and consequence (and hence risks) of marine accidents (Fowler and Sorgård 2000). The model enables the assessment of each set of the risk control options within a single framework. However, the MARCS has been designed to analyse historical data of a limited number of serious accidents categories such as groundings, collisions, structure failures, foundering, and fire/explosions while ships are underway. The framework excludes fire/explosion during port operations, cargo losses overboard, cargo damages and spills and other “non-serious” and “minor” events involving PDG. In addition, it is limited to tanker ships, general cargo ships, bulk ships and ferry ships, excluding other ship types carrying PDG.

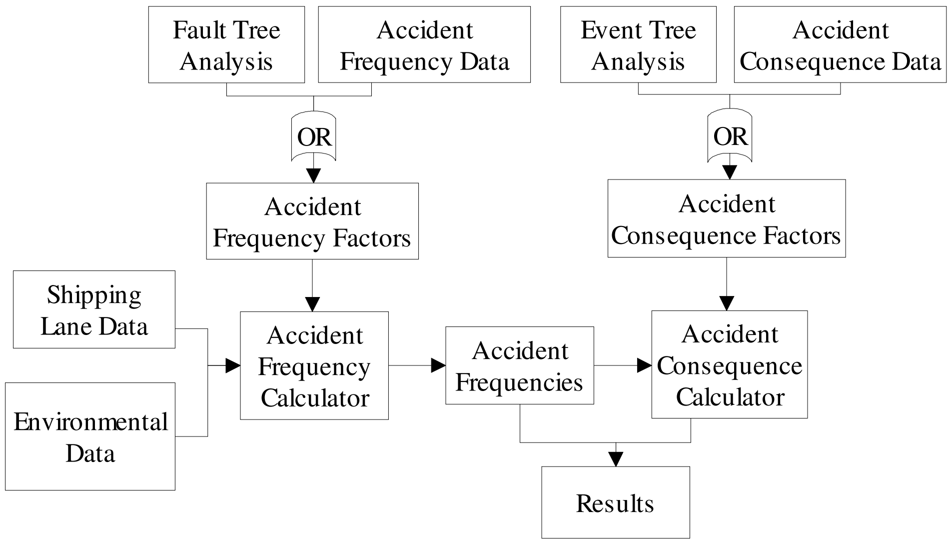


**Figure 14**: Marine Accident Risk Calculation System (MARCS) (Fowler and Sorgård 2000)

### 3.2.2.5 USCG Risk-Based Decision-Making (RBDM) Guidelines

The U.S. Coast Guard (USCG 2001) has developed very comprehensive Risk-Based Decision-Making (RBDM) Guidelines. The concepts, tools, and examples provided in the guidelines facilitate and address decision-making needs. The guidelines consist of four key parts (Volumes 1-4) including 12 risk assessment tools that support USCG maritime safety decisions.

- *Volume 1* is a guidance that provides specific advice and examples needed throughout the guidelines. The guidance in the selection and application of risk assessment tools is provided in Volume 2 and 3.
- *Volume 2* contains seven Chapters providing risk-based decision-making guidelines and an overview of risk assessment tools.

- *Volume 3* contains 14 Chapters describing key steps for risk assessment procedures, including: 1) getting started with risk assessment and 2) selecting and using risk assessment tools.
- *Volume 4* is an electronic library of resource materials related to risk-based decision making guidelines and examples of each risk assessment tool.

The RBDM guidelines are based on a large number of tools developed by various organisations and individuals, some of which are exclusively developed for the USCG, such as Port and Waterway Risk Assessment Guides (PWRA) and Waterway Evaluation Tool (WET). They are based on the works carried out in the field of marine safety and environment protection, including port and waterways risks, human error, fires/explosions, and oil spill risks. The Port and Waterway Risk Assessment Guides (PWRA) are specifically designed for the assessment of risks associated with vessel transits within a waterway. They have been developed by George Washington University for the USCG. The Waterway Evaluation Tool (WET) is a computer tool designed to help the USCG to assess waterway performance and determine the best allocation of resources to enhance waterway management. The second edition of the RBDM guidelines (USCG 2001) has been improved by the evaluation of USCG units' experiences. The 150 survey responses, representing about 50 different USCG units and offices, have provided information and suggestions. In order to improve the guidelines, RBDM applications such as the Port Activity Risk Index (PARI) and Vessel Risk Index (VRI) have been evaluated. This has included surveying and incorporation of the best practices from the maritime industry. In addition, several new risk assessment tools have been introduced and tested onsite at different facilities.

#### 3.2.2.6 QRA and Risk-Effect Model (REM)

Quantitative Risk Assessment (QRA) for transportation of hazardous substances is a risk assessment approach that has been developed in the Netherlands for application in road, train, pipeline and inland waterway transport. Based on specific risk criteria, individual and societal risk is calculated, considering aspects such as volume of transport, substances transported, population data along transport routes, and weather effects. Results are displayed as individual risk contours along the transport route and as societal risk curves per kilometre section.

In response to the Dutch government's concerns for safety of the transport and development of a risk management policy, a large research project "Safety of Inland Water Transport" was carried out with the aim to develop a Risk-Effect Model (REM) (Donk and Rijke 1995). The model is designed with the purpose of assessing risks of inlandwater transport of dangerous cargoes in the Netherlands (Erkut 1996). The model consists of a number of modules enabling assessment of traffic, accidents, damage, outflow, environmental and safety and economic risks, and effects of the decision-making (see Figure 15). The main steps of risk analysis for the transport of dangerous goods described in the model are (Donk and Rijke 1995) (Erkut 1996):

- Identification of the causes of possible events;
- Assessment of the probability of possible accidents, boundary conditions;
- Calculation of the physical effects of an accident;
- Assessment of the probability of consequences for people and the environment;
- Assessment of the individual risks, societal risks, environmental risks and economic risks.

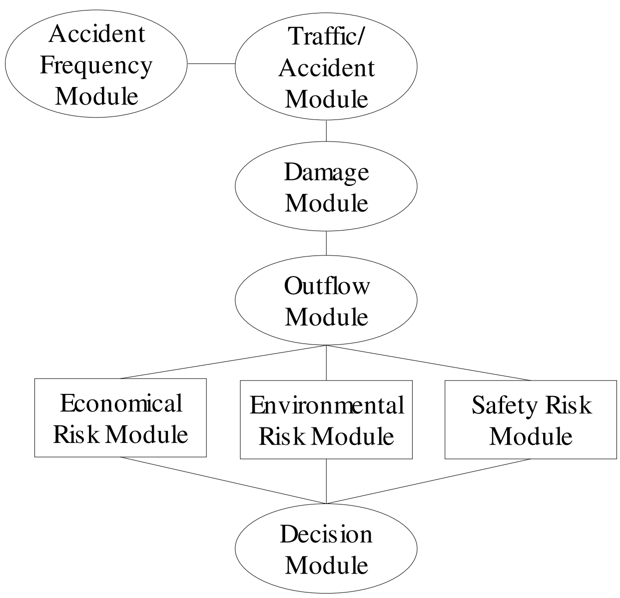


**Figure 15**: The Risk-Effect Model (REM) in the final phase (Donk and Rijke 1995)

### 3.2.2.7 Risk Assessment Framework for Maritime Safety Management System

A novel risk assessment framework has been proposed by Sii et al. (2001) for safety engineering applications in the maritime safety management system. The framework employs Taguchi17 concepts. The classical Taguchi method consists of "off-line" quality control as opposed to "on-line" quality control or statistical process control (Sii et al. 2001). Taguchi's two-step optimization process focuses on the product's performance on the target. The fundamentals of the Taguchi concepts consist of (Sii et al. 2001 from Roy 1990):

- Quality should be designed into the product and not inspected into it;
- Quality is best achieved by minimizing the deviation from the target. The product should be designed in such a way that it is immune to uncontrollable environmental factors (noise factors);
- The cost of quality should be measured as a function of deviation from the standard and the losses should be measured system-wide.

Risk assessment for the maritime safety management system consists of the following steps (Sii et al. 2001, pp 331-358):

1. *Define the problem*. The first step is to describe the specific maritime safety problem in detail. Then define the objective parameter that is to be optimized.
2. *Identify factors and their interactions*. The brainstorming technique is normally used among a panel of experts to identify all possible factors, their levels and interactions, and other information about the optimization problem. Factor screening may be required to provide a quick and simple way of ranking factors according to their importance in the optimization. This will reduce the number of identified factors in order to perform the optimization more efficiently.
3. *Select appropriate orthogonal arrays (OA)*. To select the correct standard OA, it is necessary to determine the total degrees of freedom to find the minimum number of level combinations to be tested. The number of factors and their interactions as identified after the screening in step two will determine the total degree of freedom.
4. *Conduct experiment*. This step begins with the selection of a correct quality loss function to represent the description of loss attributed in the

[17] Dr. Genichi Taguchi (Sii et al. 2001)

case. This is a mathematical analysis, and the S/N ratio for each treatment is calculated according to the selected standard Signal-To-Noise (S/N) ratio expressions. The calculated S/N ratios are then normalized before proceeding to the next step.

5. *Conduct analysis* of variance (ANOVA) and other Taguchi-related analyses. Perform all the relevant operations in ANOVA. The main effects of each factor and interaction of factors are determined, and then the sum of squares of the main effect for each factor is computed. The variance of each factor is calculated.
6. *Identify significant factors and their interactions*. The contributions of each factor and their interactions are determined through division, i.e. the sum of squares of each factor is divided by the total sum of squares of all the factors. Pooling is recommended when a factor is determined to be insignificant by performing a test of significance against the error term at a desired confidence level.
7. *Find the optimal combination of factor* levels to minimize the system risk level. The non-linearity analysis is carried out to investigate the non-linearity of the Signal-To-Noise (S/N) ratio with respect to factor levels of each factor and their interactions to identify the optimal combination of factor levels. The non-linearity graphs are developed to demonstrate the outcomes of the investigation.
8. *Recommend for implementation*. Safety-related recommendations concerning engineering design, operation and management are made based on the outcomes of the optimization.

### 3.2.2.8 Other frameworks

Some other frameworks include the following (EC 1999):

- *Environmental Indexing* of ships, a ship-type specific system, which estimates likely or actual ship-derived pollution, and compares this with desired reference levels to calculate a ratio or index for the individual ship.
- *Environmental Accounting* of individual ships, an approach focusing on the actual pollution from ships, which provides a system to keep track of the operational emissions and releases from individual ships.
- *The Green Award System*, assessing environmental performance, in which compliance with international and national laws and regulations,

technical and operational standards on-board the individual ship and management standards on-shore are audited and scored.

- *The International Maritime Safety Rating System* (IMSRS) constitutes an approach based on management system audits and physical condition checks.
- *The Port State Control (PSC)* approach focuses on the identification of deficiencies of ships and their follow-up, using a scoring system in order to reduce the number of sub-standard ships.
- *Human and organisational factors assessment*, for which several approaches have been identified, mainly concentrating on human errors and emphasizing the importance of management and environment on the other hand.

### 3.2.2.9 Marine accident/risk analysis procedures in the EU

A survey was carried out in 13 EU member states concerning the "state-of-the-art" marine accidents investigation procedures, practices, recording and analysis (see Table 12) (EC 1997). Some important questions posed to the participants were related to the member states' involvement in human element research areas, the investigation of correlations between vessel traffic and incidents, the employment of the Formal Safety Assessment (FSA) approach, and whether appropriate measures had been taken to improve accident/risk analysis procedures.

The results of the survey (see Table 12) have shown that:

- Most member states have been, to various extents, involved in the human element research areas.
- Eight (8 out of 13) members have performed analysis to explore correlations between vessel traffic density and incidents. The degree of analysis varied, but only one of the members had performed extensive studies in that respect.
- Only 5 (5 out of 13) members have explicitly stated having employed the FSA approach in risk/accident studies. However, other members (8) either did not respond, or had no FSA in place, or the application of FSA was under consideration, or only provided data to other responsible agencies for research into FSA.
- Only one half (6 out of 13) of the respondents have explicitly stated to be actively working on the improvement of procedures.

**Table 12**: Accident/risk analysis procedures in EU Members (EC 1997)

| Nr. | Country/ Member | Human element research areas | Analysis of correlations of traffic density and incidents | Application of Formal Safety Assessment (FSA) | Improvement of current procedures |
|---|---|---|---|---|---|
| 1 | *Demark* | Yes: data collection procedures and databases will be evaluated. | Yes, to some degree | Yes | Yes |
| 2 | *Finland* | a) Human error on bridge and maritime accidents; b) Safety of Finnish maritime transport; c) Safe procedures for pilotage | Yes, for the safety of Finnish maritime transport only | Yes, for the safety of Finnish maritime transport only | Yes, through international cooperation and courses for selected experts. |
| 3 | *France* | N/A | N/A | N/A | N/A |
| 4 | *Germany* | Yes, in depth research into the causes of the human factor | Yes, used for risks in navigation | Under consideration | Continuously considered |
| 5 | *Greece* | Yes, within the framework of MASIS project | Yes | No | Ministry of Mercantile Marine is responsible. |
| 6 | *Ireland* | No | No | No | Procedures currently under construction. |
| 7 | *Italy* | Yes, participated in MASIS I&II, THAMES, ATMOS II projects | No specific research in this area. | RINA chairs working party on human element of IACS. | N/A |

| Nr. | Country/ Member | Human element research areas | Analysis of correlations of traffic density and incidents | Application of Formal Safety Assessment (FSA) | Improvement of current procedures |
|---|---|---|---|---|---|
| 8 | *Netherlands* | Yes, as cause only | Yes, correlations of accidents and traffic studied extensively. | Undertaken for small crafts and being considered for open top containers. | No investigation procedures. |
| 9 | *Norway* | Yes, as cause only | Yes, e.g. Estonia, Green Ship project | - | SAFIR pc-based system reporting of accidents and incidents; Green Ship Project; NAUTICUS system for ship classification. |
| 10 | *Portugal* | - | Yes | - | - |
| 11 | *Spain* | Yes | Yes | Yes | Yes, improved accident reporting format, including definitions of essential parameters. |
| 12 | *Sweden* | Yes | Not currently, but made earlier in COST 301 | Yes | Yes |
| 13 | *UK* | No | No, but MAIB data have been used by others for this purpose. | Provided data to UK Marine Safety Agency for research into FSA. | Not formally, but procedures are continually reviewed and, if necessary, revised. |

**Box 8: Swedish marine accident/risk analysis procedures**

Table 16, shown in the Attachment to this report, summarises accident analysis practices employed by the SMA. They include these important aspects: the order of analysis procedures, all types and the total number of variables taken into consideration, type and the number of variables analysed at a time, methods of analysis employed, and formats of presentation of the results. Analysis procedures and results presentation generally follow this order:

- Introduction: background, definitions, scope and other background information for both marine accidents/near accidents and accidents/diseases to people.
- Marine accidents/casualties and near-accidents – all categories
- Exposure data for: vessels, manning on merchant ships and commercial fishing vessels.
- Individual marine accidents and near accidents including: grounding, collision (with another ship and object), leakage/capsize/weather damage, shifting of the cargo, fire/explosion, engine failure, spillage, and other e.g. container damage and an incident with a lifeboat.
- Occupational accidents and injuries and work-related diseases for persons employed on board commercial ships, commercial fishermen and passengers.

Marine accidents and their consequences, which are consequences in terms of spills or releases, and occupational accidents and injuries and work-related diseases for categories of people mentioned above are largely analysed by univariate and bivariate summary statistics (e.g. frequencies, percentages and numbers). Summary statistics combine maximum three variables analysed at a time. Analysis results are presented in tables and cross tables, bar and pie chart formats. In total, some 50 variables have been used in accident analysis. The main categories of variables considered are:

- Events: categories or types, severity/extent, numbers;
- Consequences of events: damages, spills, leakage, number of vessels lost;
- Occupational accidents, injuries and work-related diseases, categories of accidents/ injuries/ diseases, people occupations, passengers, numbers, absence;
- Human: manning/occupations, employee/passengers, age, sex;
- Exposure: vessel, seamen/fishermen, employee nationality;

**Box 8: Swedish marine accident/risk analysis procedures**

- Vessel properties and activities: type, number, size (grt), operational mode, construction material, year built, registration, and state (loaded/ballast);
- Cargo: type of cargo;
- Time: year and month;
- Causes: primary causes and contributing factors, discrepancy;
- Visibility/conditions: visibility, light, darkness and combinations;
- Location: Swedish territorial and international waters.

Narrative descriptions (4 cases) are used to illustrate some typical events. Based on combinations of the accident and exposure data, the risks of marine accidents (i.e. only in terms of vessels involved – see above exposure data) and occupational accidents, injuries and work-related diseases are estimated. The latter are compared to the risks of employees nationally. Statistical inference, which is seldom encountered in the field, even in the articles published in scientific journals, has not been employed.

With some variations in contents and the degree of details, a similar format has been used by the IMO (IMOn1998, 1999, 2000) and relevant authorities in some countries (e.g. USCG 1995), maritime-related information providers and class societies (e.g. Lloyd's Register of London, Casualty Return, LRS 1985–1996) and others. None of the maritime authorities and organisations mentioned has made use of comprehensive inference statistics.

### 3.2.3 Evaluation of frameworks

The following Section provides a summary evaluation of risk assessment frameworks and related practices in shipping and some other industries and sectors (see the highlighted area in Figure 16). The discussion is centred on the aspects presented below. These aspects are explored based on the understanding gained through the review and study of the frameworks and practices presented above and several others sources.

- The scope of application
- Tangible benefits
- Specific vs. generic
- Quality
- Simple vs. complex
- Quantitative vs. qualitative assessment

- Pluralistic and interdisciplinary
- Risk management and technology
- Legal aspects
- Risk assessment frameworks in the shipping industry

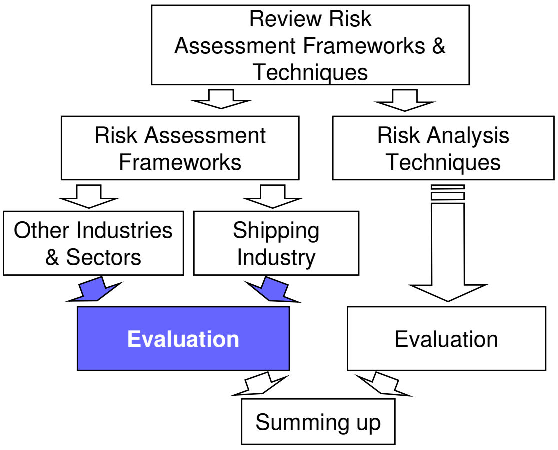


**Figure 16**: Evaluation of risk assessment frameworks and practices

## The scope of application

The literature review shows that risk management is an evolving discipline. For a long time, risk assessment and management have been everyday human activities. However, in recent years, the perception in the field has changed considerably. Risk management has become, in particular in recent years, a hot topic. In many countries, it has become an increasingly important component of industrial and national policy-making concerning many issues related to health and safety, and environmental quality, see for example these sources (IMO 1997) (EC 1997a) (Australia DGSM Act 2001).

The development of risk assessment frameworks and their applications in human health and safety emerged in the early decades of the 20th century. However, in recent years, an ever-increasing number of frameworks have been developed by many different national or international bodies, organisations in different industries and sectors and individuals – see for example (EC 1997a) (IMO 1997) (Fowler and Sorgård 2000) (OECD 2001) (USCG 2001) (ISO 2004). They address a wide array of areas and issues related to risk management, such as human healthy and safety, and environmental protection, production, transportation, storage and the use of chemicals, nuclear plants, offshore industries and many different types of businesses.

Although generally relying on some fundamental principles, risk assessment frameworks are very diverse, not least in terms of the scope of coverage and application, quality, standardization, and legal aspects. This is attributed to many interrelated factors, including the diversity of interests, issues, priorities, histories, legislation, and systems of countries, industry, sector or activity.

### Tangible benefits

Risk assessment has become a proven technology that addresses risks in a structured manner and ensures that risks are managed in the most cost effective way. Industries and sectors have reported tangible benefits from the improvement or introduction and application of more advanced risk assessment standards. The use of formalised risk assessment has assisted decision makers in focusing attention on the more important risks. Approaches have proven in practice to achieve goals faster, for less money, and with human health and the environment still protected. For example, in the U.S.A., the implementation of the Risk Based Corrective Action (RBCA) approach has saved large quantities of time and money whilst maintaining human health and environmental protection, yielding savings of as much as 40% over conventional investigations (USEPA 1992).

### Specific vs. generic

Several national and international organisations have developed risk assessment standards that are very industry, sector or risk issue-specific that frequently adapt different models and approaches. On the other hand, some frameworks are developed in a more standardised format. The question of the development of a generic risk assessment framework is often debated and considered as a necessity, but it has not found complete acceptance, as there are many both in favour and against (EC 2000). Some argue that standardised risk assessment procedures are desirable and facilitate understanding of decisions made in other countries or domains, as the risk-related information and data are becoming more compatible. Yet, some others argue that formal prescriptive guidelines are neither desirable nor realistic for wider use (EC 2000). Given the specifications of countries, industries or sectors, standardised formats are not entirely useful or readily applicable. The risk issues, methodologies and practices are, to some extent, unique. In recent years, however, efforts have been made to develop standards, but they are not yet widely accepted and employed across different countries and industries.

### Quality

In some cases, formal procedures for assessing environmental or ecological risks are poorly developed. Some risk assessment guidance manuals address only procedures and general philosophy. Some others contain guidance on risk assessment, but provide no guidelines for the implementation of risk management strategies and measures. In some industries, such as chemical, nuclear, aviation, offshore and automobile industries, there are more advanced and more sophisticated risk assessment frameworks than in other industries and sectors.

### Simple vs. complex

Risk assessments range from simple screening assessments and daily routines using standard assumptions, to highly structured, complex, and resource-intensive activities providing inputs to major decision-making.

### Quantitative vs. qualitative assessment

Risk assessment standards vary from qualitative, quasi/semi-quantitative to fully quantitative. Risk assessments have been performed for many years in various industries in various ways. However, in recent years, the quantitative approaches, which are known as Quantitative Risk Assessment (QRA) or Probabilistic Risk Assessment (PRA), have become increasingly popular. Complex systems and operational situations, more data and information, increasing safety and environment concerns, and advanced technology are some of the factors that have created the need for systematic, transparent and quantitative risk/safety assessments. The qualitative approaches are easiest to apply with least resource demands and skill sets required, but provide the least degree of insight. The quantitative approaches are most demanding, but potentially deliver the most detailed understanding. The semi-quantitative approaches lie in between these extremes.

In some countries, the application of QRA or PRA has become legally binding, particularly in areas such as human health and safety, environmental protection, and regulatory. According to IMO (2004), QRA has been employed in the nuclear, chemical, petrochemical and offshore industries under regulatory frameworks, which has also been, in many cases, introduced in assessment of risks related to ship operations. However, in many countries, there are still no legal requirements, and risk assessors and decision makers are free to judge how to assess risks. In some countries, governments are using these approaches, among other things, to frame regulatory risk control measures. For example, efforts have been made in the USA to incorporate the QRA approach in the design, development and amendment of the regulations governing chemical-related activities, including transportation.

## Pluralistic and interdisciplinary

Contemporary risk management has become a cross-disciplinary process that makes use of many different approaches, techniques, and tools, and relies on the knowledge of many different branches and disciplines of science. Thus, safety and environmental risk assessments may combine knowledge and methodological elements of toxicology, systems engineering, environmental sciences, and statistics. The purpose is to employ different approaches and methods, and ensure that the process is based on the experiences of many people – risk assessors, decision makers and other interested parties. A pluralistic involvement also ensures a broader acceptance and practicability of the recommendations from the concerted actions.

### Risk management and technology

The new and more advanced technology has revolutionised the entire risk management process. By means of computers, software packages, databases and new advanced methods, many organisations in different industries and sectors are more and more accurately assessing risks. Computer tools, for example, are being developed and used in mapping risks on local and national levels. The advances in computer technology have allowed regulators and risk analysts to model and predict the levels of risks of contaminants. Based on data gathered at the source area, models can predict how far, deep, and fast contaminants will spread in the environment. This predictive ability allows regulators to more accurately define final cleanup goals and discuss the extent of remedial efforts.

### Legal aspect

In some countries, for example, in Europe (EC 1993) (EC 1996), the USA (USEPA 1989) and Canada, and other OECD countries (OECD 2000), and industries and sectors (Brown 1993), risk assessment procedures are dictated by relevant international, national or industry instruments. In particular, this is required in industries or sectors, like the chemical industry, nuclear power plants, healthcare services, transport of dangerous goods and hazardous materials wastes management. Quantitative risk assessment has already been used in the nuclear, chemical, petrochemical and offshore industries under regulatory frameworks, and has also been introduced in ships in many cases. Some countries have strict requirements for application of risk assessment standards, resulting in highly developed systems. Standards are being developed to clearly and consistently document the important parameters, data, calculations, and conclusions from all the stages of risk assessment. Results of risk assessment, which are intended to support the decision making process, are reported in accordance with these guidelines by using standardised reporting formats. However, in many countries, assessments are carried out on a more ad-hoc basis, with little or no formal co-ordination.

Many international standards are not legally binding. They do not replace national laws, regulations and accepted standards. Application of some standards (e.g. ISO standards) does require certification, while some others do not. However, this does not exclude certification as a means of recognition for good practices. This means that business incentives also play an important role in the application of and compliance with required standards.

### Risk assessment frameworks in shipping industry

Risk assessment frameworks and practices in the shipping industry share similar characteristics with other industries and sectors described above.

Considerable efforts have been made in the shipping community to establish a common understanding of risks and how best to assess them, and develop and further improve approaches, methods and techniques for assessment of risks resulting from ship operation and other related activities. Numerous risk assessment frameworks have been developed for applications in the shipping and offshore industry. They vary from highly generic models designed for general application to highly specific models designed for a particular application, for example, an activity, a risk element or issue, a site or a substance.

***Risk issues***: Numerous frameworks are designed to address a wide range of different maritime risks issues. These issues include one or combinations of the following: accidents in general (i.e. not necessarily involving dangerous goods), occupations, human safety and health, environmental performance related to operational emissions and releases, property damage, compliance with international and national laws and regulations, physical and operational conditions and identifying the deficiencies on ships and their follow-up, standards on-board the individual ships and management standards. Some other frameworks are specifically designed for specific individual and aggregated risks associated with the transport of oil/oil products, LNG, LPG and some chemicals carried by tankers or barges in large quantities in bulk, dangerous goods vessel traffic in inland waterways, storing and handling of dangerous goods in terminals or ports. A number of frameworks, or some elements thereof, which have originally been developed in other industries, are adapted for application in the shipping industry.

***Risk management system*:** Although they are called assessment "frameworks", "standards" or "approaches", some frameworks cover a wide range of risk management activities that are beyond assessment. Some of them address a wide range of activities, such as cost-benefit analysis of risk reduction options, setting policy, organising, planning and implementing actions and monitoring. In order to facilitate the process, some frameworks incorporate one or several risk analysis techniques.

***Legal aspects***: There are no special international requirements to directly impose the application of risk assessment standards on shipowners. The regulations apply in some countries in their offshore operations, and require operators to undertake risk assessment.

***Quantitative approaches***: The public pressure and the increasing interests from the scientific community have jacked up the attention of the maritime industry to the need of quantitative or probabilistic and systematic risk assessment. Attitudes have changed in the industry from a position of scepticism to good support for the QRA approaches.

***Proactive***: Contemporary risk management attempts to proactively understand the risks and problems associated with the system. The promotion of a safety culture based on a proactive approach, as opposed to a reactive one, is important for improving safety and marine environmental protection in shipping. For that purpose, the International Maritime Organisation (IMO) has adopted the International Safety Management (ISM) Code and the use of Formal Safety Assessment (FSA) techniques in the development of new rules and regulations. In recent years, efforts have been made to adapt the FSA for specific proposes or sectors of the maritime industry, including transport of bulk dangerous cargoes and oil spills, cruise ships, container ships, and fishing industry.

### 3.2.4 Summary

Considerable progress has been made in the field of risk management. There are many diverse risk assessment frameworks or standards, but no single framework available has the capability to serve all safety and environmental problems and needs in the shipping industry. They do not offer a complete suite for risks analysis in the maritime transport of PDG. Given the specifications of the system and the risks associated with it, the maritime transport system of PDG is, to some extent, different from other sectors, including the transport of dangerous bulk cargoes, so that any standardised format is not entirely useful – "one size does not fit all." Further, despite an extensive search, no specific risk analysis framework for application in the maritime transport of PDG has been found. Therefore, a risk analysis framework is needed for readily application in the maritime transport of PDG.

The following key stages and steps, which constitute the main structure of the framework for preparing and performing risk analysis, have been identified from the review of the frameworks presented above (see also the summary in Table 13):

Stage 1: Preparations for analysis

Stage 2: Risk analysis

- Step 1: System definition
- Step 2: Hazard identification
- Step 3: Exposure and consequence analysis
- Step 4: Likelihood (frequency/probability) estimation – quantification
- Step 5: Risk estimation and presentation

Stage 3: Conclusions and recommendations

These highly generic stages and steps are further expanded and developed for readily application in risks analysis of the maritime transport of PDG. Risk analysis is facilitated by analysis techniques. In the following Section, a number of risk analysis techniques are reviewed and presented.

**Summary – the structures/procedures of frameworks**

Table 13 provides a summarised list of the frameworks/practices reviewed:

**Table 13**: A summary of risk assessment frameworks

| Nr. | Framework/ guidelines | Structure/ procedures | Developed by/or on behalf of | Applications: industry, sector or aspect |
|---|---|---|---|---|
| 1 | Offshore industry | • Multi-attribute utility analysis (MAUA)<br>• Analytical hierarchy process (AHP) | Offshore Operators Association (UKOOA), UK and Health & Safety Executive (HSE), UK | • Offshore industry<br>• Occupational Safety and Health |
| 2 | ILO Guidelines on Occupational Safety and Health Management Systems | • Policy: policy and worker participation<br>• Organizing: responsibility and accountability, competence and training, documentation and communication<br>• Planning and implementation: initial review, system planning, development and implementation, objectives and hazard prevention<br>• Evaluation: performance monitoring and measurement, investigation of work related injuries, ill-health, diseases and incidents, audit and management review<br>• Action for improvement: preventive and corrective action and continual improvement | International Labour Organisation (ILO) | • Occupational Safety and Health |
| 3 | Environmental Protection Agency (USEPA, USA) Risk Assessment Guidelines | • Hazard identification<br>• Dose response assessment<br>• Exposure assessment<br>• Risk characterization | USEPA's Risk Assessment Forum, USA | • Environment |
| 4 | USA Occupation, Safety and Health Administration Rules | • Employee involvement in process<br>• Safety information<br>• Hazard analysis<br>• Operating procedures and practices<br>• Training and education<br>• Start-up safety | USA Occupation, Safety and Health Administration | • Occupational Safety and Health |

| Nr. | Framework/ guidelines | Structure/ procedures | Developed by/or on behalf of | Applications: industry, sector or aspect |
|---|---|---|---|---|
| | | • Organisation integrity<br>• Managing change<br>• Investigation of incidents<br>• Emergency preparedness<br>• Compliance audits | | |
| 5 | Chemical industry | • Compliance cost assessments<br>• Cost Benefit Analysis (CBA)<br>• Cost Efficient Analysis (CEA)<br>• Checklists<br>• Simple scoring and weighting<br>• Multi-Criteria Analysis (MCA) | Chemical industry | • Chemical industry: chemical accident risks<br>• Safety and health Environment |
| 6 | The Chemical Accident Risk Assessment Thesaurus (CARAT) | • Hazard identification<br>• Hazard release and exposure scenarios<br>• Source and subject interaction<br>• Expression of the risk | OECD Working Group Chemical Accident | • Chemical accident risks<br>• Safety and health<br>• Environment |
| 7 | ISO 9000 and ISO 14000 Standards<br><br>Environmental Management Systems (EMSs) | • Agree on an environmental policy<br>• Conduct an environmental review<br>• Agree on an organizational structure and individuals with environmental responsibilities<br>• Develop a register of environmental effects<br>• Set up a register of relevant legislation<br>• Set objectives and targets<br>• Prepare a management manual<br>• Implement operational control procedures<br>• Train employees<br>• Carry out environment auditing<br>• Have an external audit<br>• Gain registration | International Standardization Organisation (ISO) | • General<br>• Environment |
| 8 | International Standard IEC 300-3-9 | • Risk analysis<br>- Scope definition<br>- Hazard identification<br>- Risk estimation<br>• Risk evaluation<br>- Risk tolerability<br>- Analysis of options | Technical Committee of the International Electro-technical Commission (IEC) | • Standardizations in electrical and electronic industry |

| Nr. | Framework/ guidelines | Structure/ procedures | Developed by/or on behalf of | Applications: industry, sector or aspect |
|---|---|---|---|---|
| | | • Risk Management<br>- Decision making<br>- Implementation<br>- Monitoring | | |
| 9 | Formal Safety Assessment (FSA) | • Identification and ranking of hazards<br>• Quantified assessment of the risks arising from the hazards identified in step 1<br>• Identification of regulatory options for controlling the risks defined in step 2<br>• Cost/benefit assessment of the risk control options identified in step 3<br>• Recommendations for decision making | International Maritime Organisation (IMO) and UK Government | • Shipping/maritime industry<br>• Marine accident risks in general<br>• Safety and health<br>• Marine environment |
| 10 | Safety Case | • Setting policy<br>• Organising, planning and implementing<br>• Review and feedback to assess performance against the policy<br>• Regular auditing to monitor and verify<br>• Regular inspections to check compliance | Health and Safety Executive (HSE), UK | • Safety and health |
| 11 | Quantitative Risk Assessment (QRA) Technique | • Port and hazardous trade definition<br>• Hazard identification<br>• Frequency estimation<br>• Consequence estimation<br>• Risk presentation | Det Norske Veritas (DNV) Technica Ltd., UK | • Marine accident risks in general<br>• Risks of maritime transport and port traffic of bulk dangerous cargoes<br>• Safety and health<br>• Marine environment |
| 12 | Marine Accident Risk Calculation System (MARCS) | • Analysis of contributing factors<br>• Frequency estimation<br>• Consequence estimation<br>• Risks estimation and presentation | • European Union:<br>• Det Norske Veritas (DNV),<br>• Danish Maritime Institute (DMI),<br>• Kelvin Hughes,<br>• Rotterdam Port Authority (RPA)<br>• National Technical University of Athens (NTUA) | • Marine accident risks in general<br>• Safety and health<br>• Marine environment |
| 13 | USCG Risk-Based Decision-Making (RBDM) Guidelines | • Getting started with risk assessment<br>• Selecting risk assessment tools<br>• Performing risk | United States Coast Guard (USCG) | • Marine accident risks in general<br>• Safety and health<br>• Marine environment |

| Nr. | Framework/ guidelines | Structure/ procedures | Developed by/or on behalf of | Applications: industry, sector or aspect |
|---|---|---|---|---|
| | | assessment | | |
| 14 | Risk-Effect Model (REM) | • Identification of the causes of events<br>• Assessment of the probability of accidents<br>• Calculation of effects of accidents<br>• Assessment of the probability of consequences of people and environment<br>• Assessment of the individual, societal, environmental and economical risks | Netherlands | • Marine accident risks in general<br>• Risk of maritime transport of dangerous cargoes in inlandwaters<br>• Safety and health<br>• Marine environment |
| 15 | Novel Risk Assessment Framework for Maritime Safety Management System | • Define the problem<br>• Identify factors and their interactions<br>• Select appropriate orthogonal arrays (OA)<br>• Conduct experiment<br>• Conduct analysis of variance (ANOVA) and other Taguchi-related analyses<br>• Identify significant factors and their interactions<br>• Find the optimal combination of factor levels to minimize the system risk level<br>• Recommend for implementation. | Sii et al., 2001 | • General - maritime systems |
| 16 | Swedish Maritime Administration (SMA) marine accident/risk analysis procedures | • Introduction: background, definitions, scope<br>• Analysis of marine accidents and near-accidents – all categories<br>• Exposure data analysis for vessels and manning on merchant ships and commercial fishing vessels<br>• Analysis of individual marine accidents and near accidents<br>• Analysis of occupational accidents and injuries and work-related diseases | Swedish Maritime Administration (SMA) (2002) | • Marine accident/risks in general<br>• Risks of oil spills<br>• Safety and health<br>• Marine environment |

## 3.3 Risk analysis techniques

This Section reviews numerous risk analysis techniques (other similar terms often used are tools, models, or methods) (see the highlighted area in Figure 17) developed and applied in risk analysis across different industries, sectors and activities, including the shipping industry. A brief overview summary is provided for each technique, including information on applications, procedures, strengths and limitations, and other characteristics. Detailed information about risk analysis techniques is provided in a number of publications, including (CCPS 1989, 1992, 1992a) (CMPT 1999) (Brown 1993) (Ellis 2002) (Ruxton 1996) (HSE 1997, 2002) (USCG 2001) (Sii et al. 2001) (Simha 2002) (IMO 2002) (Hong and Dugan 2004) (Gowen 1996) (Piccinini and Ciarambino 1997). The following risk analysis techniques have been reviewed:

- Hazard Checklists (HCl)
- Preliminary Hazard Analysis (PrHA)
- Hazard Review (HR)
- Preliminary Risk Analysis (PrRA)
- Change Analysis (ChA)
- What-if Analysis
- SWIFT Analysis
- Relative Ranking/Risk Indexing (RI)
- Pareto Analysis (PA)
- Failure Modes and Effects Analysis
- Hazard and Operability (HAZOP)
- Fault Tree Analysis (FTA)
- “5 Whys” technique
- Event Tree Analysis (ETA)
- Human Reliability Analysis (HRA)
- Event and Causal Factor Charting
- Other risks analysis techniques
- Cost analysis techniques

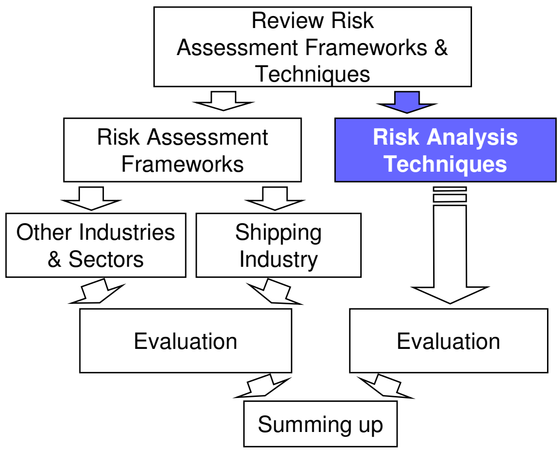


**Figure 17**: Risk analysis techniques

### 3.3.1 Hazard Checklists (HCl)

Hazard Checklists (HCl) are written lists of questions intended to prompt consideration of a full range of safety issues. They are used to review a design or operation and see whether regulations are observed and good practices are incorporated. In some industries, very detailed prescriptive checklists have been developed and widely used. Generic hazard checklists are standard lists of hazard categories that are generally created from previous risk assessments and expert judgements. They also make use of interviews, documentation reviews, and field inspections. The American Petroleum Institute, for example, has developed a range of 14 series regarding safety and environmental management checklists for offshore activities. They are mainly used to address process and drilling risks, but not the marine issues. Checklist analysis is applicable to any activity or system, including equipment and human factors issues. A special graphical type of checklist, known as the Root Cause Map, is used for root cause analysis.

### 3.3.2 Preliminary Hazard Analysis (PrHA)

The Preliminary Hazard Analysis (PrHA) technique is used to identify hazards, assess the severity of potential accidents that may happen, and identify measures for reducing or eliminating the risks associated with the hazards. It is applicable for any type of risk analysis application to any activity or system. However, the PrHA primarily focuses on identifying weaknesses or problems of a system in its early stage of design, when there is little detailed information or there are few operating procedures. This can save time and money that might be required for redesign if the problems were discovered at an early stage. It is a broad and preliminary study for further detailed risk analysis. The analysis can be performed by an individual or a team who are knowledgeable about the type of system or activity in question. The team of experts usually participates in brainstorming and review meetings of documentation and field inspections. The analysis typically generates qualitative descriptions and ranking of the hazards related to a process or system, which can later be used to prioritise recommendations for reducing or eliminating hazards. The quality of the analysis will depend on the quality and availability of information, and training and experience of the individuals or teams. The PrHA is performed based on a standard worksheet containing the following elements: hazards of potential accidents, causes, accident severity categories, major effects, and corrective or preventive measures.

### 3.3.3 Hazard Review (HR)

The Hazard Review (HR) (also known as Hazard Survey or Safety Review) is mainly a qualitative review of an activity or system to identify the hazards and to gain qualitative understanding of their significance. The technique is commonly used as a hazard identification technique in many industries and sectors. The hazard review is based on various sources, including previous safety assessments, accident investigations and statistics, previous experience, regulations and codes of practices. The review of past accidents is an important first step to ensure that the lessons from the past are learned. Regulations in some industries require operators to provide 5-year accident histories. The hazard review is a starting point for the hazard identification process, but may not be sufficient for a detailed study.

### 3.3.4 Preliminary Risk Analysis (PrRA)

Preliminary Risk Analysis (PrRA) is a systematic approach, whose primary purpose is to identify and characterize the risk associated with accidents that may occur during operations. This is a team-based approach that relies on systematic examination by experts and interests of a wide range of issues related to a system or activity. A standard form worksheet is used for the analysis. These are some categories of information that are generated during the analysis process:

- Identification and description of accidents
- Qualitative descriptions of potential problems (causes and contributing factors) including the most significant contributors to accidents
- Current safeguards in place
- Quantitative estimates of risk
- The list of recommendations for reducing risk and quantitative evaluation of the effectiveness of recommendations.

This technique is used for generating risk profiles across a broad range of activities, including activities in ports, for example loading and unloading.

### 3.3.5 Change Analysis (ChA)

Change Analysis (ChA) is a technique that is used to investigate systematically the possible risks and identify the appropriate risk management strategies and measures in changing situations. The technique is applied to systems, operating practices, and policies that are changing. It is also employed in new activities that will be performed, and which may contribute to an actual accident or may introduce additional or new risks. For example, the analysis may focus on the question: “How can changes in the system affect the outcomes?” This can be used as a root cause analysis method in accident investigations as well as a predictive and proactive risk analysis tool in changing situations. In combination with other techniques such as the preliminary risk methodology, the ChA can be used to identify changes in the overall risk profiles in a system or activity, such as ports and waterways.

### 3.3.6 What-if Analysis

What-if Analysis is a brainstorming technique that uses a systematic, but broad and not very structured, questioning procedures to generate qualitative descriptive information. The technique generates information about the potential deviations that may result in accidents or system performance problems, describes safeguards in place and provides a list of recommendations for appropriate measures for preventing accidents. It is usually performed by one or more teams of experts with diverse backgrounds and experiences. Experts participate in group-review meetings of documentations and field inspections. The quality of the analysis relies on the quality of the data. In particular, it relies on the expert judgements, which, in turn, depend on the training and experience of the experts and team leaders. This technique, which can be used as a high-level or detailed risk analysis technique, is applicable to any activity or system. It can be used alone, but most often it is used in conjunction with other structured techniques such as checklists analysis.

### 3.3.7 SWIFT Analysis

A more structured form of the “What-if Analysis” technique is the “Structured What-if Analysis” (SWIFT) technique. The SWIFT technique is used to identify hazards based on brainstorming and checklists, in which the discussion systematically addresses the system elements and/or operations. SWIFT analysis is usually performed by a team of experts familiar with the system and system operations, under the supervision of a SWIFT technique specialist. During the brainstorming, the question “What if?” is posed. However, other forms of questions such as “How could this happen?” or “Is it possible?” are also posed. The procedures and results of analysis are documented in a standard format, i.e. SWIFT worksheets, containing the brainstorming hazard sheet, the generic SWIFT checklist sheet, the log sheet that covers hazards in a logical sequence, “What-if?” and other questions posed, causes, consequences, safeguards, and the list of recommendations.

### 3.3.8 Relative Ranking/Risk Indexing (RI)

The Relative Ranking or Risk Indexing (RI) technique assesses the lists of properties that are the dominant contributors to problems of a system or activity to generate index numbers. These index numbers are used in making relative comparisons of various alternatives. The technique is also used in shipping. For example, it is used for the purpose of establishing priorities (e.g. in terms of resources and time) for boarding and inspecting the ships. Further, the technique is employed for the purpose of comparisons of options concerning the ship or shore side facility modifications. In order to generate index values, ships or activities are scored in a number of categories, called factors. The ship’s attributes used to calculate the index numbers include the ownership, the flag, the class society, type of ship, and the boarding history. The Port State Control (PSC) in different countries makes use of this technique to target their own flag ships and foreign flag ships. The technique employs a systematic process that can be performed by an individual or a small group. The analysts may not necessarily be risk experts, but they are required to have some training in the ranking systems. The data are generally gathered by interviews, documentation reviews, and field inspections.

### 3.3.9 Pareto Analysis (PA)

The Pareto Analysis (PA) is a technique that is used to identify and prioritise the most significant items, for example causes and contributing factors or effects of accidents. This technique employs the Pareto rule (or 80-20 rule), which says that about 80 percent of the effects are generated by about 20 percent of the causes. The PA technique is applicable from activity or operation to system level, such as ranking activity or system accidents and their causes. This technique can also be used to evaluate changes in risks after modifications in the system or activity. Based on the statistical data, the PA technique can provide quantitative results that can be graphically shown, for example on bar charts.

### 3.3.10 Failure Modes and Effects Analysis (FMEA)

Failure Modes and Effects Analysis (FMEA) is a qualitative, systematic and highly structured technique that is used to investigate how a system or system components can result in performance problems. The key steps of the analysis process include:

- Identification of causes and contributing factors;
- Description of safeguards in place;
- Identification of actual and potential effects;
- A list of recommendations for managing risks.

FMEA, which can be used as a system-level and component-level risk analysis technique, is applicable to any well-defined system, especially well suited for evaluation of mechanical and electrical systems, such as ship propulsion, steering or fire fighting systems. Often, it is used to facilitate planning and optimising system maintenance. This technique can also provide quantitative frequency and/or consequence estimates and rankings. A quantitative version of FMEA is the “Failure Modes, Effects, and Criticality Analysis” (FMECA). This technique uses a formal procedure that begins with a systematic list of all components in the system. This usually includes:

- The component’s name;
- The function of the component;
- The possible failure modes;
- Causes and contributing factors of failure;
- Indication/detection of failures;
- Effects of failure on primary system function and other components;
- Safeguards in place and preventative/repair and mitigation action;
- Estimation and rating of the frequency and severity of failure;
- A list of recommendations for managing risks.

Risk analysis relies on the quality of data and expert experience. Relevant data and information are gathered through interviews, field inspections and documentations. A single analyst, a group with system experts or interdisciplinary teams with diverse knowledge and experiences can perform the analysis.

### 3.3.11 Hazard and Operability (HAZOP)

Hazard and Operation (HAZOP) is a hazard identification technique that uses a formal, structured and systematic team review of a system or process to:

- Identify possible deviations from normal operations and their causes and consequences;
- Show what safeguards are in place;
- Recommend appropriate measure to prevent accidents.

This technique has initially been developed to identify and evaluate hazards in a chemical process plant. By employing the brainstorming procedures, the technique is used to identify hazards and operational problems. A multidisciplinary team of experts, under the guidance of an independent HAZOP leader, performs the brainstorming. The HAZOP technique uses a standard list of guidewords (e.g. "more," "less," "no") combined with process conditions (e.g. speed, flow, pressure) to systematically consider all possible deviations from the normal conditions. For each deviation, possible causes and consequences are considered, and whether additional safeguards should be recommended. Information is provided in a standard format. The following information is documented in the HAZOP worksheets: section, intention, deviation, causes, accidents, consequences, safeguards, and recommendations. This technique primarily generates qualitative results. It is mainly used for identification of hazards and operability problems of continuous process systems, especially fluid and thermal systems, procedures and sequential operations. The technique has primarily been designed for continuous chemical processes.

### 3.3.12 Fault Tree Analysis (FTA)

Fault Tree Analysis (FTA) is an analysis technique that models possible combinations among system elements, such as equipment failures, human errors, and external events and conditions leading to specific accidents. The FTA technique relies on the backward search method employing logic tree (Boolean logic) of the relationships. The technique shows how hazard events can occur through the escalation of a single or a combination of a wide range of latent initiating events. It also shows the safeguards in place and how they can fail to prevent escalation of events. The FTA technique is applicable for any risk analysis, but it is used most effectively to analyse accidents or problems that are characterised by a large number and complex combinations of events. It can be used as a tool to understand causal factors and determine actual root causes of accidents. Working groups with system experts usually perform the analysis. They gather relevant data and information through various approaches, including statistical records, interviews and field inspections. By employing this technique, one can generate qualitative descriptions and, when sufficient data are available, quantitative estimation of the risk elements. In qualitative and semi-quantitative approaches, it may not be necessary to estimate frequencies. The tree structure is deemed sufficient to demonstrate the ways in which events arise. A list of recommendations is also developed for managing risks. The main elements most commonly used to construct a fault tree are:

- The top event is the one that is analysed, which is represented by a rectangle;
- Intermediate events are system states or occurrences that contribute to the accident, which are represented by rectangles;
- Basic events are the lowest levels of resolution in the fault tree, which are represented by circles;
- Undeveloped events are those that are not further developed in the fault tree, which are represented by diamonds;
- “AND” gates - the output event associated with this gate exists only if all of the input events exist simultaneously;
- “OR” gates - the output event associated with this gate exists if at least one of the input events exists.

The FTA procedures consist of the following key steps:

- Definition of the system or activity of interest;
- Definition of the top or initial event;
- Definition of the top structure of the tree;
- Exploring each branch of the tree structure in detail;
- Solving the fault tree for possible combinations of events;
- Identification of important failures;
- Quantitative analysis;
- Recommendations.

### 3.3.13 “5 Whys” technique

The “5 Whys” technique is a simpler form of the FTA technique, especially designed for accident investigations. It is a brainstorming technique that attempts to identify root causes of accidents by asking “why” these events did occur or conditions did exist. The analysis process involves selection of one event associated with an accident (i.e. the top event) and asking the question: Why did this event occur? The answers to the questions would lead to the most direct causes of the events or sub-events. For each of these causes or sub-events, the question “why” is repeated until it reaches the “root cause.” The process is also repeated for the other events associated with the accident. The “5 Whys” technique is used as an effective tool for identifying root causes of accidents and determining causal factors. The technique has three main limitations. First, it is mainly based on brainstorming that is often time consuming, especially when it involves large teams. Second, the brainstorming process is very difficult to duplicate and, therefore, the results may not be reproducible or consistent. Third, like some other techniques, the 5 Whys technique does not ensure that all root causes can be identified.

### 3.3.14 Event Tree Analysis (ETA)

Event Tree Analysis (ETA) is an analysis technique that models the range of possible outcomes of one or a category of initiating events. The model describes safeguards, called lines of assurance (LOA), in place and explores how these safeguards and external influences affect the chain of events. The ETA technique can provide qualitative descriptions or, when sufficient data are available, quantitative estimates of event frequencies of various failure sequences and contributing events. The purpose of qualification is to attain the structure of the tree, where each branch can expand exponentially, but omit the stage of quantifying the branch frequencies. The quantification requires large amounts of statistical data, and it is generally time consuming. Lists of recommendations for managing risks are also provided. The technique can generally be employed in any type of risk analysis, but it is mostly used to model events where multiple safeguards are in place to prevent or interrupt escalation of events. A team of experts, who gather relevant data and information through statistical records, interviews and field surveys, usually performs the analysis. An event tree consists of a number of elements including:

- Initiating event: the occurrence of some failures that produce events with undesired consequences;
- Line of assurance (LOA): the safeguard/protective systems or human actions that respond to prevent the initiating events and interrupt their escalations;

- Accident sequence or scenario: the specific pathways through which the initiating events escalated to events with undesired consequences.

The ETA procedures consist of the following key steps:

- Definition of the system or activity of interest;
- Identification of the top or initiating events;
- Identification of the lines of assurance and physical phenomena;
- Definition of accident scenarios;
- Analysing accident sequence outcomes;
- Recommendations.

Both the FTA and ETA techniques share similar principal procedures. The FTA is employed to analyse causes and contributing factors. It shows how the system can fail. On the other hand, the ETA is used to analyse the consequences of the events.

### 3.3.15 Human Reliability Analysis (HRA)

Human Reliability Analysis (HRA) is a special form of FTA and ETA, designed for modelling and analysing the range of possible accidents that may happen while performing a procedure. The HRA technique is best suited for situations that are characterised by complex combinations of errors and equipment failures. The technique is especially used for detailed evaluation of human operations in procedural tasks. It is often used as a supplement to a broader risk analysis by being used in conjunction with another technique. For example, it is used in conjunction with the "Hazard Checklist" analysis technique that focuses on specific human reliability issues. The HRA event tree visually illustrates the combination of errors that may lead to various types of accidents in a system or process. A letter represents the probability of success or un-success or failure in each step in the procedure. The lower case letters (e.g. a) indicate the probability of successes, while the upper case letters (e.g. A) indicate the probability of errors or failures. A trained individual or team with system expertise can perform the analysis working through interviews, documentations and field inspections. Depending on the type, quantity and quality of data, the HRA technique can produce qualitative and quantitative results that can be highly practical for reducing human error in a procedure. The analysis provides the following categories of information:

- Qualitative descriptions of events;
- Identifying the possible combinations of events as a result of technical failures and in particular human errors at various steps of a procedure;

- Quantitative estimates of human error probabilities and relative importance of various accident sequences and contributing events, when data are available;
- Lists of recommendations for reducing or avoiding risks;
- Quantitative evaluations of recommendation effectiveness, when data are available.

HRA results can also be used to supply cost/benefit analyses or quantitative risk assessments. Like other techniques, the quality of the HRA results will depend on the quality of data and information available.

### 3.3.16 Event and Causal Factor Charting (ECFCh)

Event and Causal Factor Charting (ECFCh) is an analysis technique that consists of a graphical description (in form of a chart) of the sequence of events and conditions associated with an accident. The chart provides a logical progression of events. The principal block elements of a chart include: condition, event, accident, primary and secondary event lines, and causal factors. For the purpose of ECFCh analysis, these elements are defined as follows:

- Condition is a distinct state that facilitates the occurrence of an event. Conditions may be sea and weather conditions, system or system component status, health conditions, or anything else that affects an event.
- Event is a point in time defined by a specific action occurring.
- Accident is any action, state, or condition in which a system deviates from its design intents. This event, which includes actual accidents and near-misses, is the focus of the analysis.
- Primary event line is the key sequence of occurrences that lead to an accident, and is made up of events and conditions. The primary event line may not provide all of the contributing causes. This line always contains the accident, but events and conditions in this line may not necessarily end in an accident event.
- Secondary event line is the sequences of occurrences that lead to primary events or primary conditions, and is also made up of events and conditions. Most event and causal factor charts have more than one secondary event line.
- Causal factors are those events or conditions that, if eliminated, would have prevented an accident or reduced its effects. These factors include

human errors, equipment failures, environment (e.g. weather and sea hazards) and the combinations thereof.

### 3.3.17 Other risk analysis techniques

Some other risk analysis techniques used across different industries and sectors, in particular in the chemical industry, are:

- Reaction Matrix (RM)
- Action Error Analysis (AEA)
- Work Safety Analysis (WSA)
- Management Oversight and Risk Tree (MORT)
- Consequence Analysis (CA)
- Cause-Consequence Analysis (CCA)
- Energy Barrier Analysis (EBA)

### 3.3.18 Cost analysis techniques

A wide range of techniques have been developed and used for cost analysis as part of the risk management process some of them include:

- Simple screening and choice methods
- Abatement cost function analysis
- Financial analysis
- Cost-Benefit Analysis (CBA)
- Cost-Effectiveness Analysis (CEA)
- Input-Output Models (I-O)
- General Equilibrium Models (GE)
- Multi-Criteria Analysis (MCA)

These techniques, which vary from simple to highly sophisticated and quantitative, are applied in many areas for different purposes, for example, in policy appraisal and assessment of regulatory measures. Both CBA and CEA are among the most commonly used techniques. In the chemical industry, for example, a number of countries are relying on quantitative impact analysis and several have been working for the adoption more sophisticated economic appraisal techniques, including CEA and CBA. The usage of the fully quantitative techniques is considered as most advanced, for example, in the USA, UK, Canada, Australia, and the Netherlands. These countries rely on the risk quantification and, when possible, apply economic valuation techniques in order to place monetary estimates on changes in the human safety and health and environmental risks.

It is beyond this report to discuss in detail techniques presented above. Detailed discussions concerning these techniques and their application in practice are provided in a number of publications (see OECD 1994, 1997, 2000).

### 3.3.19 Evaluation of risk analysis techniques

Based on understanding gained through the above review, and the experiences of two prominent organisations (U.K. Health and Safety Executive (HSE 2002) and the U.S. Coast Guard (USCG 2001)) and others (see Brown 1993) as well as the author's personal research work experience (see Mullai and Paulsson 2002, Mullai 2007), in this Section risk analysis techniques are evaluated (see the highlighted area in Figure 18).

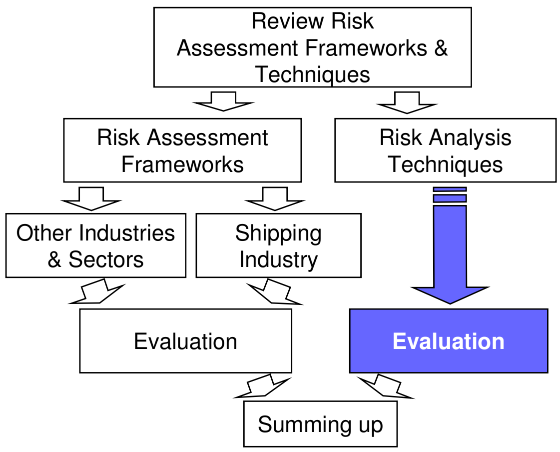


**Figure 18**: Evaluation of risk analysis techniques

Strengths, limitations and other key characteristics and merits of each risk analysis technique have been presented in Table 14. In this Section, the discussion focuses on some important characteristics, such as application, scope of analysis, data analysis method employed, complexity and efforts required to carry out risk analysis. The review showed that there are many different types of risk analysis techniques to choose among. The factors affecting the choice of techniques are provided.

**System or activity application**

There are many different analysis techniques developed and used for a wide range of issues concerning almost any system or activity, including maritime systems. However, one technique may not work well in every situation. Some techniques are better suited for some activities or systems than for others. Further, some techniques are specifically designed to analyse complex systems, activities or problems, while others focus on particular types of systems and risks. For example, the FMEA technique is best suited for the analysis of the risks in well-defined systems, such as electronic control or mechanical systems. The HAZOP technique often does not work very well for these types of systems. This technique is specially designed for the analysis of fluid and thermal systems and sequential procedures or operations. The PrRA technique is primarily used in the analysis of risks associated with accidents occurring during operations.

**The scope of risk analysis**

Analysis techniques are applied in many different areas for different purposes. They are most often used as a supplement to broader risk assessment. Some techniques serve common purposes. Further, numbers of techniques are used for a specific analysis purpose, for example for the identification of system or activity hazards only. The Hazard Review and PrHA, for example, are used as a starting point for identifying system or activity hazards, but they may not be appropriate for a detailed study. They usually serve as precursors for further risk analysis, while some other techniques have a wider scope of application (e.g. PrRA) spanning from hazard identification through estimation and evaluation of the significance of hazards and risks and consideration of risk management measures. Some of them may stand alone, but certain techniques can be used as a supplement to or integral part of another technique, for example combining “Hazard checklist” with “What-if”, or “PrRA” with “ChA”, to address a broader area than they have originally been intended for.

**Data analysis methods and data used**

Some techniques use both qualitative and quantitative approaches, while others are simple and produce only qualitative results, with no quantitative estimates of risk elements. A simplistic approach may offer value for minimal investment, but it cannot answer complicated risk-related questions. For example, the “Hazard Review” technique is designed to identify system or activity hazards and gain qualitative understanding of their significance only. Numerous techniques (e.g. FTA and ETA) use different types of data and information acquired from a wide range of sources by different methods, including statistics, interviews, inspections, surveys, documentations, and expert judgements. But some techniques, such as PrHA or What-if, rely heavily, if not entirely, on the knowledge and judgements of subject matter experts. In such cases, if experts do not participate in risk analysis, or if the system is a new technology having little or no early operational history, the results of analysis might be highly uncertain.

**Complexity and level of efforts required**

The techniques vary widely in form, complexity and the level of efforts required for conducting risk analysis. Certain techniques are simpler, broader and less structured (e.g. the “What-if” technique) providing information that is difficult to audit. Some techniques can be performed at low cost by an individual analyst or a small group, who may not necessarily be risk experts, usually providing a starting point for a more thorough analysis. On the other hand, some techniques (e.g. FMEA, FTA, and ETA) are very formal, well structured, and systematic. Techniques such as HAZOP, FTA and ETA are designed to make use of large multidisciplinary teams of experts under the guidance of independent leaders. Generally, the application of these techniques requires a higher level of expertise, and large amounts of resources and data. The analysis process is generally complex and time consuming.

**Table 14:** Characteristics of risk analysis techniques

| Nr | Risk Analysis Technique | Strength | Weakness | Results/ information provided: Events description | Results/ information provided: Risk estimation | Results/ information provided: Relative importance of accident contributors | Results/ information provided: Recommendations | Types of activity/ system | Level of efforts/ complexity | Level of expertise required |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | *Pareto Analysis* | - Provides quantitative results. | - Focuses only on the past.<br>- Produces considerable variability in levels of risk assessment resolution.<br>- Dependent on availability and applicability of data. | | Yes | Yes | Yes | All | Low-medium | Low-medium |
| 2 | *Checklist Analysis* | - Makes use of previous risk studies.<br>- Systematically assess the accumulative experiences of industry.<br>- Can be prepared by a single analyst or a small group.<br>- Uses high-level or detailed analysis, including root cause analysis. | - Limited to previous experience only.<br>- Gives less insight into the nature of the hazards, may miss some potential problems.<br>- Traditionally only provides qualitative information. | | | | Yes | All | Low-medium | Low |

| | | | | Results/ information provided | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 3 | *Risk Ranking/ Risk Index* | - Provides a high-level assessment. | - Results can be difficult to link to absolute risks.<br>- Appropriate ranking tool may not exist.<br>- Does not account for unique situations. | | Yes | Yes | Yes | All | Low-medium | Low-medium |
| 4 | *PrPA* | - Effective and efficient for identifying high-risk events. | - High-level analysis, failures not explored in detail<br>- General recommendations, due to the high-level of analysis | Yes | Yes | Yes | Yes | All | Medium | Medium |
| 5 | *Change Analysis* | - Predictive and proactive risk analysis technique. | - Relies on points of comparison of two or more systems or activities.<br>- Does not traditionally involve quantification of risk.<br>- Depends very much on expert judgements.<br>- Specially for analysis of system changes. | Yes | Yes | Yes | Yes | All, special[18] | Low-medium | Low-medium |
| 6 | *What-If Analysis* | - Highly effective in identifying system hazards.<br>- A simplistic approach that offer | - Loose structure and reliance on judgements, likely to miss some | Yes | | | Yes | All | Medium | Low-medium |

[18] All, especially for the analysis of recent changes in systems

| | | | | Results/ information provided | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | great value for minimal investment. | potential problems.<br>- Difficult to audit for thoroughness.<br>- Mostly provides qualitative information.<br>- The danger in this technique lies in the unasked questions. | | | | | | | |
| 7 | *FMEA/ FMECA* | - Effective for collecting information needed.<br>- Widely used/understood, provides greater understanding of the system.<br>- Systematic and comprehensive.<br>- A single analysis can perform the analysis. | - Examination of human errors is limited, focus on technical failures, and operational errors may be overlooked.<br>- Examination of external influences is limited.<br>- Focus on single-event initiators of problems; combinations of failures may be overlooked.<br>- Complex interactions resulting from more than one failure are often omitted.<br>- Is more often performed qualitatively due to lack of reliable performance data | Yes | Yes | Yes | Yes | All, special[19] | Medium-high | Medium |

[19] All, especially for well-defined systems such as electrical or mechanical systems

| | | | | Results/ information provided | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | on components.<br>- Examines one or a few modes of operations.<br>- Especially for well-defined systems. | | | | | | | |
| 8 | *HAZOP Analysis* | - Widely used and understood.<br>- Uses the experience of operating personnel<br>- Systematic and comprehensive<br>- Effective for technical faults and human errors.<br>- Employs a team approach requiring the interaction of several disciplines or organisations.<br>- Many companies favour the method because it forces thorough examination and promotes employee involvement in a productive setting – factors that lead to improved plant operations. | - Depends very much on expert judgements.<br>- Optimised especially for fluid and thermal systems and sequential operations or procedures.<br>- Requires development of procedural descriptions that often are not available in detail.<br>- Documentation is lengthy.<br>- One of the most time-consuming and expensive methods. | Yes | No | No | Yes | Special[20] | Medium-high | Medium |
| 9 | *FTA* | - Highly effective in determining combinations of events and failures.<br>- Systematic, logical and detailed | - Usually used to examines only one specific event at a time; other fault trees should be developed. | Yes | Yes | Yes | Yes | All | High | Medium-high |

[20] Especially for fluid and thermal systems and sequential operations or procedures

| | | | | **Results/ information provided** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | system approach.<br>- Applicable for any type of complicated systems or activities – often used in maritime systems.<br>- Quantification is possible. | - Art as well as science, the level and organization of the tree vary from analyst to analyst.<br>- Quantification requires a high level of expertise. | | | | | | | |
| 10 | *ETA* | - Highly effective in determining how various initiating events can result in accidents.<br>- Shares similar strengths with FTA. | - Usually limited to one initiating event; numbers of event trees may be needed.<br>- System elements dependencies can be overlooked. | Yes | Yes | Yes | Yes | All | High | Medium-high |
| 11 | Event and Causal Factor Charting | - An effective tool for understanding the sequence of contributing events. | - Does not necessarily ensure that the root causes have been identified.<br>- Can overwork simple problems that may not require an extensive investigation. | Yes | | No | Yes | All | Low-medium | Low-medium |
| 12 | Preliminary Hazard Analysis PrHA | - Used as a proactive tool because identifies weaknesses of the system at the early stage of life, thus saving time and money. | - Requires additional analyses to more fully understand and evaluate hazards and potential accidents.<br>- Relies heavily on the knowledge of subject matter experts. | Yes | Yes | No | Yes | All | Low-medium | Low-medium |
| 13 | Hazard Review (HR) | - Makes use of existing experience from a wide range of sources. | - Lack of structure makes it difficult to audit. | Yes | No | No | Yes | All | Low-medium | Low-medium |

| | | | | Results/ information provided | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | - Can be performed by a single analyst at low cost.<br>- Requires minimal information about the installation, and so is suitable for concept design. | - Limited to previous experience, and thus has limited value for novel installations.<br>- Does not produce a list of failure cases for a QRA. | | | | | | | |
| | | | | | | | | | | |

### 3.3.19.1 Factors affecting the choice of techniques

The review showed that there is a wide rage of different risk analysis techniques available. The previous Section discussed some of the techniques used for risk analysis in many industries and sectors, including the maritime industry. Many techniques can be employed for risk analysis in any type of activity or system. However, some techniques are readily and better suited for some activities or systems than for others. Choosing the right technique for the right situation, system or activity is important. With respect to the ability to prevent accidents, selection of the right method may be as important as analysis outcomes (Brown 1993). What techniques are better suited for risks analysis in the maritime transport of PDG? The choice of a particular technique is determined by a number of factors. This Section discusses some of the interrelated factors that may affect the choice.

**The purpose of risk analysis**

The purpose of risk analysis is a very important factor to be considered. Many issues and factors can shape the purpose of the analysis. One purpose of risk analysis or study is to enhance the understanding of risks required in the improvement of existing safety and health, environmental and property protection in the maritime transport system of PDG. This may require a detailed and systematic analysis of all essential elements of risks.

**Legal requirements**

Should risk analysis procedures meet regulatory, legal, or stakeholder requirements? In some countries, industries or sectors, there are special legal requirements for choosing the risk assessment methodology. Although connotations of risks and risk assessment are found in some documents, no legal requirements for risks analysis in the international maritime transport of dangerous goods have been found. Therefore, analysts are free to select those techniques that are best suited to the specific objectives of the risk study.

**Type of results/information needed**

The type of research results needed is also an important factor. Numbers of techniques are specially designed to analyse certain risk elements, for example, transport hazards, causes and contributing factors of accidents/ incidents only. In order to meet the objectives of the risk study, a wide range of different categories of risk-related information may be needed. Therefore, a detailed risk analysis in the maritime transport of PDG needs to provide information covering all essential system and risk elements. However, one single technique may not cover all elements.

**Data, resources and time available**

The amount, type, form, quality and timeliness of data and information available to the risk analysts vary considerably. The variation, which is affected by many interrelated and complex factors, affects, in turn, the choice of the risk analysis technique. For example, the life stage of a system, system component or activity limits the amount and quality of information available to the team involved in risk analysis. When an analyst or team of experts is assigned with the task of performing risk analysis on a new maritime activity or system component, it may not be possible to obtain detailed information for the activity or system in question. Therefore, the analysts have to choose those techniques that rely on expert judgements. Generally, large amounts of high quality data and information are very expensive to obtain. The amount of resources needed increases as the amount and the quality of data increase. The choice is between simple and complex techniques. Risk analysis by means of simple techniques can be performed by an individual analyst or a small group at low cost, but provides less detailed results with a lower degree of certainty. On the other hand, risk analysis by means of complex techniques can be performed by large multidisciplinary teams of experts requiring large resources, but provides more detailed results with a higher degree of certainty.

**Complexity and size of risk analysis**

The effort required to perform risk analysis is proportional to the number and complexity of the system elements and problems, types and numbers of events. Maritime transport of PDG consists of a large number of subsystems, equipment items, and operating steps that increase the time and effort needed to perform risk analysis. Not all techniques are suitable for analysis of very complicated problems.

**Type of activity or system**

Some analysis techniques are better suited for some activities or systems than for others. For example, the FMEA technique is best suited for the analysis of electronic or mechanical systems. The choice of techniques is also affected in different ways by types of operations. For example, it will depend on whether this is a permanent (e.g. operation in fixed facilities or installations), temporary (e.g. operations in ports), or transit (e.g. transport of dangerous goods), continuous or sporadic operation. Continues operations require more sophisticated techniques because they provide detailed data. For example, the HAZOP technique works well for sequential operations or procedures. The analyst may select a simple technique (e.g. “Hazard checklist”) to analyse sporadic operations or evaluate one-time maintenance.

**Concerning issues**

Risk analysis is often conducted on an ad-hoc basis. Risk issues become a primary agenda in different ways, including concerns about the severity and/or frequency of accidents that occur in a system or activity (e.g. transport of dangerous goods). Organizations or authorities usually invest large amounts of resources and, subsequently, use more sophisticated techniques for those systems and situations that present significant risks. Risks in nuclear power plants, the chemical industry, or aviation are some examples. Such techniques take into consideration many different types and large numbers of data from different sources. They may also provide relevant information for all essential risk elements. They are more likely to generate detailed, reliable and valid results.

### 3.3.19.2 FTA and ETA techniques

Numerous factors and strengths point to the principles of FTA and ETA techniques as the most suitable principles for application in risk analysis in the maritime transport of PDG. The following discusses the aforementioned techniques in greater detail. The motivations for choosing the underlying principles of the FTA and ETA techniques are also provided.

The Fault Tree Analysis (FTA) and Event Tree Analysis (ETA) are different, but at the same time they are closely linked and share similarities (Hong and Dugan 2004). The FTA is a deductive or top down/backward logic-based (Boolean logic) search technique (Brooke and Paige 2003) (Hong and Dugan 2004). The FTA involves specifying a top event to analyze (always a system failure), followed by the logic tree of relationships that identifies, traces, and depicts all the causal events and associated elements in the system leading or contributing to an undesirable event (top event) (Dehlinger and Lutz 2004) (CCPS 1992). The FTA has been widely applied in many industrial sectors concerning system reliability, maintainability and safety analysis (Simha 2002), in particular for analysing and evaluating risks in complex systems (Abdollah 2004).

The ETA is an inductive or forward logic-based search technique (Dehlinger and Lutz 2004) (Hong and Dugan 2004). The ETA starts from an initiating event and includes all possible paths whose branch-points represent successes and failures (can sometimes also represent partial failures) (Hong and Dugan 2004). The quantification of an event tree is used to predict the frequency of each outcome (Hong and Dugan 2004). In principle, the techniques deal with two different risk elements– respectively, the FTA covers the cause analysis and the ETA covers the consequence/effect analysis. This means that they can conjointly cover the analysis of the entire "cause-effect" chain, which is the "whole" risk analysis process. With some modifications, both techniques can be suited conjointly to form a single hybrid risk analysis model for risk analysis of marine accidents involving PDG. Thus, the maritime transport hazards and their causes and contributing factors can be analysed based on deductive or top-down/backward logic (i.e. FTA), and the consequences of dangerous goods hazards can be analysed based on inductive or forward logic (i.e. ETA).

Although dealing with two different risk elements, both techniques share similar principle procedures. They both follow similar sequential and logical procedures, but into two different directions: as mentioned above, the FTA follows top-down/backward (deductive) and the ETA follows forward (inductive) logic. The ETA and FTA are so closely linked that fault trees are often used to quantify events that are parts of event tree sequences (Hong and Dugan 2004). The logical processes employed to evaluate event tree sequences and quantify the consequences are the same as those used in FTA (Hong and Dugan 2004). A fault tree can be used in conjunction with an event tree (Andrews and Dunnett 2000). Fault trees can be constructed to develop causes of each subsystem failure identified and constructed in the ETA (Andrews and Dunnett 2000). The ETA and FTA are often used together (Hong and Dugan, 2004).

The FTA and FTA are two important (Abdollah 2004) and most widely used techniques (Brown, 1993). Both techniques have proven in practice to be essential tools for risk analysis (Dehlinger and Lutz 2004; Clements 2002; Lutz and Woodhouse 1997; Nivolianitou et al. 2004). The FTA and ETA techniques are used in many risk analysis applications, but they are most effectively used for high-risk and complex systems and activities (Abdollah 2004), which are characterised by a large number of complex combinations of events (Nivolianitou et al. 2004). For example, they are commonly used in the chemical processes industry (CCPS 1989, 1992) (Faisal et al. 2001), chemical storage plants (Nivolianitou et al. 2004), nuclear power plants, the military (Brown 1993) and offshore industries (Andrews and Dunnett 2000). The ETA has initially been applied in risk assessments for the nuclear industry (Andrews and Moss 1993). Both techniques are used in risk studies concerning maritime systems (HSC 1991). The maritime transport system of PDG and the risks associated with it satisfy the mentioned properties (see Mullai 2006). The maritime transport system of PDG is a dynamic system consisting of many different complex and interrelated elements. Problems and external factors affecting the system are also many, interrelated and complex. In recent years, due to threats posed by the vast amounts of different dangerous goods carried in packaged form, in many parts of the world, the maritime transport of packaged goods (including containers and other forms of cargo transport units) has become a concerning issue (a “high risk” system). This transport mode has received considerable attention.

As system analysis methodologies, both FTA and ETA are used in quantitative risk analysis, in particular, in identifying system interrelationships due to shared events (Hong and Dugan 2004) (Nivolianitou et al. 2004). Marine accidents involving PDG are often the results of shared events, factors and conditions.

The FTA and ETA techniques are based on graphical modelling (Nivolianitou et al. 2004) (CCPS 1992). The analysis performed by means of these techniques can be well-structured, visual, systematic, logical and easily understood. Such analysis is not offered by many techniques described in this Chapter. The results of the risk study can also be better documented and understood.

Both FTA and ETA techniques allow the analysts to make use of other methods, including qualitative, semi- or quasi-quantitative and fully quantitative methods. They can make use of large amounts and different types of data and information, such as statistical data, documentations, interviews, inspections, surveys, and expert judgements. In addition, other analysis techniques, for example the “What-if” and “5 Whys”, can also be used as supplementary or integrated elements.

The FTA and ETA are among the most highly developed tools. In recent years, many efforts have been made to further refine the FTA and ETA. For example, the most recent approaches to aid analysis of the fault-tree diagram are the binary decision diagram (BDD) (Andrews and Dunnett 2000) and the neural network approach (Bartlett and Andrews 2002). Researchers have also recognised the benefit and possibility of combining fault tree and event tree for probability risk assessment. Several institutions, such as Loughborough University (Sinnamon and Andrews 1996), Bordeaux University (Rauzy 1996) and University of Virginia (Gulati and Dugan 1997; Dugan and Doyle, 1996), have been working to produce a more advanced assessment technique based on a BDD formulation of the system failure logic. Based on these recent works, Andrews and Dunnett (2000) have proposed a BDD-based approach to combine fault tree and event tree in order to overcome the inefficiency and inaccuracy of methods for non-coherent systems. Hong and Dugan (2004) have considered the possibility of converting from static to dynamic fault tree (DFT). They have also attempted to find a feasible way to combine DFT and ET (Hong and Dugan 2004). Bartlett and Andrews (2002) have attempted to adapt a Neural Network (NN) approach in order to facilitate the analysis of the fault-tree diagram. In this approach the fault trees are considered as inputs of the neural networks. The above works illustrate the fact that, for many different reasons mentioned earlier, the scientific communities have constantly been working at further development, improvement, refinement or adapting existing risk analysis tools and approaches and the development of new ones. Some of the above works have “broken” traditional rules established in the 60’s and 70’s by making new adjustments.

In summary, FTA and ETA are two important risk analysis techniques employed in many industries and sectors. The principal procedures (backward-forward logic or deductive-inductive approaches) are adapted and further developed for application in risk analysis of the maritime transport of PDG.

### 3.3.20 Summary

The following Section is a summing up of the review and evaluation of risk frameworks and techniques (see the highlighted area in Figure 19). Table 15 shows the main stages and steps of the risk analysis framework, and the structures of backward and forward logic analysis, which are employed respectively in the Fault Tree (FTA) and Event Tree Analysis (ETA) techniques. Figure 20 provides a visual representation of their structures.

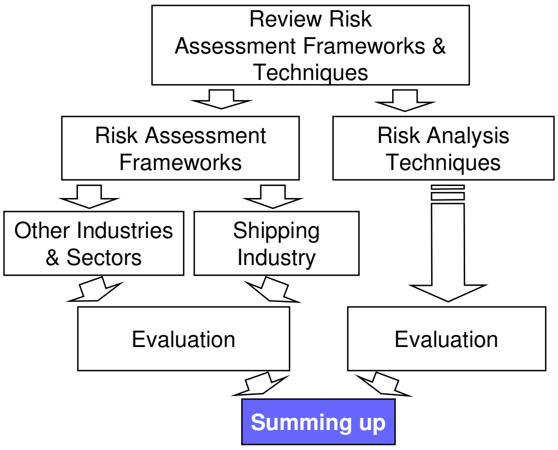


**Figure 19**: Summing up

The review showed that risk assessment frameworks are very diverse – varying from very specific to highly generic. However, no single framework available has the capability to serve all problems in shipping, including safety and health, security, and environmental and property risks from dangerous goods. They do not offer a complete suite for analysis of risks in the maritime transport of PDG. The maritime transport system of PDG and risks associated with it, are, to some extent, unique when compared to other industries or sectors, including the maritime transport of bulk dangerous cargoes, so that any standardised format is not entirely and readily applicable in the field. For example, the maritime transport system of PDG is specific with respect to technical and operational aspects of the transport system, such as types of ships, dangerous goods, dangerous goods hazards and packaging/CTU, maritime transport hazards, and the wide range of dangerous goods-related activities, including packing, loading, discharging, stowage, segregation, securing, transport, communication, documentation, training and emergency responses.

The FTA is a specific technique that is used to identify and, if necessary and possible, quantify failures in the system. The ETA is a specific technique that is used to analyse and estimate consequences and, if necessary and possible, the likelihood of the consequences. These techniques are used in numerous risk/accident studies in maritime systems, for example, grounding, oil spills, fire, machinery and other technical failures, and loading and unloading activities in ports. They are also used in road and rail transport of dangerous goods, such as dangerous liquid, gases and liquefied gases in tanks and other forms of packaging. Given the complexity and dynamics of the system, and problems and risks associated with it, types and amounts of data, and advantages offered by both techniques, the principal procedures of the FTA and ETA techniques are considered as the most appropriate procedures for risk analysis of the maritime transport of PDG. Although relying on the same principles, these techniques are not readily and entirely suitable. The principle procedures of FTA (top-down or backward logic – deductive approach) and ETA (forward logic – inductive approach) are suited conjointly to form a single hybrid model for readily application in risk analysis in the maritime transport of PDG, which is then integrated into the risk analysis framework. Efforts have been made to integrate specifics onto the generic levels. The logic of the model largely reflects the maritime transport system and risks associated with it.

**Table 15**: The structure of the risk analysis framework, FTA and ETA

| ***The structure – key stages and steps*** | | |
|---|---|---|
| *Risk analysis framework* | *Fault Tree Analysis* | *Event Tree Analysis* |
| 1. Preparations for analysis | 1. Define the system or activity of interest | 1. Define the system or activity of interest |
| 2. Risk analysis | 2. Define the top or initial event | 2. Identify the top or initiating events |
| 2.1. System definition | 3. Define the tree top structure | 3. Identify lines of assurance and physical phenomena |
| 2.2. Analysis process | 4. Explore each branch in detail | 4. Define accident scenarios |
| 2.2.1. Hazard identification | 5. Solve the fault tree for possible combinations of events | 5. Analyse accident sequence outcomes – risk estimation |
| 2.2.2. Exposure and Consequence analysis | 6. Identify important failures | 6. Recommendations |
| 2.2.3. Likelihood estimation - quantitative analysis | 7. Quantitative analysis –frequency estimation | |
| 2.3. Risk estimation and presentation | 8. Recommendations | |
| 3. Conclusions and recommendations | | |

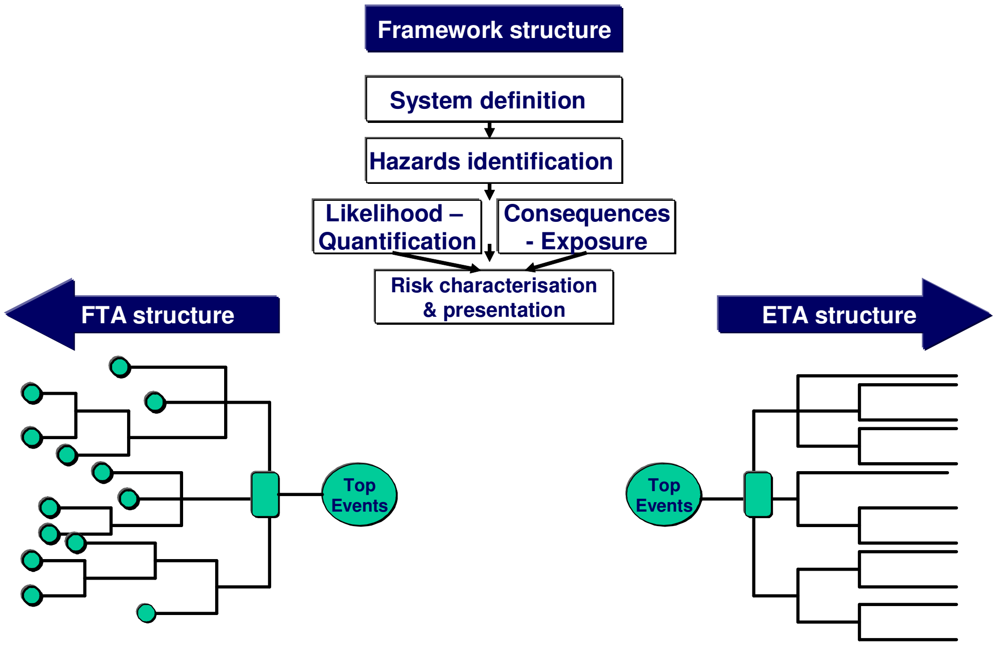


**Figure 20**: Visual representation of the risk analysis framework and the principle procedures of FTA (top-down or backward logic – deductive approach) and ETA (forward logic – inductive approach

# 4 CONCLUDING REMARKS

Understanding the risk management system is very important in studying and managing risks. In this report, attempts have been made to provide "state-of-the-art" knowledge and contribute to enhancing understanding in the field of risk management and methodology. Numerous risk assessment frameworks and risk analysis techniques, and some of the world's best practices employed in shipping and other industries and sectors, have been explored. The literature study showed that there are many different frameworks and techniques to choose from. In this report, merits and limitations of risk analysis techniques and factors affecting their choices have been explored. The content of this report will assist risk analysts, risk managers and other experts in the field to make more informed choices and decisions. The contents of this and another report (see Mullai 2006) have served as a theoretical platform for developing a risk analysis framework for readily application in the maritime transport of packaged dangerous goods (see Mullai 2004).

The following Section, which is organised by topic in a tabular format, concludes with some key remarks concerning topics and issues raised in this report. Based on inferences and understanding gained in this study, some research areas and questions for future studies are suggested to the members of scientific communities, responsible and competent authorities, policy or decision-makers and other interested parties in the BSR. Some recommendations for enhancing safety and health and environment protection and reliability in the transport of dangerous goods in the BSR are also provided. The research areas and questions and recommendations provided in this and another report (see Mullai 2006)[21] are interlinked.

[21] Mullai A (2006) *Maritime Transport and Risks of Packaged Dangerous Goods*, Safe and Reliable Transport Chains of Dangerous Goods in the Baltic Sea Region (DaGoB) Project Publication Series 4:2006, Turku School of Economics, Logistics, Turku, Finland.

| Nr | Concluding remarks | Research areas/questions | Recommendations |
|---|---|---|---|
| | Some key concluding remarks are as follows: | Consider or reconsider the following research areas and questions: | Consider or reconsider the following recommendations: |
| ***1*** | ***Terms, definitions and concepts*** | | |
| | • The field of risk management has significantly evolved, in particular in recent years.<br>• The field is characterised by a large number of different terms, definitions and concepts. There are no unified definitions of the central concepts in the field.<br>• There are often misconceptions and misuses. In some cases, different terms are used interchangeably. Further, a single term is used differently in different meanings and contexts.<br>• Variations arise due to different factors, including variations in perceptions, attitudes, needs and risk and system specifications of industries and sectors across | • Study the state of understanding/ knowledge in the field of risk management in the industries and countries of the BSR.<br>• What is the level of knowledge in the field, including: formal educations and trainings, researches and expertise?<br>• How well are central concepts of risk management understood and defined?<br>• Identify and study the best practices in risk management education, training and researches in the industries and countries of the BSR, the EU and other parts of the world. | • Enhance/ provide a unified understanding of central concepts in the field of risk management.<br>• Create a common database with all essential terms and definitions.<br>• Further improve risk management education and training programmes in the field.<br>• Introduce these programmes in the countries lacking them. Provide financial and technical supports and expertise, if needed.<br>• Encourage and finance risk management researches/ studies.<br>• Disseminate the best practices in risk management education, training and research. |

| Nr | Concluding remarks | Research areas/questions | Recommendations |
|---|---|---|---|
| | different countries and regions.<br>• In this report, attempts have been made to provide a unified understanding in the field. | | |
| ***2*** | ***Risk management system*** | | |
| | • The risk management system is a stepwise process consisting of two main interrelated but conceptually distinct phases: risk assessment (analysis and evaluation) and risk management.<br>• Each phase in the system has a hierarchical structure form consisting of different levels, in which the highest levels are further broken down into stages, steps and sub-steps.<br>• Risk communication, risk perception, risk evaluation criteria are important integrated components of the system.<br>• The literature study shows that the risk management system and its | • Identify and study the practices in the overall risk management process including: risk analysis, risk evaluation, risk management and risk communication. | • Promote the exchange and dissemination of data and information and research results concerning dangerous goods transport and risks issues, risk management and risk methodology in the BSR. |

| Nr | Concluding remarks | Research areas/questions | Recommendations |
|---|---|---|---|
| | constituent components may be considered fields or branches of science on their own rights. | | |
| ***3*** | ***Risk analysis/assessment*** | | |
| | • Risk assessment is an essential component of the risk management system consisting of risk analysis and risk evaluation.<br>• The purpose of risk analysis is to provide answers to the fundamental questions concerning risks. It provides decision or policy makers with useful and logically structured inputs and perspectives about risks as well as recommendations for a better risk management.<br>• Comprehensive risk studies including the transport of dangerous goods are often carried out on ad-hoc basis.<br>• Risk analysis is in principal a well structured scientific process, which is | • Review and study the state of knowledge on risks of transport chains of dangerous goods in the BSR.<br>▪ Are there documented comprehensive risks studies in individual industries and countries and the BSR as the whole?<br>▪ How often are risks analysed/ assessed? Are risks analysed/ assessed on ad-hoc or regular basis?<br>• Review and study measurement units used for measuring the transport system and risk elements in the BSR:<br>▪ How are the system and risk elements measured?<br>▪ What types of measurement units | • Conduct risk analyses/assessments on a regular basis in each respective countries and the BSR as a whole.<br>• Disseminate the results of risk studies.<br>• Improve risk-related data and information, including data quality, reliability, accessibility, availability, scope and formats.<br>• Acquire or develop advanced technological solutions for capturing, compilation, transmission and storing of risk-related data and information.<br>• Design a single risk-related data and information framework integrating or connecting all risk-related databases and sources available in each country and the BSR as the whole, including |

| Nr | Concluding remarks | Research areas/questions | Recommendations |
|---|---|---|---|
| | facilitated by specific risk frameworks and techniques. The review shows that one framework or technique may not offer a perfect suit for all situations and systems – "one size does not fit all."<br>• Based on the review of some of the world's best practices, frameworks and techniques, and personal research work experience in the field, a risk analysis framework has been adapted for readily application in the maritime transport of PDG. This phase consists of the following main stages: preparations for analysis, risk analysis, and conclusions and recommendations.<br>• Each stage of the risk analysis framework, in turn, consists of a number of steps and sub-steps which are specifically adapted for | are employed in measuring the performance of the systems and risks associated with them?<br>• Review and study the state of risk-related databases and other sources including: data quality, reliability, accessibility, availability, scope and formats.<br>• Review and study the best risk-related databases in the BSR and other countries in the world. Some of the world's best databases are found in the USA.<br>• Identify and study the best practices in risk analysis/ assessment of the transport of dangerous goods in the countries of the BSR, the EU and other parts of the world. | these categories of data and information:<br>▪ Dangerous goods accidents and incidents;<br>▪ Dangerous goods traffics;<br>▪ Dangerous goods regulatory systems;<br>▪ Records of dangerous goods inspections;<br>▪ Reports of risk studies;<br>▪ Information on the environment, including the most sensitive and protected areas;<br>▪ Inventories of the safety, environment protection and emergency response systems;<br>• Design and maintain a single/common database for reporting and recording of all types of marine-related accidents/ incidents (including ship and shore-related marine pollutions) in the BSR. The following should be agreed among |

| Nr | Concluding remarks | Research areas/questions | Recommendations |
|---|---|---|---|
| | application in the maritime transport of PDG.<br>• The quality, quantity, diversity, availability and accessibility of risk-related data and information are prerequisite for validity and reliability of risk analysis results. The review of many databases and risk studies show that risk-related data and information is inhabited with a wide range of issues. | | parties:<br>▪ A mandatory accident reporting system;<br>▪ Accident records should be available and accessible for all member states;<br>▪ The database should contain all relevant variables representing essential system and risk elements. Consult the world's best databases (e.g. USA databases);<br>▪ Compile data on Excel or other convenient data formats;<br>▪ Use of a common language – the most convenient common language may be English. |
| ***4*** | ***Risk evaluation criteria*** | | |
| | • In order to determine the level of risks, estimated risks are compared against risk evaluation criteria available for the transport of | • Identify and study risk criteria employed in risk evaluation in the transport of dangerous goods in the BSR, including these questions: | • If in existence, harmonize risk criteria in all the countries of the BSR to the degree of the local conditions.<br>• Improve or develop (facts-based) |

| Nr | Concluding remarks | Research areas/questions | Recommendations |
|---|---|---|---|
| | dangerous goods.<br>• In many industries, including the shipping industry, and countries, a wide range of risk evaluation criteria are established based on certain principles. They are usually developed and/or approved by responsible authorities at the highest levels of policy or decision making.<br>• These criteria include evaluation criteria for different types of individual and compound risks of the transport of dangerous goods, such as human safety and health risks, environmental risks, property risks and other risks.<br>• In many industries and countries, risk evaluation criteria may be lacking altogether. | ▪ Are there risk criteria available in all countries of the BSR?<br>▪ If yes, what types of risk criteria are available? How are they developed? On what basis are they developed?<br>▪ If they do exist, what are the differences and similarities among risk criteria in the BSR? | individual and compound risk evaluation criteria for:<br>▪ Individual transport modes including related activities: road, rail, water, air, pipeline;<br>▪ Intermodal transport;<br>▪ All transport modes combined;<br>▪ Other individual and combined systems and activities of the chemical supply chain or the life cycle;<br>▪ Individual risks including:<br>- Human risks: individual and societal risks - human safety and health (fatality and injury risks) and other effects;<br>- Environmental risks: water, land and air;<br>- Property risks;<br>- Other risks: suspensions, interruptions, disturbances<br>- Economic risks: the above risks |

| Nr | Concluding remarks | Research areas/questions | Recommendations |
|---|---|---|---|
| | | | measured in monetary units.<br>▪ Aggregated risks: all individual risks combined.<br>• Develop specific individual and compound risk criteria for the transport chains of dangerous goods in the BSR as a whole. |
| ***5*** | ***Risk communication*** | | |
| | • Risk communication is a constituent component of the risk management system. It plays an important role in risk assessment, risk management and attitude towards risks.<br>• Risk communication, including public information about risks of dangerous goods, has become a norm in many countries and industries.<br>• Risk communication concerning risks of the transport of dangerous goods encompasses a wide range of activities, including dissemination/ sharing of risk-related issues, | • Study the state of risk communication in the countries of the BSR, including:<br>▪ What are risk communication policies, approaches and channels?<br>▪ What is the degree of the transparency in decision-making?<br>▪ What is the degree of the availability and accessibility of risk-related data and information to all parties concerned including the general public?<br>▪ Are the industries and public interests actively involved in the policy or decision making processes | • Disseminate the best practices in risk communication in the countries of the BSR, the EU and other parts of the world. Adopt and employ these practices.<br>• Make sure that all parties concerned including the general public are represented and actively involved in decision-making processes concerning transport of dangerous goods. Make sure that these processes are transparent and open to the public scrutiny.<br>• Improve the dissemination/sharing of |

| Nr | Concluding remarks | Research areas/questions | Recommendations |
|---|---|---|---|
| | research results, data and information, practices and experiences.<br>• In some countries, risk communication aims to enhancing:<br>- Knowledge about risks of dangerous goods;<br>- Participation of all parties concerned in risk management;<br>- Participation of all parties concerned, including the general public, and transparency in dangerous goods-related decision-making processes. | concerning transport and risks of dangerous goods? What is the degree of their involvement?<br>▪ How are the following communicated, disseminated or shared among all parties concerned in the countries of the BSR:<br>- Risk-related issues and concerns;<br>- Risk-related data and information;<br>- Results of risk studies;<br>- Best practices in risk analysis/ assessment, risk management and risk communication.<br>• Identify and study the best practices in risk communication in the countries of the BSR, the EU and other parts of the world. | all risk-related data and information, issues, research results and practices in risk assessment and risk management.<br>• Improve or develop new risk communication approaches and channels.<br>• Adopt or develop advanced technological solutions for facilitating risk communication. |
| | **Risk management – strategies and measures** | | |
| | • There is a wide range of approaches or choices to deal with risks. However, the principal risk management strategies are | • Review and study the state of risk management strategies and measures concerning the transport of dangerous goods in the industries and countries | • Improve existing risk management strategies and measures.<br>• Develop and implement more effective risk strategies and measures based on |

| Nr | Concluding remarks | Research areas/questions | Recommendations |
|---|---|---|---|
| | avoidance or elimination, reduction, transfer and acceptance.<br>• In order to achieve the aforementioned risk management strategies, a wide range of risk management measures – including methods, techniques, approaches, tools – are also available.<br>• Risk management measures can be categorised based on the purpose of enactment, legal aspects and their nature.<br>• In many situations, several strategies and measures are often combined to achieve efficiently and effectively risk management goals.<br>• At the present and in the near future, contemporary society relies and will rely very heavily on and, subsequently, desires the wide range of chemicals and related activities, including transport of dangerous | of the BSR.<br>▪ Study the effectiveness and efficiency of risk management strategies and measures.<br>▪ How are they developed and implemented? Are they developed and implemented based on sound risk assessment and cost-benefit analysis?<br>▪ Have they unnecessarily become a burden for the industries?<br>▪ Are they impending unnecessarily facilitation of the transport and other related industries and activities?<br>▪ What are the views of industries? What are their experiences and concerns?<br>▪ Are all interests, including the public interests, involved? Are their views and concerns taken into consideration?<br>• Review and study the state of | sound risk assessments and cost-benefit analysis. They should be based neither on hazards (causes and contributing factors) nor consequences nor political considerations alone.<br>• Find risk management strategies and measures to achieve the twin goals: a) enhance the human safety and health and the environment and property protection; and b) facilitate (enhance reliability, effectiveness and efficiency) the transport of dangerous goods. Reconcile their differences; avoid conflicts.<br>• Design tools or criteria for measuring and evaluating the effectiveness and efficiency of risk management strategies and measures.<br>• Measure and evaluate the effectiveness and efficiency of risk management strategies and measures on regular basis. |

| Nr | Concluding remarks | Research areas/questions | Recommendations |
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| | goods. It exploits and enjoys many benefits attached to chemicals. But, the benefits and costs/ risks of chemicals are inseparable.<br>• Almost all risk management strategies and measures involve costs. It may be nearly always possible to take measures that would reduce risks further, but the costs would outweigh the expected benefits. Further, strategies and measures can be practically or economically impossible, if not counterproductive. Therefore, in many cases, a balance between costs and benefits is needed. | inventories of emergency response (search and rescue) systems available in industries and countries of the BSR concerning human safety and health, environmental and property protection.<br>• Review and study the state of co-operation and co-ordination in emergency responses at the industry, local, national and regional levels. Study the efficiency and effectiveness of these systems and operations.<br>• Identify and study the best practices in risk management in the countries of the BSR, the EU and other parts of the world. | • Enhance bilateral and multilateral co-operation and co-ordination in safety and health, and marine environment protection, and emergency responses in the BSR.<br>• Encourage non-control, voluntary or self regulating measures for improving human safety and heath, environmental and property protection.<br>• Disseminate the best practices in risk management in the BSR, the EU and other parts of the world. |
| | ***Risk analysis/assessment frameworks and techniques*** | | |
| | • Risk analysis/assessment, as well as other elements of the risk management system, is generally a systematic and rigorous scientific process that is usually facilitated by | • Review risk analysis/ assessment frameworks and techniques employed across research institutions, industries, sectors and relevant authorities in the countries of the BSR. | • Disseminate and employ the most advanced risk and cost-benefit analysis/ assessment frameworks and techniques.<br>• Harmonize in accordance with relevant |

| Nr | Concluding remarks | Research areas/questions | Recommendations |
|---|---|---|---|
| | frameworks or techniques.<br>• In this report, a wide range risk analysis/ assessment frameworks and techniques developed and employed, in particular in recent years, in shipping and other industries and sectors have been explored, inventoried and evaluated. They include some of the world's most advanced frameworks and techniques and best practices in the field.<br>• There are many different frameworks and techniques to choose from – e.g. qualitative/quantitative, system or risk element specific or generic etc. Making the right choice is an important step of risk analysis/ assessment. No single standardised format available has the capability to serve all types of systems and risks.<br>• In this report, some of the | - What types of risk analysis frameworks and techniques are employed? How are they employed?<br>- Are risks analysed/ assessed based on the most advanced frameworks and techniques?<br>- Are risk analyses based on quantitative and/or qualitative methods/ approaches? | legal frameworks, if any, or agree on the common risk analysis/ assessment procedures that would generate a higher degree of reliability and validity of research results.<br>• Further improve or develop risk analysis/ assessment frameworks and techniques employed in the chemical supply chain, including transport.<br>• Acquire or develop advanced technological solutions for facilitating risk analysis/assessment and management processes. If necessary and possible, adjust these solutions to characteristics and conditions of the BSR. |

| Nr | Concluding remarks | Research areas/questions | Recommendations |
|---|---|---|---|
| | characteristics, including merits and limitations, of techniques have been explored. Further, factors affecting the choice have also been explored, including:<br>- Resources available;<br>- Data and information available;<br>- System and/or risk elements to be studied;<br>- Legal and/or decision maker requirements;<br>- Risk issues and concerns;<br>- The extent of the risk study – e.g. qualitative, quantitative, initial or preliminary study, etc. | | |
| | | | |

# ATTACHEMENTS

## A.1 Swedish Maritime Administration (SMA) - marine accident analysis procedures

Table shows the SMA marine accident/risk analysis procedures (SMA 2002*)*

| Order | Types and numbers of variables | | Summary statistics |
|---|---|---|---|
| | Combinations of variables | Nr. | Presentation |
| | Introduction: background, definitions, scope | | |
| | | | |
| I | ACCIDENTS AND NEAR-ACCIDENTS | | |
| | | | |
| I.1 | Accidents and near-accidents – all categories | | |
| | Type of event-Year | 2 | Cross table |
| | Number of events- Registered vessels | 2 | Bars |
| | Type of event-Type of vessel | 2 | Cross table |
| | Type of vessel-Year | 2 | Bars |
| I.2 | Exposure data | | |
| | Number of vessels registered in Sweden 2001/2002 | | |
| | Vessel size | 1 | Bars |
| | Type of vessel-Vessel size (grt) | 2 | Cross table |
| | Type of vessel-Year | 2 | Cross table |
| | Number of active/signed-on seamen 2001/2002 | | |
| | Manning-Year | 2 | Cross table |
| | Manning-Sex | 2 | Bars |
| | Manning | 1 | Cross table |
| I.1.1 | Foundered vessels - number of lost vessels | | |
| | Type of vessel-Year (1998-2002) | 2 | Bars |
| | Type of event-Year | 2 | Bars |
| | Narratives - foundered vessel (1 case) | | |
| I.1.2 | Marine casualties | | |
| | Severity of event | 1 | Pie |
| | Severity of event-Type of vessel | 2 | Bars |
| I.1.3 | Serious casualty (1998-2002) | | |
| | Type of event-Year | 1 | Bars |
| I.1.4 | Accidents and near-accidents (2002) – all categories | | |
| | Location: Swedish territorial waters | 1 | Bars |
| | Location: international waters | 1 | Bars |
| I.1.5 | Marine casualties | | |
| | Type of event-Cargo-Loaded/ Ballast | 3 | Cross table |
| | Loaded/Ballast-Type of vessel | 2 | Pie |
| | Type of event- Vessel size (grt)-Year built | 3 | Cross table |

| | | | |
|---|---|---|---|
| I.3 | Individual events | | |
| I.3.1 | Grounding | | |
| | Type of vessel | 1 | Table |
| | Type of vessel-Primary causes | 2 | Bars |
| | Type of vessel-Contributing factors | 2 | Bars |
| | Consequences-Pilot-Type of vessel | 3 | Cross table |
| | Year-Month | 2 | Bars |
| | Visibility conditions | 1 | Pie |
| | Light conditions | 1 | Pie |
| | Combination: Visibility/ Light | 1 | Pie |
| I.3.2 | Collision with another vessel | | |
| | Type of vessel | 1 | Table |
| | Type of vessel- Primary causes | 2 | Bars |
| | Type of vessel-Contributing factors | 2 | Bars |
| | Damage/leakage-Pilot- Type of vessel | 3 | Cross table |
| | Operational mode of the vessel-Type of vessel | 2 | Cross table |
| | Visibility conditions | 1 | Pie |
| | Light conditions | 1 | Pie |
| | Combination: Darkness/Visibility | 1 | Pie |
| | | | |
| I.3.3 | Collision with another object: | | |
| | Type of vessel | 1 | Table |
| | Primary causes- Type of vessel | 2 | Bars |
| | Contributing factors- Type of vessel | 2 | Bars |
| | Damage/leakage-Pilot-Type of vessel | 3 | Cross table |
| | Operational mode of the vessel | 1 | Table |
| | Visibility conditions | 1 | Pie |
| | Light conditions | 1 | Pie |
| | Combination: Darkness/Visibility | 1 | Pie |
| | | | |
| I.3.4 | Leakage/capsize/weather damage | | |
| | Type of vessel | 1 | Table |
| | Primary causes- Type of vessel | 2 | Bars |
| | Damage to hull/ leakage-Type of vessel | 2 | Table |
| | | | |
| I.3.5 | Shifting of the cargo | | |
| | Type of vessel | 1 | Table |
| | Primary causes-Type of vessel | 2 | Bars |
| | | | |
| I.3.6 | Fire/Explosion | | |
| | Type of vessel | 1 | Table |
| | Primary causes-Type of vessel | 2 | Bars |
| | Operational mode of the vessel-Type of vessel | 2 | Cross table |
| | Type of vessel-Vessel's construction material | 2 | Bars |
| | | | |
| I.3.7 | Engine failure | | |
| | Type of vessel | 1 | Table |
| | Primary causes- Type of vessel | 2 | Bars |
| | Damage to hull/Leakage-Type of vessel | 2 | Cross table |
| | | | |

| | | | |
|---|---|---|---|
| I.3.8 | Spillage | | |
| | Type of vessel | 1 | Table |
| | | | |
| I.3.9 | Other - e.g. container damage and an incident with a lifeboat | | |
| | Type of vessel | 1 | Table |
| | Primary causes- Type of vessel | 2 | Bars |
| | | | |
| II | OCCUPATIONAL ACCIDENTS AND INJURIES AND WORK-RELATED DESEASES | | |
| | | | |
| | Introduction: background, definitions, scope | | |
| | | | |
| II. 1 | Persons employed on board | | |
| | Persons employed on board (exposure) | | |
| | Persons | 1 | Table |
| II.1.2 | Occupational injuries | | |
| | Manning-Year (1993-2002) | 2 | Cross table |
| | Injured seamen/100 active seamen-injured employees/100 employees nationally-Year (Risk) | 3 | Bars |
| | Severity of accident/ work-related diseases -Year (1998-2002) | 2 | Cross table |
| | Manning (women and men)- Severity of accident/ work-related diseases | 2 | Cross table |
| | Sex (women)-Manning-Severity of accident/ work-related diseases | 3 | Cross table |
| | Sex (men)-Manning-Severity of accident/ work-related diseases | 3 | Cross table |
| II.1.3 | Occupational accidents | | |
| | Manning-Discrepancy | 2 | Cross table |
| | Sex (Women)- Discrepancy | 2 | Bars |
| | Sex (Men)- Discrepancy | 2 | Bars |
| | Narrative - 2 case | | |
| II.1.2.1 | Occupational injuries | | |
| | Age group- Sex (women)- Estimated absence | 3 | Bars |
| | Age group- Sex (men)- Estimated absence | 3 | Bars |
| | Number of active seamen (exposure) | | |
| | Manning-Age | 2 | Cross table |
| II.1.3.1 | Occupational accidents | | |
| | Number of seamen-Number of accidents-Age | 3 | Cross table |
| | Number of accident-/100 Active seamen-Age (Risks) | 3 | Bars |
| | Sex (women)–Manning-Age | 3 | Cross table |
| | Sex (men)–Manning-Age | 3 | Cross table |
| II.1.4 | Work-related diseases | | |
| | Year (1998-2002)-Causes | 2 | Cross table |
| | Sex (women/men)-Causes | 2 | Bars |
| | Causes-Manning (women and men) | 2 | Cross table |
| | Causes-Manning-Sex (women) | 3 | Bars |
| | Causes-Manning-Sex (men) | 3 | Bars |
| | Number of work-related diseases-/100 Active seamen (manning) (Risks) | 3 | Bar |
| | Sex (women)-Manning-Age | 3 | Cross table |
| | Sex (men)-Manning-Age | 3 | Cross table |
| | | | |

| | | | |
|---|---|---|---|
| II.2 | Commercial fishermen | | |
| II.2.1 | Occupational accidents | | |
| | Year (1998-2002)-Consequences | 2 | Cross table |
| | Discrepancy | 1 | Bars |
| | Narrative - (1 case) | | |
| | Age-Absence | 2 | Bars |
| II.2.2 | Exposure data | | |
| | Number of vessel-Vessel size-Number of fishermen | 3 | Cross table |
| II.2.3 | Work-related diseases | | |
| | Causes-Year | 2 | Cross table |
| | Causes-Age | 2 | Cross table |
| | | | |
| II.3 | Passengers | | |
| | Passenger death/injuries | | |
| | Death/injuries-Type of vessel | 2 | Cross table |
| | | | |

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This report deals with the risk management system and risk analysis frameworks and techniques. The report is part of the Safe and Reliable Transport Chains of Dangerous Goods in the Baltic Sea Region (DaGoB) project and the author's own research.

The main aims of the DaGoB project include: a) improve co-operations at various levels among parties concerned in transport of dangerous goods in the BSR; b) provide up-to-date information on cargo flows, supply chain efficiency and risks related to transport of dangerous goods; and c) disseminate and transfer the knowledge gained from the project on local, national, regional and international levels.

The author's research work concerns the development of a risk analysis framework for readily application in the maritime transport system of Packaged Dangerous Goods (PDG) as well as the demonstration and validation of the framework in practice. One of the main parts of the thesis is the "Frame of Reference", which provides relevant definitions, concepts and theoretical models in the essential interrelated research areas, such as: a) the maritime transport system of PDG; b) risks of dangerous goods accidents/incidents; and c) the risk management system. The "Frame of Reference" serves as a theoretical platform for the development of the risk analysis framework. The framework development involves exploration of many relevant concepts and their relationships. It is based on the review of a wide range of risk assessment frameworks and techniques and some of the world's best practices in the field. This report deals with one of the research areas, namely: the risk management system.

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