# A Risk Analysis Framework for Maritime Transport of Packaged Dangerous Goods – A Validating Demonstration

VOLUME I

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ISRN LUTMDN/TMTP--1044:1--SE
ISBN 978-91-976974-0-8

# ACKNOWLEDGMENTS

There are many people who I wish to thank. Firstly, I am grateful to my supervisors – Docent Everth Larsson and Docent Andreas Norrman, Department of Industrial Management and Logistics, Division of Engineering Logistics, Lund Institute of Technology, Lund University – who have contributed, in many respects, to this and other research works. I very much appreciate their time and efforts, and their constructive and valuable inputs. Many thanks go to other academics that have reviewed, commented and given valuable feedbacks on the draft manuscript during the research process.

I am thankful to Ulf Paulsson for his cooperation in the Sundrisk project and other works in the department and for his friendship. I wish him success.

In memory of my first supervisor, Sölve Arvedson – a sea captain, an expert in the field and the first rector of the World Maritime University, Malmö – who initially assisted and guided me in this long journey.

Special thanks to all fine people – the present and previous faculty staff, staff and my colleagues – at the Department/Division of Engineering Logistics for their valuable comments and discussions, communication, administrative and technical support and the pleasant working environment: Professor Sten Wandel, Dr. Stefan Holmberg, Adjunct Professor Stig-Arne Matsson, Robert Lindroth, Mikael Ståhl Elvander, Laila Hjalmarsson, Anita Jensen, Dr. Maria Björklund, Fredrik Friblick, Dr. Daniel Knudsen, Professor Gunilla Jönson, Associate Professor Mats Johnsson, Bertil Lidén, Hyll Henrik, Paul Björnsson, Eva Berg, Luca Urciuoli, Carina Johnsson, Johan Lundin, Charlotte Berg and many others. Thanks also go to all members of Division of Production Management.

Björn Loonström, Swedish Coast Guard Head Quarter, and Johan Horck, World Maritime University, thank you for providing me with some valuable materials used in this research. Thanks to Cecilia Denne and Susan Eklöw, the World Maritime Library staff, for their assistance in searching and acquiring information.

I wish to thank the DaGoB Project office, Turku School of Economics, Logistics, Turku, Finland, Mikko Suominen, Sirpa Nummila and others, for partly financing this research, and for their valuable work in revising, editing and making possible the publication of two parts of this thesis.

I would like to thank my dear sisters Juliana, Nermin and Elizabeta and their family for being always there for me. I owe great gratitude to my brother, Eduard, and my gracious parents, Myzejen and Qemal, for everything they have given and done for me. I wish I thanked them enough here and now. Finally, I am very grateful to my beloved wife, Mirela, and to my precious daughters, Sonia and Simona, who always and unconditionally supported and stood by me “in the rainy and sunny days” – all my best wishes to you!

# ABSTRACT

In this Volume of the thesis, which consists of two volumes, a risk analysis framework for application in the maritime transport system of packaged dangerous goods (PDG) is presented. In many countries, dangerous goods risks have been ranked high among public concerns. Such concerns are mainly due to the increasing volume of dangerous goods, human safety and health and environmental risks and threats they pose, and the general belief that these risks should be managed more efficiently and effectively. The literature study shows that, in recent years, the risk management system has become a "hot" topic for many countries and organisations. Many risk assessment frameworks have been developed in the shipping and other industries, sectors or areas. In the maritime industry, they are primarily developed for analysis of the risks for the industry in general and in particular for maritime transport of bulk dangerous cargoes such as oil, oil products, liquefied gases and other bulk liquid chemicals. The FSA (Formal Safety Assessment) framework of the International Maritime Organisation, which is one of the most widely used ("authoritative") frameworks in the shipping industry, is a generic framework. However, the framework is not intended for application in all circumstances, including the risks of the maritime transport of PDG. Consequently, the FSA is adapted or simply applied or tested in several maritime-related systems, activities and issues, but not in the maritime transport of PDG. Furthermore, a specific risk analysis framework for application in maritime transport of PDG has not been found. Therefore, on the basis of understanding gained from the extensive literature study of some of the world's best frameworks and techniques, guidelines and practices in shipping and other industries and sectors, and analysis of large amounts of empirical data, a risk analysis framework has been developed for readily application in the maritime transport system of PDG. Efforts have been made to strengthen validity and reliability of the framework. This study contributes to the communities of academics and practitioners. In Volume II of this thesis, the framework is demonstrated step-by-step in practice based on large amounts of empirical data. Recommendations for improving risk methodology and human safety and health and protection of the marine environment and property are provided.

# SUMMARY

Increasingly large amounts of many different types of dangerous substances, materials and articles (dangerous goods/cargo) are carried by water in bulk (e.g. oil, oil products, liquefied gases and some chemicals) and in *packaged form* (*packaged dangerous goods* – PDG[1]). According to the International Maritime Organisation (IMO), between 10 and 15% of cargoes carried by water are PDG. Many different types and sizes of ships carrying large quantities of many different types of PDG penetrate populous residential areas and environmentally sensitive zones. Marine accidents involving PDG have adverse effects on human health and safety, the marine environment and property. One of the worst marine accidents ever recorded involved PDG (Halifax, Canada, 1917).

As a result of economic growth and transport and environmental policies, maritime freight/ passenger traffic is expected to expand in the future. The consequences of the growth in dangerous goods maritime traffic are reflected in an increase in human and environmental risks. In many countries, the risks of dangerous goods have been ranked high among public concerns. Such concerns stem mainly from the large, and still increasing, volume of dangerous goods, the severe effects of accidents and the general belief that risks involving dangerous goods should be managed more efficiently and effectively. In addition, in recent years and in particular after the 9/11 events in the USA, security of maritime transport of PDG has become a pressing issue in many parts of the world.

In the maritime industry, as in many other industries, sectors and activities, the risk analysis process is facilitated by certain standardised formats (i.e. frameworks, techniques, or tools). Such issues as data availability, costs and time are often cited as major barriers in conducting risk analyses. In practice, these issues discourage systematic and thorough risk analyses.

The literature study showed that numerous studies have been conducted on the risks concerning various systems and activities of the chemicals or dangerous goods supply chain. However, the literature in the field of the risks of marine accidents and incidents involving PDG is limited. Many studies focus on the risks of major accidents involving bulk dangerous cargoes such as oil, oil products, LNG, LPG and a few

[1] These include different types of packaging and cargo transport units (CTUs) such as: freight containers, cargo tanks, shipborne barges on barge-carrying ships, freight containers, bulk packaging, portable tanks, tank-containers, road tankers, swap-bodies, vehicles, trailers, immediate bulk containers (IBCs), unit loads and other cargo transport units. Detailed definitions and descriptions of the concepts of dangerous goods, the packaging system, risks and other constituent components of the maritime transport system are provided in Chapter 3, Vol. I, and Mullai, 2006a.

chemicals carried in bulk. Many quantitative studies are confined to the use of a few variables, sometimes to one or two variables only. In many cases, the essential data have been discarded. The literature review also shows that, in recent years, many risk assessment frameworks have been developed in many areas, including human safety and health and marine environment protection. In the maritime industry, numerous frameworks have been developed to facilitate the analysis of the individual or aggregated risks associated with maritime systems in general, the offshore industry, and the transport, handling and storage in ports of large quantities of bulk dangerous cargoes. Despite all these efforts, no specific risk analysis framework for maritime transport of PDG has been found. The frameworks available are not readily suitable for an analysis of the risks of maritime transport of PDG. Thus, the IMO's FSA framework, which is one of the most "authoritative" frameworks in the shipping industry in recent years, is a highly generic framework. According to the IMO, the framework is not intended for application in all circumstances, including the risks of maritime transport of PDG. The FSA is adapted, applied or tested in several maritime-related systems, activities and issues, such as cruise ships, bulk carrier and hatchway watertight integrity of bulk carriers, oil spills, fishing vessel, offshore industry, container ships, ports and ships in general, which are not necessarily related to risks of maritime transport of PDG.

Given the above context, this study addresses the interrelated challenges of improving risk methodology and human safety and health and protection of the marine environment and property. Hence, the twin objectives of this study are to: a) *develop a risk analysis framework for maritime transport of PDG*; b) e*nhance understanding of dangerous goods risks and provide recommendations for improving human safety and health and protection of the marine environment and property*.

Due to the very nature of the maritime transport system of PDG, the risks associated with it and many different influencing conditions and factors, it was considered important to adopt a systems approach in this study. There is a wide range of research strategies available. Each strategy offers a particular perspective on reality. Given the research objective and interrelated areas of the study, and the determining conditions described in Chapter 1, Vol. I, such as data accessibility and availability, resources and time available, research area specifications, validity and reliability of results and advantages of the hybrid strategy, this study combine field and library studies. The research design (see Chapter 2, Vol. I) reflects the particular circumstances of this study. It shows how all the essential research processes are designed to achieve the research objective. These processes proceed from preparations for the study, through information and data collection and analysis processes, towards the development of the framework. The framework is developed on the basis of the insights and understanding gained by reviewing, examining and analysing a large amount of different types of data and information. The data are collected and analysed by employing the combination of various methods and techniques described in Chapter 2, Vol. I.

The development of the framework involves many relevant concepts and their relationships. The validity and reliability of the framework, and consequently the quality of the results generated by it, depend very much on how well and precisely the constituent concepts are defined. For that and other reasons stated in the introduction to Chapter 3, Vol. I, the “Theoretical Framework” (a detailed version of this chapter is provided in Mullai, 2006a, 2006b), provides definitions and descriptions of the essential concepts in important interrelated research areas, namely the maritime transport system of PDG, the risks of dangerous goods, and the risk management system. The development of the framework is both theoretically and empirically grounded. The risk analysis is generally a rigorous process that is often facilitated by specific frameworks, techniques, tools or standards. In order to gain insights into and enhance understanding of the field, some of the world’s best risk management practices, risk management and analysis/assessment frameworks and techniques employed in the shipping and other industries, sectors or areas have been studied and presented in Chapter 3, Vol. I and Mullai, 2006b.

On the basis of the analysis of large amounts of empirical data (see Chapter 4, Vol. I), the main stages, steps and sub-steps explored in Chapter 3, Vol. I, and Mullai, 2006b, are further developed and suited for application in the risk analysis in the maritime transport system of PDG. The analysis of some representative marine accident case histories is presented in Chapter 4, Vol. I. The risk analysis framework is described in detail in Chapter 5, Vol. I. The framework, which characterises the maritime transport system and risks associated with it, consists of three main stages, namely: *Stage 1* – preparations for the risk analysis; *Stage 2* - risk analysis; and *Stage 3* – conclusions and recommendations. Each stage contains a number of steps, sub-steps or tasks. In order to facilitate the risk analysis process (Stage 2), several analysis techniques are suggested, including the principle procedures of the Fault Tree (FTA) and Event Tree (ETA) Analysis techniques. The risk analysis process attempts to provide answers to the “triple definitions”: "*What has gone and can go wrong*?” "*What are the consequences*?” and "*How likely is that to happen*?" These questions lead to other important questions that require additional answers and subsequently efforts, time and resources.

The results of the study are synthesised in Chapter 7, Vol. I. Given the research objectives, the main result and (theoretical and practical) contribution is the risk analysis framework for readily application in the maritime transport system of PDG, as well as other populations, systems, or phenomena of interest, i.e. other systems and activities of the dangerous goods supply chain. The framework provides a blueprint for preparing and performing the risk analysis in the field in a more effective and efficient manner. This study contributes to the improvement of the risk analysis methodology and human safety and health and protection of the marine environment and property. This study also contributes to enhancing understanding of the research areas presented in Chapter 3, Vol. I, namely: the maritime transport system of PDG, dangerous goods risks and the risk management system. Detailed lists of recommendations for improving risk methodology and human safety and health, and protection of the marine environment and property, and some important future research questions and areas are provided in Chapter 7, Vol. I, and Mullai, 2006 and 2006b.

In Chapter 1-7, Vol. II, the risk analysis framework (presented in Chapter 5, Vol. I), is step-by-step demonstrated in practice on the basis of other datasets, which are collected from the U.S.'s data sources, than those used in the development of the framework. Recommendations for improving human safety and health, and protection of the marine environment and property are provided in Chapter 7 and Appendix 3, Vol. II. The chapter concludes with some final remarks concerning validity and reliability of the framework.

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## ABBREVIATIONS

| | |
|---|---|
| AAPA | American Association of Port Authorities |
| ACS | American Chemical Society |
| BMEPC | Baltic Marine Environment Protection Commission |
| CARAT | Chemical Accident Risk Assessment Thesaurus Database |
| CCPS | Center for Chemical Process Safety |
| CRN | Comprehensive Risk Analysis and Management Network |
| CSC | International Convention for Safe Containers, 1972 |
| CTU | Cargo Transport Unit |
| DG | Dangerous Goods |
| DETR | Department of the Environment, Transport and the Regions, UK |
| DNV | Det Norske Veritas |
| DSC | IMO Sub-Committee on Dangerous Goods, Solid Cargoes and Containers |
| EC | European Commission/Community |
| ECOSOC | Economic and Social Council of the United Nations |
| EMSA | European Maritime Safety Agency |
| ETA | Event Tree Analysis |
| EU | European Union |
| FSA | Formal Safety Assessment |
| FTA | Fault Tree Analysis |
| GHS | Globally Harmonized System of Classification and Labelling of Chemicals |
| HCB | Hazardous Cargo Bulletin |
| HAZMAT | Hazardous Materials (a term used in USA for dangerous goods) |
| HMIS | Hazardous Material Information System (U.S.) |
| HNS | International Convention on Liability and Compensation for damage in connection with transport of Hazardous and Noxious Substances (IMO) |
| HSC | Health and Safety Commission, UK |
| HSE | Health and Safety Executive, UK |
| IBC | Intermediate Bulk Container |
| ICHCA | International Cargo Handling Coordination Association |
| IEC | International Electro-technical Commission |
| ILO | International Labour Organisation |
| IMDG Code | International Maritime Dangerous Goods Code |
| IMO | International Maritime Organisation |
| ISM Code | International Safety Management Code |
| ISO | International Standards Organisation |
| IT | Information technology |
| LNG | Liquefied natural gas |
| LPG | Liquefied petroleum gas |
| LRS | Lloyd's Register of Shipping |
| LUCRAM | Lund University, Sweden, Centre for Risk Analysis and Management |
| MAIB | Marine Accident Investigation Branch |

| | |
|---|---|
| MAIIF | Marine Accident Investigators' International Forum |
| MARPOL 73/78 | International Convention for the Prevention of Pollution from Ships, 1973/1978 |
| MEPC | Marine Environment Protection Committee, IMO |
| MSC | Marine Safety Committee, IMO |
| NRC | National Response Center (U.S.) |
| OBO | Ore/bulk/oil carrier |
| OECD | Organisation for Economic Co-operation and Development |
| P&I Cub | Protection and Indemnity Cub |
| PSC | Port State Control |
| PDG | Packaged Dangerous Goods |
| Ro-ro | Roll on/roll off |
| RMSI | Risk Management Specific Interest Group |
| SMA | Swedish Maritime Administration |
| SOLAS 74 | International Convention for Safety of Life at Sea, 1974 |
| SRA | Society for Risk Analysis |
| TEU | Twenty-foot Equivalent Unit (containers) |
| UN | United Nations |
| UNCTAD | United Nations Conference on Trade and Development |
| UNEP | United Nation Environment Programme |
| U.S./USA | United States of America |
| U.S. BTS | U.S. Bureau of Transportation Statistics |
| USCG | United States Coast Guard |
| U.S. DOT | U.S. Department of Transportation |
| USEPA | U.S. Environmental Protection Agency |
| VTS | Vessel traffic service/system |
| WHO | World Health Organisation |
| WMU | World Maritime University |

# 1. Introduction

*Initially, this chapter provides the context of the issues related to maritime transport of packaged dangerous goods. Then, the problem areas are explored and described. The literature review of the "state-of-the-art" knowledge in the field explores the importance and the need for this study. The research questions are formulated and the research objectives are set. The scope of the study is also defined. Finally, an outline of the report and a list of groups of people who might be interested in the study are provided at the end of the chapter.*

## 1.1. Background

### Increasingly large amounts of many different chemicals

Increasingly large amounts of many different types of dangerous substances, materials and articles (dangerous goods - DG)[2] are present in communities around the world. Millions of tonnes of a wide range of chemicals are globally produced, transported and used each year. There are 100,000 different substances registered for sale in the European Union (EC, 2003). The United States, which has the world's largest GNP, is the largest economy and the largest consumer of natural resources. In 1994, it was estimated that approximately 4 billion tons of hazardous materials (hazmat) were shipped in the USA, or approximately a half million shipments per day (Glenn, 1994). In recent years, the number of shipments has almost doubled (Ross, 2002; U.S. DOT, 2000, 2004). Chemicals are also present in transit via highways, railways, waterways, air and pipelines. Large amounts of these materials, substances and articles are carried by water in the form of energy, such as oil and oil products, liquefied petroleum gases (LPG) and liquefied natural gases (LNG), chemicals, nuclear and other dangerous goods or hazardous materials. They pose risks for human safety and health and the marine environment (PCSD, 1996; EC, 2001).

### Maritime transport system of packaged dangerous goods and its risks

Dangerous goods/cargoes are carried by water in bulk (e.g. oil, oil products, liquefied gases and many chemicals) and *packaged form* (hereinafter *packaged dangerous goods – PDG*[3]). It is estimated that between 10-15% of cargoes carried by water are

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[2]Terms such as "chemicals", "dangerous/hazardous – materials, substances, articles, goods, products or cargo" are often used interchangeably. However, the terms "*dangerous cargo*" and "*dangerous goods*" are commonly used in maritime transport. The term "hazardous materials" or "hazmat" is used in particular in the U.S. In Vol. I and II, the terms *"dangerous goods"* and *"hazmat"* are most frequently used. A detailed discussion about the concept of "*dangerous goods*" is provided in Chapter 3, Vol. I, and Mullai, 2006a.

[3]According to the International Maritime Organisation (IMO, 1996a), PDG are dangerous goods (materials, substances and articles) carried in any form of containment such as: freight containers, cargo tanks, shipborne barges on barge-carrying ships, freight containers, bulk packagings, portable tanks, tank-containers, road tankers, swap-bodies, vehicles, trailers,

PDG (IMO, 1996a). Compared to bulk transport and other modes of transport, given its system's specifications, maritime transport[4] of PDG is, to some extent, specific. Many different types and sizes of ships, including general cargo ships, container ships, and ro-ro cargo ships, carrying large quantities of many different types of *PDG* penetrate estuaries, harbours and narrow channels to take them through or into large centres of population and environmentally sensitive areas. Unlike bulk transport, PDG are carried together with non-dangerous goods and passengers on board cargo/ passenger ships (e.g. ro-ro ships/ferries). Dangerous goods are also carried in "limited quantities", for example in the form of passengers' personal effects, on board passenger (cruise) and ferry ships. The principal international rules for the carriage of PDG by water are set in the International Maritime Dangerous Goods (IMDG) Code, which has been harmonised with the "United Nations Recommendations on the Transport of Dangerous Goods" and other modal regulations. In order to enhance human safety and health and prevent environmental pollution in maritime transport, a large number of legislative measures are developed and adopted in many countries and regions, for example, in the European Community (EC, 2002a). Either at political or operational levels within the EU, interest in the problems concerning safety and marine environment protection in maritime industry activities has been increasing (Biancardi et al., 1996).

Marine accidents and incidents involving PDG[5] resulting in the release of these materials and substances have adverse effects on human health and safety, the marine environment and properties. For example, one of the worst marine accidents ever recorded in the history involved *PDG* (Halifax, Canada 1917). In this catastrophic accident, the entire city and port areas were devastated, leaving thousand of people dead and injured. Marine accident case histories (HCB, 1986-2003) have shown that many ships carrying PDG have been involved in serious and very serious marine accidents, such as grounding or stranding, collision, engine and structure failure, capsizing, and fire/explosion. Many ships have been totally lost in the coastal and sensitive areas, but only in a few cases has the nature of the cargo involved been reported. Further, in only a few cases are PDG recovered from sunken ships. In

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intermediate bulk containers (IBCs), unit loads and other cargo transport units (CTU). A detailed discussion about the concept of "packaging and packaged dangerous goods" is provided in Chapter 3, Vol. I, and Mullai, 2006a.

[4]Transport by water is described by different terms. In this report, for the purpose of consistency, the term "maritime transport" is most frequently used. A detailed discussion about the concept of "maritime transport" is provided in Chapter 3, Vol. I, and Mullai, 2006a.

[5]In maritime industry, the terms "*marine accident and incident*" and "*marine casualty*" are used to describe undesirable *marine events* in connection with ship operations. These terms are used by some of the prominent organisations, such as the International Maritime Organisation (IMO), U.S. Coast Guard, Swedish Maritime Administration (SMA), Marine Accident Investigators' International Forum (MAIIF) and many more. In this report, for the purpose of constituency, the term "*marine accident/incidents*" or "*marine events*" are most frequently used. A detail discussion about the mentioned concepts is provided in Chapter 3, Vol. I, and Mullai, 2006a.

addition, in economic terms, the risk costs of dangerous goods can represent more than 13 percent of the transport costs (Dennis, 1996).

The consequence of the growth in dangerous goods maritime traffic, and vessel traffic in general, corresponds with the increase in human, property and environmental risks. Thus, the main sea areas of concern in the European Union are the Mediterranean Sea, the Black Sea, the Baltic Sea, in particular in the area between Sweden, Denmark, and Germany, and the North Sea. Large amounts of different types of dangerous goods including PDG (BMEPC, 1993) are handled and transported in the Baltic Sea Region. In addition, there is also considerable passenger traffic in many parts of the world. Passenger traffic in the EU waters is about 350 million passenger journeys per year (EMSA, 2004). As the result of EU transport and environment policies to move goods and passenger transport off roads, further growth is expected in the future in maritime traffic, including goods, passengers and goods/ passengers.

### Growing concerns about the risks of dangerous goods

In many countries, the risks of dangerous goods have been ranked high among public concerns. For example, according to the European Maritime Safety Agency (EMSA, 2004), as a result of recent accidents in Europe there is growing public concern about the lack of safety at sea and about the pollution caused by the maritime sector. Further, in recent years, in particular in the aftermath of the 9/11 events in the USA, security and safety of maritime transport of PDG have become concerning issues for individual organisations, industries, responsible governmental authorities and agencies and the general public. Such concerns stem mainly from the high and still increasing volume of dangerous goods, deliberate acts including theft, hijackings, severe effects of accidents, in particular accidents involving explosive, toxic and radioactive materials and substances, and general belief that risks involving dangerous goods should be better managed. The lack of knowledge about the impact of many chemicals on human health and the environment is also a cause for concern (EC, 2001).

Human safety and health and pollution of the marine environment from increasingly large amounts of different types of dangerous goods transported and handled in the BSR (Baltic Sea Region) are also concerning issues for all countries in the region. It is estimated that over 300 million tons of different types of dangerous goods are transported annually in the BSR (TSE, 2006). In response to the growing concerns about the dangerous good risks, the main objectives of the DaGoB (Safe and Reliable Transport Chains of Dangerous Goods in the Baltic Sea Region) project included: a) providing up-to-date knowledge of the risks of transport of dangerous goods; and b) disseminating and transferring the knowledge gained in the project on local, national, regional and international levels.[6]

[6] The project, which is partly financed by the European Union (European Regional Development Fund) within the BSR INTERREG III B Neighbourhood Programme, involved numbers of partners from the countries of BSR, such as Finland, Sweden, Germany and the Baltic States. For more information see: www.dagob.info

### Risk analysis – a time-consuming, resource and labour intensive activity

First and foremost, a better (sound and proactive) risk management requires a systematic and thorough risk analysis that can provide detailed, structured and reliable information about risks. In shipping, as in many other industries, sectors and activities, the risk analysis - the entire process from preparation through analysis, organization and presentation of the risk-related information – is a rigorous scientific process that is generally facilitated by certain standardised formats (i.e. frameworks, techniques or tools). Data accessibility and availability, costs and time are often quoted as big barriers in conducting risk analyses. Detailed analyses are generally very time-consuming, resource and labour intensive. For example, the costs of the risk analysis in chemical risk management have ranged from U.S. $180,000 to U.S. $8 million (OECD, 2000). Some EU projects (1994-1998 and 1998-2002) (EU, 2002b) concerning, among other things, safety, health and marine environment protection, have involved numbers of participants (up to 11 participants per project) from large and well-known industrial organisations, research and educational institutions. They have lasted in the range between 12-36 months per project, and have cost in the range of 200,000 - 2.8 million Euros per project. In practice, data, costs and time constraints can discourage comprehensive risk analyses, which, in turn, can lead to inadequate risk management.

## 1.2 Problem areas

The purpose of this section is to present concerning "academic" and "practical" issues, and the "state of the art" knowledge in the field. This section also highlights the importance and the needs for this study.

### Risk analysis/assessment frameworks – "One size does not fit all"

The IMO and classification society rules have traditionally been developed by experts' judgments, responding to previous accident experience, and in general prescribe specific design solutions (HSE, 2002). They have rarely been based on rigorous risk assessment (HSE, 2002).

However, the IMO, the classification society and other relevant organisations have been, in particular in recent years, working in newer risk-based rules. In recent years, many frameworks[7] or models for facilitating risk analysis/assessment and management processes have been developed or improved and applied in many areas, including human safety and health and marine environment protection. The quality, degree of detail and specifications of the frameworks vary in scale. Some frameworks or models are presented below.

[7] The scope of these frameworks varies widely. Some frameworks are specifically designed to facilitate individual elements or activities of the risk management system, such as risk analysis, risk assessment (analysis and evaluation) or risk management. Some others encompass the wide range of activities of the overall risk management system. For more information see Chapter 3, Vol. I, and Mullai, 2006b.

In the shipping industry, frameworks are developed to facilitate the assessment of individual or aggregated risks associated with *maritime systems in general,* which are not necessarily related to dangerous goods hazards (Sii et al., 2001a, 2001b; Fowler and Sorgård, 2000) that include the *offshore industry* and *transport and handling and storage in ports of large quantities of bulk dangerous cargoes* such as oil, oil products (Reed et al., 1999; Onyekpe, 2002), liquefied natural and petroleum gases (LNG and LPG) (Fay, 2003) and other liquid chemicals in particular. Certain frameworks are developed and serve a specific purpose in a specific country. For example, in response to the Dutch government's concerns for safety of transport and the development of a risk management policy, a large research project, "Safety of Inland Water Transport", was carried out with the purpose of developing a risk-effect model (REM) (Donk and Rijke, 1995). The model was designed with the purpose of assessing the risks of inland water transport of dangerous cargoes in the Netherlands (Erkut, 1996). The model consists of a number of modules enabling the assessment of traffic, accidents, damage, outflow, environmental and safety and economical risks, and effects of the decision-making.

*Quantitative Risk Assessment (QRA)*: Risk assessment frameworks have been developed by or on behalf of the shipping and offshore industry interests. For example, a risk assessment framework has been developed by DNV Technica Ltd. (UK) as part of a major risk study for the transport of bulk dangerous cargoes in British waters for the Heath and Safety Commission/Executive (HSC/HSE), which is known as the Quantitative Risk Assessment (QRA) Technique (HSC, 1991). This systematic approach was employed for the first time to assess the risks of maritime transport of dangerous goods in British waters and ports. The study, and subsequently the framework, was confined to the risks of major accidents affecting people ashore from bulk shipments of dangerous cargoes, such as crude oil, flammable and toxic liquefied gases, flammable liquid petroleum products, flammable liquids and ammonium nitrate (i.e. dry bulk cargo). The study did not consider the risks of maritime transport of the large amounts of different types of dangerous goods carried in packaged form, the injury and other health risks, and the marine environment risks. The work has inspired many experts and organisations in developing techniques, for example, for assessing the risks from dangerous cargoes in port areas (Saccomanno and Cassidy, 1993).

*HSE's Risk Assessment Framework for Offshore Operations/Installations* (HSE, 2002): The risk assessment framework, which has been developed by Den Norske Veritas on behalf of the UK's Health and Safety Executive (HSE), provides a structured basis and addresses marine hazards on offshore installations. Marine hazards, which are defined in the guidelines as any potential accident on an offshore installation connected with its interface with the marine environment, include (HSE, 2002):

- Loss of position keeping (e.g. mooring, dynamic positioning, rig move)
- Loss of structural integrity (e.g. hull, ballast tank, support structure failure)
- Loss of stability (e.g. ballast system failure, cargo loads)
- Loss of marine/utility systems (e.g. propulsion, power generation, hydraulics)
- Collision (e.g. shuttle tanker, support vessel, passing vessel)

According to the guidelines, marine hazards exclude accidents connected with drilling, hydrocarbon releases, fires, dropped objects, helicopter transportation, diving or other personal hazards. The guidelines primarily cover mobile offshore installations, which include semi-submersibles, jack-ups and heavy lift vessels. They also cover floating production systems, which are often based on semi-submersibles or ship hulls.

Numerous models have been developed for the analysis of risks/accidents or safety in maritime transport in general, i.e. not necessarily related to dangerous goods (Sii et al., 2001a, 2001b), with some or little direct relevance to the risks of dangerous goods. The following are some illustrative examples.

*The Maritime Accident Risk Calculation System (MARCS)* model (Fowler and Sorgård, 2000), which was further developed during the Commission of the European Communities (CEC) project "Safety of Shipping in Coastal Waters" (SAFECO), has been designed to assess a number of serious marine accident, excluding other events such as fires and explosions during port operations, cargo losses overboard, cargo damages and spills and other "non-serious", "minor" or "near miss" events. Certain types of ships carrying or having PDG were not included. The hazards and effects of dangerous goods are also not considered.

*SEALOC*, which is a project concerning assessing concepts, systems and tools for a *Safer, more Efficient And Lower Operational Cost* of *the maritime transport of dangerous goods,* is an European project funded by the European Commission (EC, 1998a). The objectives of the project included: 1) analyse and quantify consequences of one of the best known accidents, the Amoco Cadiz accident; 2) evaluate the safety issues in the Mediterranean Sea in the case of liquefied petroleum gases (LPG) transport; 3) *evaluate the safety issues in the North Sea in the case of container transport*. With regard to the risks of marine incidents involving PDG, this project has been confined to the carriage of containers by sea in the North Sea only. It does not consider consequences for the marine environment (fauna and flora). Nor does the study specifically consider the human risks (fatalities and injuries) due to hazards of dangerous goods carried in packaged form. Large quantities of different types of dangerous goods are carried by water around the world in a wide range of packaging types other than the freight containers and other cargo transport units mentioned in the report.

*The Washington State Ferry (WSF)* risk assessment model has been designed to assess and evaluate passenger and crew risks and develop recommendations in the ferry service (Grabowski et al., 2000; Merrick and Dorp, 2001). The model is used to analyse the causes (e.g. propulsion failures, steering failures, navigational and other equipment failures) of accidents (e.g. collisions, groundings, fires, explosions or foundering) that can cause fatalities, injuries, properties and environment damage. All these might not necessarily have been caused by or involved dangerous goods.

*Accident models*: Based on the review of some earlier works in the fields (e.g. Greenwood and Woods, 1919; Hollnagel, 2004; Heinrich, 1931; Benner, 1978; Reason, 1990; Leveson, 2004 and others), Hollnagel et al. (2006) elaborate in detail on different perceptions of accident phenomenon, which they called them accident models. The following is a very brief summary of accident models presented in Hollnagel et al. (2006). Hollnagel et al. (2006, from Benner, 1978) point out that during the process of the accident investigation or study – from preparations through reporting of the findings – numerous difficulties and constraints are encountered. In particular, the difficulties may arise in the identification of the data, the determination of the scope of the study, documentation and presentation of the findings, and the development of recommendations. In the case of risk analysis concerning dangerous goods, these difficulties may be amplified by various factors, including issues related to the amount, diversity, quality, availability and accessibility of the risk-related data, and the estimation, presentation and evaluation of risks. The value and need for accident models have been recognised a long time ago. The accident models vary from the early simple models (single-factor models), which have been proposed in the early 20's century, via simple (e.g. the "Domino" model proposed by Heinrich in 1931) and complex linear causation models (e.g. "Swiss cheese" model proposed by Reason in 1990), to systematic and functional models. The latter model is proposed by Hollnagel himself in 2004. The accident models are differentiated in how accidents are perceived and explained. In the simple linear model, an accident, which is caused by the unsafe act of a person and/or mechanical or physical hazard, is viewed as disturbance inflicted on a stable system. The model explains accidents as the linear propagation of a cause-effect chain. In the complex linear model, an accident is viewed as the outcome of interrelations between real time of unsafe acts of operators and latent conditions in the system, such as weakened barriers and defences represented by the holes in the slice of "cheese". The system accident model, which is probably inspired by the holistic or systems thinking approach, neural network, non-linear or other models or theories conceived and employed in other domains of science, explains accidents as non-linear phenomena emerging in a complex system. According to the latter model, accidents are due to an unexpected combination, concurrence or aggregation of conditions or events. A temporal property emerges when two or more things happen at the same time and thereby affecting each other. (Hollnagel et al., 2006)

The aforementioned accident models concern views and explanations about accidents in general, i.e. not necessarily related to the marine accidents and in particular the accidents involving dangerous goods. The risks and risk analysis/ assessment processes are more than just accidents and explanations of accident phenomena. Furthermore, the experience gained from the analysis of large amounts of marine accidents suggests that certain views are neither applicable in all situations nor entirely correct. Thus, in many cases, marine accidents are certainly attributed to combination of two or more causes (acts, conditions, events, things), but this does not always and necessarily mean that a temporary property emerges when two or more things happen at the same time and thereby affecting each other. In the maritime transport, weather or sea hazards, which are among the main causes of vessel incidents, can directly affect or contribute to technical/ mechanical or operational failures, but in no way the other way around. Further, many marine incidents are not that very complex linear or non-linear phenomena. The statistical incident data show (NRC, 2005) that many incidents are simply attributed to deliberate acts. Thus, approximately 14% of all hazmat incidents (ca. 454,000 incidents) reported to one of the U.S.'s largest database during the period 1990-2004 (NRC, 2005) are unknown releases, including illegal releases.

*The "Novel Risk Assessment Techniques for Maritime Safety Management System"* (Sii et al., 2001b) presents risk assessment techniques as novel methods, consisting of three safety and decision making tools, which can be used to integrate safety into the ship design process at the early concept design stage. The list of significant factors (variables) that have been taken into consideration for assessing the safety and determining the risk level include preventive maintenance policy, degree of machinery redundancy, fire fighting capability, management quality, survey program, navigation equipment level, corrosion control, and crew operation quality. These parameters have little direct relevance to the risks of marine accidents involving PDG.

There are also numbers of models that cover many other different aspects of shipping, for example, the design and construction and classification assessing the risk and the reliability of the system (Farquharson et al., 2002), commissioning and operation (Ruxton, 1996). For example, the Safety Management Assessment System (SMAS) is a screening process developed *specifically for assessing human and organization factors* (HOF) in systems (Heea et al., 1999). The SMAS does this by comparing the system with the characteristics of high reliability organizations (HRO).

Many risk assessment frameworks or models, for example the *"Quantitative Risk Assessment" (QRA)*, are developed and used to assess the risks of transport of dangerous goods by road (Cassini, 1998; Brockhoff, 1992, 1995) and rail (Spadoni et al., 1995), with some model parameters for the estimation of the risks of certain substances, such as chlorine, ammonia, LPG, gasoline and diesel fuel (Brockhoff, 1992). A comprehensive QRA model has recently been developed in Europe for application to risks of road tunnels (Saccomanno and Haastrup, 2002).

*The IMO's Formal Safety Assessment (FSA)* is a methodology for assessing risks related to maritime safety and marine environment protection and for evaluating the costs and benefits of IMO's options for reducing these risks (IMO, 1993, 1997, 2002). The literature review shows that the FSA has been widely used in maritime-related risk studies (see Rao and Raghavan 1996; Trbojevic and Carr, 2000; Lee et al. 2001; Lois et al. 2003). Since its first introduction to the IMO by the UK's representatives in 1993, the FSA has been discussed, reviewed, refined or further developed several times by the IMO's main committees – the Maritime Safety Committee (MSC) and the Marine Environment Protection Committee (MEPC). In 2001, the IMO's Guidelines for the FSA were approved. These guidelines are intended to outline the FSA methodology as a tool that can be used in the IMO rule-making process. The FSA 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; and Step 5 – Recommendations for decision-making.

Figure 1.1 shows the flow chart of the IMO's FSA methodology.

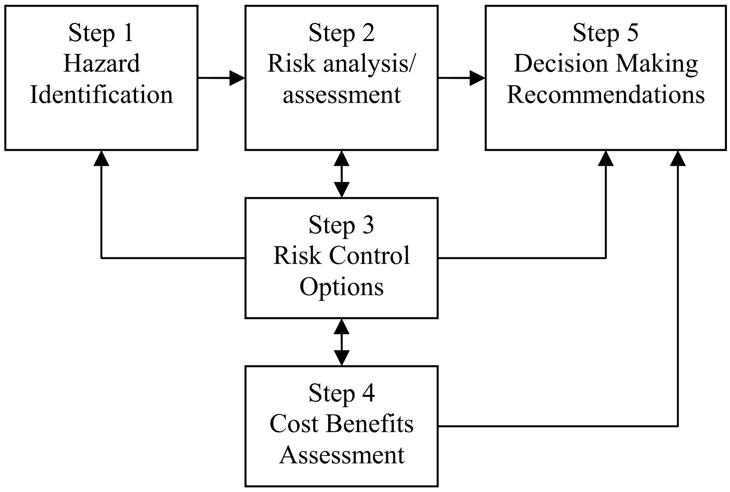


**Figure 1.1: Flow chart of the IMO's FSA methodology (IMO, 2002)**

The FSA is a highly generic framework. However, according to the IMO's Guidelines (IMO, 2002), *the FSA is not intended for application in all circumstances* – "one size does not fit all." A thorough review of the IMO's guidelines (IMO, 2002) also shows that the FSA is not readily applicable to the risk analysis in maritime transport of dangerous goods, including *packaged dangerous goods*. The FSA lacks some essential concepts related to the maritime transport system of dangerous goods and risks associated with it, such as "distribution or transport hazards", "the list and hazards of dangerous goods", "release, dispersion, concentration of dangerous substances", "exposure to dangerous goods hazards", "routes of exposure", "dose-effect relationships", and "categories of risk receptors". Recognising the limitations of the FSA, the IMO has encouraged its states as well as maritime scientific communities to further develop, refine or adapt the FSA for specific maritime-related systems and risk issues. In this context and in response to the specific needs in the industry, in recent years, the FSA has been adapted, applied or tested in several maritime-related systems and issues concerning human safety and health, and the marine environment and property protection. The extensive literature study shows that the FSA has been applied or tested in the following systems: *cruise ships* (Lois et al., 2003), *bulk carrier* (IMO, 2004a) and *hatchway watertight integrity of bulk carriers* (Lee et al., 2001), oil spills (Ventikos and Psaraftis, 2004), *fishing vessel* (Loughran et al., 2002), *offshore industry* (Wang, 2002), *container ships* (Wang and Foinikis, 2001), *ports* (Trbojevic and Carr, 2000) and *ships in general* (Wang, 1999), which are not necessarily related to the risks of maritime transport of PDG. The literature study also suggests that the FSA is not explicitly grounded on the empirical data. In the aforementioned studies, the FSA has simply been applied or tested based on the data, in some cases on the limited data, available at hand. Further, the data are analysed and the results are presented in such ways that they "fit very well" into the FSA.

Numbers of risk management and analysis/assessment frameworks and techniques, including the FSA, are presented in Chapter 3, Vol. I, and Mullai, 2006b.

In summary, although relying on the same principles, no single framework has the capability of serving all essential human safety and health, environmental and property protection as well as security issues and needs in shipping. Despite an extensive search and literature study, no specific risk analysis framework for application in the maritime transport system of PDG has been found. Available frameworks are not readily suitable for application in the risk analysis of the maritime transport system of PDG.

### Risks of maritime transport of PDG

The issues and methodological and management aspects of risks are interlinked. The limitation in the studies of the risks of marine accidents involving PDG is also reflected in the methodology aspects. Numerous studies have been conducted in chemical lifecycle risks. However, despite the increasing concerns, the knowledge in the field of *the risks* of *marine events involving PDG* is still limited. In many countries, in particular in Europe (Goulielmos, 2001; Gade and Redondo, 1999) and North America (LaBelle and Anderson, 1996), the main concerns have been the risks of major accidents involving dangerous bulk cargoes (EEA, 1995), such as oil, oil products, LNG, LPG, and a few chemicals carried in bulk (Romer et al., 1995; Fowler et al., 1995; Konstantinos and Ernestini, 2002), excluding other materials and substances. The accidents involving environmental impacts from oil spills are perceived as the most "relevant risk" (Kirchsteiger, 1999). Further, numerous studies cover individual major and dramatic marine accidents such as Exxon Valdes (Miraglia, 2002; Gilfillan et al., 1999), Braer (Hall et al., 1996), Sea Empress (Batten et al., 1998), and Erika, based on which numerous important international maritime regulations have been introduced or amended. Yet an "implicit" analysis framework in the field is not available.

Depending on their purposes, many quantitative risk studies are confined to a few variables, sometimes to one or two variables only, in which the essential data are discarded. The following are some typical variables that are alone or in combination used in analysis: categories of marine events, types and sizes of ships, types of cargoes (e.g. oil, oil products and chemicals carried in bulk), fatalities and injuries, time, weather conditions, and the location or position of accidents. In some cases, risk studies lack "transparency" and variables are poorly designed, violating even the fundamental principles of categorisation.

### Data sources - marine accident/incident databases

The maritime transport risk-related data are employed for different purposes by different organisations in different countries and regions. The data sources vary from public access, limited access (for example for "members only"), non-accessible to confidential and very confidential. In some parts of the world, the data are of poor quality and insufficient, if they exist at all.

One of the most important data sources is the accident and incident (or casualty) database containing case histories. There are numbers of databases around the world designated for industrial accidents, including those involving dangerous goods at fixed installations and during transportation. They vary in content and structure, for example, the degree of detail, the quality of data, time and place and sector or industry coverage. For the purpose of this study, numbers of marine accident/incident databases have been reviewed, and many of them have been closely studied (see Chapter 5, Vol. I, and Mullai, 2004, 2006a). Some of the most comprehensive databases are found in the USA, European countries (e.g. Sweden, the UK, the Netherlands, Norway, and Germany), Canada and some other OECD countries. Although detailed and well structured, some databases cover marine accidents in general (i.e. all marine-related accidents/incidents), and oil spills in particular, with little or no information about PDG. Despite extensive search, no single designated database available (i.e. databases for the public use) for marine events involving PDG has been found. Numerous private and public databases are specially designed for oil spill events, in particular for major oil spills. Further, many databases contain only the data on "serious" and "very serious" marine accidents or casualties that are associated with (and/or): fatalities, serious injuries, serious/very serious marine environment pollution, and losses or large damage to properties (ships and cargoes).

For the past two decades, the Hazardous Cargo Bulletin (HCB) database has provided monthly marine/inlandwaters accidents/incidents that have occurred around the world, including information about events involving PDG. The specific categories of data provided for these types of events include: technical or shipping names of materials and substances involved, types of packagings involved, types of ships carrying PDG, categories of marine events that are not reported elsewhere, such as, for example, releases of toxic fumes or spills, damage and losses overboard of containers etc., and fatalities and injuries due to dangerous goods hazards. The data are collected from some of the well-known maritime interests, including Lloyd's List, Fairplay, Reuter, the USCG and many others. In combination with other databases and sources of information, this database can be a useful data source for analysis of the risks associated with maritime transport of PDG. But, as in many other databases, the accident/incident description is provided in a narrative or qualitative format, which makes using the data, in particular in a quantitative risk analysis, time consuming and difficult.

## 1.3 Research questions

Given:

- Increasingly large amounts of many different types of PDG carried by water through and into large centres of population;
- Risks and threats that maritime transport of PDG pose to humans, the marine environment and properties;
- Increasing concerns and the attention the issues of the risks of maritime transport of dangerous goods receive;
- Databases and risk-related data and information issues;
- Limitations of knowledge in the field;

It is essentially important and necessary, in the first place, to enhance understanding about these risks and thereby improve safety and health and marine environment protection in maritime transport of PDG. However, prior to this, given a) the specifications of the maritime transport system of PDG and the risks associated with it, and b) the absence of an analysis framework, it is important to develop a framework that can facilitate the risk analysis in maritime transport of PDG. Given the above context, the following overriding research question arises:

> *How to improve the risk analysis process and thereby improve human safety and health, and marine environmental and property protection in maritime transport of PDG?*

## 1.4 Research objectives

This study addresses the above question by attempting to deal with the methodological aspects of risk management. Hence, one of the main research objectives of this study is to:

> *Develop a risk analysis framework for maritime transport of packaged dangerous goods*.

The application of the framework will assist risk analysts and make the risk analysis process more efficient and effective.

It is important to note that, in their common use, the terms “framework” and “model” may be used interchangeably as they share common meanings. In this study, however, *framework* constitutes a broader concept representing the structure (stages and steps) of the overall risk analysis process, i.e. the entire process from *preparations* for analysis through *the analysis process*, *conclusions* and *recommendations*.

In order to demonstrate the application of the risk analysis framework developed in Chapter 5, Vol. I, in practice and to test and thereby enhance its validity and reliability, in Chapters 1-7, Vol. II, the framework is demonstrated step-by-step. The demonstration is based on *other datasets* than those used in the model development, which consist of large amounts of diverse qualitative and quantitative data collected from U.S. sources. Understanding risks concern answers to these fundamental questions: *What has gone or can go wrong? What are the consequences? What is the frequency or likelihood? How often, much/many?* (Kaplan and Garrick, 1981) Hence, another interrelated and equally relevant and important objective of this study is to:

> *Enhance understanding of dangerous goods risks and provide recommendations for improving human safety and health and protection of the marine environment and property.*

## 1.5 Research scope

As implicitly indicated in the background and explicitly stated in the research questions and objectives, this study focuses on the methodological aspects and issues of risks. The systems, risks associated with them, and risk frameworks and techniques employed are interlinked. Figure 1.2 shows the scope of the study graphically.

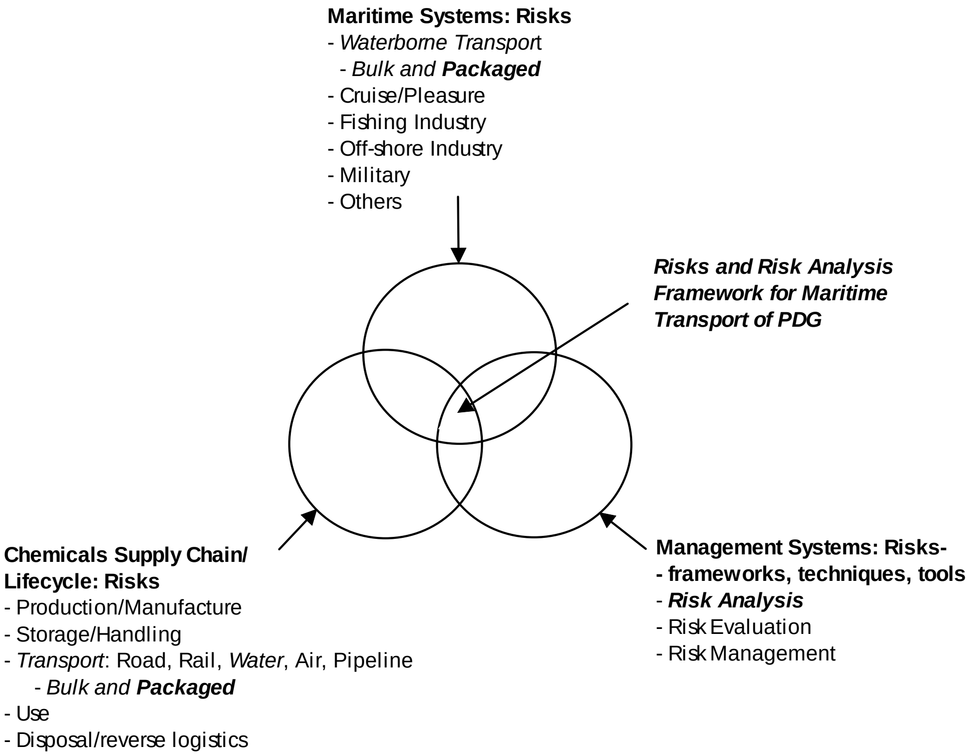


**Figure 1.2: Research scope**

**Risks – dangerous goods risks**: The systems and activities are exposed and pose different types of risks in different forms. In this study, *the dangerous goods risks* posed due to their hazardous properties, such as explosion, fire, corrosion, toxic/poison, infection, radiation, and marine environment pollution are considered. However, in order to test and enhance the external validity of the framework and provide a full validating demonstration, the demonstration is extended to the analysis of the risks in other systems and activities of the dangerous goods supply chain.

**Maritime systems – maritime transport of packaged dangerous goods (PDG):** Many important human activities and systems are connected with the water environment, i.e. seas and navigable inland waters such as rivers, lakes, canals etc. From case histories (HCB, 1986-2003) the following main categories of systems are identified: *maritime transport*, cruise/pleasure, fishing industry, offshore industry (oil/gas rigs or platforms), military activities, and other activities (e.g. research activities, construction works etc), each of which poses different risks to humans, the marine environment and properties. This study mainly focuses on *risks of maritime* *transport of packaged goods*. In many regions and countries, maritime traffic of PDG (directions and amounts and types of PDG) may not be known. The IMO and other organisations have only estimated the share or percentage of this traffic. Many dangerous goods are carried as general cargoes in cargo transport units (CTU). Furthermore, case histories have shown that dangerous goods are, in many cases, not declared and are carried illegally onboard ships, including ro-ro ferries.

With a few exemptions, for example nuclear fuel carrying ships, maritime transport of PDG, unlike bulk transport, is not a separate system in its own right, but is rather an integrated element of the waterborne transport system. Generally, PDG are carried and handled together with other non-dangerous goods (e.g. in general cargo and container ships) and passengers (e.g. ro-ro ferries). However, given the specific properties of the system and risks associated with it, the maritime transport system of PDG is, in many respects, "unique".

**Risk management system – frameworks and techniques:** For many organisations, risk management is an integrated element of the overall management system. The risk management system encompasses three principal interrelated, but distinct, elements, namely risk analysis, risk evaluation and risk management (see Chapter 3, Vol. I, and Mullai, 2006b). They are facilitated by a wide range of specific framework, standards or tools. This study primarily focuses on the development of a *framework* that can facilitate *the risk analysis* process.

In addition to the time and resources available, the framework is also confined by the availability of data. The framework development is based on the empirical data available at hand. However, because of the holistic or systems thinking approach that is generally required in the risk analysis, the framework is developed in such a way that it takes into account interconnections among systems. A clear demarcation of the systems' boundaries may not be possible, as the systems interact and influence each other, as do the risks associated with them. The following are some illustrative examples from marine accident case histories (HCB, 1986-2003):

- *Causes and contributing factors*. Many marine accidents involving PDG are due to inherent problems in other systems and activities, for example, to inherent faults in packaging design and construction. Many accidents, for example collisions, contacts and fires/explosions, are due to interactions with other systems.
- *Consequences*. Consequences of marine accidents involving PDG are not confined to the maritime transport system only.
- *Exposure*. The exposure (e.g. human) estimation is an important element of the risk analysis process. It takes, inter alia, into account populations exposed to dangerous goods hazards that are beyond the maritime transport system of PDG, for example crew and/or passengers of other ships or objects (e.g. oil/gas platforms), stevedores and local communities ashore.

Chapters 1-7, Vol. II, provides a validating demonstration of the risk analysis framework presented in Chapter 5, Vol. I. The research scope of the validation demonstration is defined in Chapter 1, Vol. II.

## 1.6 Outline of thesis

This thesis consists of two volumes that consist of seven chapters each. The following is an outline of the thesis.

## Volume I

**Chapter 1: Introduction**
This chapter provides the context of the issues related to the maritime transport system of packaged dangerous goods. Then, the problem areas are explored and described. The literature review of the "state-of-the-art" knowledge in the field explores the relevance, importance and the need for this study. The research questions are formulated and the research objectives are set. The scope of the study is then defined. Finally, an outline of thesis and a list of groups of people who might be interested in the study are provided at the end of the chapter.

**Chapter 2: Methodology**
The chapter begins with a discussion of important aspects of paradigms and basic beliefs and assumptions guiding the scientific research. Then, the discussion continues with the research strategies, research design and processes, types of data, data sources, and data collection and analysis methods employed. The process of developing the framework is described in some details. A discussion on validity and reliability of the research results is provided at the end of this chapter.

**Chapter 3: The Frame of Reference – a summary**
The purpose of this chapter is to provide a summary of the theoretical platform for the development of the risk analysis framework. In this chapter, relevant constituent concepts, definitions and theoretical models in the essential interrelated research areas are defined and described, including the maritime transport system of PDG, the dangerous goods risks, the risk management system including risk management and analysis/ assessment frameworks and techniques. The Frame of Reference is further expanded in Mullai, 2006a, 2006b.

**Frame of Reference – the detailed version**
A detailed version of the Frame of Reference presented in Chapter 3, Vol. I, can be found in two research reports (Mullai, 2006a, 2006b), which have been part of and published in the publication series of a European project – DaGoB (Safe and Reliable Transport Chains of Dangerous Goods in the Baltic Sea Region) project. The following provides the outline of both publications.

**Publication 1:** Mullai A (2006a) *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.

This publication consists of the following chapters.

**Chapter 1: Introduction**
This chapter contains an introduction, purposes, materials and methods, and the outline of the report.

**Chapter 2: Maritime transport system of packaged dangerous goods (PDG)**
In this chapter the main components of the maritime transport system are defined and described, including objects of transport, means of transport, transport related activities, transport infrastructure and facilities, actors, information systems and dangerous goods traffic. The regulatory system governing maritime transport of PDG is also described. This chapter focuses on the technical and operational aspects of the maritime transport. It is mainly organised based on the transport model provided in this chapter and the IMDG Code.

**Chapter 3: Risks of dangerous goods**
This chapter provides terms, definitions and concepts related to the main risk elements. It begins with the description of different types of risks, risk elements and how they are related to the concept of risks. Then, definitions and concepts of risks associated with transport of dangerous goods are provided.

**Chapter 4: Concluding remarks**
This chapter provides some concluding remarks, recommendations, and future research areas and questions concerning the maritime transport system and risk issues.

**Publication 2:** Mullai A (2006b) *Risk Management System (RMS) – Risk Assessment Frameworks and Techniques*. Safe and Reliable Transport Chains of Dangerous Goods in the Baltic Sea Region (DaGoB) Project Publication Series 5:2006, Turku School of Economics, Logistics, Turku, Finland.

This publication consists of the following chapters.

**Chapter 1: Introduction**
This chapter contains an introduction, purposes, materials and methods, and the outline of the report.

**Chapter 2: Risk Management System (RMS)**
In this chapter attempts have been made to provide a unified understanding in 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 extensive literature study and understanding gained in this research, a conceptual model of the risk management system is presented. The rest of the chapter defines and describes the main elements of the model.

**Chapter 3: Risk assessment frameworks and techniques**
This chapter reviews and evaluates some risk analysis, assessment and management frameworks, techniques and practices in the shipping and other industries and sectors across different countries, mainly in some OECD countries, such as Europe and North America, which are relevant to the field of human safety and health and environmental and property protection.

**Chapter 4: Concluding remarks**
This chapter provides some concluding remarks, recommendations, and future research areas and questions concerning the risk management system including risk analysis/ assessment and management aspects.

**Chapter 4: Analysis of marine accident case histories**
Based on the data analysis methods described in Chapter 2, Vol. I, marine accident case histories are analysed. This chapter presents some illustrative examples. Both understanding gained and information generated in analysis have served the development of the framework.

**Chapter 5: A risk analysis framework for maritime transport of PDG**
This chapter presents a risk analysis framework developed for readily application in the maritime transport system of PDG as well as other systems of the dangerous goods supply chain. The framework consists of the main stages, and each stage consists of a number of steps and sub-steps for planning and performing the risk analysis in the field. For the purpose of analysis, the principles of two analysis techniques, namely backward and forward logic analysis, which are employed in the Fault Tree (FTA) and Event Tree (ETA) Analysis techniques, are adopted and integrated into the framework. A summarised version of this chapter is published in the following:

Mullai A (2004) *A Risk Analysis Framework for Maritime Transport of Packaged Dangerous Goods*. In Brindley, C (2004) Supply Chain Risk. Ashgate Publishing Company, UK, Chapter 9, pp. 130-159.

**Chapter 6: Reflections on the risk analysis framework demonstration**
In this chapter some reflections on the demonstration process of the risk analysis framework presented in Chapter 5, Vol. I, are provided. The chapter discusses some issues concerning the application of the framework.

**Chapter 7: Conclusions and recommendations**
This chapter provides concluding remarks about the research work, recommendations for improving the risk methodology and human safety and health and protection of the environment and property, contributions of this study to practitioners and academics alike, and suggests areas for future researches.

## Volume II

In Chapters 1-7, Vol. II, based on the combination of a large amount of qualitative and quantitative data and various data analysis methods, the risk analysis framework is demonstrated step-by-step in practice. The validating demonstration combines risk analysis of a representative marine accident case history (i.e. the m/v "Santa Clara I" accident case), which is known in the U.S. and the world's maritime community, as well as other cases, and a diversity of statistical datasets collected from U.S. data sources. Statistical data include two very large incident datasets. They were obtained by merging incident records of two of the largest hazardous materials (hazmat) incidents databases in the U.S. These datasets consist of a very large number of variables representing the system and risk elements, and spanning the period 1990-2004. These databases are: a) the U.S. Hazardous Material Information System (HMIS) database containing ca. 186,000 incident cases and covering the period 1993-2004; and b) the U.S. National Response Center (NRC) database containing ca. 454,000 incident cases and covering the period 1990-2004.

## 1.7 Readership - target groups

This thesis covers numbers of interrelated research areas concerning risk methodology, risks and the maritime transport system. The target groups, to whom this study intends to contribute, include the wide range of relevant individuals, groups, institutions, organisations and authorities from both academics and practitioners' communities, including:

- Local, national, regional and international organisations, authorities or agencies concerned with dangerous goods products and the dangerous goods-related systems and activities and safety, health and environment and property protection and security, including:
  - Policy or decision makers and enforcement agencies
  - Maritime organisations and authorities
  - Human safety and health authorities/commissions
  - Organisations and authorities involved or concerned with production/ manufacturing, storage, packing, handling, procurement, transport, use of dangerous goods
  - Organisations and authorities responsible for crises and security management
  - Boards of the accident investigation
  - Coast Guards
  - Search, rescue and response teams or agencies
  - Police authorities and inspectors
  - Port and customs service authorities
- Shipping and cargo interests, including:
  - Shipping companies
    - Shipowners
    - Ship management companies
    - Ship operators
  - Shippers, consignors, consignees
  - Designers and constructors of ships, other means of transport, containers and other packages
  - Marine (ship and cargo) insurer, P&I clubs
  - Class societies
  - Others

    - Port/terminal operators
    - Cargo handling companies, stevedores
    - Third party logistics
    - Freight forwarders
- Scientific communities, including:
  - Research and educational institutions, universities
    - Marine/maritime systems, engineering, technology, management
    - Fire safety engineering
    - Ecosystem, ecology, marine environment
  - Centres/institutions for maritime studies, including maritime transport, risks, safety, health, the marine environment protection.

# 2. Methodology

*This chapter discusses the research strategies, research design and processes, types of data, data sources, and data collection and analysis methods employed. Then, the process of framework development is described. A discussion on validity and reliability of the research results is provided at the end of this chapter, which begins with a discussion of the important aspects of paradigms and basic beliefs and assumptions guiding scientific research.*

## 2.1. Paradigms

Here the discussion focuses on the philosophy of science in an attempt to relate central concepts to the area covered in this study.

> *Paradigm issues are crucial; no inquiry ought to go about the business of inquiry without being clear about just what paradigms inform and guide his or her approach.* (Denzin and Lincoln, 1994, p. 117)

### 2.1.1. The concept of paradigm

Scientific research is a strenuous and devoted attempt to force nature into conceptual boxes supplied by professional education (Kuhn, 1970). Scientific research differs from other non-scientific inquiries because it a) *has the goal* (aim or objective) to *increase knowledge*, *answer questions* and *solve problems*, and b) is a *logical, rigorous and controlled process* (Ackoff et al., 1968).

One of the characteristics that clearly identify a field as a science is that scientific studies are guided by paradigms. The term *paradigm* derives from Late Latin *paradigma,* from Greek *paradeigma,* from *paradeiknynai* to show side by side, to compare, from *para-* + *deiknynai* to show (AHD, 2000; MWD, 2004). The term appeared for the first time in English in the 15th century, meaning "*an example or pattern*," and still maintains similar meaning (AHD, 2000). The term *paradigm* was used for the first time in the scientific community in the 1960s, when Nobel Laureate David Baltimore cited the work of his colleagues and, since then, *paradigm* is used in science to denote a *theoretical framework* (AHD, 2000). However, Thomas Kuhn is largely credited with the modern use and further development of this concept. Kuhn (1970, p. 10) refers to "paradigm" as a term that relates closely to "normal science", suggesting that it consists of:

> *Some accepted examples of scientific practices, including law, theory, application and instrumentation, that provide models from which spring particular coherent traditions of scientific research* Kuhn (1970, p. 10).

Denzin and Lincoln (1994, p. 99) define the term paradigm as:

> *A basic set of beliefs that guide action. Paradigm deals with first principles, or ultimate. They are human constructions. They define the world-view of the researcher.*

The concept of paradigm has been discussed by Kuhn in his work "*The Structure of Scientific Revolution*" (Kuhn, 1970). The following section is a reflection on paradigms based on Kuhn's work. Paradigms are essentially important to scientific inquiries as they supply, inter alia, a wide range of concepts, assumptions, theories, frameworks, models, and methodological instruments. Paradigms can assist scientists in many different ways, from problem identification and formulation through research strategy selection, data collection and problem solving. When individual scientists can take paradigms for granted, they may no longer need to attempt to build their field anew, starting from first principles and justifying each and every concept introduced (Kuhn, 1970). Paradigms are also essentially important in forming the foundations for the professional education of students who want to become members of a particular scientific community.

However, according to Kuhn (1970), paradigms, in particular in paradigm-based or normal scientific research, are also associated with a number of arguably interrelated shortcomings, including:

- Attempts to force nature into an inflexible box provided by paradigms, rather than reflect the reality objectively;
- Lack of efforts to study new phenomena, develop new theories, discover new things or anomalies, and lack of tolerance for those who try;
- When new or unknown research results or anomalies appear that may challenge or even threaten existing theories, there may be a tendency to discard them or bring the research results and the accepted theory into closer agreement;
- Given the power of suggestion, an existing theory or hypothesis may be a recipe for contamination of the research results;
- Lack of objectivity and independent thinking; conservative individuals may accept without question a particular problem solution taught or dictated by theory; science students may accept theories on the authority of a text;
- Due to tunnel-vision or one-track-mindedness, new things or anomalies may not be noticed;
- Commitments, sometimes amounting to indoctrination (mind set), to the preferred theory or methodology – theoretically or methodologically biased.

With reference to the contents of this thesis – concepts, theories, methods, techniques, models – paradigms have played an important role in this research. But, at the same time, every effort has been made to avoid their shortcomings, for example by combining the following:

- Becoming familiar with a wide range of theories and research methodologies;
- Understanding the history of early and contemporary science;

- Relying on the empirical data and employing "let the data talk" and "grounded theory" approaches; and
- Adopting critical thinking.

### 2.1.2. Basic beliefs

Basic beliefs or assumptions are constituent elements of paradigms, representing a world view that defines, for its holder, the nature of the "world", the individual's place in it, and the range of possible relationships to that world and its parts (Denzin and Lincoln, 1994). The basic beliefs concern three fundamental questions (Denzin and Lincoln, 1994): *Ontology* (metaphysics) *questions*: What is the form and nature of reality and what is there that can be known about it? *Epistemology questions:* What is the nature of the relationship between the knower or would-be knower and what can be known? *Methodology questions:* How can the inquirer (would-be knower) go about finding out whatever he or she believes can be known?

Throughout history, many domains of science have been committed to sets of beliefs that, in turn, have defined inquiry paradigms. Proponents of each paradigm, somehow, share a common set of basic beliefs and assumptions. Based on their answers and basic beliefs to the three fundamental questions stated above, Guba and Lincoln (Denzin and Lincoln, 1994) have analysed and presented four classes of inquiry paradigms in the social sciences, which are positivism, post positivism, critical theory, and constructivism. Basic beliefs vary on a scale from realism to relativism (ontology), from objectivism to subjectivism (epistemology), and from nomothetic to idiographic[8] (methodology). These beliefs guide, but at the same time constrain, the research work (Denzin and Lincoln, 1994). Science is characterised by confrontations among proponents of these beliefs.

In the course of this and previous formal studies and research and professional experiences, I have acquired a set of paradigms and beliefs that have guided this research work. My personal position regarding the fundamental questions, which have either consciously or unconsciously affected this research work, is influenced by: a) exposure to various research methodologies, including both qualitative and quantitative methods, transport and risk management practices and theories, and the wide range of specific risk analysis/ assessment techniques and tools; b) research work experience in the field of the risks of maritime transport of dangerous goods; c) educational and professional experiences and personal beliefs. Some key aspects of this position are briefly summarised below.

I believe that *reality exists* independently of human awareness. The risks of the transport of dangerous goods are for real. Many people are killed or injured due to accidental releases of dangerous goods. However, I am aware of human nature – of our biology and behaviour (body and mind). The perceptions of dangerous goods risks are

[8] Psychology: idiographic: of or relating to the study of individuals, compare to nomothetic: of or relating to the search for general laws or traits (CED - Collins English Dictionary, 1992; AHD - American Heritage Dictionary, 2000).

multidimensional, involving people's beliefs, attitudes, judgments, feelings, and social and cultural values and dispositions. They are essential elements of human behaviour towards the risks, which are, in many cases, taken into account in risk analyses and evaluations. Further, decision-making is often based on the social dimensions of the risks.

Based on the nature of data, data collection and analysis methods and fundamental assumptions employed, studies are divided into qualitative and quantitative, each of which numbers its proponents. Sometimes people draw a clear and hard distinction between qualitative-quantitative domains, leading to polarized academic debates. The proponents of each camp argue the superiority of their kind of data and methods over the other. In my view, one domain has no superiority over the other. Quantitative data can be based on qualitative judgments. On the other hand, qualitative data can be represented and manipulated numerically. At some levels, quantitative and qualitative data are inseparable and interchangeable. The history of science shows that, alone, neither type of research has the capacity to deal with all kinds of issues. In many situations, qualitative and quantitative researches are combined to deal with a wide range of research questions. Both types of research are often used for confirmatory/ deductive and exploratory/inductive purposes alike. Furthermore, both types of studies have produced remarkable results.

Man acquires *knowledge* through sense perception (empiricists) and reasoning (rationalists). A posterior knowledge is gained by reference to the facts of experience, i.e. the *empiricist method* of inquiry, whereas a priori knowledge is the knowledge that has derived from reasoning alone, i.e. the *rationalistic method* of inquiry. I agree with the view that man may acquire knowledge by either one or a combination of the mentioned methods of inquiry. Reasoning is an essential element of scientific research. The history of science shows that many well-known scientific works, theories, methodologies, inventions, ideas and many more, including Kuhn's (1970) and Yin's (1994) works, which have eventually no empirical data, are solely based on the combination of reasoning and accumulated (one's own and other's) past experiences. Many risk analysis frameworks, techniques and tools are developed and improved based on the accumulated experiences of many generations. Further, numerous risk analysis techniques are specially designed with experts' judgments in mind. However, I think that a blank brain (mind) cannot reason in a scientific manner.

Because of potential contaminations and errors in observations and interpretations, inter alia, by theories, methodologies (including frameworks and techniques), beliefs, assumptions, or past experiences, many knowledge claims and theories are tentative. They have been subject to revisions, modifications or improvements on the ground of new evidence, assumptions, or methods. In a wide range of areas, science cannot guarantee one hundred percent certainty all the time in everything. Yet, the scientific approach is the most, if not the only, objective mode of pursuing knowledge (Hunt, 1991). Over the years, as the review of accident case histories and many studies has shown, our knowledge about the risks of dangerous goods has gradually been improved. It has become more reliable and objective. This is partly attributed to the improvements of risk/accident methodologies and the expansion of the data.

The purposes and products of sciences are not solely confined to the development of laws, theories, frameworks, or models to explain, predict and control phenomena, as some may argue or understand. Science deals with everything that concerns humanity, the surrounding environment and their interactions. Scientific enterprises do not only concern "grand theories", models, frameworks, or "rocket science." The following list of key words is explored through the literature study. It is not exhaustive and includes some synonyms. The list that characterises the diversity of the purposes and products of science includes:

- *Purposes of science* including (to): understand, develop, discover, design, invent, create, adopt, adjust, modify, refine, improve, enhance, solve, answer, help, explain, explore, interpret, identify, analyse, evaluate, clarify, predict, generalize, describe, organise, classify, structure, make, recommend, fill gap/hole, bridge, turn unknown into known etc.
- *Products of science – the body of scientific knowledge,* including: knowledge, understanding and information, answers to questions, statements, generalizations, concepts, theories, hypotheses, laws, rules, regulations, frameworks, models, techniques, tools, instruments, procedures, guidelines, ideas, hardware, software, inventions, creations etc.

The review of many scientific publications shows that many research questions and objectives are, to some extent, formulated based on the combination of the above categories of key words (purpose/product). The body of scientific knowledge, which may be considered as the broadest concept of the products of science, is the product of a collective human enterprise for generations in which individual scientists make individual contributions that are further improved and extended by mutual criticism and cooperation.

## 2.2. Systems thinking

The subject of the study can be approached in different ways. Based on the views and basic assumptions of reality (i.e. the way of thinking), research approaches are divided into three main categories *actor*, *analytical* and *system approaches* (Arbnor and Bjerke, 1994). Risk analysis, in particular a thorough and detailed analysis, takes, in practice, a *holistic* or *systems thinking approach*.

Holism (from the Greek word *holos*, which means *whole*) is a theory that states the universe is correctly seen in terms of interacting wholes that are more than the mere sum of elementary particles (MWD, 2004). Holism is concerned with wholes or with complete systems rather than with the analysis of parts (MWD, 2004). Holism and systems thinking share common meanings. The systems approach is based on the systems thinking theory or paradigm. Systems thinking was first introduced in the mid-20$^{th}$ century. Since then, the concept of paradigms has been expanded, adapted and widely applied in many fields of science and education (e.g. Richardson, 1991; Forrester, 1990; Senge, 1992; Senge et al., 1994).

A system is defined as a regularly interacting or interdependent group of items forming a unified whole (MWD, 2004; EB, 2004). Systems may be part of a system hierarchy. For example, the maritime transport system of PDG can be viewed as an integrated subsystem of the overall transport system (i.e. road, rail, air, water and pipeline). The transport system is considered a system incorporated into a larger system, which is the chemical or dangerous goods supply chain. There are many different types of systems, such as humans and human activities, technological and natural systems. They are described and presented in different forms, such as graphical models, mathematical models, words or language.

Systems thinking proponents view a system and its surrounding environment as a complex entity of interrelating and interdependent parts. Systems thinking emphasises the relationships and the processes that make up the system context, rather than the separate entities or the sum of the parts (Cummings, 1980). This is a way of thinking where the dominance of the whole is recognised. Whereas the analytical approach, which is based on linear and mechanistic thinking – linear causation - involves breaking a problem into components, studying each part in isolation, and then drawing conclusions about the whole. According to systems thinkers, linear thinking has become ineffective to address modern problems (Kofman and Senge, 1993), because current issues are interrelated in ways that challenge linear causation. Proponents of systems thinking or non-linear and organic thinking advocate circular causation, where one variable may be both the cause and effect of another. With reference to the history of science, this is not entirely a new concept. Cause-and-effect relationships have been discussed long before by earlier philosophers of science.

Due to the very nature of the maritime transport system of PDG and its surrounding environment and the risks associated with it, it was considered important to adopt a systems approach in this study. The system is characterised by dynamics, complexity and large numbers of interacting elements. This approach is also motivated by the fact that decision-making in this area is generally costly. In order for the decision makers to evaluate the risks involved, identify a better course of action and make a better decision, it is important, in the first place, to have highly accurate, reliable and comprehensive information. They also need to know about the problems and consequences of system outcomes that lie beyond the maritime transport system. This can be achieved, among other things, by means of methodological tools that are designed with these needs in mind and employ a system analysis thinking perspective.

## 2.3. Research strategy

The strategy is a plan of actions intended to accomplish a specific goal (AHD, 2000). Denzin and Lincoln define the research strategy as follow (1994, p. 202):

> *The strategy of inquiry comprises the skills, assumptions and practices used by the researcher when moving from a paradigm and research design to collection and analysis of data. Strategies of inquiry connect researchers to specific approaches and methods for collecting and analyzing empirical materials.*

A strategy may combine more than one method, technique or tool. For example, the case study is a research strategy that relies on the combinations of several data collection methods and techniques, such as interviews, observations and documents. By definition, a single method or technique (e.g. participant observation – according to Denzin and Lincoln, 1994, pp. 199-207) may also constitute a strategy in its own right, i.e. it has a plan of action to answer the research question and achieve the objective. The terms such as research "strategy", "method" or "approach" are often used interchangeably.

There is a wide range of research strategies available. Each strategy, somehow, offers a particular perspective of the reality. Some qualitative strategies are specially designed and suited for a particular situation. Researchers are often confronted with the questions of *what*, *when* and *why* to use research strategies. According to Yin (1994), each research strategy has particular advantages and disadvantages, depending upon three conditions: (a) the type of *research question* posed; (b) the extent of *control an investigator has over actual behavioural events* and; (c) *the degree of focus* on contemporary as opposed to historical events. Table 2.1 shows how each of these conditions is related to research strategies.

**Table 2.1: Relevant situations for different research strategies (Yin, 1994, p. 6)**

| Strategy | Form of research question | Requires control over behavioural events? | Focus on contemporary event? |
|---|---|---|---|
| Experiment | How, why | Yes | Yes |
| Survey | Who, what, where, how many, how much | No | Yes |
| Archival analysis | Who, what, where, how many, how much | No | Yes/No |
| History | How, why | No | No |
| Case study | How, why | No | Yes |

According to Yin (1994), one important condition for differentiating among the various research strategies is to identify the type of research question being asked. The "what" question may be either exploratory or explanatory, in which analysis of archival records and survey would be favourable. The "how" and "why" questions are more likely to favour histories, experiments and case study. Based on conditions set in Table 2.1, the determining conditions for this research consist of:

(a) The type of *research question* posed: The question of the risk analysis framework is intrinsically linked to the questions answered by risk analysis, which encompasses the whole range of questions.
(b) The extent of *control an investigator has over actual behavioural events*: I do not have control over the events.
(c) The *degree of focus* on contemporary as opposed to historical events: In many situations, it may become difficult to determine precisely what contemporary or historical events are. Risk analyses deal with the past and present and anticipate the future.

Based on the above evaluation, the *case history*[9] is the most likely favourable research strategy for this study. There is no precise definition of what may constitute a "case history." In its common use, the term may share similar meanings with terms such as "history" and "archival documents", as described by Yin (see Table 2.1). From the context of many risk/accident studies in the field (DNV, 1995, 1996; Carol et al., 2001; Brigitte and Carsten, 1997), it is understood that the "case history" consists of different forms of accounts or records of marine accidents and incidents. One case history describes one event in which one or more ships/objects have been involved.

According to Yin (1994), the goal, that is the goal of taking into account the above conditions when determining the research approach, is to avoid gross misfits, that is when one is planning to use one type of strategy but another is really more advantageous. But the above conditions (see Table 2.1), which have no empirical grounds but are rather based on Yin's personal judgements only, are neither exhaustive nor cover all situations. According to Yin (1994), each strategy can be used for all three purposes, namely exploratory, explanatory, or descriptive, which have large areas of overlapping. The questions are only "the more likely to favour" (i.e. be very wide and less specific), which may be far from specific conditions in specific research areas. A question may take various forms that can be equally justifiable rationales for selecting alternative strategies or more than one strategy. The "who", "where", "how many or much" questions may also, as much as the mentioned questions, favour the experiment, history or case study strategy. For example, experiments or tests are performed to determine the risk receptors "who"' are exposed to toxic substances and "where." The question "where" can justify both exploratory and explanatory studies. For example, one important question in the risk analysis is: "Where did the accident

[9] Yin does not provide a clear definition of "history" strategy and "archival documents" strategy. Nor does he describe similarities and differences between these two strategies. However, I assume that Yin adopts a similar dictionary meaning of the term "archive". According to the Collins English Dictionary (1992), the term "archive" means: (noun) a collection of records; a place where such records are kept; (verb) to store (documents, data, etc.) in an archive. Archive: from Late Latin arch"vum, from Greek arkhžion repository of official records, from arkhe government. Case histories are accident/incident accounts or records stored in a database (i.e. an archive). By definition, the case history may be considered as a research strategy in its own right.

happen?” This question is, at the same time, exploratory (i.e. to explore the locations of the accidents), and explanatory (i.e. to explain the reasons why certain accidents happen more frequently in some places than in others). Similarly, depending on formulation, a “what” question can justify both exploratory and explanatory studies, for example: “What has happened?” and “What are the causes of accidents?”

In addition, Yin’s list of research strategies, which is confined to only five strategies, is not exhaustive. Denzin and Lincoln’s list consists of these types of qualitative research strategies (Denzin and Lincoln, 1994): phenomenology, ethnology, grounded theory, ethnomethodology/ ethnoscience, discourse analysis, participant observation, and qualitative ethnology.

Yin’s determining conditions (see Table 2.1) are not the only ones determining the research strategy. Many other important interrelated factors, some of them beyond the researcher’s control, can affect the choices in the research strategy. Apart from the question and purpose, the research strategy is also determined by the skills of the researcher and resources available (Denzin and Lincoln, 1994). The following are some illustrative examples in the field, some of which are the conditions determining the research strategy for this study.

***Resources and time available***: In almost every financed risk project a certain amount of resources and time is allocated. The breadth and depth of the study, subsequently data collection methods, are *constrained by the resources and time*. The costs of the project results may outweigh their benefits. For example, because of the costs involved, the chemical industry has often been reluctant to conduct risk assessments for many chemicals. The most advanced risk management models or tools are produced in the developed countries, in particular, in the countries with the highest GDP per capita and R&D funds.

***Data availability and accessibility***: In particular, studies in the field of dangerous goods risks are constrained by data availability and accessibility. The *risk-related data are not always available for public use*. One of the cases collected for this study is marked: “*For your study and for personal use only*.” The literature study showed that many risk studies have been confined to the data available at hand, and consequently confined to those research strategies that are suited for this type of data. A large amount of data and information for this study is collected from *public sources*.

***Research area or topic specifications***: Although large risk studies may combine a wide range of data and methodologies, risks of dangerous goods is a specific area in which certain types of data, data sources and data collection and analysis methods are more preferable than others. The literature review shows that the vast majority of risk/accident studies have relied heavily on the *case histories* collected from *marine accident/incident databases* (e.g. Haastrup and Brockhoff, 1991; Facchini and Brockhoff, 1992; Romer et al., 1995; Christou, 1999; Konstantinos and Ernestini, 2002). Other sources also confirm that risk studies based on historical data, which is one of the most frequent types of data used, are generally preferred (DNV, 1995; Carol et al., 2001). The case history has become one of the prevailing forms for representing accident knowledge (Brigitte and Carsten, 1997). Therefore, it is important to reflect and, subsequently, rely, in the first place, on *the case history* in framework development. In a few cases (one or two cases), according to the literature review, the study also used the *questionnaire method*. In one case, a questionnaire was sent to some countries to state the number of fatalities and injuries in ships flying their own national flag. The study faced problems and its results became doubtful, as many respondents from some regions had either not responded or understated the numbers. Besides, due to the size and diversity of the data, questionnaire and interview methods have to rely on the data recorded in the databases. Direct investigations of maritime accidents – e.g. by *observations*, *interviews*, *documents* and *artefacts* – are impossible tasks for individuals and large teams of researchers alike. Some of the reasons include:[10]

- In every country, investigations are conducted by authorised and legally vested teams of experts;
- In many countries investigations are closed to the public;
- Investigations are resource and time intensive enterprises – a single investigation requires large amounts of resources and takes several years.

In Sweden, the data on marine events involving Swedish ships is gathered from one or a combination of the following: a) the protocol of the maritime declaration; b) the master's reports; and c) the investigations undertaken by surveyors, the coast guard, and the police (SMA, 2002). However, in order to collect data and have insights into the maritime transport system's components and some related issues, the *field study* (*observations*, *interviews* and *documentation*) and other strategies are also applicable.

***The skills of the researcher***: Risk analyses vary from simple analysis employing qualitative approaches usually based on one or a few cases and, sometimes, based on experts' judgements only, to thorough and highly complicated quantitative analysis making use of vast amounts of different types of data and employing sophisticated risk techniques and tools. The researcher's choices are constrained by his/her best abilities – what he/she can and cannot do. It is not necessary that every researcher be a statistician. Australia's Dangerous Goods Safety Management (DGSM) Regulation (sections 17 and 18) specifies the competences (e.g. education, formal training, and expertise) required to perform risk assessment at different levels and activities (DGSM Act, 2001). In order to develop a risk analysis framework for maritime transport of PDG, adequate expertise on risk analysis techniques and procedures was required. Therefore, many risk analysis/assessment frameworks developed and employed in shipping and other industries and sectors have been reviewed.

***Legal requirements***: For example, in the USA (OECD, 2004) there are specific *legal requirements* to employ quantitative risk analysis techniques (known as QRA) in the analysis of dangerous goods transport risks or to measure and express the risks based on exposure estimations. These requirements call for collection of large amounts of

[10] Some facts are extracted from: IMO (1997), Databases and accident investigations in the EU, "The state-of-the-art" document, pp 1-20.

different types of data, and, therefore, for those research strategies that are accordingly suitable including *case histories*. In addition, maritime transport of dangerous goods is a highly regulated activity. The legal requirements are reflected in the development of the risk analysis framework. Many legal documents, for example rules, regulations, conventions, codes of practices, guidelines etc., are collected through libraries and Internet sources and examined.

***Needs and requirements of the decision-makers or the project's financiers***: In some countries, due to the risks posed by dangerous goods, large amounts of resources are invested, inter alia, with the purpose to develop comprehensive risk analysis tools. Some of the most advanced risk management tools are developed in the USA, and funded by governmental agencies, including those funded by the Superfund (30 billion U.S. $). Many of these tools are developed to meet governmental agencies' needs and requirements. Through libraries and the Internet, many documents concerning dangerous goods transport policies, decision-making, public hearing proceedings and many more have been collected and examined.

### 2.3.1. Field and library study

Based on their specific data collection and analysis techniques and procedures, studies are also divided into *field* and *library* studies. They may be considered research strategies in their own right. Glaser and Strauss (1967) discuss at some length the characteristics of these types of studies. The library study is viewed as potentially valuable as field study, observations and interviews. Through library study the researcher can extend the range of data with relatively lesser expenditure of time, money and effort. But, according to the authors, this requires some imagination, ingenuity, and above all more appreciation for these types of materials.

Field and library studies share similarities, but, at the same time, they have differences. The number of representatives of materials, for example books or magazines, is, to some extent, equal with observers, informants or interviewees. One of the procedures in the field is to select a key location where the researcher can station him/herself for observation. In the library, however, one has to go to those shelves where he/she can find relevant data. One problem concerning both field and library researcher is to figure out whom to talk with. The only exception is that the library researcher finds his/her way in a short distance, to the library. Both kinds of researchers hear/read what different representatives say in different occasions and times. Glaser and Strauss (1967) have identified some of the most typical advantages of library study, which are: a) accessibility in terms of spatial obstacles; b) willingness to render information and data required; c) the possibility to return again to the original source of data; d) library materials offer a wide range of comparison groups, but this requires researcher ability to discover and maximize these groups; and e) comparatively greater depths of the materials.

According to Glaser and Strauss (1967), the main issue is not which study has more advantages than the other, but the need for assessing realistically which may be best used alone or in combination in a particular situation. They describe three parallel tactics that can be very useful in field and library study: a) follow certain sequences of relevant events; b) explore and collect different information from different positions about the same subject; c) track down the meaning of key words noticed from the people that are using them constantly.

### 2.3.2. Multi-modal or hybrid strategy

There are no strict rules about when to use more than one strategy, as in many situations more than one strategy are equally attractive to the study (Yin, 1994, p. 9). Many argue that good research results can be achieved by applying, when possible, a multiple/multi-modal or hybrid strategy. There is a methodological pluralism tendency that views science more as an activity of interrelated enterprises than as a single activity defined by scientific methods (Little, 1991). The reasons behind this tendency include:

- Disciplinary boundaries in science are blurring (Denzin and Lincoln, 1994);
- Although research areas are becoming more and more related, each area has its own distinctions that require distinct models and theories (Little, 1991), yet they can be complementary (Denzin and Lincoln, 1994);
- Research strategies have their advantages and disadvantages. When using more than one strategy, one can "eliminate" the weaknesses of one strategy with the strengths of the other. Other advantages of the hybrid strategy include the ability to extend and/or fill gaps in the data and data and methodological triangulations.

In summary, a research strategy incorporating various methods is likely to enhance quality of the research results.

Risk projects are multidisciplinary studies that combine many different methods, tools and expertise. For example, the Sundrisk project, which incorporated different partial projects on the maritime risks in the Öresund region (Sweden), is carried out within the settings of Lund University (Sweden) Centre for Risk Analysis and Management (LUCRAM). LUCRAM (2004) brings together a wide range of competences from different departments/faculties, including industrial management and engineering logistics, industrial electrical engineering and automation, mathematical statistics, communication systems, fire safety engineering, psychology, sociology, social and economic geography, and ergonomics and aerosol technology.

Given the research objective and interrelated areas of the study (see Chapter 1, Vol. I) and determining conditions described above, such as data accessibility and availability, resources and time available, research area specifications, and advantages of the hybrid strategy, this study combines the research strategies (methods and techniques) shown in Figure 2.1.

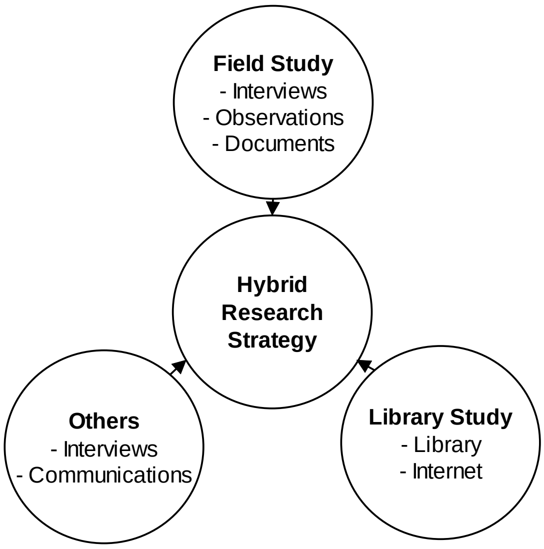


**Figure 2.1: Research strategies - methods and techniques**

The following section discusses the research design and process.

## 2.4. Research design and processes

Yin (1994, p. 19) describes research design as follows:

> *The research design is a logical sequence that connects the data to a study's initial research question and, ultimately, to its conclusions. It is an action plan for getting from here to there, where here may be the initial set of questions and there is the set of conclusions (answers) about these questions. Between "here" and "there" may be found a number of major steps, including the collection and analysis of relevant data.*
>
> *Another way of thinking about a research strategy is a "blueprint" of research, dealing with at least four problems: what questions to study, what data are relevant, what data to collect, and how to analyse results.*

In spite of careful preparations, many studies do not end exactly as planned. The researcher makes changes in his/her plan, but the issue is that in any newly encountered situation the investigator must be able to be adaptive and flexible (Yin, 1994).

On the other hand, Guba and Lincoln (Denzin and Lincoln, 1994, pp.199-200) take a broader view, defining research design as a road map for the researcher that concerns four basic questions: a) *How will the design connect to the paradigm being used?* That is, how will empirical materials be informed and interact with the paradigm in question? b) *Who or what will be studied?* c) *What strategies of inquiry will be used?* d) *What methods or tools will be used for collecting and analysing data*? In terms of the degree of rigorousness, depending on the type and the process of inquiry and the paradigmatic perspectives, research designs vary from rigorous design principles (positivist proponents) to less structured directives (post-positivist and non-positivist proponents) (Denzin and Lincoln, 1994).

Taking into consideration the above views and the specific situations in this study, the research design adopted here (see Figure 2.2) shows how all essential research processes hold and work together to address the research question and achieve the objective. Research designs vary, as any given situation is likely to be particular and unique (Denzin and Lincoln, 1994). This research design reflects the particular situations of this study.

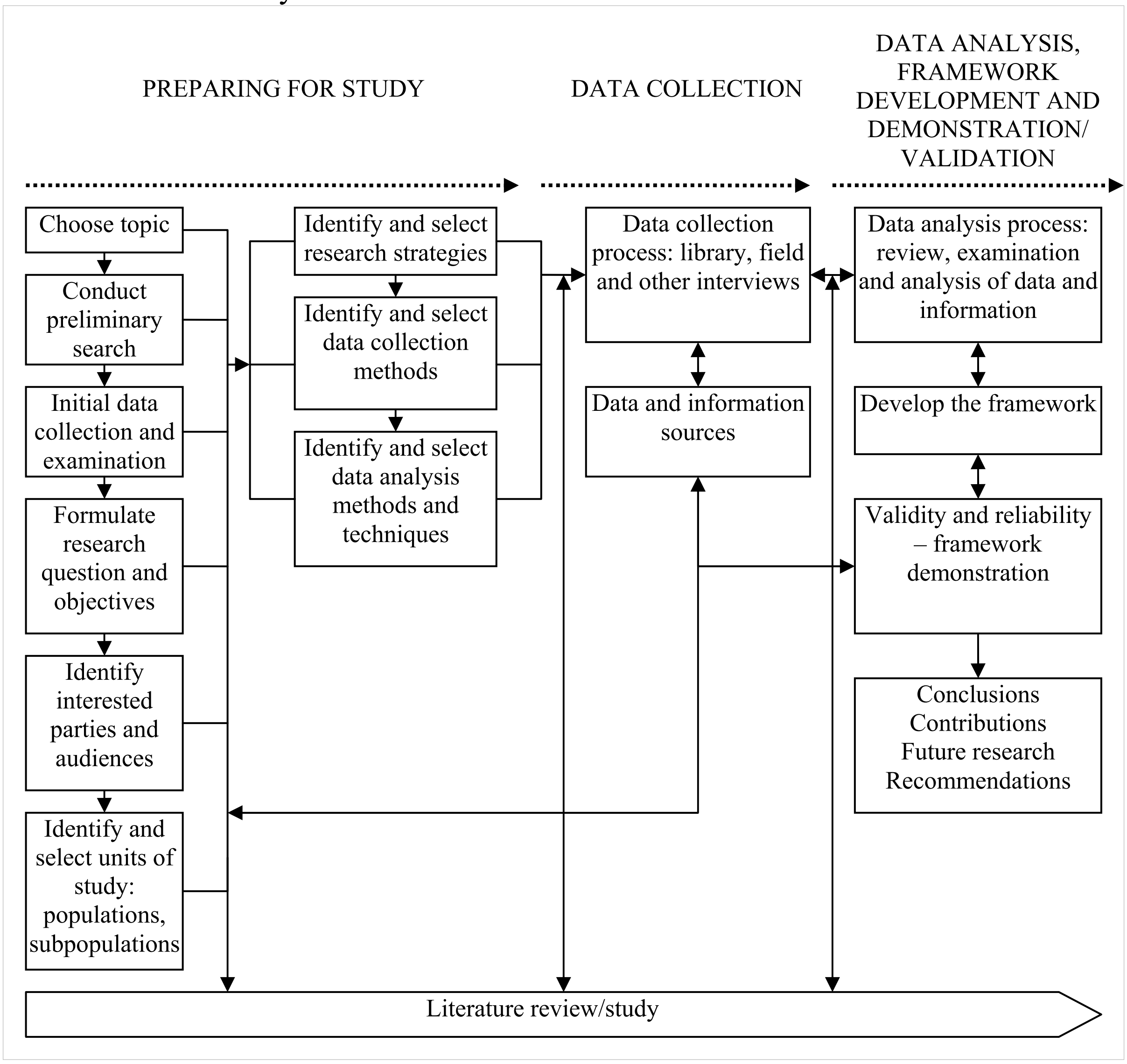


**Figure 2.2: Research design**

The research processes carry on from preparations for the study, including choosing the topic, literature review, formulating the research question and objectives, selection of the research strategies and data collection and analysis methods and techniques, through data collection and analysis processes and finally toward *framework development*. Processes have been generally cyclic, where many activities are performed several times and simultaneously. The key steps of the research process, some of which have already been described in detail, are presented below.

### 2.4.1. Preparing for the study

This stage included the following activities:

***Choosing the research topic: the initial research question and objective*:** Initially, the research was to carry out an analysis accidents involving the maritime transport of packaged dangerous goods (PDG). The question was formulated: *How to improve human safety and health, marine environment and property protection in the maritime transport of PDG?* The question and the objective were refined during the process. From my own seagoing experience and educational background, I understood that the topic was intriguing, but, at the same time, difficult and sensitive. People are not very willing to talk about accidents, in particular those involving dangerous goods.

The risk issues of maritime transport of dangerous goods are important for the responsible authorities that are assigned with the task of safeguarding public safety and health and the maritime environment. In recent years, the risks of dangerous goods, including the risks of maritime transport of PDG, have become a "hot" topic. However, given the inquiring-mind nature of the human being, sciences deal with everything surrounding human, regardless of whether important, relevant or interesting.

***Conducting a preliminary search***: A preliminary search was conducted in the field in order, inter alia, to:

- Get an overview and learn more about the topic;
- Identify the units or objects of study;
- Identify potential data sources and types of data needed;
- Identify data constraints such as data availability and accessibility; and
- Identify reasonable data collection methods and techniques.

The preliminary search was carried out in libraries and on the Internet, where numerous data and information sources were identified.

***Initial data collection and examination*:** After the data sources were identified and the initial data (i.e. the case histories) collection was begun and presented, the project was given the "go ahead." Then, I started "a full-scale" data collection. Initially, the data were collected in hardcopy. In order to prepare for analysis, they were then compiled in the computer as electronic data. The amount of data was large, and compilation became a very labour-intensive and time-consuming process –data compilation alone took several months. The size of the data collected from the HCB database only is large. The data are provided in a narrative form. Due to the nature of qualitative analysis approaches, the case histories that do not "add" or "lead" to any new category or property must be discarded. Yet they contain essential information for the risk analysis. Then, given the size and format of the data, the following questions arise:

*How to make better use of the data*? *How to analyse the data*? These "personal" questions turned into research questions. Although literature review has been at the centre of the research process, these questions led to a literature review focusing on the methodological aspects of the risks/accident analysis.

***Conducting the literature review***: Prior to an investigation, it is necessary to carry out a literature review (e.g. Yin, 1994; Karlsson et al., 1994). This is an important procedure in which other research works carried out in the field are reviewed. An experienced investigator conducts an extensive literature review to develop more insightful questions about the topic (Yin, 1994). The researcher becomes familiar with the "state-of-the-art" body of scientific knowledge (Denzin and Lincoln, 1994). The literature review may serve a wide range of purposes, but the main purposes combine the identification of the following:

- "Gaps" or "holes" in a specific area where no information or theory is available;
- Non-traditional areas where there is little or no literature;
- Outdated information or theory;
- Whether the available knowledge is incomplete, incorrect, or biased;
- Whether an existing theory or model is wrong, invalid, or incomplete;
- Whether there is a need to modify, adopt, refine, or test a theory or a model.

The literature review is, of course, an integrated part of the library study in which many data sources, data and information are explored. But, given its main purposes, it may become pointless to provide the results of a literature review in the methodology chapter. Although the research process is often cyclic, the logical organisation of the information requires that the main results should be presented in Chapter 1, Vol. I, in order to:

- Highlight relevant research issues and support the need for the research;
- Show the "state-of-the-art" knowledge, that is the point at which science has arrived and thereby show the research contributions;
- Identify specific research questions and set the objectives. In many cases, the research question is identified and the objective is set based on and supported by the information explored in the literature review.

An extensive search was carried out in many different sources, including both "peer-reviewed" ("the academics' world") and other ("the practitioners' world") sources. Hundreds of multi-disciplinary and international scientific and technical refereed and peer-reviewed journals, among others on the risks, safety and health and maritime environment topics were reviewed. However, the border between two "worlds" is rather blurred. Scientific knowledge does not come solely from academia; it comes from different corners in different forms, including the knowledge generated by the "practitioners". Many remarkable scientific achievements and discoveries are attributed to practitioners.

The search is carried out based on authors, journals, subjects/fields, and titles. The literature review and the entire library search are based on the combinations of many different key words and strategies, including the following categories:

- *Transport/carriage*: marine, maritime, sea, water, waterborne, shipping etc.
- *Goods/cargo*: dangerous goods or cargo, hazardous materials, harmful materials or substances, chemicals etc.
- *Packaging/units*: packaged, containers, cargo transport units (CTU), vehicles etc.
- *Maritime events/risks*: accidents, incidents, casualties, disasters, losses, risks, safety, health, maritime environment etc.
- *Risk methodology*: management, handling, control, prevention, avoidance, transfer, analysis, assessment, evaluation – practices, standards, frameworks, methods, techniques, models, theories etc.

The review established what studies had been previously conducted, showing that:[11]
- Many risk assessment frameworks and techniques have been developed in many areas, but no specific risk analysis framework for maritime transport of PDG was available.
- Knowledge of the risks of maritime accident involving PDG is limited. Many studies dealt with maritime accidents in general and the risks of major accidents involving bulk dangerous cargoes such as oil, oil products, LNG, LPG, and a few chemicals carried in bulk in particular.
- Risk/accident studies are largely confined to a single case analysis and summary or descriptive statistical analysis, for example cross-table analysis, and in some cases based on regression or cluster analyses. The analysis is often limited to a few numbers of variables, occasionally to just one or two variables that do not require any special effort to organize.

The literature review led to some specific areas including statistics, risk management practices and standards and risk analysis/assessment techniques. In order to achieve the research objectives, it was considered imperative to gain the required expertise in these areas.

In the course of the initial search, literature review and library study, I found that there was not one single study on the risks of maritime transport of PDG. Many studies were conducted on maritime risks/accidents in general and risks/accidents involving maritime transport of bulk dangerous cargoes such as oil/oil products and chemicals in particular. On the ground of insufficient data, IMO dropped the matter of studying losses overboard of containers from its agenda (HCB, 1996). Container losses constitute one of the risk issues involved in the maritime transport of PDG.

***Formulate the research question and objectives***: The literature review led to insightful questions about the problem and definition of the purposes of the study. Taking into consideration the time and the amount of work required, it was decided to deal first with methodological issues of risks, i.e. the development of the risk analysis framework. The research question and objective (see Chapter 1, Vol. I) guided my efforts throughout the research process.

[11] Note: Key results of the literature review are presented in Chapter 1, Vol. I

***Identify the audiences/interested parties***: Who are the audiences for the research results? Who could be interested in the results? Who could be interested in the risk analysis framework? Who is going to use it? These kinds of questions focused my efforts to develop a framework with the risk analyst and the risk manager or decision-maker in mind. The list of interests and audiences is provided in Chapter 1, Vol. I.

***Selecting units of study: populations and samples*:** One important step in the research process is to determine *what and how many to study*? (Denzin and Lincoln, p. 201, 1994,) Selecting or sampling is concerned with determining what and how many observations or the numbers of elements (sample) of a population are to be made or studied when it is not possible or practical to make all observations or study the entire population that is ideally desirable (Ackoff et al., 1968). According to Yin (1994) and Denzin and Lincoln (1994), the unit of study may be an individual, individuals, *event*, *entity*, country economy, policy, *cases or instances of phenomena* and social processes. Given the research question, the objective and the scope, the main interrelated units or objects of the study shown in Table 2.2 have been selected.

**Table 2.2: Units of study**

| Type of unit or object of the study | Population | Selected samples: sub-populations | Purpose: to study, understand | Some motivations for selections |
|---|---|---|---|---|
| Event | Marine accidents/ incidents: databases | • Marine accidents/ incidents involving PDG:<br>- Hazardous Cargo Bulletin database<br>- Other databases | • The system and its outcomes: the risk of maritime transport of PDG | • Representativeness<br>• Accessibility<br>• Availability<br>• Time and costs<br>• Extend and fill gaps in the data |
| Entity | Maritime transport system | • Maritime transport of PDG:<br>- Ports: Malmö, Trelleborg, and Ystad | • The system: maritime transport system of PDG | • Representativeness<br>• Traffic, activity<br>• Vicinity<br>• Time and costs |
| Practice, activity, model | Frameworks, techniques, models | • Risk analysis/ assessment frameworks employed in:<br>- Shipping industry<br>- Other industries, sectors or activities<br>• Risk analysis techniques employed in:<br>- Shipping industry<br>- Other industries, sectors or activities | • Frameworks, techniques: the structures, procedures. | • Representativeness<br>• World's best<br>• Commonly used<br>• Most advanced<br>• Similarities and differences among systems or activities |

In order to achieve the research objectives it was considered important to study a) the maritime transport system, b) the risks associated with the system, and c) risk analysis practices, frameworks and techniques. One basic premise is that one cannot make improvements in a system until one understands how the current system operates (Harrell and Tumay, 1995).

***Maritime accidents involving PDG***: The case history is one of the prevailing approaches to studying the risks of maritime transport. Case histories also provide knowledge about the system, system components and activities and other pertinent issues. Maritime accidents are recorded in databases varying widely in terms of:

- The degree of detail: from very brief to very detailed;
- The structure: from unstructured narrative or text-format to very structured;
- Accessibility: non-accessible or confidential, or for public use available in public sources;
- Ownership of databases: government or public and private;
- Costs of data acquisition: involving costs and free of charge;
- Types of events recorded: all types, or major oil spills from tankers only;
- Location of events: world-wide, regional, national, local and organisational;
- Time coverage: from very recent to a half century or more;
- Language: English and other languages.

Despite considerable efforts made to gain access to some relevant data sources, the data, with only two exemptions, were either not available for public use or involved costs. The following are some accessible and available units of study.

***Hazardous Cargo Bulletin*** (HCB) Log/database (contents) is selected as a unit of study, as it is representative of the world's databases and maritime accidents. It is a valuable data source available for analysis of the risks of maritime transport of PDG. The database, which is for public use and free of charge (available in the library), is specially designed for recording and reporting of hazardous materials (or dangerous goods) transport, including maritime transport of PDG, and storage accidents and incidents occurring around the world. The database is used by numerous researchers (e.g. Romer et al., 1995; Christou, 1999) as either their only data source or in combination with other sources. Case histories contain certain information that is very little reported or not reported elsewhere, i.e. available public sources. Event description (in the "event details" column) is provided in an unstructured text-format. Case histories are collected from a wide range of sources, some of which are well-known and reliable independent data sources.

***Other databases and case histories***: Given the limitations of the HCB database, in order to extend and fill gaps in data and further enhance understanding about the system and the risks associated with it, other units of study (i.e. databases and case histories) are also selected (see Table 2.3). For example, the Swedish Maritime Administration (SMA) database is one of the most detailed and well-structured databases being reviewed. However, this database does not contain sufficient information concerning events involving PDG. Yet because of the degree of detail and the structure, this database has been a very useful source in studying and understanding the system and its risks, and in development of the framework. In addition to the mentioned databases, many individual case histories are also collected from different sources. These cases also included very detailed accident investigation reports.

***Maritime transport system: maritime transport of PDG***: The system consists of many different components, activities and actors. In order to study the system, the ports of Malmö, Trelleborg and Ystad were selected as units of study. They were chosen based on representativeness, traffic, activity, and vicinity. Many essential maritime transport-related activities, such as manoeuvring and loading/unloading, stowing and documentation of PDG, take place in ports. Case histories (HCB, 1986-2003) show that many problems of maritime transport of PDG are of a shore-side origin. Further, many accidents and incidents involving ships carrying PDG have occurred in ports. The ports of Malmö and Trelleborg are among the main and largest ports of Sweden. All three ports handle passenger, cargo and cargo/ passenger transports, including PDG. In addition, all three ports are located in the southern part of Sweden, close to Lund University, which makes the study less time consuming and less expensive.

***Frameworks, techniques, and models***: Many different frameworks, techniques or models (tools) have been developed, in particular in recent years, to facilitate risk management activities, such as risk analysis, risk evaluation and decision making. They vary across countries, industries, sectors or activities. In order to develop a framework for analysis of the risks of maritime transport of PDG, a comprehensive understanding of these tools and their applications was required in the first place. Therefore, some of the best risk management practices and advanced risk assessment frameworks and techniques employed in shipping have been selected and studied (see Chapter 3, Vol. I and Mullai, 2006b). Because of similarities among systems and risks, a number of best practices and tools developed in other industries, sectors and activities have also been selected and studied (see Chapter 3, Vol. I, and Mullai, 2006b). In addition, many tools have a wide range of applications.

***Selecting research strategies, data collection and analysis methods*:** The preliminary search, literature review, definition of the research question and objectives and identification of potential audience/interests assisted in identification and selection of the suitable research strategies, data collection (see section 2.4.2 in this chapter) and analysis (see section 2.4.3 in this chapter) methods and techniques. The research strategies are described earlier in this chapter (see section 2.3). Appropriate adjustments have been made according to the situations in the course of the research process.

### 2.4.2. Data and information collection – methods, data sources and data

*How, where, what* and *how much* data are collected? With reference to the determining conditions and the research objectives, for the purpose of this study every reasonable effort has been made to collect the relevant data and information from different sources by employing different methods and techniques (Table 2.3). One of the important principles of data collection is to use many different sources of evidence (Yin, 1994). Table 2.3 shows the same category of the data (e.g. case histories) collected from different sources. Further, a single method is used to collect different types of data.

Far from contradicting one another – either philosophically or practically – the research strategies (methods and techniques) employed in this study have complemented each other. The study has called for and benefited from both the field and the library study. Initially, the library and the Internet were used as sources of information that assisted in preparing and doing the field study. On the other hand, the field research is used to extend and support research conducted in the library. Interviews and discussions with different people assisted in identification and collection of data from different library and Internet sources. Examining case histories, observations and interviews conducted in the field have enhanced my understanding and provided more insights about the research topic.

*Types of data*: This research combines different types of data: primary and secondary data, qualitative and quantitative data, and hardcopy or printed texts and electronic data. Secondary data are not necessarily less reliable just because they are not firsthand data. Nor are the methods employed to collect secondary data less reliable. At some levels, quantitative and qualitative data are inseparable and interchangeable. Quantitative data can be based on qualitative judgments. On the other hand, qualitative data can be represented and manipulated numerically. For example, accident frequency can be expressed in either form. As this study shows, qualitative or text-format data can be converted into quantitative data. Today, large amounts of electronic data (e.g. accident databases) are available in libraries and on the Internet.

**Table 2.3: Research strategies, data methods and techniques, data sources and types of data and information**

| **Strategies: data collection methods** | | **Sources/ locations** | **Data and information description** |
|---|---|---|---|
| Case histories, documentations, other archival documents<br><br>Library study<br>• Library<br>• Internet | Library search<br><br>Lund University, WMU, Malmö and other libraries | Hazardous Cargo Bulletin Incident Log | - Maritime accident/incident case histories (2577) (1986-2003), worldwide |
| | | Lloyd's Register Of Shipping | - Casualty Return: Maritime Casualties (1980-1996), worldwide |
| | | IMO Database on serious and very serious casualties | - Casualty Statistics and Investigations (1994-1996), world wide |
| | | Other sources | - Literature and documents on risk management: practices, frameworks, techniques and tools<br>- Documents, statistics, reports |
| | Internet search | U.S. Coast Guard Database | - Maritime accident/incident case histories (263) (1947-1999), U.S. |

| Strategies: data collection methods | | Sources/ locations | Data and information description |
|---|---|---|---|
| | | | waters |
| | | Maritime Accident Reporting Scheme (MARS) Database | - Maritime accident/incident case histories (422) (1992-2001), worldwide |
| | | IMO Database on serious and very serious casualties | - Maritime Casualties (1998-2000), worldwide |
| | | Other databases | - Maritime accident/incident case histories |
| | | P&I Club | - Loss Prevention News (1995-2001)<br>- Carefully to Carry (1996-2001)<br>- Loss Prevention Bulletin |
| | | TT Club | - Publications and circulars<br>- Archival documents |
| | | Different sites | - Case histories – accident investigation reports, articles<br>- Literature and documents on risk management: practices, frameworks, techniques and tools<br>- Statistics, surveys, research reports & articles etc.<br>- Other literature and documents |
| Field study<br>• Interview<br>• Observation<br>• Documentation | | Ports: Trelleborg, Malmö and Ystad | • Interviews and observations<br>• Documents |
| • Other interviews and communications | | • Swedish Maritime Administration (SMA)<br>• Swedish Coast Guard<br>• Drogden VTS, Denmark<br>• World Maritime University<br>• European Commission | - SMA Database – Maritime accident/incidents (1985-1999), Sweden/Danish waters<br>- Danish Database – VTS Drogden, Maritime accidents/ incidents (1997-1998), Denmark/Swedish waters<br>- Case histories – accident investigation reports, articles<br>- Interviews and communications<br>- Documents |

The following section discusses the data collection process.

#### 2.4.2.1. Library study

Libraries and the Internet are integrated parts of the library study.

***Electronic search and key words:*** Searching through electronic sources has been an important part of the research process. Electronic searches, either in libraries or on the Internet, are based on the usage of keywords that are entered into the search field. Used in various combinations, the keywords have led to many sources and materials that were relevant for the research topic. For the purpose of this study, a wide range of electronic data sources are consulted.

***Libraries***: In spite of the rivalry from the Internet, libraries continue to be one of the best sources of information for many fields, including maritime transport of dangerous goods. This was a good place to perform the initial search, become familiar with the topic and collect relevant data and information for this research. The library contains many different relevant books, journals, periodicals, research reports, statistics, magazines, newspapers, government documents, databases and many other materials that are registered in computerised catalogues. The library catalogues were searched, when accessible through the Internet, from the department and from the library. Bibliographies/references of the published research works have also been reviewed. Through the Internet I have had direct access to Directory of Databases (DoD), Electronic Library Information Navigator (ELIN), Direct Science, Libris and Lund Dissertation Abstracts.

Various relevant types of data and information have been collected from Lund University libraries (UB 1, UB 2, and Juridical Library) and the World Maritime University Library. Many other libraries, such as IMO Library and Swedish Universities Libraries, and other libraries in other parts of the world have been accessed through the Internet.

***Internet - electronic data sources***: The Internet has become a major source of data and information. It has become an "ocean" of information requiring special skills to master the search. Today, it would be surprising if a researcher has access to the Internet and hasn't used it. The Internet provides varieties of powerful search engines. A number of *maritime accidents databases and statistics available for public use* are searched, identified and downloaded as electronic data in the hard disc. Every year more and more databases are being released and becoming available on the Internet. Increasing numbers of sources, such as private and public organisations, research centres and institutions for maritime studies, governmental agencies and international organisations etc., are available via the Internet. Many *different documents* are reviewed and collected from these sources.

However, not everything is available in libraries and on the Internet. Through field study and other interviews and communications with different people in many organisations, I have extended the range of data and information and gained insights in the research topic.

#### 2.4.2.2. Field study

The goal of field research is the same as that of other research approaches: to gather the data and information and acquire the understanding needed to answer the research question and achieve the objectives. The difference is where one conducts the research. However, for certain research questions and objectives, the field study is a very important way, perhaps the only way, to collect data and information. In the field study the researcher can study things that few or no researcher has investigated before. For the purpose of this study, valuable unprinted and unpublished information was collected through field study and other contacts.

Field studies were conducted in three Swedish ports, namely Malmö, Trelleborg and Ystad. As mentioned earlier, they were chosen based on cargo/passenger transports, vicinity and accessibility. These are the main ports of the southern part of Sweden. One of my supervisors had close contacts with some people (experts) working in these ports.

Field studies combined observations, interviews and documentation. Observations and interviews were conducted based on the principal guidelines laid down in the literature adjusted to the specific situations. Data collected in the field study comprise notes, records, transcriptions and documents. Documents consist of ports and vessel traffic statistics, dangerous goods/CTU inspections reports, and other documents.

In every case, the consent to conduct interviews and observations has been asked and gained.[12] Confidentiality has been fully respected. I have been straightforward in explaining the purpose of my study and how data are collected.

**Interviews in the field**

*Interview* is defined as a conversation or questioning of a person for the purpose of eliciting information for publication (MWD, 2004) (CED, 1992) (FD, 2004); a meeting at which information is obtained from a person (MWD, 2004).[13]
The interview technique can offer a number of advantages, for example control over the type and amount of data, deeper and more detailed information, observation of behaviour related to questions and circumstances, and possibility to clarify uncertainties and questions. People have different degrees of willingness to talk, from eager to unwilling. Some questions that affect the interview are: How much time is available? Is the topic sensitive? Are people comfortable or willing to talk about the topic? When it comes to a system or their own problems, people feel uncomfortable and are reluctant to converse.

[12] The Nuremberg Code provided a statement concerning the rights of human participants to be informed and freely choose to participate in research. Federal Register (1991), U.S. Federal policy for the protection of human subjects; notices and rules, part II. U.S. Federal register, 56, 28001-28032

[13] From middle French entrevue, from (s') entrevoir to see one another, meet, from entre- inter- + voir to see. Merriam-Webster Dictionary (2004).

Interviews may take different forms, for example individual and focus group interviews, in-depth interviews, survey interviews, in-person, telephone and Internet interviews etc. Today, computer-mediated communications and interviews are becoming common. E-mail and web-page surveys, which are often facilitated by purpose-built software, are commonly used in many fields.

Interviews are divided into structured and unstructured (Patel and Tibelius, 1987). The structured interview may consist of a list of specific questions. The interview process proceeds generally according to the list. In unstructured interviews the wording of questions is open-ended. Respondents are able to choose their ways of expression and use their own terms when answering questions. In this study, both types of interviews are combined. First, interviews were kept broad, letting the interviewee tell the story. In order to avoid wording that might influence answers, questions were kept as neutral as possible. Then, specific carefully thought-out questions were asked to obtain more specific information and fill gaps left during the initial interview. Questions were clearly worded in order to avoid any misunderstanding. When certain questions did not draw any response, I did not persist, but went on to the next question. I was not allowed to record interviews on some sensitive questions.

In order for people to feel more comfortable, avoid work disruptions and combine interviews with observations, the interviews were conducted at interviewees' own workplaces.

Regardless of the interviewee, careful preparations were made prior to interviews. Because of the research topic specifications, I chose to interview a group of people who had knowledge in maritime transport and port operations and the required expertise in maritime transport of dangerous goods-related activities in particular (see Appendix 1, Vol. I). In order to have more viewpoints, different people's opinions were taken into account.

During interviews and observations, records and notes were made, and immediately thereafter they were reviewed, thought out and further developed. Further notes and questions for the next meeting or observations were also written down.

### Direct observations

Observation is defined as the act of observing, seeing, fixing the mind upon, recognizing or taking notice of facts or things; the act of making and recording measurements (MWD, 2004; CED, 1992; WND, 2004). With respect to the degree of participation in the system or people's activities, observations vary from full or complete to non-participant observations. This study used non-participant observations.

The observational research approach has many positive features. Observations that do not necessarily need to be structured around some hypotheses are usually flexible. First hand observations are important sources of information. The researcher is able to collect detailed and unique information – a picture tells more then thousands of words.

When people are unwilling to talk, observations can provide more accurate data. However, there are also constraints on the observation technique, such as those related to the time available, observability, and accessibility and researcher bias.

In this study, observations were combined with interviews. Before conducting observations, permission to visit sites in ports and ships was received from responsible authorities in advance or after the interview. Some persons were contacted and asked by my supervisor. The time and the place of the appointment were made before hand by telephone. On arrival, I identified myself and the research work I was doing. I visited numbers of *sites in ports and ship operations*. Direct observations on marine accidents and problems related to PDG were not doable – "mission impossible."

While reflecting on the observations made earlier, follow-up field trips were necessary as further questions emerged and more insights had to be acquired by further observations. In order to record interesting facts, details or impressions, I took notes while conducting observations. In order not to attract any attention or reaction that would have changed people's behaviour, I did not use the camera. Observations were open, but, in many cases, observees were unaware of my presence. People's reactions were observed naturally as they were acting routinely in their daily work. For example, I have observed *loading, discharging,* and *cargo securing* (e.g. vehicles and wagons) operations where other people (e.g. workers, drivers or passengers on ferry ships) were around.

### Other interviews – discussions and communications

The topic has been discussed with numerous experts in the field, including my supervisors, professors and lecturers at the World Maritime University (WMU), former maritime accident investigators and former sea captains and mariners and other experts from different relevant organisations (see Table 2.3 and Appendix 1, Vol. I). Many experts not only provided insights and materials but also suggested other data sources.

Many interviews were both structured and unstructured. However, some interviews were flexible and informal discussions or conversations. Interviewees were encouraged to share their thoughts and expertise. Some interviews were short, lasting only a few minutes. In some other cases, they were communications with the purpose of identifying relevant sources and obtaining data. When I was unable to talk to people in-person, I used other means of communication such as telephone, e-mail and fax as the next resource. In such cases, a phone appointment for a time convenient for both of us was made prior to communication. In summary, the field studies (interviews and observations) covered a wide range of areas, including:

- Ports and port operations, for example types of ports, interactions of different modes of transport;
- Ships and ship operations: for example types of ships, activities such as loading, discharging, cargo securing and other activities;
- Dangerous goods shipments and documentation processes;
- Container/CTU inspections and problems related to the transport of PDG.

The field studies served different purposes, including:

- Gain first hand experience and insights into the maritime transport system.
- Gain insights and later check variables designed, including operational definitions and assumptions: e.g. types of ships and ship activities, types of packaging/cargo transport units, types of cargo/PDG, location etc.
- Extend data and information: collect documents containing information that is not available elsewhere, such as container and CTU inspection reports, statistics and other documents.

**Personal experience**

The researcher's role in the research process is unquestionably very important. For many different reasons, some of which are mentioned earlier in this chapter, the researcher can affect, either consciously or unconsciously, the research process in many different ways – from the selection of research strategy and data collection and analysis methods, assumptions and definitions, through data analysis and interpretation and the final results. My 12-year seagoing experience, research work experience (Mullai and Paulsson, 2002) and formal education and training have also contributed to this study.

### 2.4.3. Data and information analysis

The framework is developed based on the combinations of various modes of data analysis that are described below.

***Explanation-building and chronological events analysis***: data *examination*, *categorization*, and *tabulation*. Yin (1994, p. 102) indicates that there is no fixed formula for what data analysis approach to employ in the case study strategy, as it depends very much on the researcher's style. In a case study, according to Yin (1994, pp.102), data analysis may consist of *examining*, *categorizing*, *tabulating* or *recombining* the evidence. Yin (1994, pp.102-118) suggests various modes or techniques of data analysis to be employed in a case study, including *explanation-building* analysis, *chronological events* analysis, *pattern matching* logic analysis, and *time-series* analysis. In order to secure effective analysis, analysis strategies are often used in combination. In this study, the first two modes of analysis have been more applicable. The explanation-building analysis relies on the identification and stipulations of a set of causal links about a phenomenon. The chronological events analysis consists of processes in which events are arrayed into chronological orders permitting the researcher, based on the sequence of cause-effect, to determine the causal events. Thus, the risk analysis techniques are, among other things, based on *chronological events* analysis of the large amounts of data contained in the case histories. The data is thoroughly *examined*, *categorised* and *tabulated*.

***Exploration – grounded theory***: Grounded theory is a general methodology for developing theory that is grounded in data systematically gathered and analysed (Denzin and Lincoln, 1994). The qualitative analysis of the case histories and other data has largely been an exploratory process. In contrast to interview or survey/questionnaire approaches, in which the researcher has, to a large extent, control over the type and amount of data collected, in the case history the researcher has to rely on the exploratory type of inquiry. Exploration relies very much on the researcher's cognition, i.e. the mental act or process by which knowledge is acquired, including perception, intuition, and reasoning (CED, 1992). Thus, through exploration of case histories, many conceptual or theoretical categories and properties of the system and the risks are generated. In accordance with the principal rules of grounded theory methodology (Glaser and Strauss, 1967), every exhaustive effort has been made to saturate as completely as possible the core theoretical categories and properties.

***Comparative analysis*** is a general analysis method that uses the logic of comparison. Many research methods and strategies make use of this method. Constant comparative analysis is an important strategic method for generating theory (Glaser and Strauss, 1967). The method has been used extensively in this study, where the comparative units have been, for example, case histories, frameworks and techniques.

***Content analysis*** is discussed in numbers of texts (Krippendorf, 1980; Carney, 1972; Weber, 1990), describing it as an analysis method that examines and determines the presence of certain concepts within a wide range of texts, including any piece of writing or occurrence of recorded communication such as books, essays, interviews, formal and informal communications, newspapers, articles, reports, and historical documents. The central idea of content analysis is to reduce data (text-format) into categories of concepts and analyse them. This method employs two basic categories of analysis: *conceptual analysis* and *relational analysis* or cognitive mapping, each of which consists of a number of steps described in detail by Carley, 1990; Carley, 1992a, 1992b; Carley and Palmquist, 1992; and Carney, 1972. Conceptual analysis establishes the existence and frequency of concepts, while relational analysis examines and makes inferences about the relationships among concepts. Different computer softwares have been developed to assist researchers in content analysis processes. Since case histories (see Appendixes 2 and 3, Vol. I) contain data in text-format, the content analysis method has been a very useful tool in the framework development. By following conceptual and relational analysis procedures, the data are coded, broken down into categories of concepts at different levels, and then the relationships among concepts are examined.

### 2.4.4. The development of the framework

The development of the framework has been a long, cyclic and complex process. Figure 2.3 shows the forthcoming chapters of the report that move step-by-step through the process. The following is a brief discussion.

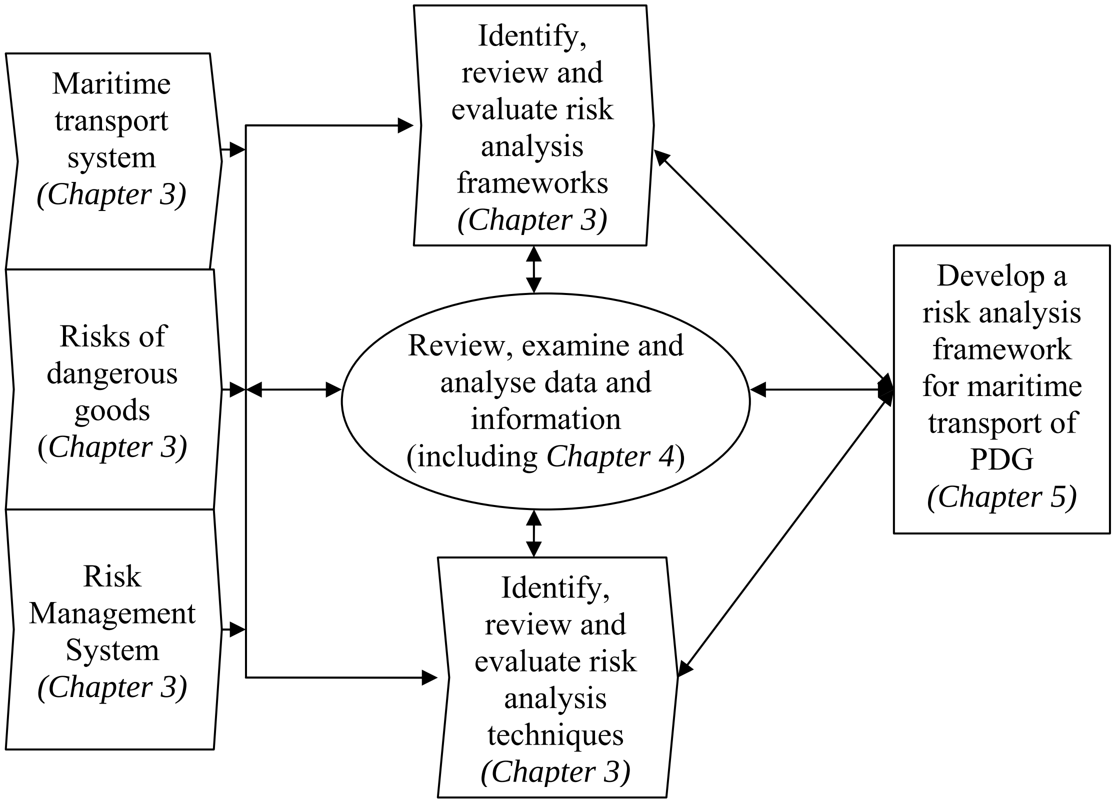


**Figure 2.3: Framework development process**

***The process of data and information review, examination and analysis*** has been at the centre of the entire process (including Chapter 4, Vol. I). The framework is developed based on the understanding, experiences, insights and results acquired through a) the review and study of the relevant literature and other information, b) examination and analysis of the empirical data, and c) interviews and observations in the field studies.

***The frame of reference*** provides the basis for development of the framework. In order to generate compatible and shareable risk-related information in the risk analysis, it is essentially important to have a unified understanding of the central concepts and theories related to the maritime transport system and risks of dangerous goods (see Chapter 3, Vol. I, and Mullai, 2006a) and the risk management system (see Chapter 3, Vol. I, and Mullai, 2006b). The topic is very specialised and complex topic and, therefore, a comprehensive understanding of the central concepts is required. Furthermore, the design of the framework (concepts/variables and their relationships), and subsequently the results of risk studies, relies very much on the precision of concepts and definitions. Due to the lack of comprehensive understanding and expertise in the field, numerous frameworks, techniques or models are poorly designed, committing errors with regard to the essential concepts of risks and risk management.

***Risk analysis frameworks and techniques*** are tools developed with the purpose of assisting risk management processes. The concept "framework" is broader than "technique." Frameworks are standards, guidelines, or procedures that may encompass a wide range of risk management activities. Techniques are mainly designed to facilitate the analysis process. There are many risk analysis/assessment frameworks and techniques varying in quality, degree of detail and scope. In order to improve and further develop these tools, a comprehensive understanding of their structures, procedures and applications was required. Based on the library study and interviews with various experts in the field, some of the best frameworks and advanced techniques developed in shipping and other industries, sectors of activities were identified, reviewed and evaluated (Chapter 3, Vol. I, and Mullai, 2006b).

The framework constitutes the structure (stages/steps or elements/sub-elements) of the overall risk analysis process, that is the entire process from preparations through the analysis process to conclusions and recommendations. Based on data examination and analysis, generic stages and steps were further developed and suited for the analysis of the risk of maritime transport of PDG. They contain information on the central questions: w*hat* and *how* to do risk analysis? Elements of the structure are organised in sequential and logical order and at different levels of resolution.

The analysis process of the risk-related data and information is often facilitated by specific risk analysis techniques. Many techniques were reviewed and evaluated based on cross comparison (see Chapter 3, Vol. I, and Mullai, 2006b). The review and evaluation showed that techniques are applied for different purposes in different situations, including maritime oil spill accidents. But none of them is used in connection with the analysis of the risks of maritime transport of PDG. Given the complexity of the system and the risks posed by PDG, and the features and advantages of techniques, the techniques of the backward-forward logic analyses, which are employed respectively in the Fault Tree Analysis (FTA) and Event Tree Analysis (ETA), are selected as the most suitable approaches for the risk analysis in the maritime transport of PDG.

FTA and ETA are not readily applicable in the field. Additionally, one technique alone is not sufficient to deal with all risk elements. FTA and ETA are analysis techniques that model respectively failures and outcomes of the systems. Therefore, the principal structures of both techniques are suited conjointly to form *a single hybrid model* for application in the analysis of the risk of maritime transport of PDG (see Chapter 5, Vol. I). These structures are further developed to suit the system and the risk specifications. The elements of the structures that are common among techniques and the framework are omitted. Adjustments are largely made based on the understanding and insights gained through examination of the empirical data. For example, the "top events", which is the point at which FTA and ETA merge and at which the analysis process begins, are identified and categorised based on the examination of the case histories. The model is, in turn, integrated into the risk analysis framework.

***Integrate other forms of analysis****:* Because of their limitations, risk analysis techniques cannot cover all risk elements, i.e. they are not entirely suitable to generate all the required risk-related information. Furthermore, because of the large amount and the diversity of the data and information and the system's complexity, a complete and perfect sequential and logical organisation of the information offered by the techniques is also not possible. For example, techniques are not suitable to deal with exposure, dispersion, concentration and effects of contaminants into the environment and its habitats. Other models based on case histories and analytical or mathematical models are suggested to deal with these risk elements. The logical sequential organisation offered by FTA and ETA is recommended to be combined with other, more "relaxed" qualitative methods, such as "let the data talk" and "grounded theory" approaches.

### 2.4.5. Validity and reliability – framework demonstration

The research should satisfy both validity and reliability (Sue, 1999). This section discusses the principles of validity and reliability and how they are applied in this study to avoid threats and enhance the quality of the research results. The main research result consists in the development of the risk analysis framework, which in turn consists of concepts and their relationships. The framework sets measurement systems for the analysis and measurement of the system and risk elements and influencing factors and conditions.

Based on strategies and tactics suggested by Yin (1994), Batterham and George, (2003), Dunn (2002), Lieberson (1991) and others quoted in this section, every reasonable measure has been taken to enhance the quality of research. Because of the relationships between validity and reliability and their threats, these measures served one or both purposes, i.e. validity and reliability. Yin (1994, p. 33), based on numerous textbooks including Kidder and Judd, (1986, pp. 26-29 in Yin, 1994), summarizes four tests (criteria) that have been commonly used to establish the quality of empirical social research. In order to enhance the quality of the study, Yin (1994, p. 33) suggests certain tactics and a cross-reference to the phase of research when each tactic is to be used for each test (Table 2.4).

**Table 2.4: Case study tactics for four design tests (Cosmos Corporation, Yin, 1994, p.33)**

| Test | Description | Case study tactics | Phase of research in which tactic occurs |
|---|---|---|---|
| Construct validity | Establishing correct operational measures for the concept being studied. | • Use multiple sources of evidence<br>• Establish the chain of evidence<br>• Have key informants review draft case study report | - Data collection<br>- Data collection<br>- Composition |
| Internal validity | For explanatory or causal studies only, and not for descriptive or exploratory studies: establishing a causal relationship, whereby certain conditions are shown to lead to other conditions, as distinguished from spurious relationships. | • Do patter-matching<br>• Do explanation-building<br>• Do time-series analysis | - Data analysis<br>- Data analysis<br>- Data analysis |
| External validity | Establishing the domain to which a study's findings can be generalized | • Use replication logic in multiple case studies | - Research design |
| Reliability | Demonstrating that the operations of a study – such as the data collection procedures — can be repeated with the same result. | • Use case study protocol<br>• Develop case study database | - Data collection<br>- Data collection |

The following section discusses the issues of validity and reliability.

#### 2.4.5.1. Validity

Validity in research is a hierarchy of procedures to ensure that what one concludes from a research study can be stated with some confidence (Mentzer and Flint, 1997). Therefore, validity is an important consideration in research results assessment. Validity evaluation relies heavily on human judgment, and it is, therefore, hard to carry out, report and defend (Crooks and Kane, 1996). The very breadth and complexity of many concepts makes them difficult to work with in practice. Validity is always vulnerable to one new piece of negative evidence (Crooks and Kane, 1996). Furthermore, in science, one can draw invalid conclusions not only on the ground of methodological and conceptual issues, but also because of scientific convention (Sue, 1999). For example, a "well-established" method can be reliable, consistently measuring the same thing, but the results generated from it may still be invalid.

The literature discusses different types of validity, such as construct validity, internal validity, external validity (or generalizability), statistical conclusion validity, and context validity (Dunn, 2002), each of which has additional subdivisions (Mentzer and Flint, 1997). However, a traditional division of validity consists of construct validity, internal validity and external validity (Yin, 1994; Dunn, 2002). These are important and should be equal partners in scientific research (Sue, 1999; Batterham and George, 2003). These three types of validity are discussed below.

### Construct validity

Construct validity concerns the degree to which a study accurately reflects or assesses the specific concepts that the researcher is attempting to measure (Yin, 1994). The question addressed by construct validity concerns (Mentzer and Flint, 1997): How can one be certain that the phenomena have been correctly defined and measured in the study? Construct validity of theoretical categories, concepts, or labels will be diminished for reasons that include inadequate formal and operational definitions of constructs and the failure to examine relations among multiple overlapping constructs (Dunn, 2002).

In this study, in order to enhance construct validity, the following measures have been taken:

***Establish correct measures*** (Yin, 1994). In order to measure correctly and exhaustively the constituent concepts of the risks of maritime transport of PDG, the framework incorporates a wide range of different relevant concepts (see Chapter 5, Vol. I). The framework is developed based on the knowledge and understanding gained through the combinations of a) the examination and analysis of the empirical data, i.e. grounded on the empirical data, b) the library study and literature review, and c) observations, interviews and materials gathered during the field studies. The quality of the framework, and subsequently the quality of the results generated by it, depends very much on how well and precisely the constituent concepts are defined. The framework development – relevant concepts and their relationships are identified and accordingly defined – is grounded on the empirical data (see Chapter 4 and Appendixes 2 and 3, Vol. I). The risk studies in maritime transport are largely based on these types of data. Several concepts are also defined on the basis of the definitions provided by some of the well-known sources, such as the IMO, USCG, LLP, Lloyd's Register of Shipping, classification societies, marine insurance providers, maritime institutions and authorities (e.g. SMA - Swedish Maritime Administration) (see Chapter 3, Vol. I, and Mullai, 2006a). Some of the sources mentioned are among the world's largest maritime information providers that collect, compile and analyse the vast amounts of marine accident data. In addition, a number of concepts are derived from the well-established regulatory systems governing maritime transport of PDG, in particular the IMDG Code.

***Use multiple sources of evidence*** (Yin, 1994). In order to develop a framework that reflects the combination of a) the elements of the marine transport system and b) the phenomenon associated with the system of the system's outcomes, i.e. the risks associated with the transport of PDG including influencing factors, the most relevant multiple-sources of the data have been used (see Chapter 2, Vol. I). These sources include marine accident case histories from different marine accident databases, formal investigation reports and scientific articles concerning individual cases.

***Establish the chain of events*** (Yin, 1994). A large part of this study is focused on exploration and explanation of the chain of events – the causes and consequences of marine accidents involving PDG (what, how and why did they happen?). The aim has been to understand the relationships between events, conditions and factors, and build a model that can describe and explain the way in which accidents have happened and escalated. For that purpose, the data analysis combines various established analytical methods described in this chapter.

***Have the draft report reviewed by key informants*** (Yin, 1994). As with many similar, and even different, types of studies, given the main data sources available, it has been impossible to employ this procedure. However, as mentioned above, the framework is developed based on the data contained in formal marine accidents investigation reports. In many western countries, the legal requirements of accident investigation procedures require that the responsible authority provide the witnesses (informants) with a transcript of their statements, so that the informants can check whether their statements have been accurately reported.

### Internal validity

Internal validity is a concern for explanatory or causal studies only, in which an investigator is trying to determine causal relationships – whether an event *x* led to another event *y* – and not for descriptive or exploratory studies (Yin, 1994; Sue, 1999). However, the review of many formal and informal studies has shown that there is no clear division between these two types of studies. Almost every study, at the same time, describes and explains the subject of the study. This study has both exploratory and explanatory characters. The interest in making causal inferences goes beyond quantitative research.

In order to enhance internal validity the following measures have been taken:

In qualitative research, a variety of strategies are used to strengthen internal validity, including triangulation, persistent observations, and negative case analysis. The review and analysis of the large amount of diverse types of data and information collected from different sources (covering a wide period, 1986-2003) satisfy the strategies mentioned, and, therefore, strengthen internal validity.

***Establish a causal relationship****, whereby certain conditions are shown to lead to other conditions* (Yin, 1994). The relationships among concepts are empirically and theoretically grounded. The relationships are explored through the combinations of various modes of data analysis described in Chapter 2 and employed in Chapter 4, Vol. I, including explanation-building, time-series analysis, conceptual and relationship analyses. The risk analysis framework has a theoretical foundation. The research strategy and design has taken into consideration the review and study of the relevant theories – risk management practices, frameworks, techniques and tools (see Chapter 3, Vol. I, and Mullai, 2006b). The framework relies, inter alia, on some of the world's best risk management practices and tools, where the relationships among many relevant concepts are well established. For example, the Fault Tree Analysis (FTA) technique is based on the principles of "backward logic." However, these principles are highly generic or abstract. Therefore, based on understanding gained through analysis of the empirical data, they are adjusted and made readily applicable to the specific system or phenomena in question, i.e. risks of maritime transport of PDG.

### External validity - generalizability

External validity is the extent to which the results of the research are generalizable or transferable to the populations and settings of interest (Sue, 1999). With regard to case study, Yin (1994) states that external validity is concerned with whether the study's results are generalizable beyond the immediate case study. In essence, the questions concerning external validity are: Are the results readily applicable to other situations? Are the study's findings of a sample population true for other members of the population at large, in other places, and at other times?

According to Kazdin (1999), there are some limited circumstances in which generality of findings is not always relevant or necessary (Kazdin, 1999). But Sue (1999) argues that the lack of external validity may render research results meaningless for the actual population of interest.

The central issue concerning external validity (generalizability) is sampling. Sampling techniques and procedures are provided in the literature dealing with sampling theory and statistics, for example Hubert and Blalock, 1979; Hair et al., 1998; Bakeman, 1992; Ackoff et al, 1967. Sampling is concerned with determining what, and how many, observations are to be made when it is not possible or practical to make all the observations that are ideally desirable.

The important issues that sampling takes into consideration are the sample size, composition or representativeness, and randomness. The sample must be representative of the population in question (Gelb and Gelb , 1989). Prior to sampling, this question may arise: Is it important to sample most of the group, or to sample a representative portion? (Gelb and Gelb, 1989). However, although a sample may not be truly representative, it could still produce useful information (Bollen et al., 1993). Sample selection must also be randomized (Hubert and Blalock 1979; Gelb and Gelb, 1989). Sampling is divided into probability and non-probability sampling (Hubert and Blalock, 1979), each of which is further subdivided. Each sampling type is based on certain criteria and procedures. Statistical inference based on non-probability sampling is not legitimate (Hubert and Blalock, 1979; Hair et al., 1998). Non-probability sampling is appropriate in an exploratory study, the main goal of which is to obtain valuable insights in the area being studied. Such insights may lead to some testable hypotheses. However, non-probability sampling methods are used when the purpose of the study is to make generalizations about a population being sampled (Hubert and Blalock, 1979).

The number of cases (i.e. the sample size) is a basic characteristic of external validity, with implications for analysis methods employed and the kind of conclusions that can be drawn (Bollen et al., 1993). There are different opinions about small versus large samples. Many researchers prefer the greater depth of knowledge that may accompany a sample with a large number of cases (Bollen et al., 1993). A large sample is considered to be more adequate than a small sample for drawing general conclusions (Lieberson, 1991). Compared to smaller samples, the larger samples offer numerous advantages. According to Tilly (1984), comparative studies based on a large number of cases or observations may yield results with a higher degree of confidence than studies that examine a relatively small number of cases or observations. This is because the large number of cases or observations gives a sense of security (Tilly, 1984). Others have pointed out that this is because comparisons geometrically increase as the number of cases increases (Bollen et al., 1993). A larger sample provides a higher "degree of freedom" (Jackman, 1985; Przeworski and Teune, 1970). The possibility of errors in measurements in a large sample has lesser impact on the results compared to a small sample (Lieberson, 1991). Another problem with smaller sample sizes is that there could easily be an "over-fitting" of the data such that the results may be artificially good because they fit the sample very well, yet have no generalizability (Hair et al., 1998).

In this study, in order to enhance external validity, the following measures have been taken:

***Select and collect large and representative samples***: In this research, by means of the research strategy and design, attempts have been made to satisfy the mentioned conditions. A detailed discussion about the sampling procedures and the units of analysis selected is provided in Chapter 2, Vol. I. For example, prior to sampling of marine events, these two questions arose: Which sub-population of marine events should be selected for the study? How many marine events should be selected? The samples selected in this study satisfy both representativeness and randomness. The samples of marine accidents involving PDG (see Chapter 3, Vol. I, and Mullai, 2006a) constitute a sub-population of the "population" of marine events. The only selection requirement was that these events met the criteria of marine accident/ incidents involving PDG, as defined in Chapters 1 and 3, Vol. I, and Mullai, 2006a. In order to enhance validity as well as reliability, and because of the many advantages offered by large samples, a large number of representative case histories has been selected, collected and analysed.

***Analytical generalization***: According to Yin (1994), studies may rely on statistical or analytical generalization. This study relies on the latter type of generalization. In many situations, because of combinations of different factors, for example, the purpose of the study, and the data, time and resources available, statistical analysis may be neither necessary nor feasible. Furthermore, according to grounded theory, it may be needed in only one case to identify the existence and direction of the relationship between two variables, events or things, for which statistical inferences analysis may not be possible.

***Establishing the domain to which a study's findings/results can be generalized*** (Yin, 1994): As stated in Chapter 1, Vol. I, the objective of this study is to develop a risk analysis framework for application in the domain of risks of maritime transport of PDG. Figure 2.4 shows graphically the conceptual structure of the framework, which consists of concepts and their relationships. However, the framework is much more than the concepts represented in graphic formats. It contains numerous theoretical categories and properties represented in word formats, which are very specific for the risks of maritime transport system of PDG. The constituent concepts vary from a high level of abstraction to more specific – from high to low levels of resolutions. The framework is readily applicable and specific to the intended domain, where the key concepts are illustrated with examples. However, the framework application is not confined to the "uniqueness" of the maritime transport system of PDG and risks associated with it. Given the representativeness of the units of study, the vast amounts of different types of data and information, and the analysis approaches selected and employed (see Chapters 2 and 4, Vol. I), the framework has a high degree of generalization. Because of the high level of abstraction, the framework has a wide domain of application. In addition, the maritime transport system and its outcomes (i.e. risks) share many similarities with other systems and their outcomes. For example, the framework could be employed in the analysis of maritime risks in general, risks of oil spills, risks in other modes of transportation and related activities, risks in the supply chain of dangerous goods, human and environmental and property risks.

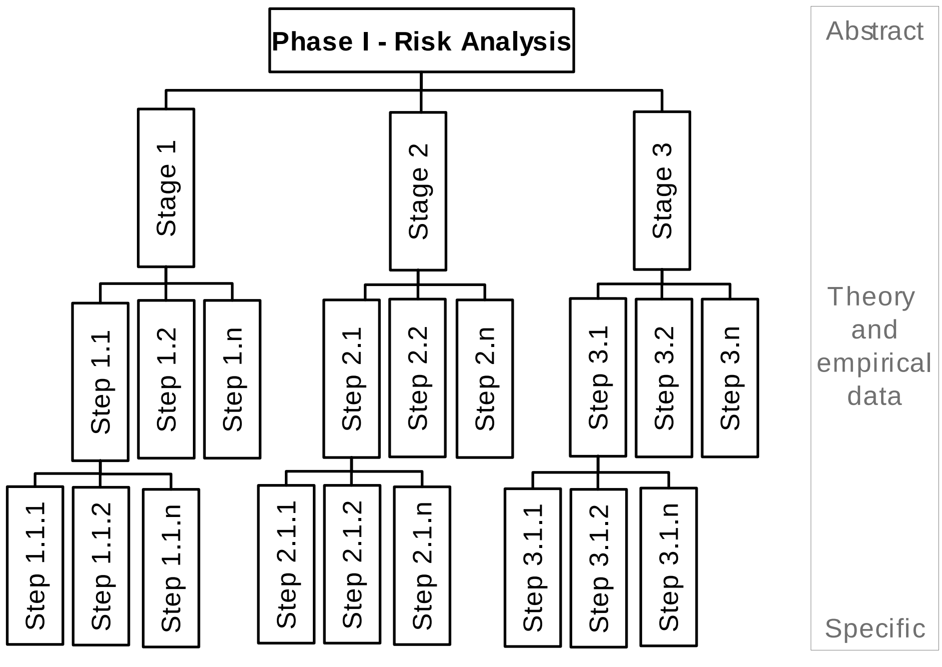


**Figure 2.4: Framework structure – the level of abstraction**

#### 2.4.5.2. Reliability

The terms "reliability", "repeatability", "reproducibility", "retest reliability", "consistency" and "stability" are often used interchangeably in the literature. *Reliability* is defined as the quality of a measure that possesses reproducibility (Batterham and George, 2003). Reproducibility indicates the degree to which a measure or a test produces the same results when applied repeatedly in the same circumstances (Nelson, 1997). Reliability is a prerequisite for test validity (Sue, 1999).

Yin states that the goal of reliability test is to minimise the errors and biases in a study (Yin, 1994). All measurements or tests are attended by measurement errors, which are broadly divided into two types – *random error* and *systematic bias* (Batterham and George, 2003). In connection with the case study approach, Yin (1994, p. 36) states that the objective reliability test is to be sure, if a later investigator *followed exactly the same procedures* as described by an earlier investigator and concluded the same case study all over again, the later investigator would arrive at the same results (findings/conclusions). Yin's statement ("theory") may not necessarily hold true in all situations, in particular in the social sciences. "Following exactly the same procedures" may be a necessary condition for many situations, but not a sufficient condition. Further, this is not the only condition.

The concept of reliability is relatively straightforward, but less clear is how best to assess and quantify reliability (Batterham and George, 2003). The literature review has shown that there is no general consensus about these issues. According to Batterham and George (2003), reliability is never perfect, as many factors can influence the reliability of a measure or a test. Any factor, regardless of how small it is, related to measurement situations that differ from measurement to re-measurement can adversely influence reliability as well as validity. Some of these factors include a) the dynamics and complexity of the phenomena or systems studied, b) the nature of the human element (body and mind) and its inputs into research processes, c) types of studies and research results generated ("results" encompasses a wide range of things). Measurements do not always involve physical, simple, static or universal systems or phenomena. According to Gottschalk (1995), reliability is affected by the inescapably human nature of researchers, and for this reason errors can only be minimized, not eliminated. Furthermore, during the time interval between two studies the presence and effects of the variety of influencing factors may lead to changes in variables during the study, which may not necessarily be indicative of poor reliability (Batterham and George, 2003).

Given the above issues, for two studies to arrive independently at the same results by following exactly the same procedures mean one or combination of the following scenarios:

- The results of both studies are reliable, according to Yin (1994);
- The results of the earlier study may be reliable, while for the latter, i.e. retest or re-measurement, they may be unreliable, or visa-versa;
- The results of both studies may still be unreliable.

In addition, the studies that follow the same procedures may still be reliable, even when they arrive at different results. Furthermore, studies may follow different procedures, but still arrive at the same reliable results. The history of science is full of examples of the mentioned scenarios. The history of pesticides is a good example. The invention or discovery of pesticides was once considered as one of the greatest scientific achievements of the 20th century. Pesticides were used extensively worldwide. But, many years later, it was discovered that pesticides have caused negative effects in the living organisms that outweigh their benefits. Today, the production and use, and subsequently transportation, of many pesticides are banned in the EU. The results of the earlier scientific studies, tests and re-tests, which might have followed the same or different procedures, were incomplete and, therefore, not entirely reliable and valid. The previous studies had failed to take into consideration and measure pesticides' bioaccumulation into the food chain.

In addition, if all studies following the same procedures were to arrive at the same results, then for one problem there would have been only one or very few solutions. However, in science, there are many examples where for a single problem or need many different solutions have been found or invented, for example, models, frameworks, guidelines, hardware or software. On the other hand, one solution may be applicable to many different situations. As this report shows (see Chapter 3, Vol. I, and Mullai, 2006b), there is a wide range of different frameworks, techniques or models available in the field of risk management, some of which are based on and serve the same risk issues.

In this study, in order to enhance reliability (minimise any error and bias) as well as validity, the following measures have been taken:

***Data triangulation***: In order to corroborate, fill gaps and extend the data, many diverse types of data and information are collected and analysed. For example, many individual case histories are based on multiple sources.

***Select the best data sources***: The relevant data and information are collected from the "best" and most "reliable" data sources available and accessible. The data have been checked several times to make sure that the data compilation is error free and complete.

***Select and employ data analysis methods*** such as contents and comparison analysis. Based on the contents analysis procedures and concepts, the data have been consistently coded in the same way in the analysis of every case history. Comparison is not only a very useful mode of analysis for exploration purposes; it is also important in enhancing the reliability of the study's results.

***Employ the grounded theory approach***: According to grounded theory, the accuracy of the data may not necessarily be deterministic in all situations, especially when the purpose of the study is to generate theoretical categories and properties – concepts, constructs and variables and their relationships. Generating theory may not necessarily be the facts, upon which a theory stands, but the conceptual categories and properties (Glaser and Strauss, 1967).

***Develop the study database*** (Yin, 1994): The research approach employed in this study is more transparent than many other approaches. This study relies largely on the data acquired from databases available for public use (see Chapters 2 and 4, Vol. I). The data availability allows transparency and verification of the rigorousness and logic in research processes, from data collection through data analysis and framework development to conclusions and recommendations. Validation, testing or replication of the research results (framework) by others is much easier as compared to many other research approaches and data sources.

#### 2.4.5.3. Framework demonstration

The above sections (see sections 2.4.5.1 and 2.4.5.2) discussed in some detail the principles of validity and reliability. The key measures taken prior to and during the process of the framework development to avoid threats and errors and enhance the validity and reliability of research results were also discussed. Chapters 1-7, Vol. II, serve the following interrelated purposes:

- Provide a full validating demonstration of the framework, i.e. how the framework works in practice. The results generated from the demonstration will enhance understanding of risks associated with the maritime transport system of dangerous goods and beyond. Recommendations for improving human safety and health and marine environmental and property protection are also provided.
- Test and thereby further enhance validity and reliability of the framework and research results generated by applying it. In order to enhance external validity of the framework, the demonstration is extended to other systems and activities of the dangerous goods supply chain.

Framework demonstration is based on analysis of *other datasets*, which combines both qualitative and quantitative or statistical datasets. The main datasets were:

- The m/v "Santa Clara I" accident case history (U.S. DOT, 1992; Whipple et al., 1993; McGowan, 1993; Merrick, 1993; Crokhill, 1992) and other cases as well;
- The two largest hazmat incident databases in the USA:
  - The U.S. Hazardous Material Information System (HMIS) database (1993-2004)
  - The U.S. National Response Center (NRC) database (1990-2004);
- Economic censuses: Commodity Flow Survey (CFS) - Hazmat Transportation Reports
- Population censuses: Statistical data for the U.S. population collected from 1990 and 2000 population censuses of the U.S. Department of Commerce and U.S. Census Bureau;
- Vessel statistics (U.S. DOT, 2001-2004);
- Other databases and data sources: including data from the U.S. Department of Transportation (U.S. DOT), the USCG, and the U.S. Bureau of Transportation Statistics.

Chapter 7, Vol. II, concludes that the risk analysis framework consists of valid and reliable variables representing the maritime transport system of dangerous goods and risks associated with it. The demonstration showed that the framework has the capacity to facilitate the risk analysis processes in this field and beyond.

## 2.5. Summary

Every reasonable effort has been made to select, combine and employ many different measures in order to avoid threats and strengthen validity and reliability of the research results. These combined measures included: selection of the appropriate research strategy and design; selection of the representative units of analysis, data collection and analysis methods; and selection, collection and analysis of a large amount of different types of data and information. Based on the analysis of a large amount of data, Chapters 1-7, Vol. II, provide a validating demonstration of the risk analysis framework presented in Chapter 5, Vol. I. Given the sample size and diversity, the results of this study may have a higher degree of validity and reliability than many other studies, including those cited in both volumes of this thesis.

# 3. The Frame of Reference – A Summary

*This chapter serves a theoretical platform for enhancing the understanding of the field and the development of the risk analysis framework. It provides the relevant constituent concepts, definitions and theoretical models in the essential interrelated research areas, such as maritime transport system of packaged dangerous goods, risks of dangerous goods, and the risk management system, including risk management and assessment frameworks and analysis techniques.*

## Introduction

Given the objectives of this study (see Chapter 1, Vol. I), the complexity of the research areas involved and the system approach and methods employed in this research (see Chapter 2, Vol. I), the purpose of the "Frame of Reference" (Figure 3.1) is to provide the relevant constituent concepts, definitions and theoretical models in the essential interrelated research areas. These areas are a) the *maritime transport system of PDG*, b) *the risks of dangerous goods*, and c) *the risk management system*. This section will serve as a theoretical platform for the development of the risk analysis framework. The theoretical platform is further expanded in Mullai, 2006a, 2006b, which provide the review and evaluation of risk assessment frameworks and techniques. Frameworks and techniques are the essential elements of the risk management system.

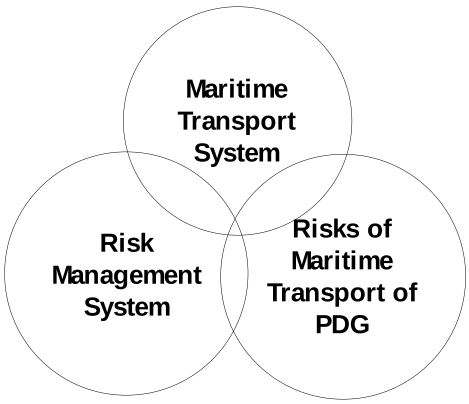


**Figure 3.1: The Frame of Reference – the key research areas**

The following is a condensed version of the Frame of Reference provided in Mullai, 2006a, 2006b.

## 3.1. Maritime transport system

The maritime transport system is linked to both the maritime industry and the overall transport chain (EC, 1996a). Transport by water is considered as a constituent part of the combined transport system (Verhaar, 1997). Maritime transport is vital to the world economy, and involves approximately 95 % (by tons) of international trade

(Wetzel, 2004). For example, approximately 95 % (by tons) of Swedish imports and exports are carried by sea (SMA, 2004). Large amounts of different types of cargoes, including dangerous cargoes varying from raw materials to manufactured goods that make up a vast and still growing volume of waterborne cargo, and passengers are moved by water.

There are numbers of maritime transport divisions viewed from different standpoints (Larsson, 1993). Some of the interrelated divisions often discussed in the literature include:

- *Transport service*: *liner* and *tramp service* (shipping) (Kendall and Buckley, 1990; Fink et al., 2002; Stopford, 1988; Coyle et al., 1994).
- *Freight/passenger*: *freight* and *passenger* (Coyle et al., 2000) and *combined passenger/ freight* (e.g. ro-ro ferry ships) transports or markets (Gordon et al., 1990). The freight market is further subdivided into dry cargo, tanker, reefer, and car carrier markets, where each division is further subdivided into sub-markets (Gordon et al., 1990).
- *Cargo parcel* – bulk/packaged: "*bulk cargo*" and "*general cargo*" or "*packaged cargo/ goods*" transport (Stopford, 1988). Bulk cargo is cargo, either dry or liquid, that is shipped unpacked in loose condition and which is of a homogeneous nature (U.S. TI., 2001). General cargo is broadly defined as "anything other than bulk" or non-bulk cargo composed of miscellaneous goods (U.S. TI, 2001). Other similar terms for general cargo are "break-bulk" and "packaged" cargoes (Kendall and Buckley, 1990).
- *Geographical area of operation*: *deep sea or ocean shipping* and *short sea or coastal shipping*. Technically, coastal shipping is defined as transport conducted within coastal waters (IMO, 1995). The term "*waterborne*" is used, for example, in EU transport project programmes (1998-2002) (EC, 2002b) to denote a broader concept of transport by water including a) *maritime transport* and b) *inland waterways transport* (i.e. rivers, canals, fjords and lakes).
- *Domestic/international*: *domestic* and *international* maritime transport (Coyle et al., 2000).

The distinctions among maritime transport divisions are very important from both theoretical and practical points of views (Metaxas, 1971). In principle, shipping statistics, shipping businesses, activities, teaching, maritime studies and researches are based on the mentioned divisions. For example, from a cargo parcel point of view, this study focuses on the maritime transport division of packaged goods, which includes *packaged dangerous goods*.

The maritime transport system is an important element of the distribution system, which consists of a number of elements that are subdivided into physical elements and activities or processes. The main interrelated elements of the transport system are presented and described in a conceptual model developed by Sjöstedt (1993) and others (KFS, 2003), including: *objects of transport* (i.e. goods and passengers); *means of transport* (i.e. ships); *infrastructure* (i.e. ports/terminals); *transport related activities* (i.e. transport, cargo handling, stowage etc). The model, however, does not contain certain important elements, such as the regulatory system governing transport. The main elements of the maritime transport system of PDG are, in many respects, specific for this transport. Given the distinct technical and operational aspects (see the IMDG Code, 2002), the maritime transport system of PDG is considered a specific element or sub-system of the maritime transport system. In following sections, the main elements of the system are defined and described.

### 3.1.1. Dangerous goods/hazmat

Dangerous goods – other similar terms are "dangerous cargoes", "hazardous cargoes" or "hazardous materials" as used in the USA – are substances, articles and materials that are classified in the SOLAS 1974, (Regulation 1, Part A, Chapter VII), as amended, and the MARPOL 1973/78, (Regulation 1, Annex III), as amended, which are both incorporated into the IMDG Code (2002, Chapter 1, pp.14-26). Dangerous goods are defined as substances, articles and materials that by virtue of their inherent hazardous properties can cause harm to human beings, the environment and properties (IMDG Code, 2002). Over 11 million chemical substances are known, and some 60,000 to 70,000 chemicals are in regular use (UNEP, 1997). Of those, approximately 3,000 chemicals account for 90 percent of the total number of chemicals in commercial and other uses (UNEP, 1997). The EU *White Paper on the Strategy for a Future Chemicals Policy* in the European Community provides the following figures concerning dangerous goods (EC, 2001):

> *The global production of chemicals has increased from 1 million tonnes in 1930 to 400 million tonnes today. About 100,000 different substances are registered in the EU market of which 10,000 are marketed in volumes of more than 10 tonnes, and a further 20,000 are marketed at 1-10 tonnes. The world chemical production in 1998 was estimated at € 1,244 billion, with 31% for the EU chemical industry, which generated a trade surplus of € 41 billion. In 1998, it was the world's largest chemical industry, followed by that of the U.S. with 28% of production value and a trade surplus of € 12 billion.*

The International Maritime Dangerous Goods (IMDG) Code (2002) provides a list of dangerous goods carried in *packaged form*. Dangerous goods are divided into 9 classes, which are further subdivided into sub-classes or divisions. The main classes are (IMDG Code, 2002):

- Class 1: Explosives – including six divisions
- Class 2: Gases - flammable gases; non-flammable gases and non-toxic gases; toxic gases
- Class 3: Flammable liquids
- Class 4: Flammable solids; substances liable to spontaneous combustion; substances which, in contact with water, emit flammable gases
- Class 5: Oxidizing substances and organic peroxides
- Class 6: Toxic substances and infectious substances
- Class 7: Radioactive materials
- Class 8: Corrosives
- Class 9: Miscellaneous dangerous substances and articles

Since 1991, all substances and materials harmful to the marine environment but not to people or the ship, have been included in Class 9. Based on the pollution severity, the IMDG Code (2002) divides marine pollutants into *marine pollutants* (P) and *severe marine pollutants* (PP). The IMDG Code (2002) provides detailed information concerning maritime transport of *packaged dangerous goods*, including the shipping name, the primary class, the compatibility group, the subsidiary class, the UN number, the packing group and the risk group.

### 3.1.2. Packaging system

With regard to the form of containment in which they are carried, dangerous goods/cargoes are carried by water in bulk and *packaged form*. Oil and oil products (class 3), liquid and solid chemicals, and liquefied gases (LNG and LPG) fall in the "bulk" cargo division. Large amounts of many different types of dangerous goods are carried in packaged form. Unlike dangerous bulk cargoes, PDG carried by water include all classes. There are many different types of packagings or containments that are designed and constructed for the purpose of the carriage, storage, handling and use of a vast range of dangerous goods. Packagings vary in size, shape, capacity, strength and materials. The principles of packaging design, construction, function and performance are described in detail in Paine (1990) and Jönson (1998). The IMDG Code (2002, Chapter 1.2, pp. 27-34) defines and describes in detail different types of dangerous goods packagings. Packagings are divided into three main levels: *primary* packaging, *secondary* packaging or shipping container and *tertiary* or unit load (Paine, 1990). In shipping, there are more than three levels of packagings. In terms of packaging levels, the IMDG Code (2002, Chapter 1.2, pp. 27-34) categorises packagings into *inner* packagings and receptacles, *intermediate* packagings, *outer* packagings and *composite* packagings. For packing purposes, substances, materials and articles of all classes, except classes 1, 2, 4.1, 5.2, 6.2 and 7, are assigned to three packing groups in accordance with the degree of danger they pose. The packing groups are (IMDG Code, 2002, Vol. 1, p. 49):

- Packing group I: Substances presenting higher danger;
- Packing group II: Substances presenting medium danger;
- Packing group III: Substances presenting low danger.

The IMDG Code (2002, Chapters 6.1-6.9) provides general and specific provisions for construction and testing of packagings, IBCs, large packagings, portable tanks and road tank vehicles.

### 3.1.3. Ships

PDG are carried by many different types and sizes of ships, which are classified in different ways (see for example the classification systems in LRS, 1996, 1997; UNCTAD, 2001; SMA, 2002). Some of the ship types carrying PDG include general cargo ships, container ships, ro-ro cargo and cargo/ passenger (ferry) ships, reefer ships, bulk carriers and other types of ships (Brodie, 1994; Stopford 1988; Gordon et. al., 1990). Unlike dangerous bulk cargoes, PDG are carried together with non-dangerous goods in cargo/passenger ships. They are also carried in "limited quantities" (IMDG Code, 2002), for example in the form of passengers' personal effects, on board passenger (cruise) and ferry ships. In practice, many ship types do not operate in a separate and self-contained market. Despite specialisations, there are some degrees of substitution among ship types (Stopford, 1988). Some ship types move freely from one market to another, for example OBO (oil/bulk/ore) and reefer ships. In addition, given ships' properties and service abilities, there is no clear-cut distinction among certain ship types (see systems mentioned above). Case histories (HCB, 1986-2003) have shown that, in some cases, pallets, tank or freight containers with dangerous goods are reported to have been carried on the decks of small coastal oil/chemical tankers or barges.

### 3.1.4. Ports

As the link between sea and land, ports are the points where different transport modes meet (EC, 1996b; Poza et al., 2003). Ports vary in type, size, management, specialization and technology. They facilitate essential ship activities (i.e. port time), such as loading and unloading, stowage, segregation and cargo securing. Ports provide a wide range of cargo handling systems including cranes, forklifts and many more. They also provide storage facilities for large amounts of many different types of cargoes, including PDG. In many countries, specialised warehouses are built and equipped to serve handling and storage of PDG. Through ports flow international and domestic dangerous goods, waterborne and land traffic (OECD, 1996a). Almost every port in the world handles dangerous goods (Roos, 1997). In 2000, the world's top 10 ports handled 42.4% and 55.8% of the total cargo volume and container traffic respectively in the top 40 ports (AAPA, 2004). In 2000, container traffic through the top 10 and 40 ports consisted of 41.5% and 74.4% respectively of the total world port container traffic of 192.3 million TEUs (AAPA, 2004; UNCTAD, 2001).

### 3.1.5. Transport related activities

The main activities related to maritime transport of PDG, which are highly regulated and specific for this mode of transport, known in the IMDG Code (2002) as "Consignment Procedures" (Part 5) and "Transport Operations" (Part 7), include: cargo handling, loading and unloading, filling (tanks), container packing, stowage, segregation, cargo securing, communication – (marking, labelling, placarding and documentation), and caring.

### 3.1.6. Packaged dangerous goods traffic

During the period 1970-2000, world cargo traffic, which includes a) oil and oil products, and b) dry cargo (iron ore, coal, grain, bauxite & alumina, phosphate and other dry cargoes), has more than doubled (Fearnley, 2000), whilst the "other dry" cargo traffic category has almost tripled – from 2,118 in 1970 to 5,951 billion ton/miles in 2000 (Fearnley, 2000). It is estimated that more than 50% of cargoes transported by water can be regarded as dangerous or harmful to the marine environment (IMO, 1996a). Between 10-15% of cargoes carried by water in packaged form, including these forms of containments: *shipborne barges on barge-carrying ships, freight containers, bulk packagings, portable tanks, tank-containers, road tankers, swap-bodies, vehicles, trailers, immediate bulk containers (IBCs), unit loads and other cargo transport units*, are packaged dangerous goods (IMO, 1996a). According to the editor of the Hazardous Cargo Bulletin (2000)[14], this figure may be higher for some ports, countries and regions. The IMO's figures are only estimations. International and domestic waterborne traffics of PDG are largely unknown in many parts of the world. The volume of PDG vessel traffic cannot be readily and reliably identified from general vessel traffic statistics. For commercial and other reasons, ports and responsible authorities do not always provide statistical information (Monnier and Gheorghe, 1996). The waterborne traffic is affected by many different factors, but the most influential factors include world economy and trade, waterborne commodity trade, trade patterns, transport costs, political events, and technological developments.

### 3.1.7. Dangerous goods transport regulatory system

Transport regulations have been a major force shaping the transport industry (Coyle et al., 2000). Transport of dangerous goods is, at various levels (international, regional, national, local and even organisational levels), governed by a complex system of regulations. This system includes regulations, rules, legislations, acts, conventions, guidelines, recommendations, and codes of practices. Some important international regulations and codes of practices concerning PDG include:

- The International Convention for the Safety of Life at Sea (SOLAS) 1974. SOLAS 1974, Part A, Chapter VII, contains mandatory requirements for the carriage of *dangerous goods in packaged form* and solid bulk.
- The International Convention for the Prevention of Pollution from Ships (MARPOL) 1973/78. MARPOL 1973/78, Annex III, contains mandatory provisions for the prevention of pollution by *harmful substances carried by sea in packaged from*.
- The International Maritime Dangerous Goods (IMDG) Code.
- The Code of Safe Practice for Cargo Stowage and Securing (CSS Code)
- Recommendations of the Safe Transport of Dangerous Cargoes and related Activities in Port Areas

The most important International Conventions related to the carriage of *packaged dangerous goods* by sea are the SOLAS 74 and MARPOL 73/78 Conventions. Both Conventions serve as the legal basis for international and national regulations.

The principal international regulations for the carriage of *packaged dangerous goods* by sea are set in the International Maritime Dangerous Goods (IMDG) Code. The Code is harmonised with the "United Nations Recommendations on the Transport of Dangerous Goods" and other modal regulations. The IMDG Code is published in two

[14] Based on a telephone interview with the HCB editor (2000)

volumes, with a third volume entitled "Supplement." The Code contains *general and specific technical and operational provisions for packaged dangerous goods*. From 1st January 2004, the IMDG Code has become mandatory (IMO, 2004b). The amendments made in May 2004 to the IMDG Code update several existing sections of the IMDG Code and include a new Chapter 1.4 (“Security Provisions”) concerning the security of the carriage of dangerous goods by sea (IMO, 2004b). These amendments, which take into account the introduction of a new IMO Code, i.e. the ISPS (International Ship and Ports Facility Security) Code, entered into force in January 2006, but applied voluntarily from January 2005. The ISPS Code is introduced by the International Maritime Organisation (IMO, 2004b) as security measures against terrorism in ports, ships and territorial waters. Implementation of the ISPS Code requirements, which took effect in July 2004, has become mandatory for all member states of the IMO.

**Note**: For more information about the maritime transport system of PDG see Mullai, 2006a.

## 3.2. Risks of maritime transport of dangerous goods

The term “risk” takes various meanings and can be used in different situations, senses and contexts by different people. Numerous sources (e.g. Kaplan and Garrick, 1981; HSC, 1991; Ertugrul, 1995) define, in essence, the concept of risk as the likelihood of consequences of undesirable events. The term “undesirable events”, which is often used as a more neutral and generic term, denotes all types of events, from unsafe situations and near-missing incidents to major or catastrophic accidents involving large numbers of fatalities and injuries and extensive environmental and property damage. The terms "marine accident and incident" and "marine casualty" denote undesirable events in connection with ship operations (IMO, 1996b, 1996c; LRS, 1996). Risks are categorised in different ways, for example, voluntary and involuntary risks (Starr, 1969; Starr et al., 1976; USEPA, 1998), statistically verifiable and non-verifiable risks (Hammonds, 1992), natural risks, technological and human activities risks and many more.

Transport of dangerous goods entails possibilities of undesirable outcomes (Scott, 1996; HCB, 1986-2003). Transport of dangerous goods poses considerable threats to public safety and health, the environment and property (Weigkricht and Fedra, 1993; HCB, 1986-2003). With some variations, many sources (e.g. MIACC, 1990; HSC, 1991; Ertugrul, 1995; Weigkricht and Fedra, 1993; RMSI, 2001), agree that the risks of dangerous goods are:

> *Risks = (Frequency or probability of occurrence of the hazardous release events) x (Estimated consequences of the hazardous release events)*

Case histories (HCB, 1986-2003) and the literature study have shown that risks are generated by any possible combinations of dangerous goods components, properties and their related activities. Dangerous goods and dangerous goods-related activities (chemicals' lifecycle), including the maritime transport of PDG, are considered the risk "generators", "producers" or "sources", whilst the exposed people, the environment and properties are considered the risk “receptors"(Ertugrul, 1995).

Some important elements of dangerous goods risks include *accidents/incidents involving dangerous goods*, *transport hazards* and their *causes and contributing factors*, *dangerous goods hazards*, the *likelihood* (frequency or probability), and the *consequences* (effects or impacts). The system and risk elements are classified and defined by various classification or coding systems, which, to some degree, are incompatible, see for example these sources (IMO, 1994a, 1994b, 1994c, 1995, 1996c, 1996d, 1996e; LRS, 1996, 1997; SMA, 2002; U.S. DOT, 1995; HSC, 1991; Byers and Hill, 1991; Bell, 1996; USCG, 2001).

In shipping, the terms "marine accident" and "marine casualty", which share similar meanings, are used to describe undesirable events in connection with ship operations (IMO, 1996b, 1996c; LRS, 1996, 1997; SMA, 2002;). With regard to the severity of events, marine event are categorised into “very serious”, “serious”, “less serious” and “hazardous” incidents (IMO, 1996c). The main categories of marine accidents/ incidents are: collision, stranding/ grounding, contact, fire/explosion, hull/ watertight damage, machinery damage, damage to ship or equipment, capsizing/listing, missing and others (IMO, 1994b, 1996b, U.S. DOT, 1995; LRS, 1996, 1997). MARPOL 78/78 provides the following definitions for the marine events involving or likely involving PDG:

> MARPOL 73/78, Appendix to Protocol I:
> *Incident* involves the loss or likely loss overboard of packaged dangerous goods, including those in freight containers, portable tanks, road and rail vehicles and shipborne barges, into the sea.
>
> MARPOL 73/78, Annex III:
> *Marine pollutants incident* is the loss or likely loss overboard of harmful substances in packaged form including those in freight containers, portable tanks, road and rail vehicles and ship-borne barges, identified in the IMDG Code as marine pollutants.
>
> MARPOL 73/78, Article II of Protocol I:
> *Incident* is a discharge or probable discharge of harmful substances in packaged form, including those in freight containers, portable tanks, road and rail vehicles and ship-borne barges.

The maritime transport system of PDG is exposed to a wide range of different transport hazards. The principal hazards include mechanical, climate/weather, chemical, electrical, electro-chemical, radioactive, biological and other hazards. Some of these hazards are typical for maritime transport of PDG. For example, dangerous goods and packages are exposed to mechanical forces, bio-deterioration and moisture. The main categories of consequences are human, environmental and properties consequences due to dangerous goods hazards. Based on the categories of risk receptors, risks are divided into human risks, environmental risks and property risks and other risks. With respect to the categories of people exposed and the severity of consequences, risks are divided into *individual* and *societal risks* (HSC, 1991; HSE, 2001).

According to the Globally Harmonized System of Classification and Labelling of Chemicals (GHS), dangerous goods hazards are classified into two main categories, a) physical hazards, and b) health and environmental hazards, for both substances and mixtures. The list of hazardous properties (IMDG Code, 2002; ACS, 1998) includes toxic, corrosive, explosion, fire, poison, infection, marine environment pollutant, radioactive and other properties such as carcinogenic, mutagenic, immunotoxic, neurotoxic, reproductive or developmental toxic properties. The extent or magnitude of effects due to dangerous goods hazards depends on the type, the physical state, and the quantity of dangerous goods and a wide range of other factors and conditions. Many dangerous substances, materials and articles possess more than one hazard, while others share similar hazards. Many dangerous goods possessing some of the hazardous properties mentioned are carried by water in *packaged form only*. The vast range of hazards posed by dangerous goods carried in packaged form is one of the properties that distinguish the risks of PDG from the risks of dangerous bulk cargoes.

**Note**: For more information about the risks of dangerous goods see Mullai, 2006a.

## 3.3. Risk management system

Despite the significant progress being made across many countries, industries and sectors, there are still misconceptions, misuses and ambiguities in the field of risk management. For example, although in the field the term "analysis" is narrower than the term "management", the Society for Risk Analysis (SRA, 2004) has chosen to broadly define "risk analysis" as the process that includes risk assessment, risk characterisation, risk communication, risk management, and policy relating to risks. Two other prominent organisations, namely the EC Health and Consumer Protection Directorate (EC, 2000a) and the Comprehensive Risk Analysis and Management Network (CRN, 2004), which is a Swiss-Swedish workshop network initiative for international cooperation between governments, academics and industries and sectors, share a similar perception of "risk analysis." Based on the extensive literature review and the understanding gained in this research, this chapter attempts to provide a unified understanding in the field.

The term "*risk management system" (RMS)* is considered the broadest term – some other similar terms are "Safety Management System" (SMS) (Demichela et al., 2004; Basso et al., 2004), "Integrated Safety Management System" (Trbojevic and Carr, 2000), "Risk-Based Decision Making"(EC, 2000b; USCG, 1999, 2001), "Risk Policy-

Making System", "Social Governance of Risks" (TRUSTNET)[15] "Integrated Socio-Economic Risk Management" (OECD, 2000), "Sound Risk Management", "Total Risk Management System" and "Safety, Health and Environmental Management System."

The "*risk management system*" is the overall integrated formal process consisting of two essentially interrelated and overlapping, but conceptually distinct, components – *risk assessment* and *risk management*. *Risk assessment* is an integrated element of the system that consists of *risk analysis* and *risk evaluation* (RSSG, UK, 1992). However, in many cases, the terms "risk analysis" and "risk assessment" are often 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). The main stages of the 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 the empirical data and many literature sources, including these sources (HSC, 1991; Ertugrul, 1995; Weigkricht and Fedra, 1993; DNV, 1995, 1996; DETR, 1999; OECD, 2000, IEC, 1995; ISO, 1999; EC, 1997, 2000b, 2000c; Vincent and Milley, 1993) and many more cited in this volume, Vol. I, and Mullai, 2006b. They are further developed for readily application in the risk analysis in the maritime transport system of PDG. A detailed discussion about the stage of the risk analysis is provided in Chapter 5, Vol. I, and Mullai, 2004.

*Evaluation* is the process of comparing the estimated risks against the established risk criteria. Risk criteria take many forms, for example, legal, ALARA ("As Low As is Reasonably Achievable"), ALARP ("As Low As is Reasonably Practicable"), and BATNEEC ("Best Available Technology Not Entailing Excessive Costs"), specific company or industry standards, conventions, scientific and technical standards.

Risk management, which may be viewed as ways of managing (Wang and Foinikis, 2001) or dealing with the risks, attempts to provide answers to the questions of how best to deal with the 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 these key steps (Weigkricht and Fedra, 1993; Vincent and Milley, 1993): identification, analysis and in consultation with all interested parties weighing of risk management strategies and measures; cost benefit assessment and consideration of other relevant factors relevant; decision-making; planning; and implementation and monitoring.

Although the list of measures and approaches for dealing with risks is endless, there are a few principal management strategies, namely *avoidance/elimination*, *reduction*,

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

*transfer and retention* (USCG, 2001; Knight, 1999). The strategies consist of a list of risk management measures that can be categorised in different ways, for example, based on the purpose of enactment (e.g. preventive and mitigation measures), legal aspects (e.g. voluntary and non-voluntary measures), and their nature (e.g. technological, operational, financial, training and education, and methodological).

Risk communication has become an important integrated component of the risk management system. It is an interactive process of exchange of relevant information and opinion among risk assessors, risk managers, and interested parties - individuals, groups and institutions.

The model (Figure 3.2) shows the main components of the risk management system. As mentioned above, the risk management system is a stepwise process comprising two interrelated but distinct generic stages: *risk assessment* (analysis and evaluation) and *risk management*. The process has a hierarchical structure consisting of different levels, in which the highest levels are further broken down into steps. Each stage consists of a number of steps that, in principle, are sequential. However, in many situations, this may not necessarily be so. The stage of the risk analysis is further expanded and adopted for the maritime transport of PDG.

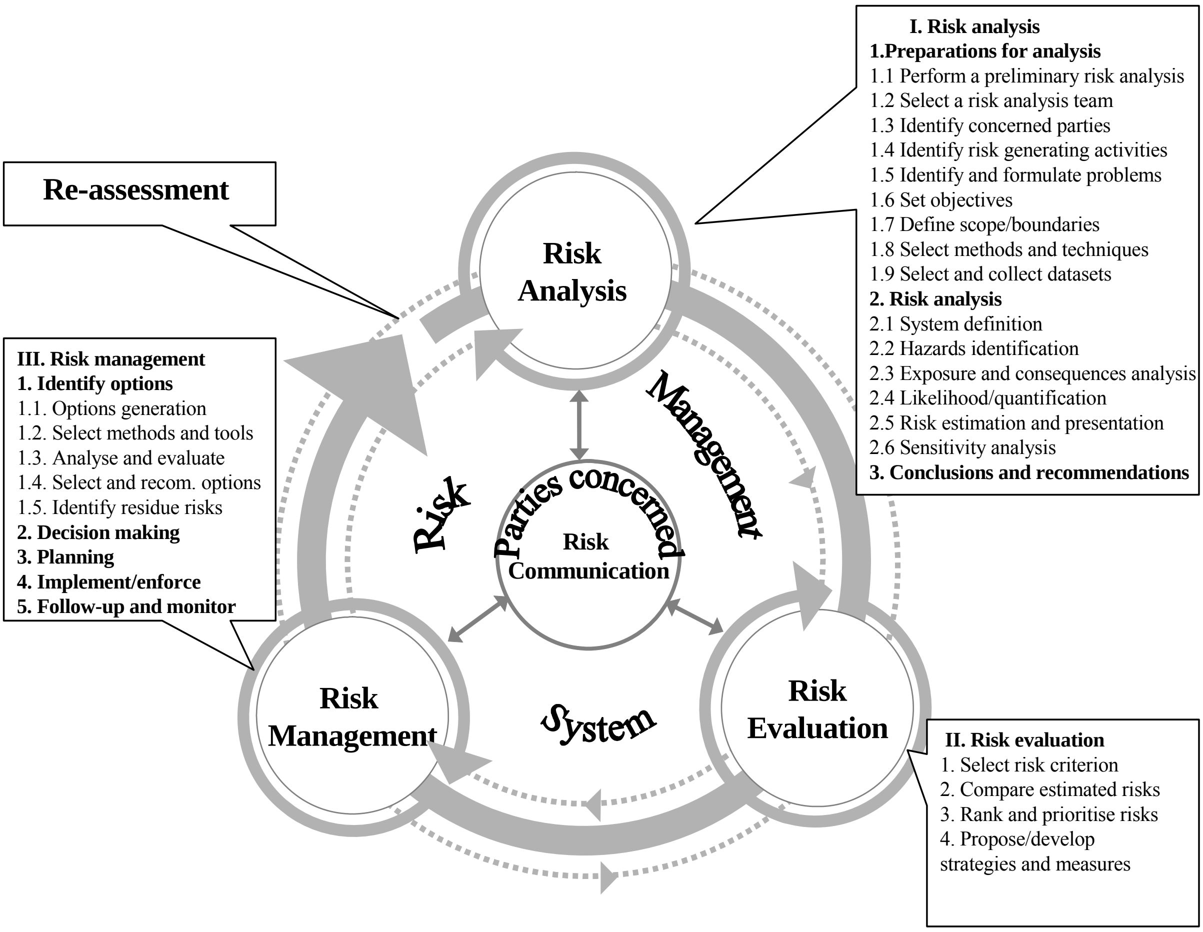


**Figure 3.2: Main components of the risk management system**

**Note**: For more information about the risk management system see Mullai, 2006b.

## 3.4. A review of frameworks and techniques

There is no generally agreed definition of what may constitute “framework” and “technique”. Similar terms that are interchangeably used include “standards”, “guidelines”, “procedures” and “approaches”. 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.” Some frameworks consist of guidelines that are beyond the risk analysis or assessment processes – *they encompass the wide range of the constituent elements of the risk management system* described above. For example, they may include activities concerning decision-making, planning, implementation and follow-up. However, the term “risk assessment framework” is most frequently used in this chapter (and Mullai, 2006b). Meanwhile, risk analysis techniques are employed as analytical tools for analysis of risk-related data. Some techniques are designed to aid analysis of a particular risk element (e.g. hazard identification), while some others are best suited for analysis of numerous risk elements.

In order to develop a risk analysis framework for application in maritime transport of PDG, many frameworks and techniques have been reviewed. Given the system and risks’ similarities and differences between maritime transport and other industries, sectors and aspects, the review covers risk management practices, risk management and assessment frameworks and techniques employed in shipping and other industries, sectors and areas. All dangerous goods related activities and aspects share in common risks that dangerous substances and materials pose to human beings, the environment and properties. Regardless of the type of system or activity, the principal elements of the risks are the same, including causes and contributing factors, frequency, consequences and exposures. Given the system and risk properties, the maritime transport system of PDG and risks associated with it are, to some extent, unique compared to, for example, maritime transport of dangerous bulk cargo (e.g. oil, oil products, LNG and LPG), other transport modes and chemical supply chain activities.

In recent years, large numbers of frameworks have been developed by many different national and international bodies, organisations in different industries and sectors, and individuals. They address a wide array of areas and issues related to risk management, such as human health and safety, environmental and property protection, production, transportation, storage and the use of chemicals, nuclear plants, offshore industry and many different types of businesses. Although generally relying on some fundamental principles, risk management and 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, legislation, and systems of countries, industries, sectors or activities. Numerous frameworks have been developed for application in the shipping and offshore industry. They vary from highly generic models designed for a 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. In this chapter, a few of many reviewed frameworks are presented:

### 3.4.1. Frameworks employed in industries and sectors

- Civil protection and rescue service (RSA, 1989)
- Offshore industry (UKOOA, 1999)
- ILO Guidelines on Occupational Safety and Health Management Systems (ILO, 2001)
- USA Environmental Protection Agency (EPA) Risk Assessment Guidelines (USEPA, 1989, 1998)
- USA Occupation, Safety and Health Administration Rules
- Chemical industry (OECD, 1996b)
- OECD Working Group Chemical Accident System (OECD, 2004)
- ISO 9000 and ISO 14000 Standards (ISO, 2004)
- International Standard IEC 300-3-9 (IEC, 1995)

### 3.4.2. Frameworks employed in shipping industry

- Formal Safety Assessment (FSA) (IMO, 1993, 1997, 2002)
- Safety Case (HSE, 1992)
- Quantitative Risk Assessment (QRA) – UK HSE/HSC, (HSC, 1991)
- Marine Accident Risk Calculation System (MARCS) (Fowler and Sorgård, 2000)
- USCG Risk-Based Decision-making (RBDM) Guidelines (USCG, 1999, 2001)
- QRA and Risk-Effect Model (REM) (Donk and Rijke, 1995; Erkut, 1996)
- SMA marine accident/risk analysis procedures (SMA, 2002)
- Other frameworks presented (EC, 1999)
    - Environmental Indexing of Ships
    - Environmental Accounting of Individual Ships
    - The Green Award System
    - The International Marine Safety Rating System (IMSRS)
    - Port State Control Approach
    - Human and Organisational Factors Assessment.

The review of the above frameworks has shown that no single framework available has the capability to serve all human safety and health and environmental problems and needs in shipping. They are not readily applicable to the risk analysis in the maritime transport of PDG. Despite an extensive search, no specific risk analysis framework for application in maritime transport of PDG has been found. Based on the review of the large numbers of frameworks and techniques, the following key stages and steps for preparing and performing the risk analysis are identified (see Mullai, 2006b and Table 3.5):

1. Preparations for analysis
2. Risk Analysis
2.1. System definition
2.2. Hazard identification
2.3. Exposure and consequence analysis
2.4. Likelihood (frequency/probability), evaluation, estimation, quantification
2.5. Risk estimation and presentation
3. Conclusions and recommendations

These highly generic stages and steps are further expended and developed in the risk analysis framework for readily application in the maritime transport of PDG.

The risk analysis process is generally facilitated by analysis techniques. Many risk analysis techniques (see the list below), which have been developed, adapted and applied in the risk analysis across different industries, sectors and activities, including maritime transport, are thoroughly reviewed and studied. They are collected from a wide range of sources, including (CCPS, 1989, 1992a, 1992b; CMPT, 1999; Brown, 1993; Ruxton, 1996; HSE, 1997, 2002; USCG, 2001; Simha, 2002; Hong and Dugan 2004; Piccinini and Ciarambino, 1997). The following is the list of techniques 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 (FMEA)
- Hazard and Operability (HAZOP)
- Fault Tree Analysis (FTA)
- "5 Whys" technique
- Event Tree Analysis (ETA)
- Human Reliability Analysis (HRA)
- Event and Causal Factor Charting (ECFCh)

Based on the understanding gained through the extensive review shown above, and the experiences of the two outstanding organisations, the Health and Safety Executive, UK (HSE, 1998, 2002) and the U.S. Coast Guard (USCG, 2001), and others (see Brown, 1993), strengths and limitations and other key characteristics of each risk analysis technique have been identified and presented (see Mullai, 2006b). Some important aspects related to risk analysis techniques, such as application, scope of analysis, data analysis method employed, complexity and efforts required, have also been discussed.

Numerous factors and strengths point to the principles of FTA and ETA techniques as the most suitable for application in the risk analysis of marine accidents/ incidents involving PDG. The Fault Tree Analysis (FTA) and Event Tree Analysis (FTA) 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 ETA is an *inductive or forward logic*-based search technique (Hong and Dugan, 2004). In principle, these techniques deal with two different risk elements – the FTA covers the cause analysis and the ETA covers the consequence or effect analysis. Consequently, they can conjointly cover analysis of the entire complex "cause-effect" chain, which is the "whole" risk analysis process. Both techniques, however, share similar principal procedures. They both follow similar sequential and logical procedures. 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). They are often used together (Hong and Dugan, 2004).

The FTA and FTA are two important (Abdollah, 2004) and very widely used techniques (Brown, 1993). Both techniques have proven in practice to be essential tools for risk analysis (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; Faisal et al., 2001), which are characterised by a large number of complex combinations of events (Nivolianitou, et al., 2004). Both techniques are used in risk studies concerning maritime systems (see HSC, 1991). The maritime transport system of PDG and the risks associated with it satisfy the mentioned properties (see Mullai, 2006a). The maritime transport system of PDG is a dynamic and complex system consisting of many different complex and interrelated sub-systems or elements. Problems, external disturbances or factors affecting the system are also many, interrelated and complex. In recent years, maritime transport of packaged goods, including containers and other forms of CTUs, has become a concerning issue (a "high risk" system) in many countries.

The FTA and ETA techniques are based on graphical modelling (Nivolianitou et al, 2004) (CCPS, 1992a, 1992b). Analysis performed by means of these two techniques can be well structured, visual, systematic, logical and easily understood. Such analysis may not be offered by many other techniques described in Mullai, 2006b. The FTA and ETA are among the most highly developed tools. In recent years, many efforts have been made to further develop the FTA and ETA. For example, 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).

In summary, in this research, efforts have been to develop a risk analysis framework based on the key stages and steps of the framework and *principle procedures* of the FTA and ETA (see Table 3.5). The principle procedures or structures of FTA (*top-down or backward logic – deductive approach*) and ETA (*forward logic – inductive approach*) are suited conjointly for application to the risk analysis in the maritime transport system of PDG, which is then integrated into the risk analysis framework (Figure 3.3). The aforementioned procedures are the principal procedures that do not exclude combined applications of the wide range of advanced qualitative and quantitative data analysis methods, models or techniques. Efforts have been made to integrate specifics onto the generic level. The logic of the model reflects the maritime transport system and risks associated with it (see Chapter 5, Vol. I).

**Note**: For more information about the risk assessment frameworks and techniques see Mullai, 2006b.

**Table 3.1: The key steps (structure) of the risk analysis framework, FTA and ETA**

| **Key steps – the structure** | | |
|---|---|---|
| *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 |
| 2.1. Hazard identification | 4. Explore each branch in detail | 4. Define accident scenarios |
| 2.2. Exposure and consequences analysis | 5. Solve the fault tree for possible combinations of events | 5. Analyse accident sequence outcomes – risk estimation |
| 2.3. Likelihood estimation, evaluation, quantitative analysis | 6. Identify important failures | 6. Recommendations |
| 2.4. Risk estimation and presentation | 7. Quantitative analysis – the frequency estimation | |
| 3. Conclusions and recommendations | 8. Recommendations | |

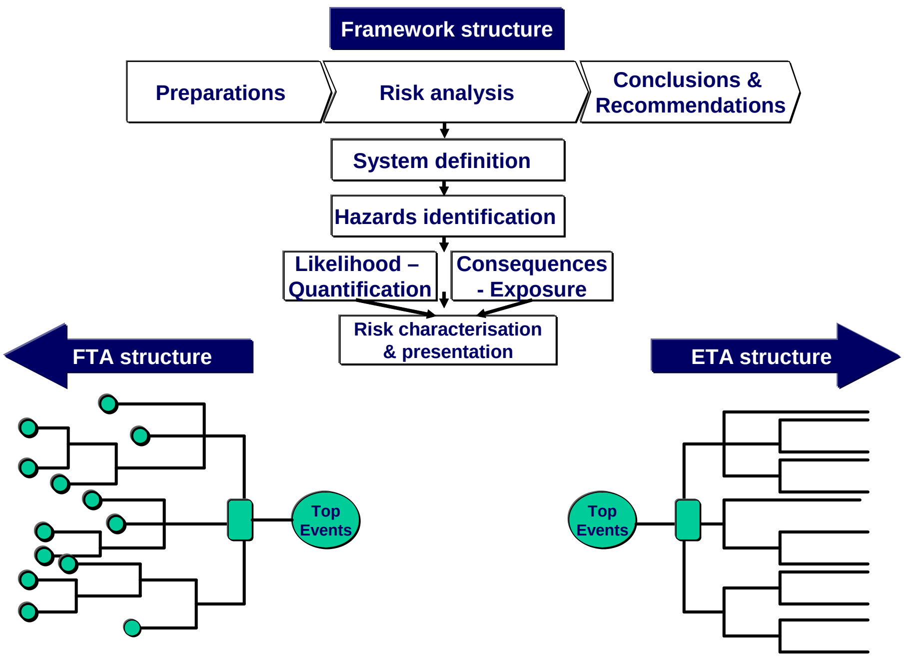


**Figure 3.3: Visual illustration of the risk analysis framework and the principle procedures of FTA (backward logic) and ETA (forward logic)**

# 4. Analysis of Marine Accident Case Histories

*Many marine accident case histories are analysed by the data analysis methods described in Chapter 2, Vol. I. In this chapter some illustrative examples are analysed. The understanding gained and the results of the analysis served the development of the risk analysis framework.*

### Introduction

The framework development is largely based on the review, exploration and analysis of a large amount of diverse empirical data (see Chapter 2, Vol. I), include the analysis of many marine accident/incident case histories, some of which are presented in the Appendixes 2 and 3, Vol. I. The purpose of the analysis is to explore the essential elements related to the maritime transport system of PDG and the associated risks, such as the courses of marine events; top events; causes and contributing factors; maritime transport hazards; the list of dangerous goods/hazmat and their hazardous properties; risk receptors exposure and the consequences of dangerous goods. The case histories vary in degree of detail. Many cases are collections of a large amount of materials from various sources. These materials have been collected through combinations of interviews and contacts with different people as well as review and examination of a large number of sources. Some case histories consist of detailed investigations or study reports prepared by the responsible maritime authorities or institutions (see Appendix 2, Vol. I). The case histories are selected on the basis of types of events, i.e. they *satisfy the conditions of marine accidents/incidents involving PDG*. The availability and the degree of detail of the information contained in the case histories and the consequences of events are other factors affecting the sampling. For many case histories, data have been collected from several different sources (see Appendix 2, Vol. I).

As mentioned above, the framework development is largely based on the analysis of many marine accident case histories presented in Appendix 2, Vol. I. For the purpose of demonstration, the following four marine accident/incident case histories are analysed in this chapter. The cases are named after the ship involved in the accident. For reasons of confidentiality, certain information contained in one of the case histories is not revealed. The data sources of the case histories are provided in Appendix 2, Vol. I.

- Case 1: M/v “Ariadne”
- Case 2: M/v “Dutch Navigator”
- Case 3: M/v “FNE”
- Case 4: M/v “Jolly Rubino”

The analysis of case histories combines several data analysis methods, including *grounded theory*, *explanation-building*, *chronological events analysis*, *categorisation*, *comparative analysis*, and *content analysis*. For more information about these methods as well as the research methodology in general, see Chapter 2, Vol. I. The degree of detail in the analysis was dependent on the amount of data contained in each case history.

## 4.1. Case 1: M/v "Ariadne"

### Summary

On 24th August 1985, the Panamanian cargo ship "Ariadne" grounded while leaving the port of Mogadishu, Somalia. She grounded 100 m from shore and 200 m from a residential area (see Figures 4.1 and 4.2). The ship was carrying 600 containers with general cargo and vehicles, including more than 40 different dangerous goods loaded in 118 freight containers, such as tetraethyl lead and sodium pentachlorophenate. Due to the prevailing weather conditions, the ship listed (up to $40^{o}$) and subsequently lost a number of containers and other cargo overboard, including containers with chemicals. The salvor that arrived at the scene attempted to refloat the vessel, but their efforts were unsuccessful. At the request of the Somali government, teams of experts from different western countries – the USA, France, the UK, Italy and Germany — arrived in Mogadishu to provide technical assistance in salvage operations, fire fighting, chemical response and marine environment assessments.

After approximately one month aground, exposed to weather hazards and in the absence of an adequate emergency response, the ship collapsed on 26 September, broke into two and subsequently caught fire. The fire, which was later brought under control, produced heavy smoke and toxic fumes heading towards the port and the residential area. Local authorities forced an evacuation of the port and city residents. The break-up of the ship caused further damage to containers and the release of secondary packagings (i.e. drums and bags) with chemicals, most of which ended up on the shore in the port and city areas. Many drums and bags were battered against the shore, releasing their chemical contents into the marine environment. A number of people reported headaches, dizziness and nausea. In addition, large amounts of diesel and heavy fuel oils were released from the broken ship. The incident caused serious marine environment and air pollution. The ship and her cargo were severely damaged and subsequently declared total losses.

This incident showed that the governments of the developing countries may not be properly equipped and prepared to handle incidents/accidents involving large varieties of dangerous goods carried in packaged form.

**Figure 4.1: M/v "Ariadne" grounded in the harbour of Mogadishu, Somalia in 1985 (IMO, 1986)**

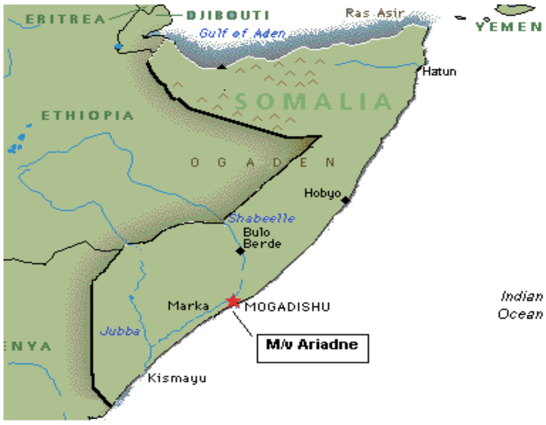


**Figure 4.2: Location of the m/v "Ariadne" accident**

### A detailed analysis

The following is a detailed analysis of the accident.

*The ship*: name: "Ariadne"; type: general/break bulk cargo, flag: Panamanian flag, built: 1979, size: 16,169 dwt.

*Cargo – dangerous goods*: The ship was carrying 9,925 metric tonnes (MT) of general cargo, including 645 MT of a wide range of dangerous goods (approx. 40 different types) loaded in 118 freight containers. The dangerous goods posed the following main hazards: fire, explosive, toxic/poison, corrosive, and marine pollutants. The following classes and numbers of consignments were loaded on board the ship:

- Class 3.1: 3 consignments
- Class 3.2: 7 consignments
- Class 3.3: 10 consignments
- Class 5.1: 1 consignment
- Class 6.1: 2 consignments
- Class 8: 1 consignment

Packaging types (pieces and tonnes)

- Drums: 1,511 pieces (pcs) - 458 tonnes
- Bags: 1,690 pcs – 41 tonnes
- Cartons: 9,260 pcs - 100 tonnes
- Pallets: 22 pcs – 10 tonnes
- Cans: 269 pcs– 18 tonnes

Examples of dangerous goods and their properties:

- Class 3.1 – Flammable liquids: UN 1208, hexane presents fire hazard, with a flash point 23$^{o}$ C.
- Class 3.3 – Flammable liquids: UN 1307, xylene presents fire hazard.

- Class 8 – Corrosives: UN 1849, sodium hydroxide forms a very corrosive caustic solution with water.
- Class 9 – Miscellaneous dangerous substances and articles: UN 3082, malathion is pesticide, toxic and bioconcentrate in biota.
- Class 3 – Flammable liquids: UN 1263, 1822 and 1933, solvent presents fire hazard
- Class 6.1 – Toxic substances: UN 1710, trichloroethylene decomposes in a fire to give off toxic fumes.
- Class 6.1 – Toxic substances: UN 2567, sodium pentachlorophenate, packing group II, marine pollutant; this was probably the worst material (250 bags, 5 tonnes) on board the ship to have affected the marine environment.
- Class 6.1 – Toxic substances: UN No. 1649 (tetraethyl lead) packing group I, subsidiary risk: flammable liquid. The ship was carrying approx. 118 tonnes of tetraethyl lead in 273 drums packed in seven freight containers. Lead is insoluble in water. The pollution from these types of substances may appear to be slight, as they may sink to the bottom of the sea and remain there. But, they can be disturbed by fishing gear and be brought onto the surface, contaminating the water. The substance can enter into the food chain, which results in serious long-term damage to the ecosystem and, potentially, to human health.

In addition, the cargo specified in the ship's documents (the cargo manifest) as "general cargo" consisted, among other things, of an unidentified amount of machinery and manufactured goods. These goods frequently contain chemical elements such as mercury, copper, lead and cadmium. For example, transformer oils may contain PCB. A large amount of dangerous goods passes through and is handled in many ports around the world, including those in developing countries.

### Chronology of events

- On 24 August, after completion of cargo loading, the ship left the port. While manoeuvring out of the port with the pilot and assisted by a tug, the towing line parted. Due to the prevailing winds, the ship was pushed and grounded on rocks bordering the inner harbour. She grounded 100 m off the beach in shallow waters near the port area and 200 m from the vicinity of the city of Mogadishu. Attempts to pull the ship off the rocks by using available local tugs failed. Due to weather hazards (winds, currents, seas, swells and tides) the ship listed, losing part of its deck cargo, including 14 containers with dangerous goods and several vehicles. More cargo was lost when the ship developed a list of $40^{o}$.
- On 26 August, the shipowner agreed with a salvage company (Murri International Salvage) based in Mogadishu on salvage of the ship based on Lloyd's Standard Form, 1980. The salvage operations began on 1 September, i.e. one week after the ship grounded. The salvor possessed two tugs and one landing craft. Due to inadequate and insufficient heavy salvage equipment and the prevailing weather conditions, the salvor failed to refloat the ship and remove all her cargo. However, the salvor managed to discharge containers loaded on deck.
- On 19 September, because of the salvor's inadequacy, the failure of the salvage efforts, a worsening of the situation and the lack of the required technical and

chemical expertise, the Somali government requested the IMO to assist, through teams of experts and advisers, in dealing with the situation.

- On 22 September, exposed to harsh weather conditions and the rocky sea bottom, the ship began cracking and leaking oil. The salvage firm lost all their pumps, and the landing craft was damaged several times by heavy swells, delaying operations.
- On 26 September, a fire broke out onboard the ship near cargo hatch no. 4. The fire was a result of nitric acid leaking from a container onto a fibreglass lifeboat in the cargo. The acid reacted with the fibreglass, creating extensive heat, which, in turn, led to a fire. The fire was associated with the release of smoke and toxic fumes that drifted towards the harbour and city area. The local authorities enforced an evacuation, which remained in force for some time, of residences and businesses along these areas. Fire ignition and explosive vapours remained potential threats throughout the salvage operations. By this time, the ship's hull was deteriorating rapidly and breaking up at no. 5 hold. Containers began falling into the sea, floating free, smashing against the cliffs and being damaged before reaching the shore.
- On 28 September, advisory teams (technical and chemical experts) arrived in Mogadishu from five countries, namely the USA, Britain, France, Italy and Germany. The experts discussed the possibility of salvaging the ship and cargo with the Somali government.
- On 29 September, after approximately one month aground and under the prevailing weather conditions (winds, tides, seas, swells and wave actions) that caused the ship's hull to work against the rocks, the ship deteriorated even further and subsequently broke into two and submerged into the sea. The two parts were separated by about 20–40 m, and in the next few days the holds flooded and part of the cargo either floated free or fell onto the sea bottom. By this time, as many as 113 containers marked as "dangerous goods" had been removed from the ship. However, many containers containing drums with chemicals, including tetraethyl lead, sodium pentachlorophenate, isopropyl alcohol and toluene, submerged with the ship's wreck. The contents of no. 5 hold fell onto the sea floor. A number of containers broke free, floated, were damaged and their contents (drums, bags and other debris) drifted ashore. Approximately 250 drums released from damaged containers beached ashore. The drums contained many different chemicals, including acetone, butyl and ethyl acetate, toluene and xylene. Most of the drums and bags were battered against the rocky shorelines, spilling their chemical contents. Unaware of the danger, local people rushed to the beaches to collect the cargo, including drums, bags and other items. Advised by the experts, the local authorities closed the beaches for days by means of policemen and soldiers.
- Under the supervision of the police, Somalis in boats and on the shore started a large-scale recovery operation of cargo (containers and drums) beached on the shore. All the materials recovered were transported to the port area for temporary storage. Many drums were severely damaged, and some of them were leaking chemicals. Somali workers wore no protective clothing while handling and attempting to plug leaking drums. In some cases, people were seen swimming around leaking drums. Despite the concerns of the foreign experts, the recovery operations continued without these measures of protection. On 10 October, all the

drums were recovered and placed together with the cargo recovered from the ship in a storage area in the port. The chemicals still presented serious hazards to the people working in the port and to the local community. A number of policemen on duty close to the storage area reported headaches, dizziness and nausea.

- On 3 October, after long negotiations, a salvage contract was signed between the shipowner's insurance company, Murri International and a Dutch salvage firm, Smit Tak, which is one of the world's largest specialised salvors. Smit Tak International was expected to bring heavy salvage equipment on the scene and start operations by the end of the month. Meanwhile, the ship's hull had deteriorated significantly. By this time, the work to discharge the rest of the cargo was in progress. The main concern was the submerged containers in no. 5 hold loaded with drums of sodium pentachlorophenate and tetraethyl lead.
- The ship's wreck was a cause of concern to the Somali government and foreign experts, as it could block the port entrance. The port of Mogadishu is a very important asset to the Somalia economy. Because of the instability of the wreck, the inadequate heavy salvage equipment of Murri International and potential explosions of the cargo trapped inside the wreck, the U.S. team proposed a postponement of the wreckage removal until Smit Tak arrived on the scene, i.e. waiting to the end of October.
- In late December, the forward part of the ship consisting of holds no. 1, 2 and 3 was towed and dumped about 35 miles off the shore into the Indian Ocean.
- The salvage operations were completed in May 1986.

### Hazard assessment

Harmful heavy metals and chlorinated organic compounds contaminated the sea, sediments, fish and other aquatic organisms around the wreck. In June 1987, the Somali government requested the IMO to assist in assessing the impact on the marine environment of chemical spillage caused by m/v "Ariadne". The Swedish Environment Research Institute (SERI, 1988) provided assistance in the assessment. The assessment of the state of the marine environment at the wreckage site consisted of analyses of many samples taken from sediments and the marine fauna and flora, including algae, corals, fish and other animals, for example, oysters, gastropods and crustaceans.

The assessment focused on an analysis of the following chemicals:

- *Mercury, copper, lead and cadmium*: according to the cargo manifest, onboard the ship there were 10 tonnes of batteries and unspecified amounts of machinery and manufactured goods, which contain one, or combinations, of the elements mentioned.
- *Lead*: 118 tonnes of tetraethyl lead; lead can enter the food chain and cause serious long- term damage to the marine ecosystem (fauna and flora) and subsequently affect human health.
- *PCB*: this substance was not listed in the cargo manifest, but according to the cargo manifest, the ship was carrying electric transformers as part of the general cargo; transformer oils often contain PCB.
- *DDT with metabolites*: 14 tonnes of DDT.

Concentrations of these substances around the wreckage were measured against the background (i.e. off shore sediments, some 25 km south of the port of Mogadishu) and other selected regions, which are summarised in Table 4.1. The assessment concluded that the substances mentioned could have contaminated the ship wreckage area in 1985. The analysis of samples taken in 1987 showed that the present concentrations were largely found to be within the range of, or lower than, what was normally observed in other parts of the world, namely the Indian Ocean, the Mediterranean Sea, the Arabian Gulf and the North Sea.

**Table 4.1: Comparisons of chemical concentrations (SERI, 1988)**

| Substance | Chemical concentrations on sediments at the site of the wreck | Level of concentration at the site of the wreck compared to | |
|---|---|---|---|
| | | Offshore sediments | Indian Ocean, Mediterranean Sea, Arabian Gulf and North Sea |
| Lead (Pb) | 1.7-3.0 mg/kg | No increased level | Lower |
| Mercury (Hg) | 5.2-7.8 ng/kg | Three to four times higher than the background - offshore sediments | Lower |
| Cadmium (Cd) | 80-350 ng/kg | No correlation with the location of the wreck | Lower |
| Copper (Cu) | 0.5-18 mg/kg | Levels within harbour area similar to offshore sediments | Normal or lower |
| PCB | 1-13.4 ng/g | Highest concentration found on the wreck | Higher/normal/lower |
| DDT | 0.1-4.0 ng/g | Highest concentration found on the wreck | Lower |

The dangerous goods (hazards: fire, toxics, marine pollution) carried on board the ship posed serious risks to people, the marine environment and local businesses. Response operations (salvagers) were unable to prevent further escalations of events. Unknown quantities of toxic chemicals entered into the marine environment. Parts of or the entire cargo of tetraethyl lead, sodium pentachlorophenate and trichloroethylene were never recovered. Many of the recovered packages were either damaged or partly or fully in contact with the seawater. Some Somali workers, those who wore no protective clothing while recovering damaged drums on shore, and policemen experienced dizziness, headaches and nausea.

### The course of events

On the basis of the information contained in the investigation report, Table 4.2 and Figure 4.3 summarise the course of events in a graphical form:

**Table 4.2: The course of events – the m/v "Ariadne"**

| Nr. | Event | Causes and contributing factors |
|---|---|---|
| 1 | Grounding | - Technical: towing line broke/parted<br>- Weather hazards: winds and currents |
| 2 | Listing – up to 40° | - Weather hazards: winds, currents, seas, swells and tides<br>- Delays in response/salvage operations<br>- Lack of adequate heavy salvage equipment<br>- Rocky sea bottom relief |
| 3 | Cargo lost overboard – containers with chemicals and vehicles | - Ship listing |
| 4 | Packages (containers – primary package, and drums/bags – secondary package) floated free/sank and breached/damaged | - Weather hazards<br>- Mechanical forces: impact, crash etc.<br>- Rocky relief<br>- Packaging type (containers, bags), design and construction: not watertight |
| 5 | Contents (chemicals) released into/in contact with water | - Packages breached/damaged, not watertight |
| 6 | Effects of chemicals:<br>- Human: in contact with chemicals, headaches, dizziness and nausea<br>- Environment: the marine environment contaminated<br>- Costs: costly operations | - Hazardous properties: chemicals released into/in contact with the marine environment<br>- People unaware of danger<br>- Lack of/inadequate expertise, equipment, resources<br>- No protective equipment |
| 7 | Fire/smoke/toxic fumes released | - Unsuccessful response/salvage operations<br>- Lack of adequate heavy salvage equipment<br>- Weather hazards<br>- Ship listing<br>- Breach/damage of packages: physical forces - impact, crash etc., packages not watertight<br>- Nitric acid leaked, contacted and reacted with fibreglass, generating heat |
| 8 | Effects of fire/smoke/toxic fumes:<br>- Environment: air pollution<br>- Human: no effects, people were evacuated<br>- Properties: cargo/ship damaged<br>- Disruptions: activities at the port and ashore suspended, large-scale evacuation<br>- Costs: costly operations, damages<br>- Threats: fire/explosion posed threat to salvage operations | - Hazardous properties of chemicals involved/released<br>- Weather conditions: winds drifted smoke/fumes towards the populated areas<br>- Lack of/inadequate expertise, equipment, resources |
| 9 | The ship wrecked: hull deteriorated, | - Weather hazards |

| Nr. | Event | Causes and contributing factors |
|---|---|---|
| | broke in two and submerged | - Rocky sea bottom relief<br>- Unsuccessful response/salvage operations<br>- Lack of adequate heavy salvage equipment |
| 10 | Packages with chemicals: submerged together with the ship, fell on the sea bottom, floated free | - The ship wrecked |
| 11 | Packages breached/damaged, contact with water | - Physical forces: impact, crash etc.<br>- Package type, design and construction: not watertight<br>- Weather hazards<br>- Rocky relief |
| 12 | Contents (chemicals) released, in contact with water | - See above (no. 6) |
| 13 | Effects of chemicals:<br>- See above (no. 6)<br>- Disruptions: activities at the port and ashore interrupted/suspended<br>- Threats/other concerns: the blockage of the port | - See above (no. 6) |

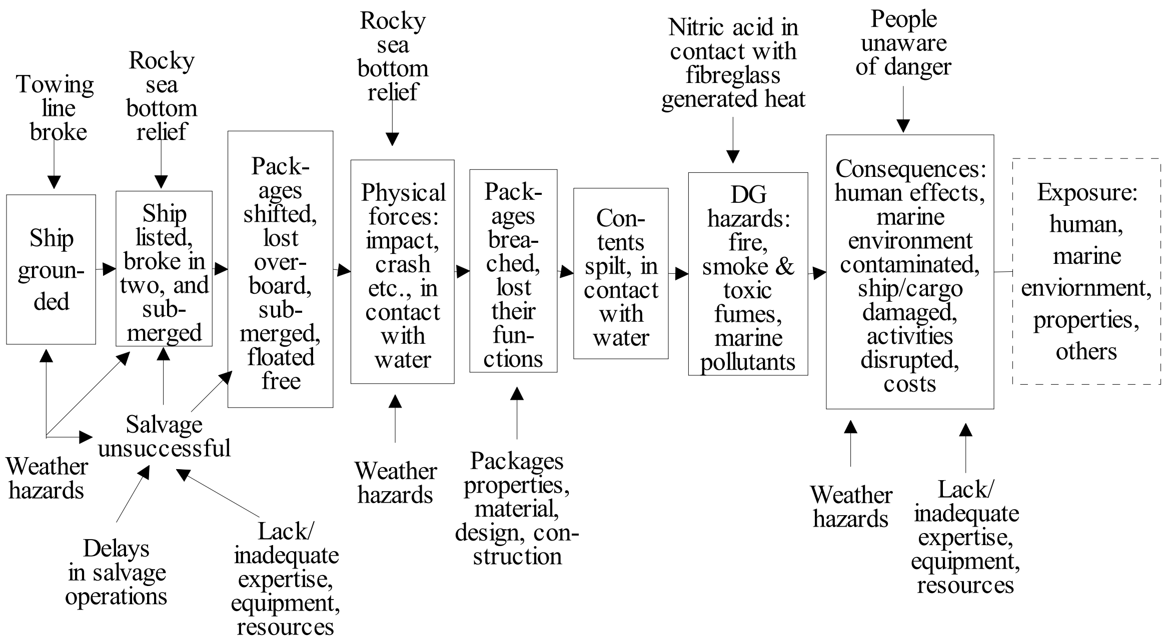


**Figure 4.3: Case 1: The course of events of the m/v "Ariadne" accident**

## 4.2. Case 2: M/v “Dutch Navigator”

Chemical experts (strike force) from the UK Maritime and Coastguard Agency were called out on April 27, 2001 to attend the 2,999 grt container ship “Dutch Navigator” arriving at the mouth of the Avon (UK) from Bilbao with nine containers damaged in heavy weather. One of the containers was carrying hexafluorosilic acid (class 8, corrosive, packaging group II) and another one sodium hypochlorite (class 8, corrosive, packaging group II/III). The response team isolated part of the dock area and advised the removal of intact containers to allow access to the damaged units. Emergency equipment was flown in from Milford Haven, and neutralising agents and protective clothing were made available for cleanup and removal of the chemicals in the containers. The strike force was stood down once the last container containing chemicals had been removed from the isolation area.

### The course of events

Table 4.3 and Figure 4.4 summarise the course of events for the m/v “Dutch Navigator” incident.

**Table 4.3: The course of events – the m/v “Dutch Navigator”**

| Nr. | Events | Causes and contributing factors |
|---|---|---|
| 1 | • Cargo securing system failed | • Weather hazards<br>• Heavy rolling/ movements |
| 2 | • Packages (secondary, tertiary) inside containers shifted, impacted, crashed etc. | • Weather hazards<br>• Heavy rolling/ movements |
| 3 | • Packages/containers breached/damaged | • Impact, crash etc... |
| 4 | • Chemicals spilt inside containers, probably also leaked outside containers | |
| 5 | • Dangerous goods hazards: corrosive hazards, acid may have reacted with cargo/materials | |
| 6 | • Consequences:<br>- Human: no one was affected, all crew safe<br>- Marine environment: no chemical spilt into the sea reported<br>- Property: parts of cargo and ship contaminated<br>- Other: activities partly suspended, part of the dock area isolated<br>- Costs: specialised costly operations | |
| 7 | • Exposure/threats:<br>- Human: all crew, strike force personnel, and other people ashore exposed<br>- Marine environment: environment exposed<br>- Property: the entire ship/cargo exposed<br>- Other: activities ashore exposed | |

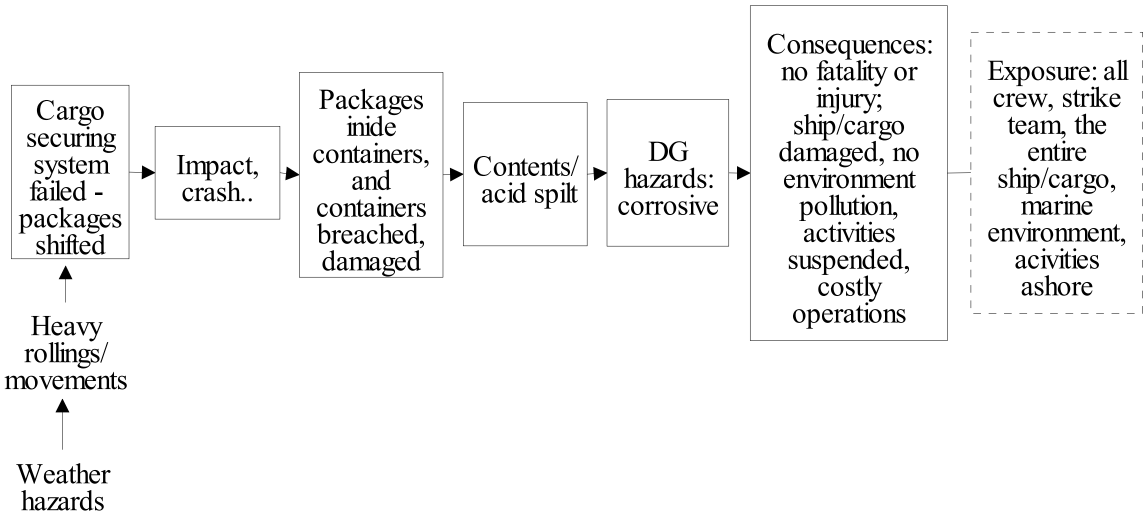


**Figure 4.4: Case 2: The course of events of the m/v "Dutch Navigator" incident**

## 4.3. Case 3: M/v "FNE"

### Summary

The Y-flag ro-ro ship "FNE"[16] (built 1979) was on a voyage from New Orleans (USA) to X port (Y country). On 1 October 1980, when the ship was north of Scotland, the prevailing hard weather caused a shifting of the cargo, including a tank container containing trimethylphosphite. The tank container came loose and contacted a refrigerated trailer, and subsequently the tank was damaged, spilling its contents onto the ship's deck. The tank's contents came into contact and reacted with the acid spilt from damaged batteries in the trailer, which produced flammable vapours. Fire broke out at 2020 hrs, followed some minutes later by a powerful explosion. The investigation suggested that the fire was probably ignited by sparks from the damaged batteries of the trailer. The fire was associated with heat, smoke and toxic fumes.

The fire fighting system was immediately brought into action, but because of a number of combined factors and conditions, the fire-fighting operations faced many problems and were unsuccessful. By this time, the fire had spread to the entire ship, and the ship therefore sent the distress signal, which was received and acknowledged at 2030 hrs on 1 October by the local coastal radio station. Severe weather conditions (9-10 on the Beaufort scale), the fire and toxic fumes created onboard the ship and restricted visibility were pointed out in the investigation as adverse factors that impeded rescue operations. At 2128 hrs, i.e. within approx. one hour from the transmission of the distress signal, the first rescue team arrived at the scene in a helicopter. The rescue operations were completed on 2 October at about 0145 hrs. The entire ship's crew and other family members onboard the ship were rescued by three helicopters. Unfortunately, five crewmembers were injured in the incident, two of whom

[16] This is a real case history, but for the purpose of confidentiality the ship's name is fictional and some data are not revealed.

developed some emotional/nervous problems. The fire was extinguished on 4 October, but a few secondary fires in containers continued up until 6 October. On 7 October the ship was then towed and returned to her owner. Both the ship and her cargo were extensively damaged.

### A detailed analysis

The following is a detailed analysis of the incident.

*The ship*: ship's name: "FNE", ship's flag: Y, ro-ro cargo ship type, built in 1979; with 8,761 grt, 4,623 nrt and 14,497 dwt, the ship had an unrestricted area of operation, was well equipped and operated periodically with an unmanned engine-room.

*The fire fighting system*: The ship's fire fighting system was divided into portable (e.g. portable extinguishers) and fixed systems. The fixed fire fighting system consisted of three systems (sub-systems): a) the water fire fighting system (hydrants); b) the sprinkler system - foam (light water - Aqua Film Forming Foam – AFFF) for car carrier ferries; this system was arranged to cover tweendecks, holds and garages; the AFFF was held in a separate tank with a capacity of 2,500 liters; and c) the CO2 system. Fire fighting pumps located in the engine room and parts of the system had a capacity of 5,500 litres/minute at 11kp/cm$^2$. In addition, there were also one or more emergency fire pumps with a capacity of 1,250 litres/minute at 12 kp/cm$^2$. The sprinkler system was divided into a number of sections. It was designed to supply a certain amount per unit time of fire fighting media per square meter of the protected surface. The system was equipped with pump injectors, which were coupled to fire pumps.

*Wells and drains*: Wells were emptied by means of bilge pumps with a capacity of 6,000 liters/minute, which were located in the engine room (pump room). As an emergency measure the wells can be emptied by the ballast pumps. In addition, fire-fighting pumps can be used as bilge pumps.

*Detection system*: Automatic detection systems were fitted in the cargo space, engine room, accommodation and other spaces. Detectors are either heat or smoke detectors. The ship's spaces were equipped with one or both types of detectors – heat and smoke detectors.

*Regulations:* The regulations concerning safety on board the ship specify that the fire fighting system should be kept in working conditions at all times and that the ship's fire stations should contain protection equipment including breathing apparatus with a specified action time and special equipment for chemical protection consisting of masks, sets of breathing apparatus of a given type and specified action time. The investigation commission concluded that the ship was in conformity with these regulations.

*Crew and family members*: The ship had a total of 22 people (19 crewmembers and three family members), including three women and two children. The master, deck officers, engine personnel and ratings all had many years of sea experience and were well qualified. The master, deck officers and engineers were equipped with relevant certificates of competency concerning handling dangerous goods in dry cargo ships and/or had attended fire fighting courses. Underway, the engine room was periodically unmanned. The engineer officer on duty was on “call duty”.  At the time of the incident, i.e. at the time when the cargo shifting occurred, the ship was in an autopilot mode of steering, and the engine room was unmanned.

*The ship’s stability*: The ship’s stability was not preserved throughout the voyage. The ship undertook numerous operations and activities, such as ballasting/deballasting, bunkering, provisioning and cargo loading/discharging, after the initial calculation of its stability. The ship’s meta-centre height (GM) at the time of the incident was judged by the commission to have been above the required minimum value.

*The cargo – dangerous goods*: The cargo consisted of unitised goods: packed timber and containerised cargo including several containers that were declared as dangerous goods in accordance with the IMDG Code. Three units were placed on tweendecks and the rest on the weather deck. Two tank-containers were loaded with dangerous goods, which had the following specifications: the state of the substance – liquid, the technical name – trimethylphosphite, class 3.3 (flammable liquids), packaging group III, with no subsidiary risk and no marine pollutant.

*Cargo securing system:* Because of the loading and unloading sequences and the time constraints, some containers on the tweendeck were loaded without special securing devices. These units, among which was one tank container with flammable liquid (class 3.3.), were only fastened with chains. Other containers in the lower hold had no container securing devices. The cargo was lashed only with chains and timbered. The ship was short of lashing equipment and other securing devices and equipment. She left the port of loading with 200–400 chain fastenings fewer than normal.

*Weather hazards*: The ship encountered a combined sea and swell with a maximum wave-height greater than 6 meters. The maximum wave height in this navigating area was over 8 meters, as reported by the local weather forecast stations.

*The voyage*: The ship was steering by autopilot. During the voyage, cargo securing was continually checked and lashing improved by tightening slack chains. However, the crew was unable to access all of the ship’s cargo spaces, especially the lower holds. In severe weather conditions, because of the danger, the crew may not be able to take measures to remedy the situation. It is too risky to work between cargo units in severe weather conditions. Initially, the ship developed a rolling of 15 degrees, where some platforms shifted on tweendecks.

*Cargo securing system failure*: At one point, the ship developed three simultaneous fast rolls with powerful lurches, causing the ship to list by 40 degrees. The cargo securing system failed — chains were broken and hooks failed. Platforms and stack-masters on the tweendeck came loose and slipped, causing lashing to break off and damaging the securing of other units, which later came adrift. If one or more units come adrift in hard weather, there is a possibility that the entire stowage could be affected. It is very likely that units that have come adrift could be severely damaged. Due to severe weather conditions, the extent of damage increases as units are repeatedly battered against the ship's structures or other units.

*Breach of the tank and the spill of its contents*: The tank container with dangerous substance was among the cargo units damaged. According to the crew's statements, they assumed that its contents had been spilt from the strange smell. Another container with drums containing rubber solution was also damaged, causing the contents to run out. The impact was so severe that the secondary package (i.e. drums) was also damaged. In addition to the sea-water spray and precipitations during the loading and voyage, spilt substances contributed further to the failure of cargo stowage and securing system by reducing the friction. Containers were not placed on deck fittings, but were rather placed on planks (sawn timber) and secured only by chains. Improper cargo stowage and securing of one single unit may make the entire stowage and securing arrangement unstable.

*Initial fire and explosion*: The flammable substance, which was spilt and spread to the entire ship's deck, developed flammable vapours. The crew reported that the fire broke out precisely where it was assumed that the tank container had leaked. The fire onboard the ship was the result of sparks generated by a leakage of electric current from the starting battery of the trailer when it was shaken from its position and probably damaged. The initial fire was followed some minutes later by a powerful explosion.

*Spread of fire*: The spread of the initial fire was not prevented. The fire spread fiercely and quickly, resulting in the development of great heat. The fire also affected other cargoes, which, in turn, started to burn and release flammable gases that later ignited. The speed at which the fire develops is dependent on various factors and conditions. Low flash point flammable liquids are likely to cause a fire which develops very quickly. The spilt flammable liquid on fire caused the fire to spread to other parts of the ship (lower holds). Furthermore, because of the very construction of the ship, ro-ro ship types have large cargo spaces without dividing bulkheads, and consequently the fire spread quickly and caused extensive damages. The ship's construction and equipment fulfilled international and national requirements. The fire fighting system was considered by the commission to be adequate. However, its performance was adversely affected by combinations of different factors and conditions. The system became useless when it was needed. The investigation commission judged that the system’s construction, capacity and pressure limits were some of the factors that hampered the fire fighting efforts of the crew. The crew was unable to determine the location of the fire and subsequently were in a dilemma: Where (in what part of the ship) to apply the required system/media? What kind of fire-fighting system to employ? What fire-fighting media to apply? The crew was unaware of fires in other parts of the ship. Secondary fires developed inside containers long after the first outbreak of fire. The fires inside containers lasted for approx. six days after the initial fire. These fires were extinguished by the salvors by applying water through holes opened in containers.

*Dangerous goods hazards:* Hazards associated with the dangerous substance included: fire/explosion – fierce fire associated with heat and followed by a powerful explosion; smoke – as a result of the fire, the ship’s spaces were quickly filled with dense smoke; toxic fumes – toxic fumes were released as the result of dangerous goods, other cargoes and materials and their mixtures burning. The heavy smoke and toxic fumes hampered fire fighting efforts, which were later abandoned. Due to fires and explosions, electric cables were destroyed and subsequently the entire electrical installation system failed, as a result of which the main engine and other machinery on board the ship came to a stop. The water fire fighting system also failed: pressure was lost because of failures and damage on the piping system and pumps. Onboard it grew dark, and the ship was left drifting on heavy seas, resulting in violent rolling (45 degrees). The use of water and fire fighting media caused the ship to list further, contributing to the spread of fire, cargo shifting and damage.

*Ship abandonment*: The failure of the fire fighting efforts and the development of dense and toxic fumes onboard the ship forced the crew to abandon the ship. Due to a combination of factors, including the fierce fire, dense smoke and toxic fumes as well as adverse weather conditions, the ship’s life saving system (lifeboats and liferafts) was out of use. All the people onboard the ship were successfully rescued by three helicopters that arrived on the scene.

*Personnel injuries*: Five crewmembers were injured in the incident, two of whom were injured while securing cargo inside the ship’s hold and one who was injured during the rescue operations. After the incident two crew members developed emotional problems.

*Damage to ship and cargo*: The ship and her cargo sustained extensive due to fire/explosion and toxic fumes.

### The course of events

Based on the information contained in the investigation report, Table 4.4 and Figure 4.5 summarises the course of events:

**Table 4.4: The course of events – the m/v "FNE"**

| Nr. | Events | Causes and contributing factors |
|---|---|---|
| 1 | The cargo securing system failed | • Adverse weather conditions<br>• Heavy ship listing<br>• The inadequate cargo securing system<br>• The inability of the crew to remedy the situation (i.e. tightening slack lashing) |
| 2 | • Cargo transport units (CTUs) including a tank container with flammable liquid broke free and came adrift<br>• The tank container damaged/breached | • The tank container hit by another CTU (the refrigerated trailer) |
| 3 | • The flammable liquid content spilt on the ship's deck and ignited | • The flammable liquid came in contact and reacted with acid from the damaged battery of the trailer, creating flammable vapours<br>• Sparks from the damaged battery |
| 4 | • Fire spread<br>• Fire followed by a powerful explosion; smoke and toxic fumes spread to the entire ship | • Adverse weather conditions<br>• Heavy listings<br>• Fire, heat, smoke, toxic fumes<br>• Explosive vapours<br>• Limited capacity and pressure of the fire firefight system<br>• The fire firefight system failed<br>• Fire fighting efforts failed |
| 5 | *Dangerous goods hazards*:<br>• Fire/explosion<br>• Smoke and toxic fumes | |
| 6 | *Consequences*<br>• Human:<br>- Evaluation - the crew forced to abandon the ship; all people (22 ) onboard the ship rescued<br>- Injury: five crew members injured or affected by the incident<br>• Property<br>- Ship and her cargo very severely damaged by fire/explosion and toxic fumes<br>• Marine environment: no environment pollution reported | • Fire, heat, smoke, toxic fumes<br>• Threats of further explosions<br>• Ship was at risk of sinking<br>• Adverse weather conditions hampered rescue operations |
| 7 | *Exposure*<br>• Human: all crew and other people on board exposed to dangerous goods hazards<br>• Marine environment<br>• Property: the entire ship and cargo | |

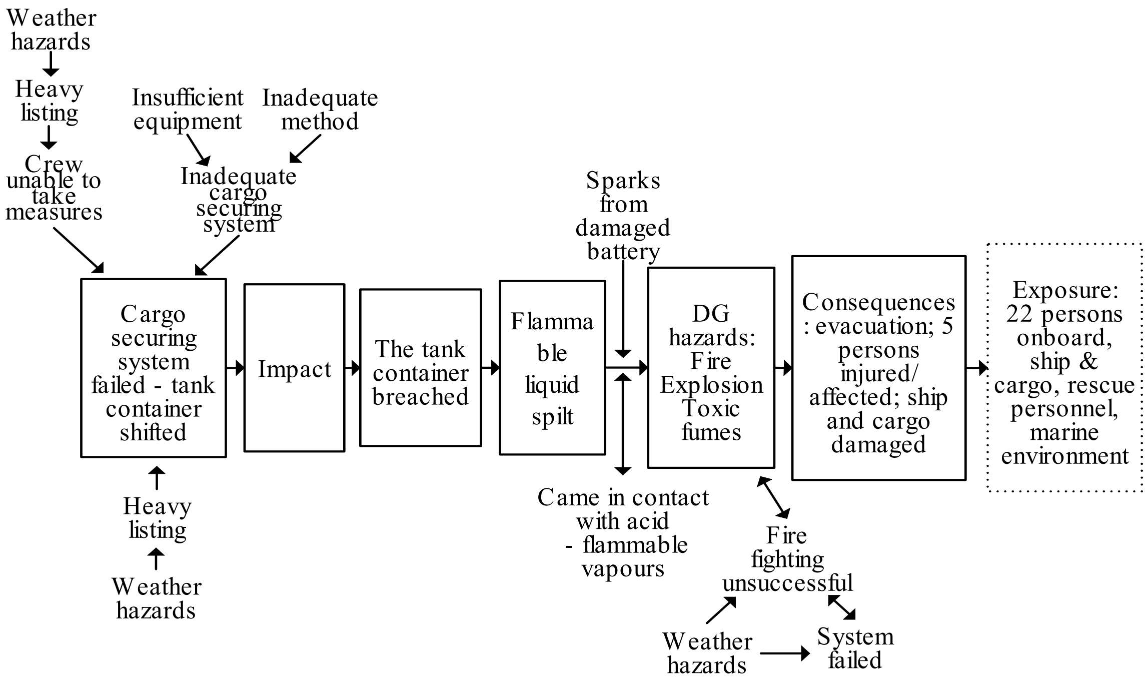


**Figure 4.5: Case 3: The course of events of the m/v "FNE" accident**

## 4.4. Case 4: M/v "Jolly Rubino"

### Summary

On 10 September 2002, the ro-ro ship 'Jolly Rubino' caught fire. The crew failed to extinguish the initial fire, which then spread throughout the vessel, causing extensive damage to the ship and cargo, including dangerous goods in drums. After failing to extinguish the fire and due to dangerous goods hazard, the master, officers and crew abandoned the ship. On the afternoon of 12 September, the vessel being under no control and in the prevailing weather conditions, drifted and ran aground 1.2 miles (approx. 2 km) north east of the Cape St Lucia lighthouse at a distance of 300 metres from the shore (see Figure 4.6). The port and starboard fuel tanks breached and opened into the sea. Due to damage to the hull, the fuel oil was spilt soon after the vessel grounded. Through large, long and difficult salvage operations, packaged dangerous goods were removed/ airlifted from the ship by means of helicopter to a land-based storage area. The weather conditions hampered the salvage operations.


**Figure 4.6: The ro-ro ship "Jolly Rubino" aground** (**SMIT Salvage, 2002**)

### A detailed analysis

The following is a detailed analysis of the incident.

*The ship*: 'Jolly Rubino' is an Italian-flagged ro-ro vessel with a deadweight tonnage of 31,262; dimensions: 190.5 m in length and 28.5 m in width.

*Cargo – dangerous goods*: the ship was loaded with, among other things, a considerable number of drums of dangerous cargo packed in freight containers. The nature of the dangerous goods was not reported.

*Salvage operations*

The Dutch salvage company, SMIT Salvage, took charge of the ship's salvage operations after signing a contract with the shipowner and the insurance company. The salvor undertook preparations for the salvage of the ship and her cargo. Equipment that was intended to be used in the salvage operation for the removal of empty, partly damaged and full drums of dangerous cargo from the fire-damaged deck area began to be taken on board by means of a helicopter. Preparations on land included designating and setting up a land-based temporary cargo holding area, located nine miles south of the ship. Dangerous cargo was planned to have been sealed in containment drums prior to transfer from the 'Jolly Rubino' to the storage site and then transported by road under escort to the Richards Bay Waste-Tech facility.

On 3 October, salvage personnel were evacuated from the ship after strong gusts of wind in excess of 70 km/h (40 knots) and increasing in velocity made conditions for flying a helicopter dangerous. Due to strong winds and dangerous working conditions, the fuel removal operation was also suspended. However, salvage personnel continued to monitor the condition of the grounded vessel, including the extent of the cracks in her hull on the starboard and port sides.

On 4 October, salvage personnel completed onboard preparations for the salvage operation involving the removal of the dangerous cargo on deck. On the ship's deck, a level working-platform was secured in place, which was used as a base for the salvage personnel during operations on the deck. Additional equipment and containment drums were landed onboard by helicopter. Once the operation was underway, a portable crane set up by salvage engineers lifted both intact and damaged barrels into the oversize containment drums prior to airlifting.

On 7 October, more than 330 barrels were airlifted from the deck of the grounded 'Jolly Rubino' to a high security temporary holding site on land. The salvage personnel followed strict safety and procedural guidelines and treated all barrels removed as potentially containing dangerous substances. The barrels were sealed into large containment drums prior to airlifting from the deck by helicopter. High swells prevented the fuel removal operation. Large amounts of pumpable fuel oils were removed from the ship.

On 14 October, after nine days of operations, approximately half of the dangerous cargo onboard the grounded ship was airlifted. SMIT Salvage personnel removed 1,000 barrels and six empty 20-foot freight containers from the deck by air, providing access to those containers still on deck that contained the rest of the dangerous cargo. Cargo was airlifted by a powerful Russian Mi-8 helicopter to the storage area. Large amounts of fuel were removed from the ship by means of storage tankers.

More than a month after the initial fire, salvage personnel reported that the fire was still smouldering in certain parts of the ship.

### The course of events

Table 4.5 and Figure 4.7 describe the course of events of the m/v “Jolly Rubino” accident.

**Table 4.5: The course of events – the m/v “Jolly Rubino”**

| Nr. | Events | Causes and contributing factors |
|---|---|---|
| 1 | Fire onboard the ship<br>The space where the initial fire started was unknown: cargo, engine room, accommodation or other space? | • Causes unknown<br>• Many probable causes |
| 2 | Fire spread to the entire ship | • Fire fighting efforts failed |
| 3 | Packages breached/damaged, burnt | • Fire/heat |
| 4 | Chemicals released, involved, burnt | • Fire/heat<br>• Packages damaged |
| 5 | Dangerous goods hazards:<br>• Fire<br>• smoke and toxic fumes<br>• threats of explosions | • Hazardous properties of dangerous goods |
| 6 | Ship grounded | • Ship lost control<br>• Crew abandoned the ship<br>• Fire, smoke, toxic fumes, threats of explosions |

| Nr. | Events | Causes and contributing factors |
|---|---|---|
| | | • Prevailing weather conditions |
| 7 | Ship damaged and listed | • Salvage operations delayed<br>• Weather hazards/conditions<br>• Sea bottom relief |
| 8 | Dangerous goods removed from the ship | |
| 9 | Consequences:<br>• Human: all crew safely abandoned the ship<br>• Marine environment: no environment pollution from PDG reported<br>• Properties: extensive damage to the ship and cargo | • Weather conditions<br>• Life saving system<br>• Salvage equipment/expertise<br>• Hazardous properties of dangerous goods |
| 10 | Exposure:<br>• Human: all crew exposed to hazards of dangerous goods<br>• Marine environment<br>• Property: the entire ship and cargo | |

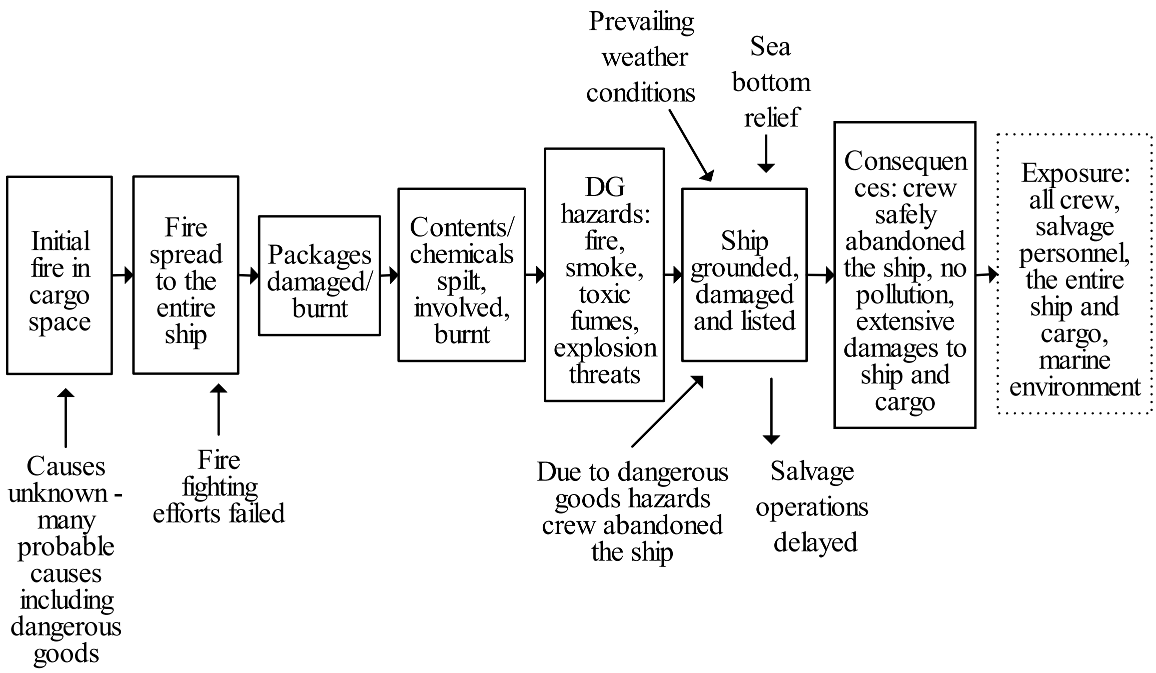


**Figure 4.7: Case 4: The course of events of the m/v "Jolly Rubino" accident**

## 4.5. The link: empirical data-theory-framework development

Table 4.6 shows the link among the data, theory and development of the framework. On the basis of the results of the data analysis (see Table 4.7), the principal stages and steps identified in the literature review and evaluation (see Chapter 3, Vol. I, and Mullai, 2006b) are further developed and adjusted for application in the analysis of the risks associated with the maritime transport system of PDG. Table 4.6 consists of two main columns. The main column on the left presents the procedures and a summary of the results of the analysis provided in Table 4.7. Based on the analysis of marine accident case histories, the main categories and sub-categories of the components of the system and the risks along with their incidences are explored. The column on the right (top) presents the main stages/steps of the risk analysis framework. Important elements to be dealt with in the analysis process are marked (from the top downwards) for each respective stage/step.

A thorough review of the data presented in Tables 4.6 and 4.7 indicates that the essential purpose and organisation of the risk analysis revolve around the answers to the fundamental questions concerning risks: "*What has gone wrong*?" "*What are the consequences*?" "*How often/much/many*?" (Kaplan and Garrick, 1981) These questions are followed by a wide range of other important questions. The answers to these questions serve the measurement of risks.

The following are the key states/steps of the risk analysis:

### Stage 1: Preparation for risk analysis

Prior to the risk analysis process, a number of interrelated important activities are performed (see some examples in Table 4.6), including: identification and formulation of the problems; setting objectives; definition of boundaries or the scope of the study; selection of risk analysis methods and tools available, selection of datasets and data collection methods etc. For example, the case histories show that data on marine accidents come from various sources (see Appendixes 2 and 3, Vol. I), some of which are not accessible to public use. Therefore, one of the important and primary tasks in preparing for the risk analysis is to identify these sources and assure their accessibility, if needed. The acquisition of the right amount and quality of relevant data is essential in risk studies.

### Stage 2: Risk analysis

The key steps and sub-steps that can assist in providing the answers to the aforementioned questions are as follows.

### System definition

The data show (see Table 4.6) that the maritime transport system of PDG and the risks associated with it consist of many specific, complex and interrelated concepts. The quality of the risk analysis results is primarily dependent on the precision of the definitions of the constituent concepts. Therefore, in order to measure correctly the risks of maritime transport of PDG, it is important, as the first step in the risk analysis process, to define and describe the key concepts. Some of the main and sub-categories of relevant concepts to be defined and described in the risk analysis are identified and shown in Table 4.6, including: categories of marine events, maritime transport hazards, main categories of causes and contributing factors, ship system, packaging system, time and location/position of accidents, the activity of the ship, cargo and dangerous goods, consequences and exposures to the hazards of dangerous goods. The maritime transport system of PDG, which includes almost every element, aspect or activity, is highly regulated, and therefore it is important to review and present the current state-of-the-art of the regulatory system governing this transport system.

### Hazard identification

The main purpose of this step is to provide answers to the question: What has gone or can go wrong? The data show that every marine accident is "unique" in its own right (see the diagrams of the course of events in each case history). Some chains of events are short and simple, but others are long and very complex. Every chain is based on cause-effect relationships, where often combinations of events (e.g. grounding) or things become the cause(s) of another event(s), i.e. effect or consequence, (e.g. cargo loss overboard and fire), and the latter becomes the cause(s) of other events (e.g. spills and marine environment pollution). For more details about these chains of events, see the respective cases.

***Top events***: Given the large number and complexity of chains of events in marine accidents, a set of events (top events) should be selected, from which the analysis should begin. The data show (see Table 4.6) that, in marine accidents involving PDG, the breach (failures and damage) of packages was a necessary common condition for the release of dangerous substances. The releases are, in turn, the necessary conditions for the dangerous substances to cause harm to risk receptors. This set of events (breach-release) can be selected as the top events.

***Transport hazards***: Packages carrying dangerous goods are exposed to a wide range of transport hazards, for example mechanical forces (e.g. impacts, crashing, and frictions), corrosion, and fire (see Table 4.6). The data show (see Table 4.6) that transport hazards have preceded failures of packages and releases of dangerous goods. These hazards are the necessary, but not always the sufficient, conditions for packages to fail and release dangerous contents.

***Causes and contributing factors***: The data show (see Table 4.6) that transport hazards are often due to combinations of different causes and contributing factors, including these principal categories:

- *Marine accidents/incidents:* this category includes marine events as defined by the IMO, LRS and other organisations, excluding fires/explosions in cargo spaces and "other" category (e.g. cargo losses, cargo shifting, toxic fumes releases, spills etc.). For example, in case 1, the m/v "Ariadne", the grounding of the ship preceded the exposure of packages to mechanical forces, failures of packages, and subsequently the releases and involvements of dangerous goods.

- *“Normal” transport:* this category includes causes and contributing factors that do not belong to the category of “marine accidents”, such as technical (e.g. cargo securing system failures) and operational (e.g. poor stowage) failures. For example, in the case 3, the m/v “FNE”, due to combinations of adverse weather conditions and an inadequate cargo securing system, a tank container with flammable liquid broke free and damaged after hitting another CTU. The flammable liquid released from the tank came in contact and reacted with acid from the damaged battery of the trailer, which created flammable vapours. The flammable liquid and vapours ignited as a result of sparks from the damaged battery.
- *Others*: this category includes other causes and contributing factors that do not fall in the above categories, for example deliberate acts. Case histories have shown that marine accidents are also due to deliberate acts.

In sum, all the categories of causes and contributing factors include the following principal elements: man, man-made, managerial, organisational and physical environment, including their relationships.

### Exposure and consequence analysis

This step includes the analysis of exposure and consequences due to hazards of dangerous goods.

***Exposure to hazards of dangerous goods***: The data show (see Table 4.6) that a wide range of risk receptors (human, the marine environment and property) are exposed to hazards of dangerous goods. The release of dangerous goods is the necessary, but not the sufficient, condition for the dangerous goods to cause harm. The exploration of risk receptors exposed to hazards of dangerous goods is an important step. Furthermore, the estimation of exposure of the risk receptors shown in Table 4.6 is an important element for measuring risks. However, the estimation of exposure requires other data and data collection procedures than marine accident case histories, such as statistical data collected on a regular or occasional basis on the essential elements of the maritime transport system of PDG and risks, for example dangerous goods flow or traffic, vessel traffic (calls), and the populations of risks receptors exposed.

***Consequences of dangerous goods***: What are the consequences of dangerous goods? The data show (see Table 4.6) that by virtue of their inherent hazards only (e.g. fire, explosion, toxics, and marine pollutants) dangerous goods have caused different types of consequences of varying magnitude or severity to different categories of risk receptors: humans, the environment (the marine environment and air), properties (see Table 4.6). Rescue and salvage operations involving marine accidents of PDG are very complicated and require a high level of expertise. They are generally time and resource intensive operations.

### Quantification – frequency estimation

Depending on the amount and quality of data available, almost every element of the maritime transport system of PDG and the risks associated with it can be quantified. Many of these elements are explored by analysing marine accident/incident case histories (see Table 4.6). Quantitative analyses encompass a wide range of procedures. Table 4.6 shows the estimation of the frequency or incidences and amounts/quantities of some important and relevant risk and system elements. The exploration and quantification are generally inseparable procedures. Frequency estimation is an important element of risk measurement.

### Risk estimation and presentation

Risks are estimated on the basis of the key elements explored and estimated in previous stages and steps, namely consequence, exposure and frequency. Some of the main categories of the risk receptors exposed to dangerous goods and consequences are explored in Table 4.6. Risks can be expressed and presented in various formats (see Chapter 5, Vol. I).

### Stage 3: Conclusions and recommendations

This is an important stage of the risk analysis. The key results of the analysis are synthesized and specific recommendations for improvements in the maritime transport system of PDG are provided.

### Summary

The results and understanding gained in the analysis of marine accident/ incident case histories, including those presented in this chapter, have served the development of the framework. Chapters 1-7, Vol. II, will further demonstrate that the risk analysis framework is largely grounded on the empirical data. The next chapter, Chapter 5, Vol. I, presents in detail the risk analysis framework for readily application in the maritime transport of PDG.

**Table 4.6: The link: Data-Theory-Framework Development**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | THE LINK: EMPIRICAL DATA-THEORY-FRAMEWORK DEVELOPMENT | | | | | | | | | | | |
| Nr. | Procedures and key results of the analysis | | Main stages/steps of the risk analysis framework –key elements to be dealt within each stage/step (as marked) | | | | | | | | | |
| | | | | STAGE 1: PREPARATIONS FOR RISK ANALYSIS | STAGE 2: RISK ANALYSIS | | | | | | | STAGE 3: CONCLUSIONS AND RECOMMENDATIONS |
| | | | | Preparations for risk analysis | Step 1: System definition | Step 2: Hazard identification | Step 3: Exposure/ Consequence Analysis | | Step 4: Likelihood estimation quantification | Step 5: Risk estimation and presentation | | Conclusions and recommendations |
| | | | | | | | Consequences (C) | Exposure (E) | | R=f(CE) | R=f(FC) | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **THE LINK: EMPIRICAL DATA-THEORY-FRAMEWORK DEVELOPMENT** | | | | | | | | | | | |
| **I** | **STAGE 1: PREPARATIONS FOR RISK ANALYSIS** | | | | | | | | | | | |
| | | - **Purpose of the study/analysis**: explore marine events involving PDG<br>- **Scope**: marine accidents/incidents involving PDG<br>- **Data collection**: library, internet, databases, field study, interview<br>- **Type of data/approach**: marine accident case histories<br>- **Amount of data/number of cases**: including four cases<br>- **Sources**: various sources<br>- **Data analysis method**: qualitative | | | | | | | | | | |
| | | | | | | | | | | | | |
| II | **STAGE 2: RISK ANALYSIS** | | | | | | | | | | | |
| | | | | | | | | | | | | |
| **Nr.** | **The main system's components and outcomes/events, i.e. risks** | **Summary – key results of the analysis** | Incidents/ frequency, quantification | | | | | | | | | |
| | **Main categories** | **Sub-categories** | | | | | | | | | | |
| 1 | **Categories of marine events** | | | | | | | | | | | |
| | | **Initial events** | | | | | | | | | | |
| | | - Grounding | **1** | | | | | | | | | |
| | | - Fire/explosion | **1** | | | | | | | | | |
| | | - Other: cargo shifting/ damage /spill | **2** | | | | | | | | | |

| | THE LINK: EMPIRICAL DATA-THEORY-FRAMEWORK DEVELOPMENT | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Subsequent events** | | | | | | | | | | |
| | | - Listing | **1** | | | | | | | | | |
| | | - Fire/explosion | **2** | | | | | | | | | |
| | | - Grounding | **1** | | | | | | | | | |
| | | | | | | | | | | | | |
| 2 | **Maritime transport hazards** | | | | | | | | | | | |
| | | - Mechanical forces | **4** | | | | | | | | | |
| | | - Corrosion | **4** | | | | | | | | | |
| | | - Fire/heat | **1** | | | | | | | | | |
| | | | | | | | | | | | | |
| 3 | **Causes and contributing factors** | | | | | | | | | | | |
| | | **Human - Man** | | | | | | | | | | |
| | | - People design, construct, operate, manage, regulate, and maintain the system | **4** | | | | | | | | | |
| | | - Crew unable to remedy the situation | **1** | | | | | | | | | |
| | | **Technical – Man made**: | | | | | | | | | | |
| | | - Failure of the cargo securing system | **1** | | | | | | | | | |
| | | - Lack of adequate heavy salvage equipment | **1** | | | | | | | | | |
| | | - Shortage of lashing equipment and other securing devices and equipment | **1** | | | | | | | | | |
| | | - Towing line broke/ parted | **1** | | | | | | | | | |
| | | **Operational:** | | | | | | | | | | |
| | | - Inadequate cargo securing | **1** | | | | | | | | | |
| | | - Delays in salvage operations | **1** | | | | | | | | | |
| | | - Poor management | **2** | | | | | | | | | |

| | THE LINK: EMPIRICAL DATA-THEORY-FRAMEWORK DEVELOPMENT | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Environment:** | | | | | | | | | | |
| | | - Heavy weather conditions: winds, currents, seas, swells and tides | **1** | | | | | | | | | |
| | | - Rocky sea bottom relief | **2** | | | | | | | | | |
| | | **Other:** | | | | | | | | | | |
| | | - Dangerous goods hazards: fire, smoke, toxic fumes, threats of explosions | **2** | | | | | | | | | |
| | | **Unknown**: Causes unknown | **2** | | | | | | | | | |
| | | | | | | | | | | | | |
| 4 | **Ship system** | | | | | | | | | | | |
| | | **Type of ship:** | | | | | | | | | | |
| | | - General/breakbulk | **1** | | | | | | | | | |
| | | - Container | **1** | | | | | | | | | |
| | | - Ro-ro ship | **2** | | | | | | | | | |
| | | **Flag:** | | | | | | | | | | |
| | | - Panamanian | **1** | | | | | | | | | |
| | | - Italian | **1** | | | | | | | | | |
| | | - Unknown | **2** | | | | | | | | | |
| | | - **Age**: 6 and 1 years | | | | | | | | | | |
| | | - **Size**: 16,169 dwt, 4,963 dwt, 14,497 dwt, 31,262 dwt = a total of 66,891 dwt | | | | | | | | | | |
| | | - **Number** of ships involved – one ship per event, a total of four | **4** | | | | | | | | | |
| | | | | | | | | | | | | |
| 5 | **Packaging system** | | | | | | | | | | | |
| | | - Tank container, refrigerated trailer, containers, pallets, drums, bags, cartons, cans, others<br>- Type and number of packages: unknown | | | | | | | | | | |

| | THE LINK: EMPIRICAL DATA-THEORY-FRAMEWORK DEVELOPMENT | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | |
| 6 | **Time of accident/ incident** | | | | | | | | | | | |
| | | **Month/date** | | | | | | | | | | |
| | | - April 27 | **1** | | | | | | | | | |
| | | - August 24 | **1** | | | | | | | | | |
| | | - September 10 | **1** | | | | | | | | | |
| | | - October 1 | **1** | | | | | | | | | |
| | | **Year** | | | | | | | | | | |
| | | - 1980 | **1** | | | | | | | | | |
| | | - 1985 | **1** | | | | | | | | | |
| | | - 2001 | **1** | | | | | | | | | |
| | | - 2002 | **1** | | | | | | | | | |
| | | | | | | | | | | | | |
| 7 | **Location of accident/ incident** | | | | | | | | | | | |
| | | - Port: port approach | **1** | | | | | | | | | |
| | | - At sea: open sea (2), coastal waters (1) | **3** | | | | | | | | | |
| | | | | | | | | | | | | |
| 8 | **Position of accident/ incident** | | | | | | | | | | | |
| | | - Mogadishu, Somalia (Africa) | **1** | | | | | | | | | |
| | | - Atlantic Ocean/ English Channel | **1** | | | | | | | | | |
| | | - North Atlantic, north of Scotland | **1** | | | | | | | | | |
| | | - Cape St Lucia, Italy | **1** | | | | | | | | | |
| | | | | | | | | | | | | |
| 9 | **Activity of the ship** | | | | | | | | | | | |
| | | - Manoeuvring | **1** | | | | | | | | | |

| | THE LINK: EMPIRICAL DATA-THEORY-FRAMEWORK DEVELOPMENT | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | - En route | **3** | | | | | | | | | | |
| | | | | | | | | | | | | | |
| 10 | **Cargo: dangerous goods** | | | | | | | | | | | | |
| | | **General cargo** | | | | | | | | | | | |
| | | - Packed timber | **2** | | | | | | | | | | |
| | | - Containerised cargo | **4** | | | | | | | | | | |
| | | - Amount known: 9,925 tons | **1** | | | | | | | | | | |
| | | - Type and amount unknown | **2** | | | | | | | | | | |
| | | **Dangerous goods**: | | | | | | | | | | | |
| | | - Many different types of dangerous goods: 40 different types | | | | | | | | | | | |
| | | - Classes of dangerous goods: 3.1, 3.2, 3.3, 5.1, 6.1, and 8 | | | | | | | | | | | |
| | | - Amount of dangerous goods: 645 tons | **1** | | | | | | | | | | |
| | | - Type and amount largely unknown | **3** | | | | | | | | | | |
| | | **List of dangerous goods**: | | | | | | | | | | | |
| | | - Hexane<br>- Sodium hydroxide<br>- Xylene<br>- Solvent<br>- Trichloroethylene<br>- Sodium pentachloroph.<br>- Tetraethyl lead Hexafluorosilic acid<br>- Sodium hypochlorite<br>- Trimethylphosphite<br>- Unknown | | | | | | | | | | | |
| | | **Dangerous goods hazards**: | | | | | | | | | | | |
| | | - Fire | **3** | | | | | | | | | | |
| | | - Explosion | **2** | | | | | | | | | | |
| | | - Smoke and toxic fumes | **3** | | | | | | | | | | |
| | | - Corrosive | **2** | | | | | | | | | | |

| | THE LINK: EMPIRICAL DATA-THEORY-FRAMEWORK DEVELOPMENT | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | - Marine pollutants | 1 | | | | | | | | | | |
| | | | | | | | | | | | | | |
| 11 | **Top events – transport hazards** | | | | | | | | | | | | |
| | | Breach (failures/damage) of packages: packages, containers, and tank container breached (4) due to: | | | | | | | | | | | |
| | | - Impact | 4 | | | | | | | | | | |
| | | - Fire, heat | 1 | | | | | | | | | | |
| | | - Corrosion | 2 | | | | | | | | | | |
| | | | | | | | | | | | | | |
| 12 | **Dangerous substances release events – drifting, dispersion, concentration** | | | | | | | | | | | | |
| | | **Aboard ship** | | | | | | | | | | | |
| | | - Chemicals spilt from breached packages | 4 | | | | | | | | | | |
| | | - Spills led to: fire, toxic fumes, smoke, explosion threats | 3 | | | | | | | | | | |
| | | **Marine ecosystem (fauna and flora):** | | | | | | | | | | | |
| | | - Damaged PDG sank, or drifted and beached | 1 | | | | | | | | | | |
| | | - Chemical dispersion and concentration on sediments and biota | 1 | | | | | | | | | | |
| | | **Air:** | | | | | | | | | | | |
| | | - Smoke and toxic fumes drifted towards populated area (1) | 1 | | | | | | | | | | |
| | | | | | | | | | | | | | |
| 13 | **Consequences** | | | | | | | | | | | | |
| | | **Human:** | | | | | | | | | | | |
| | | ***Crew***: (master, officer, AB, family members: | | | | | | | | | | | |

| | THE LINK: EMPIRICAL DATA-THEORY-FRAMEWORK DEVELOPMENT | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | - Five injured, two of whom developed emotional problems | **1** | | | | | | | | | | | |
| | | - All crew safe | **3** | | | | | | | | | | | |
| | | ***Rescue personnel:*** | | | | | | | | | | | | |
| | | - No one affected | **4** | | | | | | | | | | | |
| | | ***Port workers:*** | | | | | | | | | | | | |
| | | - Unknown numbers of people reported headaches, dizziness and nausea, the number unknown | **1** | | | | | | | | | | | |
| | | - No one affected | **3** | | | | | | | | | | | |
| | | - Parts of the port evacuated or isolated | **2** | | | | | | | | | | | |
| | | ***Local community:*** | | | | | | | | | | | | |
| | | - Local community seen swimming and picking up debris – effects unknown | **1** | | | | | | | | | | | |
| | | - Massive evacuation due to smoke and toxic fumes risks | **1** | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | | **Environment:** | | | | | | | | | | | | |
| | | ***Marine environment:*** | | | | | | | | | | | | |
| | | - The marine environment contaminated | **1** | | | | | | | | | | | |
| | | - The marine environment not contaminated - no chemicals spilt into the sea, but chemicals posed threats | **3** | | | | | | | | | | | |
| | | ***Air environment:*** | | | | | | | | | | | | |
| | | - Air pollution due to smoke and toxic fumes | **3** | | | | | | | | | | | |
| | | **Property:** | | | | | | | | | | | | |
| | | - The ship and cargo sustained extensive damage – due to contamination, fire or explosion | **4** | | | | | | | | | | | |
| | | **Others:** | | | | | | | | | | | | |

| | THE LINK: EMPIRICAL DATA-THEORY-FRAMEWORK DEVELOPMENT | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | - Disruption - activities in the port and ashore suspended due to evacuation or isolation | **2** | | | | | | | | | | | |
| | | **Costs:** | | | | | | | | | | | | |
| | | - Human costs: injuries | **2** | | | | | | | | | | | |
| | | - Evacuation costs | **2** | | | | | | | | | | | |
| | | - Ship and cargo costs | **4** | | | | | | | | | | | |
| | | - Activities suspension costs | **4** | | | | | | | | | | | |
| | | - Complicated, specialised and costly salvage operations | **4** | | | | | | | | | | | |
| | | - Other costs | | | | | | | | | | | | |
| | | **Threats** | | | | | | | | | | | | |
| | | - Fire/explosion posed threats to salvage operations | **2** | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| 14 | **Exposure** | | | | | | | | | | | | | |
| | | **Human exposure**: | | | | | | | | | | | | |
| | | - All crew – 22 people | **1** | | | | | | | | | | | |
| | | - All crew – unknown | **3** | | | | | | | | | | | |
| | | - Port workers | **2** | | | | | | | | | | | |
| | | - Rescue and recovery personnel | **4** | | | | | | | | | | | |
| | | - Local community | **2** | | | | | | | | | | | |
| | | **Environment exposure**: | | | | | | | | | | | | |
| | | - Marine and air environment | **4** | | | | | | | | | | | |
| | | **Property exposure:** | | | | | | | | | | | | |
| | | - Ship and cargo | **4** | | | | | | | | | | | |
| | | - Local community and port properties | **2** | | | | | | | | | | | |

| | THE LINK: EMPIRICAL DATA-THEORY-FRAMEWORK DEVELOPMENT | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | - Rescue equipment | **4** | | | | | | | | | | |
| | | **Others:** | | | | | | | | | | | |
| | | - Activities ashore | **2** | | | | | | | | | | |
| | | | | | | | | | | | | | |
| III | **STAGE 3: CONCLUSIONS AND RECOMMENDATIONS** | Summary of the key findings and recommendations<br>Suggests for future research questions and areas | | | | | | | | | | | |
| | **STAGES/STEPS** | | **2.4** | **1** | **2.1** | **2.2** | **2.3** | | **2.4** | **2.5** | | | **3** |

**Table 4.7: Some key results of the analysis of four marine accident case histories - a summary**

| Nr. | System and risk elements | Case 1: M/v "Ariadne" | Case 2: M/v "Dutch Navigator" | Case 3: M/v "FNE" | Case 4: M/v "Jolly Rubino" | Summary<br><br>* Number of incidences |
|---|---|---|---|---|---|---|
| | | | | | | |
| 1 | ***Category of marine events*** | -Initial event: grounding<br>-Subsequent events: listing, fire, foundering, cargo loss | - Initial event: other category - cargo shifting/ damage/ spill | - Initial event: cargo shifting/ damage /spill<br>- Subsequent events: Fire/explosion | - Initial event: fire<br>- Subsequent event: grounding | Initial events<br>- Grounding (1)*****<br>- Fire/explosion (1)<br>- Other: cargo shifting/ damage /spill (2)<br><br>Subsequent events<br>- Listing (1)<br>- Fire/explosion (2)<br>- Grounding (1) |
| 2 | ***Maritime transport hazards*** | - Mechanical forces: impact, crash<br>- Corrosion | - Mechanical forces: impact, crash<br>- Corrosion | - Mechanical forces: impact, crash<br>- Corrosion | - Probable hazards<br>- Fire, heat<br>- Corrosion<br>- Mechanical forces | - Mechanical forces (4)<br>- Corrosion (4)<br>- Fire/heat (1) |
| 3 | ***Causes and contributing factors*** | - Grounding: technical - towing line broke/ parted<br>- Weather hazards: winds, currents, seas, swells and tides<br>- Rocky sea bottom relief<br>- Delays in salvage operations<br>- Lack of adequate heavy salvage equipment | - Failure of the cargo securing system<br>- Heavy weather conditions<br>- Heavy rolling/ movements | - Failure of the cargo securing system<br>- Heavy weather conditions, 9-10 Beaufort scale<br>- Maximum wave height over 8 meters<br>- Heavy listing, 40 degrees<br>- Inadequate cargo securing system<br>- Shortage of lashing equipment and other securing devices and equipment<br>- Crew unable to remedy the situation | Fire:<br>- Cause unknown<br>- Numerous probable causes<br>Grounding:<br>- Ship lost control<br>- Crew abandoned the ship due to fire, smoke, toxic fumes, threats of explosions<br>- Prevailing weather conditions | Human - Man<br>- People design, construct, operate, manage, regulate, and maintain the system<br>- Crew unable to remedy the situation (1)<br>Technical – Man made:<br>- Failure of the cargo securing system (1)<br>- Lack of adequate heavy salvage equipment (1)<br>- Shortage of lashing equipment and other securing devices and equipment (1)<br>- Towing line broke/ parted |

| Nr. | System and risk elements | Case 1: M/v "Ariadne" | Case 2: M/v "Dutch Navigator" | Case 3: M/v "FNE" | Case 4: M/v "Jolly Rubino" | Summary<br><br>* Number of incidences |
|---|---|---|---|---|---|---|
| | | | | | | (1)<br>Operational<br>- Inadequate cargo securing<br>- Delays in salvage operations<br>- Poor management<br>Environment<br>- Heavy weather conditions: winds, currents, seas, swells and tides<br>- Rocky sea bottom relief<br>Other:<br>- Dangerous goods hazards: fire, smoke, toxic fumes, threats of explosions<br>Unknown: Cause unknown |
| 3 | ***Ship system*** | - Type: general/ breakbulk cargo ship<br>- Flag: Panamanian<br>- Built/age: 1979/ 6 years<br>- Size: 16,169 dwt<br>- Number of ships involved (1) | - Type: container ship<br>- Size: 2,999 grt, 4,963 dwt<br>- Number of ships involved (1) | - Type: ro-ro ship<br>- Built/age: 1979/1 year<br>- Size: 8,761 grt, 4,623 nrt, 14,497 dwt<br>- Number of ships involved - 1 | - Type: ro-ro ship<br>- Size: 31,262 dwt<br>- Flag: Italian<br>- Number of ships involved - 1 | - Type: general (1), container (1), ro-ro ship (2)<br>- Flag: Panamanian (1), Italian (1)<br>- Age: 6 and 1 years<br>- Size: 16,169 dwt, 4,963 dwt, 14,497 dwt, 31,262 dwt = total 66,891 dwt<br>- Number of ships involved – 1 ship per event, a total of 4 |
| 4 | ***Packaging system*** | - Containers: 118 pcs<br>- Pallets<br>- Drums<br>- Bags<br>- Cartons<br>- Cans<br>- Others | - Containers<br>- Pallets<br>- Drums<br>- Others | - Tank container<br>- Refrigerated trailer<br>- Containers<br>- Pallets | - Containers<br>- Drums | - Tank container<br>- Refrigerated trailer<br>- Containers<br>- Pallets<br>- Drums<br>- Bags<br>- Cartons<br>- Cans |

| Nr. | System and risk elements | Case 1: M/v "Ariadne" | Case 2: M/v "Dutch Navigator" | Case 3: M/v "FNE" | Case 4: M/v "Jolly Rubino" | Summary<br><br>* Number of incidences |
|---|---|---|---|---|---|---|
| | | | | | | - Others<br>- Type and number of packages: unknown |
| 6 | ***Time of accidents*** | - August 24, 1985 | - April 27, 2001 | - October 1, 1980 | - September 10, 2002 | Month/date<br>- April 27<br>- August 24<br>- September 10<br>- October 1<br>Year<br>- 1980<br>- 1985<br>- 2001<br>- 2002 |
| 7 | ***Location of accidents*** | - Port: port approach | - At sea: at open sea or in coastal waters | - At sea: open sea | - At sea: coastal waters | - Port: port approach (1)<br>- At sea: open sea (2), coastal waters (1) |
| 8 | ***Position of accidents*** | - Mogadishu, Somalia (Africa) | - Atlantic Ocean/ English Channel | - North Atlantic, north of Scotland | - Cape St Lucia, Italy | - Mogadishu, Somalia (Africa) (1)<br>- Atlantic Ocean/ English Channel (1)<br>- North Atlantic, north of Scotland (1)<br>- Cape St Lucia, Italy (1) |
| 9 | ***Activities of ships*** | - Manoeuvring | - En route | - En route | - En route | - Manoeuvring (1)<br>- En route (1) |
| 10 | ***Cargo - dangerous goods onboard*** | General cargo:<br>- Amount 9,925 tons<br>- Containerised cargo<br>Dangerous goods:<br>- Types of dangerous goods involved: 40 different types<br>- Classes of dangerous | General cargo:<br>- Containerised cargo<br>- Types and amounts unknown<br>Dangerous goods<br>- Classes of dangerous goods:<br>- Two types of | General cargo:<br>- Packed timber<br>- Containerised cargo<br>Dangerous goods:<br>- Flammable liquid<br>- Class 3.3<br>- Packaging group III,<br>- No subsidiary risk | General cargo:<br>- Packed timber<br>- Containerised cargo<br>- Types and amounts unknown<br>Dangerous goods:<br>- PDG - unknown | General cargo<br>- Packed timber (2)<br>- Containerised cargo (4)<br>- Amount: 9,925 tons (1)<br>- Type and amount unknown (2)<br>Dangerous goods:<br>- Many different types of |

| Nr. | System and risk elements | Case 1: M/v “Ariadne” | Case 2: M/v “Dutch Navigator” | Case 3: M/v “FNE” | Case 4: M/v “Jolly Rubino” | Summary<br><br>* Number of incidences |
|---|---|---|---|---|---|---|
| | | goods: 3.1, 3.2, 3.3, 5.1, 6.1, and 8<br>- Amount of dangerous goods: 645 tons | dangerous goods involved<br>- Both class 8, corrosive<br>- Packaging groups II and II/III | - No marine pollutant | | dangerous goods: 40 different types<br>- Classes of dangerous goods: 3.1, 3.2, 3.3, 5.1, 6.1, and 8<br>- Amounts of dangerous goods: 645 tons (1)<br>- Type and amount largely unknown (3) |
| 11 | ***Dangerous goods list, hazards involved*** | List of dangerous goods involved:<br>- Hexane, sodium hydroxide, xylene, solvent, trichloroethylene, sodium pentachlorophenate, tetraethyl lead etc.<br>Dangerous goods hazards:<br>- Fire, explosive, poison, corrosive, and marine pollutants | List of dangerous goods involved:<br>- Hexafluorosilic acid<br>- Sodium hypochlorite<br>Dangerous goods hazards:<br>- Corrosion: acid reacted with cargo, packaging materials and ship | List of dangerous goods involved:<br>- Trimethylphosphite<br>Dangerous goods hazards<br>- Fire, explosion, heat, smoke and toxic fumes | List of dangerous goods involved:<br>- Unknown<br>Dangerous goods hazards:<br>- Fire<br>- Smoke and toxic fumes<br>- Threats of explosions | List of dangerous goods:<br>- Hexane, sodium hydroxide, xylene, solvent, trichloroethylene, sodium pentachlorophenate, tetraethyl lead etc.<br>- Hexafluorosilic acid<br>- Sodium hypochlorite<br>- Trimethylphosphite<br>- Unknown (1)<br>Dangerous goods hazards:<br>- Fire (3)<br>- Explosive (2), threats of explosions<br>- Poison: smoke and toxic fumes (3)<br>- Corrosive (2)<br>- Marine pollutants (1) |
| 12 | ***Immediate causes of dangerous substance release or involvement – top events*** | - Packages/ containers breached due to impact | - Packages/ containers breached due to impact, corrosion | - Tank container breached due to impact | - Packages breached due to fire/heat, corrosion and impacts | - Packages, containers, tank container breached (4) due to:<br>- Impact (4)<br>- Fire, heat (1)<br>- Corrosion (2) |
| 13 | ***Dangerous substances release*** | - Marine ecosystem (fauna and flora) | - Chemicals spilt inside /outside containers | - Flammable liquid spilt on deck from damaged tank | - Chemicals spilt from breached | Aboard ship<br>- Chemicals spilt from |

| Nr. | System and risk elements | Case 1: M/v “Ariadne” | Case 2: M/v “Dutch Navigator” | Case 3: M/v “FNE” | Case 4: M/v “Jolly Rubino” | Summary<br><br>* Number of incidences |
|---|---|---|---|---|---|---|
| | ***events – drifting, dispersion, concentration*** | - Damaged PDG sank, or drifted and beached<br>- Chemicals dispersion and concentration on sediments and biota including algae, corals, fish and other animals<br>- Marine pollutants involved: mercury, copper, lead and cadmium, PCB and DDT<br>- Smoke and toxic fumes drifted towards populated area | | - Acid spilt from damaged batteries of the trailer<br>- Liquid ignited by sparks from the damaged batteries of the trailer | packages | breached packages (4)<br>- Spills led to: fire, toxic fumes, smoke, explosion threats (3)<br>Marine ecosystem (fauna and flora) (1)<br>- Damaged PDG sank, or drifted and beached<br>- Chemicals dispersion and concentration on sediments and biota<br>Air<br>- Smoke and toxic fumes drifted towards populated area (1) |
| 14 | ***Consequences*** | Effects of chemicals: toxic, marine pollutants:<br>- Human: in contact with chemicals, unknown numbers of people reported headaches, dizziness and nausea<br>- Environment: the marine environment contaminated<br>- Local community seen swimming and picking up debris – effects unknown<br>- Costs: costly operations<br>- Effects of fire, smoke, toxic fumes:<br>- Human: no one was affected, people were evacuated<br>- Environment: air pollution | - Human: no one was affected, all crew safe<br>- Marine environment: no chemical spilt into the sea<br>- Property: parts of cargo and ship contaminated – 9 containers damaged<br>- Other: activities partly suspended, part of the dock area isolated<br>- Costs: specialised and costly operations | - Human: five crew members injured, two of whom developed emotional problems<br>- Marine environment: no environmental pollution from PDG reported<br>- Air pollution due to smoke and toxic fumes<br>- Property: the cargo and ship sustained extensive fire and explosion damages<br>- Threats: fire/explosion posed threat to salvage operations<br>- Costs: complicated, specialised and costly salvage operation | - Human: no one was affected - all crew safely abandoned the ship<br>- Marine environment: no environment pollution from PDG reported<br>- Air pollution due to smoke and toxic fumes<br>- Property: due to fire the ship and cargo sustained extensive damages<br>- Costs: complicated, specialised and costly salvage operation | - Human:<br>- Crew: (master, officer, AB, family members:<br>- 5 injured, two of whom developed emotional problems (1)<br>- All crew safe (3)<br><br>- Rescue personnel:<br>- No one affected (4)<br><br>- Port workers:<br>- Unknown numbers of people reported headaches, dizziness and nausea, the number unknown (1);<br>- No one affected (3)<br>- Parts of the port evacuated or isolated (2) |

| Nr. | System and risk elements | Case 1: M/v “Ariadne” | Case 2: M/v “Dutch Navigator” | Case 3: M/v “FNE” | Case 4: M/v “Jolly Rubino” | Summary<br><br>* Number of incidences |
|---|---|---|---|---|---|---|
| | | - Properties: cargo/ship damaged<br>- Others: Disruption - activities at the port and ashore suspended, large-scale evacuation<br>- Costs: ship, cargo, injuries, activity suspensions, costly operations<br>- Threats: fire/explosion posed threat to salvage operations | | | | Local community:<br>- Local community seen swimming and picking up debris – effects unknown (1)<br>- Massive evacuation due to smoke and toxic fumes risks (1)<br>Environment:<br>- Marine environment:<br>- The marine environment contaminated (1)<br>- The marine environment not contaminated - no chemicals spilt into the sea, but chemicals posed threats (3)<br><br>- Air environment:<br>- Air pollution due to smoke and toxic fumes (3)<br><br>- Property:<br>- The ship and cargo sustained extensive damages (4) – due to contamination, fire or explosion<br>Others:<br>- Disruptions- activities at the port and ashore suspended due to evacuation or isolation (2)<br>Costs:<br>- Human costs: injuries (2)<br>- Evacuation costs (2)<br>- Ship and cargo costs (4) |

| Nr. | System and risk elements | Case 1: M/v "Ariadne" | Case 2: M/v "Dutch Navigator" | Case 3: M/v "FNE" | Case 4: M/v "Jolly Rubino" | Summary<br><br>* Number of incidences |
|---|---|---|---|---|---|---|
| | | | | | | - Activities suspension costs (4)<br>- Complicated, specialised and costly salvage operations (4)<br><br>- Threats: fire/explosion posed threats to salvage operations (2) |
| 15 | ***Exposure*** | - Human: all crew, port workers, rescue and recovery personnel, local community<br>- Marine and air environment<br>- Property: the entire cargo and ship, local community and port properties, and rescue equipment<br>- Others: activities ashore | - Human: all crew, port workers, strike force personnel, and other people ashore<br>- Marine and air environment<br>- Property: the entire ship and cargo, local community and port properties, and rescue equipment<br>- Other: activities ashore | -Human: All 22 people: 19 crewmembers and three family members, including three women and two children; rescue personnel<br>-Marine and air environment<br>-Property: the entire cargo and ship, and rescue equipment | -Human: all crew (master, officer, crew) and rescue and recovery personnel<br>-Marine and air environment<br>-Property: the entire ship and cargo and rescue equipment | -Human exposed:<br>- All crew – 22 persons (1)<br>- All crew – unknown (3)<br>- Port workers (2)<br>- Rescue and recovery personnel (4)<br>- Local community (2)<br>- Environment exposed<br>- Marine and air environment (4)<br>- Property exposed:<br>- Ship and cargo (4)<br>- Local community and port properties (2)<br>- Rescue equipment (4)<br><br>- Others:<br>- Activities ashore (2) |

# 5. A Risk Analysis Framework for Maritime Transport of Packaged Dangerous Goods

*In this chapter a risk analysis framework for application in the maritime transport system of packaged dangerous goods is presented. The framework consists of the main stages, where each stage consists of a number of steps and sub-steps for planning and performing the risk analysis in the field.*

## Introduction

### The main stages of the risk analysis framework

A risk analysis framework developed for application in maritime transport of PDG will be presented in this chapter. The framework is based on combinations of: a) the review and evaluation of some of the world's best practices, frameworks and techniques employed in shipping and other industries and other sources; b) the analysis of large amounts of empirical data (e.g. HCB, 1986-2003; SMA, 1985-1999; Lloyds Register of Shipping Casualty Return – see Chapters 2 and 4, Vol. I); c) the review of many formal and informal risk/accident studies (see references and the literature review, Chapter 1, Vol. I); and d) personal research experience in the field of maritime risks (see Mullai and Paulsson, 2002). The framework relies on the essential principles of the risk analysis.

The framework consists of three main stages, and each stage consists of a number of steps and tasks (see Figure 5.1). In order to facilitate the analysis, two analysis techniques, namely Fault Tree Analysis (FTA) and Event Tree Analysis (ETA), are integrated into the framework. Although presented in a sequential order, the process, like any other scientific research process, is usually cyclic, and some of the steps are inseparable. The process begins with problem identification and formulation, extending through data collection and analysis to conclusions and recommendations. As stated earlier, the main purpose of the risk analysis process is to inform decision makers about risks. The purpose of the framework is to facilitate the analysis process of risks of maritime transport of PDG. The framework provides essential principles and guidelines that will assist the risk analysts in preparing and performing the risk analysis/studies in a more effective and efficient manner. The main stages of the risks analysis framework are:

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|---|---|
| **Stage 1: Preparations for risk analysis** | Describes important activities that are carried out prior to the risk analysis. |
| **Stage 2: Risk analysis** | Provides the sequential steps for performing a structured risk analysis, including system definition, hazard identification, exposure and consequences analysis, likelihood estimation/ quantification, risk estimation and presentation, and sensitivity analysis. |
| **Stage 3: Conclusions and recommendations** | Based on the facts and the analysis, draw conclusions on system and risk elements. Provide recommendations for better risk management, and areas for further researches in the field. |

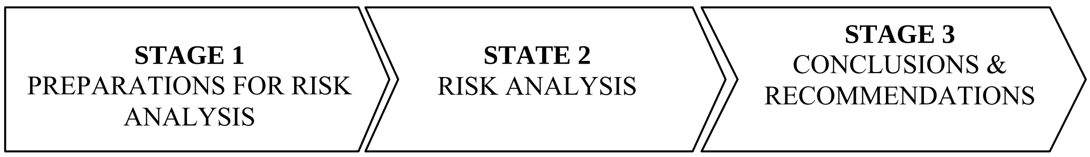


**Figure 5.1: The main stages of risk analysis**

### Informing about the risks - the "triple definition"

In order to inform about risks, three interrelated fundamental questions (see Figure 5.2) must be answered: "*What has gone and can go wrong*?" "*What are the consequences*?" and "*How likely is that to happen*?" - known as "the triplet definition" of risks (Kaplan and Garrick, 1981). The concept of the triplet definition has become widely applicable as an element of standardisation (ACS, 1998; Ruxton, 1996; IEC, 1995). The processes that facilitate the answers to these three fundamental questions constitute the core of the risk analysis process. The entire process builds on these "simple" questions, which require considerable effort before they can provide answers. The answers may be given in a qualitative or quantitative form, or a combination of both. The above questions lead to other questions that, in turn, require additional answers. Prior to answering these questions, a number of important activities are carried out for preparing for the risk analysis. The forthcoming section discusses these activities in some detail.

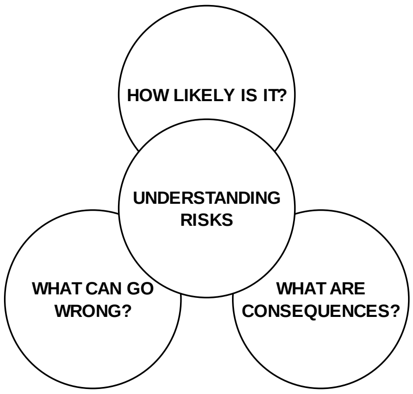


**Figure 5.2: The "triple definition"**

## 5.1. Stage 1 – Preparations for risk analysis

This stage consists of a number of important and interrelated activities that should be performed prior to a risk analysis. Some of these activities are: determine the risk analysis level (preliminary or detailed analysis); decide who should conduct the risk analysis; identify the interested parties/actors; identify activities generating the risks; identify and formulate the problems; set the objectives to be achieved; define the boundaries - the scope of the study; select the risk analysis methods and tools; select the data collection methods; determine the type and amount of risk-related data and information needed and discuss any problems related to data and data collection such as data quality, accessibility and costs (see the **highlighted area** in Figure 5.3). The process is generally cyclic and the order of the presentation may not necessarily reflect the process's sequences.

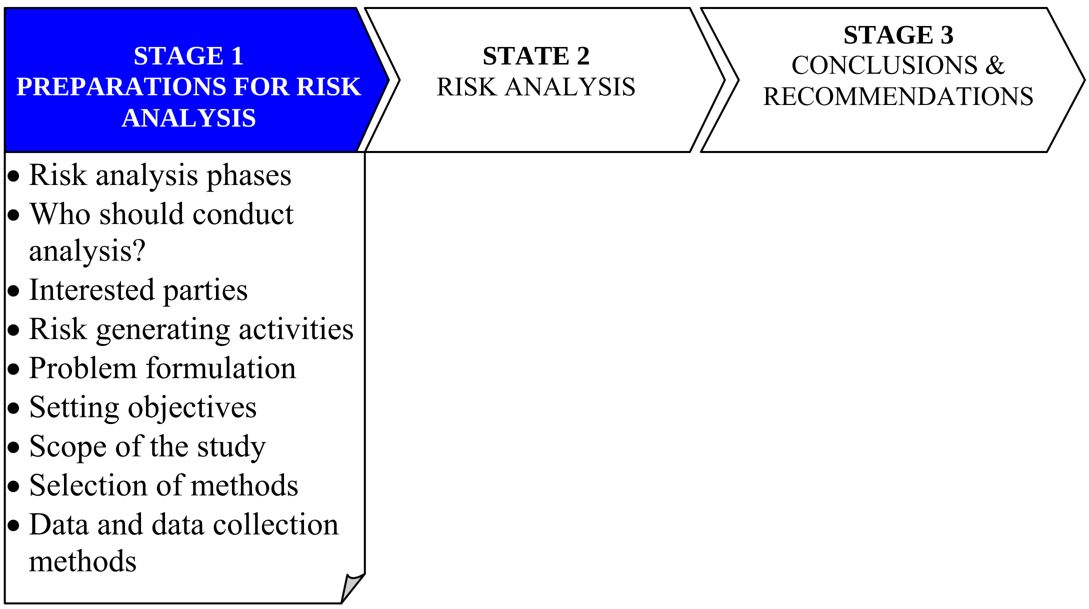


**Figure 5.3: Stage 1 – Preparations for risk analysis**

### 5.1.1. Risk analysis phases

The risk analysis can be carried out in phases. Depending on the application, the analysis ranges widely in scope and complexity. It may vary from simple screening to major analysis that requires years of effort and substantial resources (money, time, personnel and other means), which is carried out by a large team of experts using a wide range of sets of techniques and tools, data and information. Resources spent to manage risks vary significantly across countries, regions, communities and industries. As resources are limited, a proper allocation is essential. A detailed risk analysis requires more resources. Generally, large amounts of highly precise and firm risk-related data and information are very expensive to obtain. The amount of resources increases as the amount and quality of the data increase. It is, therefore, important to remember that the costs of the information provided by the risk analysis process may outweigh the benefits of having it.

#### Preliminary or screening risk analysis

In order to determine whether the risks posed by dangerous goods are likely to be acceptable or unacceptable, it may initially be necessary to undertake a preliminary or screening level analysis. If the analysis indicates that risks are acceptable, recommendations at this stage are provided for further improvements in the risk management. When risks are found to be potentially unacceptable, then the risk issue should undergo a more detailed scrutiny. The primary purpose is to identify and eliminate all insignificant hazards, and, if necessary, elimination of in-depth analysis of low-risk elements, for example in terms of the type of marine accidents/incidents, ships, dangerous goods, vessel traffic, transport-related activities, geographical locations and so on. Screening is generally conservative and broader in order not to overlook any potential hazards.

The preliminary analysis, which is performed relatively rapidly, makes use of the data and information at hand, easily accessible and inexpensive, such as marine accident case histories available from databases. Some key parameters that may be considered for a preliminary risk analysis are:

- The category and frequency of marine accidents/incidents involving PDG, for example, fire/explosion, spills/releases and cargo losses at sea;
- The number of fatalities and injuries due to hazards of dangerous goods;
- The type and amounts of dangerous goods involved;
- Whether dangerous goods have posed any serious threat (not necessarily caused harm) to human safety and health and the marine environment.

The outcome of the preliminary risk analysis provides the basis for formulating the problems and setting the objectives for a detailed analysis.

Another form of preliminary analysis is the baseline analysis. However, in contrast to the former, it makes use of both existing and other data collected by various forms of data collection methods, such as surveys and interviews. The purpose of the baseline analysis is to identify and possibly determine risk elements, such as the consequences, causes, and likelihood, to a higher level of detail and precision. But this analysis is usually focuses on a smaller number of chemicals and risk receptors than does screening.

### Detailed risk analysis

The next step may comprise a more detailed risk analysis, including detailed specification of problems, objectives, scope, selection of the method, techniques and tools to be used, further data collection activities and a detailed analysis and evaluation process. The degree of detail - i.e. the depth and breadth of the analysis - varies on a scale from low to high, depending on a number of interrelated factors and conditions, including:

- The extent of the risks posed;
- Concerns, urgency and interests of groups of people affected by risks and related decisions;
- Risk management options for managing risks;
- Cost-benefits trade-off;
- The amount and quality of risk-related data and information available.

A detailed risk analysis often begins with a lower through a higher detailed analysis. Higher levels can provide more detailed and better information, but the time, money, and energy required increase at each level.

## 5.1.2. Who should conduct risk analysis?

An important step in preparations is to identify and bring together those people who are experts in the field of maritime transport of dangerous goods. The risk analysis relies very much upon using the expertise of knowledgeable people. Decision makers and other responsible authorities have to ensure that any person carrying out the analysis is familiar with the requirements of regulations governing dangerous goods-related activities and has a practical understanding of how these activities are carried out. In addition, this may also require the use of the expertise, in particular for a detailed risk analysis, of a wide variety of professionals, including toxicologists and biochemists, from industry, government and academia. The role of expert judgements has become formal, explicit and documented. For example, Australia's Dangerous Goods Safety Management (DGSM Act, 2001) Regulation defines under sections 17 and 18 the responsibility for carrying out risk assessment. According to this regulation, a single person such as a work manager or chemist is deemed suitably competent to perform simple assessments, whilst in more complex cases, several people representing a variety of skills are needed in data collection, analysis, evaluation and presentation of the information.

## 5.1.3. Identify and involve interested parties

Risks and related matters concerning the transport of dangerous goods affect a wide range of interests, which establish objectives and agenda for the risk analysis. A critical step in the process is the identification and involvement of all key interests in identifying and resolving problem areas. With their involvement come many benefits, including greater accessibility to a larger amount and better quality of risk-related data and information, greater acceptance and better understanding of the goals. The objectives of the risk analysis reflect their concerns and interests. Their views about risks, benefits, and the acceptability of risks may range from similar or convergent to very different. In order to avoid or reduce conflicts, the legislation in a number of countries, for example Europe, the USA and Canada, requires an active involvement of the affected interests.

Who are stakeholders in shipping? With regard to human health, safety, environment and property damage assessments, there are many different interests with different needs and decision problems. The list is endless, but includes ship owners, cargo interests, charterers, shipyards, suppliers, other modes of transport operators and industries and sectors, third party logistics, agents, freight forwarders, ship owner associations, insurance companies, financial organisations, P&I Clubs, classification societies, port authorities, flag states, environmental authorities or organisations, labour union organisations and many other related interests groups that play important roles in the risk assessment decision-making processes.

### 5.1.4. Identify risk-generating activities

This step concerns identification of dangerous goods activities that generate risks. Risks arise at any stage of a chemical's life cycle, such as production or manufacturing, distribution, use, reverse logistics and disposal of dangerous goods. Case histories (case histories in Chapter 4, Vol. I, HCB, 1986-2003 and other databases, see Chapter 2, Vol. I) have shown that maritime transport and transport/distribution-related activities, such as packing, handling, stowage, and loading and unloading of PDG give rise to risks. The analysis may address the risks associated with individual activities, combinations thereof or the chemical's entire life cycle, where maritime transport of PDG and related activities have their share in contributing to risks.

### 5.1.5. Problem identification and formulation

The process starts by focusing on problem identification and formulation, and then attempts to identify what is causing the problem in order to determine the best way to deal with it. Risk issues in transport of dangerous goods become agenda through various ways, including legislation, accidents, government policy, public concerns, interested groups, media, availability of new information and technology. Furthermore, the interests of various groups, such as governmental and non-governmental agencies and authorities, the public, industry, and the scientific community, largely affect the degree of the risk issue’s urgency, analysis and the way in which risks are managed. The problems of interest, which the risk analysis in maritime transport of dangerous goods addresses, include these interrelated generic areas: human safety and health, the marine environment, economic, and other aspects, such as social concerns or security.

The problem should be viewed in its context. Risk issues in maritime transport of PDG may be viewed, for example, in the context of other sources of risks to human health and safety and the environment of the same or different contaminants, other industries, sectors, human activities or phenomena. The purpose is to provide answers to a number of questions, such as "To what extent do the risks of maritime transport of PDG contribute to the aggregated risks?" "How significant are they compared to other risks?" Furthermore, this may clarify to the decision-makers the alternative choices available to manage risks and the impact that they are likely to have on human health and safety or the environment.

### 5.1.6. Setting the objectives

Risk management is often expected to deal with several not necessarily convergent and, sometimes, conflicting objectives. For example, conflicts may arise between safety and health and marine environment protection, or short term and long-term priorities. Setting objectives implies choices determined not only by scientific considerations or technical options, but also by other considerations such as political, social, ethical, or economic. Such considerations take into account the interests of the concerned parties.

A generic objective may consist of a number of specific objectives. Initially, as the analysis progresses and more information become available, the objective is defined in general terms, and later expanded, modified and refined. The generic objective of risk studies is to provide decision makers with information and tools that will enable them to make informative decisions for managing risks, for example by taking preventive, control, or remedy measures. Some examples of the specific categories of risk study objectives are (see risk management measures in Chapter 3, Vol. I, and Mullai, 2006b):

- *Knowledge*: for example, enhance or consolidate understanding of risks and provide recommendations for managing risks; one of the purposes of the risk analysis process is to turn "unknown" into known risks for the purpose of better management;
- *Procedural*: for example, improve dangerous goods related processes, such as handling, packing, securing, transportation, and documentation;
- *Technological*: for example, improve or develop hardware, software, and IT;
- *Methodological*: for example, develop, adopt, improve or refine methods, techniques and tools for risk analysis, assessment and management.

This study addresses two of the above categories, namely the knowledge and methodological aspects.

### 5.1.7. Define the boundaries – the scope of the study

Every study is at some point confined in time and space. Because of a number of constraints, including time and resources, data and information availability and the system's complexity, it is particularly very important to define clearly the boundaries of a risk study. What is considered and what is not? The boundaries can be broadly categorised into physical or system boundaries and analytical boundaries (USCG, 2001). However, because of their interrelations, a clear-cut distinction between them may not be possible. The risk study in the field of maritime transport of dangerous goods can be delimited as follow.

***Physical or system boundaries**:* The maritime transport system of PDG consists of many components, including ships, packaging, dangerous goods, ports and waterways, and is itself a subsystem of the maritime transport system (see Chapter 3, Vol. I, and Mullai, 2006a). This is, in turn, a component or subsystem of the entire transport system/network. The transport system does not operate in isolation, but is interconnected with other systems such as activities related to the distribution of chemicals. Further, maritime transport of dangerous goods takes place in or close to densely populated areas and highly sensitive waters. Studying all the system's elements and their possible interconnections becomes a very difficult task. By defining the system's boundaries, analysts can avoid overlooking some key elements of the system and unnecessarily scrutinising some others. Sometimes, however, such boundaries are not clearly distinct. The risk study in maritime transport of dangerous goods could be confined to one, or combinations of, the following:

- Types and amounts of dangerous goods: classes 1 to 9;
- Form in which dangerous goods are carried: dangerous goods/cargoes in bulk and *packaged form*, including or excluding certain types of packaging;
- Other system elements or activities: e.g. type/size of ships, ships in transit, or loading and unloading activities;
- Geographical locations: e.g., local, regional, national and international or worldwide.

***Analytical boundaries**:* The breadth and depth of the analysis vary widely. In some cases, it may be impractical, if not impossible, to conduct a detailed study of all elements of the risk management system. Given different constraints described earlier, the analytical boundaries could be defined as follow:

- Risk management is a broad process encompassing risk analysis, evaluation and management: for example, a risk study could be confined to the risk analysis only;
- The analysis varies from purely qualitative to fully quantitative: for example, a risk study can employ a quasi-quantitative analysis approach;
- The level of analysis may be extended from high to low levels of resolution: for example, it could be decided not to analyse in detail all causes and contributing factors of the marine events such as collision, grounding, contact and so on, but rather focus on the problems related to the maritime transport systems of PDG and related activities such as packaging, packing, handling, loading, unloading, stowing, securing and carrying of PDG;
- The risk issues/types: based on the main categories of consequences, risks are divided into human, marine environment and property risks: for example, the risk study may deal with the individual or aggregated risks posed by maritime transport of PDG.

### 5.1.8. Selections of risk analysis methods and techniques

Generally, the risk analysis process is a rigorous process that is performed by means of standardised frameworks, which, in addition to many data analysis techniques in general use, employ certain techniques (see Chapter 3, Vol. I, and Mullai, 2006b). Given the wide array of techniques available, selection is not always easy. They range from qualitative, quasi- or semi-quantitative to fully quantitative and from specific to generic, providing various degrees of detail and precision. Although there is no single appropriate technique for a specific activity, some techniques are more suitable than others. Therefore, prior to the collection and analysis of data, the appropriate technique(s) is selected. However, a change in the choice is also possible after data collection. The choice is affected by a number of interrelated and complex factors including:

- The extent of the risks;
- The stated objectives and the requirements of decision makers with regard to having quantitative versus qualitative data/technique. In some countries, this is determined by the relevant regulation framework (EC, 1998b);
- The nature and amount of the risk-related data and information available. The relevant data required may not always be available, because they either do not exist or are not readily accessible by the analysts;
- Time and resources available.

### 5.1.9. Risk related data and data collection methods

The risk analysis process, regardless of how simple, should generate relevant information to aid in the decision-making process. In many cases, a wide range and large amounts of data, which may be collected from different sources by employing different data collection methods and techniques, is required to provide a detailed and comprehensive coverage of the information desired by decision makers and other interested parties. The risk analysis draws on knowledge from various fields and branches of science, such as engineering, statistics, chemistry, marine biology, epidemiology, toxicology, economy and sociology.

What data collection methods are employed? What types and how many data to collect? What are the data sources? These are some of the questions that are discussed below.

#### 5.1.9.1. Data collection – methods and processes

The review of many formal and informal studies, including those presented in Chapter 1, Vol. I, showed that the risk studies are generally based on one or combinations of the following approaches:

- Data available for the phenomena in question, which are often combined with data and information from previous studies from other places or applications of similar systems. They are adjusted to the system being studied and the conditions of the local environment;

- When a few data records exist, the analysis, or certain aspects of the analysis (e.g. dispersion and concentration of dangerous goods hazards), can be based on simulations and theoretical models; and
- Experts' judgments.

Risk studies can employ one or combinations of the data collection methods available, such as: interview, observation, field study, experiment and testing, simulation, survey, archival or documentary (e.g. manufacture, maintenance and operations reports) study, literature study, and statistics. A study can, for example, make use of the data gathered by interviews and observations of managers and employees of shipping companies or inspections of CTU (e.g. containers and vehicles) carrying dangerous goods. Risk analyses inevitably involve uncertainty that requires informed and professional judgements. The experts' judgements and experiences may become very valuable in the absence of empirical data. Because grounded in actual experiences, risk studies based on historical data, which is one of the most frequently used types of data, are generally preferred (DNV, 1995; Carol et al., 2001). In addition, the amount, variety and accessibility of data are some other reasons that historical data are so widely used.

#### 5.1.9.2. Sampling techniques and procedures

Sampling is concerned with determining what and how many observations are to be made or what population and how many members should be selected and studied, when it is not feasible or practicably impossible to make all the observations or study the entire population that would be ideally desirable. There are various conventional sampling techniques and procedures that can also be employed in risk studies. In the case of historical data, it is important to deal with these two central questions. First: Which sub-population of marine events should be selected for the study? This is a question of sampling design or scope. Second: How many marine events should be selected? This is a question of sample size. Detailed discussions about sampling techniques and procedures are provided in the literature dealing with sampling theory and statistics (Hubert and Blalock, 1979; Hair et al., 1998; Bakeman, 1992). Thus, for the purposes of a risk study, a sample size of N numbers of cases can be drawn from a "population" of marine events at hand. The sample may constitute a sub-population of marine events, containing those marine events defined as "*marine events involving PDG*" (see Chapter 3, Vol. I, and Mullai, 2006a). The sampling could be based on certain criteria and assumptions. For example, the following may be considered in sampling:

- *Marine events*: including all marine events involving PDG, excluding events involving liquids, liquefied gases and dry bulk dangerous cargoes, for example, oil and oil products, LNG and LPG;
- *Types of ships*: including all types of ships carrying or having PDG and other dangerous goods in "limited quantities";
- *Location*: for example, world-wide, region, or country;
- *Consequences*: including all categories of events from "near misses" to catastrophic events;

- *Risk receptors*: including the human, marine environment and property consequences.

Data availability and accessibility, time and the availability of resources are some other factors determining the sample size.

Data collection may take place at different phases of the research. Initial data collection may involve readily available and accessible data such as marine events records, statistics on traffic of dangerous goods and other background information. However, some data may not be readily available at hand, and they have to be collected, for example through interviews, surveys or observations. In order to provide answers to some questions that are generated during the analysis, certain data should be gathered as the analysis progresses.

#### 5.1.9.3. Some relevant data sources

As the search for identification and collection of relevant data sources for this study has shown, maritime transport risk-related data are held for different purposes by different organisations. Data sources range from public access, limited access (e.g. “for members only” or non-accessible) to confidential and very confidential. In some parts of the world, the data is of poor quality and insufficient, if not non-existent. Reasonably accurate and well-defined statistical databases are prerequisites for the risk analysis and, subsequently, for better risk management.

Good access to data and information is critical for the risk analysis. Given the sensitivity of risk issues, in particular the risks posed by many dangerous goods carried in packaged form, the limitation of the data available may be an obstacle to developing a robust risk analysis. In a risk study, public domain sources may be primarily used for acquiring relevant data. Before conducting a risk analysis, it is extremely important to identify relevant sources, and evaluate and discuss data availability, accessibility and costs with the decision makers.

There are numbers of databases designated for industrial accidents involving dangerous goods that have occurred at fixed installations and during transportation. The review of many databases shows that, except for the HMIS database (see below), the databases available are not specially designated for marine incidents involving PDG. Numerous private and public databases are specially designed for marine incidents involving oil and other chemical spills. These databases, which may be accessible through the Internet or contact with responsible authorities, contain data concerning marine incident in general, with little or no information about PDG. For example, there is limited information about the type and amount of dangerous goods involved, human and environmental consequences due to hazards of dangerous goods, the type and amount of packages involved and so on. In other words, such sources contain many case histories, but with little relevant information for the risks of marine events involving PDG. Therefore, in order to explore the risk elements, large amounts of data and information may need to be collected from a number of sources.

Even the best source available may not provide all necessary risk-related data. Therefore, data may be acquired from different sources, particularly in the case of a detailed risk analysis. In some cases, sources of data are listed in the appendixes of the codes and guidelines of practices for risk or safety management. Some sources that may contain relevant data, such as historical data, statistics, and previous studies in the form of reports or articles, for the analysis of risks in maritime transport of PDG include:

- National and international chemical industries
- Occupational health and safety authorities
- Enforcement agencies
- Class and insurance organisations
- Port authorities and associations
- Institutions or bureaus of statistics
- International and national maritime organisations administrations, associations or agencies
- Maritime information and service providers
- Centres for maritime studies
- Trade unions and employer associations
- Industry associations, for example, ship owners' associations, manufacturers, importers or suppliers, transporters of dangerous goods
- Rescue, response and emergency agencies, for example coast guards and fire-fighting services
- Databases for published literature etc.

The following are some relevant accidents and incidents databases that have been identified, and some of them are reviewed for the purpose of this study:

- *Major Accident Reporting System* (MARS), EU: This database contains information on major accidents involving dangerous goods submitted by Member States of the European Union. It has (2001) data in full and short reports on more than 450 major accident events. Only less than 10% of all MARS data that are included in short reports are for public use. SPIRS (Seveco Plants Information Retrieval System) is a complement of the MARS database that provides access to the risk related information from major hazardous industrial establishments in Europe.
- *Failure and Accident Technical Information System* (FACT): This is a database that was created at the end of the seventies by TNO, The Netherlands. It contains 19,000 industrial accidents worldwide. The information is obtained from numbers of sources, such as companies, government agencies, publications in technical periodicals and other literature. The database is only available on CD-ROM at a cost.
- *Major Hazardous Incidents Database System* (MHIDAS), Safety and Reliability Directorate, UK. This contains 7000 incidents that have occurred during the transport, processing or storage of hazardous materials. The database includes incidents that incurred casualties, required evacuation or caused damage to property or the environment. All the information is taken from public sources, and the database aims to collect information on incidents that have occurred worldwide, although the majority of incidents on the database have been reported from the UK and the USA. Access to the database can be made via a personalised service

- The *CHEMAX Database* of accidents involving dangerous goods is an in-house database from the Joint Research Centre, Ispra, and European Commission. It contains thousands of worldwide accidents involving dangerous goods, including transports and fixed installations. The data are mainly collected from public sources.
- *OECD Database* on industrial accidents, Expert Group on Chemical Accidents. The descriptions of accidents are short.
- The *Center for Chemical Process Safety* (CCPS) database includes chemical process incidents that could result in a fire, explosion, fatality, multiple injuries, or release of hazardous materials. Information is provided by participants representing different activities, including: AKZO, BP/Amoco Corporation, Dow Chemical Company, DuPont Company, Exxon Chemical Company, Mobil Oil Corporation, Procter and Gamble, Shell Oil Company, Texaco Group, Inc. and Union Carbide Corporation. Access to the database is for participants only.
- *Accidental Release Information System* (ARIP) Database, US Environmental Protection Agency. The database contains (1999) over 5,000 incidents reported in the USA. It is maintained by The Chemical Emergency Preparedness and Prevention Office (CEPPO). The information has been collected (since 1986) through a questionnaire that consists of 23 questions about the facility, the circumstances and causes of the incident, and the accidental release prevention practices. Incidents are selected on the basis of criteria that focus on significant accidents. ARIP targets those accidental releases at fixed facilities that resulted in off-site consequences or environmental damage.
- *Emergency Response Notification System* (ERNS) database.
- *Chemical Incident Reports Center* (CIRC) is an information service provided by the U.S. Chemical Safety and Hazard Investigation Board (CSB). Reports (over 2400 reports in 2003) contain information about incidents involving fixed installations and transports of chemicals that have occurred around the world, such as asphyxiations, fires, explosions and releases into the environment. The information comes from official government sources, the news media, eyewitnesses and others.
- *APELL Disasters Database* (UNEP) contains some disastrous accidents for the period 1970-1998. The events are collected from different sources, and meet the inclusion criteria of 25 dead or more; or 125 injured or more; 10,000 evacuated or more; or 10 thousand people or more deprived of water. The disasters are viewed by category, by location, or by date. The database contains several categories of technological and natural causes including rail, road and maritime transports of bulk dangerous cargoes such as oil, oil products, LNG and LPG.
- *Hazardous Material Incident System* (HMIS) (USA) contains data on spills, releases, or other incidents involving hazardous materials during transportation (approx. 186,000 incidents). All modes of transportation are included, except pipelines.
- The IchemE Accident Database developed by the Institution of Chemical Engineers. The latest version (4), which is available for payment, contains over

13,000 accidents (2003), incidents and near misses, 30% of which include lessons learned.

- The *U.S. National Response Center* (NRC) Database: The National Response Center serves as the only national point of contact for reporting all oil, chemical, radiological, biological, and etiological discharges into the environment, including maritime transport, anywhere in the United States and its territories. It gathers and distributes spill data for Federal On-Scene Coordinators and serves as the communications and operations centre for the National Response Team. The database covers the period 1982-2004 (over 460,000 incidents). Each year large numbers of events are reported; for example, in 2002, 32,185 incidents were reported.
- *U.S. Department of Health and Human Services*, Hazardous Substances Emergency Events Surveillance (HSEES) Annual Report.
- *Laboratory of Maritime Accidents* (LAMA) Database, the Department of Maritime Studies of the University of Piraeus, Greece, established in 1993.
- *ZEMA Database* belongs to a German central body, which was established in 1993 for collecting and evaluating major accident and near miss events. It is part of the Federal Environmental Agency (Umweltbundesamt, UBA). All events that are to be reported in accordance with the German regulation on major accidents (Hazardous Incident Ordinance) are centrally collected, evaluated and documented by ZEMA. The bureau is also responsible for the dissemination of the lessons learnt to all stakeholders. For each event, a separate data-sheet is published in annual reports. This work is done in co-operation with the German Hazardous Incident Commission and other national and international bodies.
- *World Offshore Accident Data* (WOAD) database.
- *Lloyd's Maritime Information Services* (LMIS) database.
- *IMO's database* ("Reports on Marine Casualties and Incidents").
- *Marine Accident Reporting Scheme* (MARS).
- *Swedish Maritime Administration* (SMA) (Sjöfartverkert) and Swedish Coast Guard Databases.
- *ARIA*, France.

In summary, in many countries, several initiatives have been taken to provide industries, governments and research institutions with information on accidents and incidents. The above list of databases may be useful to those who are interested in the risk analysis in dangerous goods supply chain. Databases have different scopes and coverage. Many databases contain “major”, “very serious” and “serious” industrial accidents that have occurred at fixed installations (e.g. plants, factories, warehouses, and terminals) and during transportation. Some databases have been established in the recent years. The data are collected from different sources, including official government channels, company or participant informants, the news media, press reports, eyewitnesses and other sources. The data vary in quantity and quality. Many “minor” incidents may go unreported and hence may not be entered into the database. A detailed accident description is missing for some databases. The review of many databases has showed, and has also been confirmed by another source (Haastrup and Romer, 1995), that the quality varies from medium to low quality. The U.S. and

Swedish databases are among the best federal/national databases being closely reviewed. In addition to the above sources, there are many non-public sources, such as consultants and industry databases. In recent years, many databases are covering not only accidents with impacts on humans, but also accidents with environmental consequences.

#### 5.1.9.4. Relevant datasets – types and amounts of data

The terms "information" and "data" are often used interchangeably, but it is generally agreed that "information" refers to the data (e.g. observations, measurements, or facts) that, in some way, have been compiled and processed, from which knowledge can be acquired.

Given the complexity of the maritime transport system of PDG and its risks, as well as the variety of decisions, a large amount of different types of relevant data and information (i.e. datasets) is often needed to facilitate each step of a risk analysis. The following are some examples:

- *Background and introduction*: the background information, reviews of previous studies in the field of the risks of maritime transport of dangerous goods;
- *System definition*: the information needed to define and describe the maritime transport system, for example in terms of marine transport of PDG, types of ships carrying dangerous goods, marine environment sensitivity, people and properties exposed, weather conditions and so on;
- *Review of regulations*: the information acquired from various documents containing regulations governing maritime transport of PDG and guidelines for good practices;
- *Analysis process*: the data and information, such as case histories, statistics, and results from previous studies, needed to facilitate hazard identification, exposure and consequence identification and estimation, likelihood estimation and quantification.

The data are of different formats and types. The data vary from quantitative to qualitative data and from raw historical data and survey data to information, reports and summaries of previous studies. The data may come in hardcopy or electronic form.

The best situation is to collect all the necessary and relevant data from a single source. But that is not always the case. The risk analysis, in particular a detailed analysis, may require the combination of numerous data sets collected from different sources, with the main purposes to *fill the gap*, if any, and/or *extend data*. For example, in Sweden, marine events are analysed, and subsequently decisions have been made based on the use of combinations of numerous data sets, which are acquired from different systems (databases) (see Mullai, 2006a) (Table 5.1).

**Table 5.1: Datasets from different databases/registers (SMA, 2002)**

| Nr. | Database/ register | Dataset |
|---|---|---|
| 1 | Sea Casualty System[17] | Marine accidents/casualties |
| 2 | Insjö System | Non-conformities or deviations and risks |
| 3 | Ship Inspection System[18] | Information concerning the ship involved in marine accidents |
| 4 | Swedish Seamen's Register | Persons employed on merchant ships |
| 5 | Swedish National Board of Fisheries and Fishermen's Federation | The number of licensed vessels registered and the number of fishermen |
| 6 | The Occupational Injury Information System[19] | Occupational accidents, injuries and work-related diseases |

Depending on their nature, the data sets can be used separately, for example in the form of primary and secondary datasets, or as a single merged set. Given the diversity of sources, merging data sets may be a problem. As mentioned earlier, maritime transport risk-related data are held for different purposes by different organisations at different levels – international, regional, national, local, industry and sector levels. Because of inhomogeneous samples of events and different levels of data completeness, it may be impossible to integrate different data sets. The definitions, descriptions, measurement units or values, and the frame of reference of the data provided by these sources may not agree, i.e. may be incompatible (see Chapter 3, Vol. I, and Mullai, 2006a), and a perfect fit among data sets may not be possible. For example, due to the lack or incompleteness of the information concerning the date, location or country, chemicals, or consequences of marine accidents, matching and making use of different data sets become difficult tasks.

Although considerable improvements have been made in safety and health and environmental protection with the introduction of accident/incident databases, in some geographical areas risk management is still not receiving enough attention. In many countries, certain types of events, such as "near-misses", are often not always reported and recorded.

There are many interrelated factors affecting the type, quantity and quality of data and data collection methods and techniques. All these, in turn, affect the analysis process and results, and subsequently the entire risk management process. Some important factors include data availability and accessibility, resources available, the risk issues, research problems and objectives, decision makers' requirements and preferences, and the risk management options. In general, the more quantitative and detailed the analysis is to be, the larger the amount of different types of data is required, the more resource-intensive is the process and the greater is the elapsed time required

[17] In Swedish SjöOlycksSystemet, SOS
[18] In Swedish FartygsTillsyns Systemet, FTS
[19] In Swedish InformationsSystemet om Arbetsskador, ISA, the Swedish Work Environment Authority

(Morgenstern and Landy, 1997; Hokkanen and Pelline, 1997). However, there are exceptions to this general rule. The analysis at a higher level of resolutions of the risk elements, which is based on the accident case histories acquired from well-established databases and facilitated by risk analysis software packages, is an example.

The following are some categories of risk-related data and information that may be needed in a detailed risk analysis of marine events involving PDG. They are based on the review of many different sources, including case histories (e.g. HCB, 1986-2003; SMA, 1986-1999 and other databases) the USCG Marine Safety Manual and other directives, the Compendium of Data Sources for USCG Marine Safety and Environmental Protections, and many formal studies on marine safety and health and environmental protection cited in this volume. The list, which is not exhaustive, contains these categories of data: dangerous goods, ships, vessel traffic, marine events, exposure and consequences, marine environment sensitivity, response, and sea and weather/atmospheric conditions.

### Types of dangerous goods handled and carried

Dangerous goods carried in packaged form are divided into classes and sub-classes according to the UN/IMDG Code classification system, classes 1 to 9 (for information see Chapter 3, Vol. I, and Mullai, 2006a). Depending on the risks posed, concerns and resources available, the risk analysis may be confined to a selected number of classes/sub-classes or a group of dangerous goods. Types of dangerous goods, including respective amounts and packaging types transported and handled, should be listed and prioritised based on the risks they pose.

### Trade or traffic identification

In the absence of regular statistics, surveys may be conducted to identify dangerous goods traffic (see examples in Mullai, 2006a) in terms of routes, total tonnage, and the number of ports or terminals handling PDG. Significant traffics can be identified for a given area - e.g. a port, a country, or a region - from the cargo groups' shipments expressed in terms of the total amount (tonnes/year) and ship visits (ships/year). Mean amounts (tonnes/year) and shipments (tonnes/ships) can be calculated from cargo groups handled in terminals.

### Historical data – marine events case histories

Some of the best insights into the risks of marine events are based on the information about the types, frequencies, and severity of past events. Case histories can provide important empirical data for hazards identification, frequencies and consequences estimations. They could be used in conjunction with other studies and experts' judgements. In addition, the data for the location in question can be used in conjunction with other data sets obtained from other sources for other locations.

### Ship properties

Types of ships carrying PDG should be identified. The main categories of ships include: dry cargo ship, container ship, bulk carrier, ro-ro ship and other types of ships (for information see Chapter 3, Vol. I, and Mullai, 2006a). The number of ships visiting or passing through or past a country, region or port should be estimated. Some important categories of information include:

- Characteristics of ships that use the port/waterway, for example, types, sizes in terms of capacity (dwt, grt, brt) and dimensions, ship's age, power, ownership, flag, class society.
- Numbers of transits/calls by ship type, including the peak transit time (e.g. hours, days, months, years) for port/waterway.
- Ships with related marine events, for example, grounding, collision, contact, and fire/explosion.
- Ships with causes and contributing factors, for example, navigation system, machinery system, and structural failure.
- Ship inspections findings, including deficiencies and detentions.
- Numbers and categories of companies or organisations related to shipping.

### Cargo properties

- Numbers of ship movements, handling or operations of PDG in a port/waterway.
- Quantity and type of PDG carried through ports and waterways.
- Numbers of leaking containers, including unknown sources of discharge.
- Quantity of dangerous goods released.

### Human safety and health – effects and exposure data

- Fatalities and injuries due to hazards of dangerous goods.
- Other effects on human safety and health from the release of DG.
- Location and size of shore side population including locations of heavy populated areas, schools and hospitals near ports and waterways, and along the maritime transport route. Data on the population have to be gathered in order to enable societal and individual risk calculations.
- Location of passenger ferry terminals, cruise ship terminals, and marinas.
- Numbers of passengers transported through ports/waterways.

### Response

- Fireboat, police, response team available, capability and timeliness including response equipment, vessels, tugs.
- Number, amounts and rates at which dangerous materials are recovered from spills or releases.

### Port and waterway

- Location of high-density vessel traffic areas and routes.
- Categories of vessel traffic.
- Location of facilities handling dangerous goods.
- Location of warehouse/storage facilities of dangerous goods.
- Location of other important facilities, for example, production, transfer, handing, and storage of dangerous bulk liquid such as oil and oil products, LNG, LPG and other chemicals.
- Number and location of response facilities, equipment, ships.

- Number and location of navigation aids.
- Characteristics of ports/waterways, for example, a port’s bottom type, depth, bridge clearances, channel lengths, widths, and depths.
- Other geographical properties and characteristics of the area.

#### Environmental – sensitivity, effects and exposure

- Marine ecosystem properties and characteristics: the current state of the environment: water, sentiments, fauna and flora;
- Location of sensitive areas and endangered species: e.g. mammals, birds, fishes, other marine life, for example designation as a Special Protection Area under the EC Birds Directive or any other area of special conservation.
- The existence of commercially exploitable biological resources and mariculture sites;
- The extent to which the area provides a public recreational amenity;
- Effects on environment by spill/release of dangerous goods - geographic area affected.
- Effects on environment by spill/release of dangerous goods - safety and health effects, quality of water, fauna and flora.
- Economic/financial impacts
- Locations of environmentally sensitive sites.

#### Sea and weather/atmospheric conditions

Hydrographical and meteorological conditions:

- Water characteristics: salinity and contents.
- Water current characteristics: speed, direction, and water circulation characteristics.
- Water level/tides.
- The state of the sea: wave directions and heights.
- Prevailing weather characteristics: winds, visibility, precipitation, temperature, humidity, and ice.
- Visibility: fog, rain, snow, ranges of visibility, numbers of days with poor visibility.
- Winds: prevailing wind direction and speed.
- Precipitates: rainfall and snowfall days and amounts.

### 5.1.9.5. Issues concerning quality of data

An important task of the risk analysis is to assist decision makers in making decisions as clear, best informed, conscious and deliberate as possible. But, among numerous problems related to the risk analysis, there are numbers of gaps in the data. These gaps may come in many forms, including: accessibility, completeness and comparability, detail, existence, integration, quality, and timeliness (U.S. BTS, 2002). The maritime transport of PDG is not an exception. The review of databases (see Section 5.1.9.4 of this Chapter) shows that many databases are fragmented and generally inadequate in connection with accident data definitions, data accuracy, and data collection and processing. In some cases, the data are not defined and recorded with the specific risk analysis and management requirements in mind. Further, the data from different activities and countries is, in many cases, inadequate, making comparison and integration very difficult. The data are potentially subject to errors arising from different factors, such as sampling variability, incomplete coverage, and inaccurate reporting and interpretations. The accuracy and completeness are often related with the severity of the event. For example, many case histories (see Chapter 1, Vol. I, HCB, 1986-2003) have shown that events involving fatalities, injuries and marine environment pollution contain more reliable and complete data because fatalities, injuries and serious pollution are easy to identify, hard to conceal and involve a wider coverage.

In many cases, risk studies rely heavily on the "secondary" data provided by various sources (see Chapters 1 and 2, Vol. I). How reliable are these sources and the data provided by them? Uncertainty surrounds the "most reliable" sources, and reliability varies considerably. However, in any study, every reasonable effort should have been made to select, verify, triangulate and supplement, and to make use of the data from the "best" sources available, e.g. the U.S. DOT (including its relevant agencies and organisations such as the USCG), LRS, the IMO, HCB, P&I Clubs and many other sources (see databases described above) on which many studies are based.

## 5.2. Stage 2 – Risk analysis

Stage 2 concerns the risk analysis process. Based on the risk-related data and information gathered in Stage 1, and the risk analysis techniques selected, risks can be analysed by the following key steps:

***Step 1: System definition –*** Define and describe the system and related activities whose risks are to be analysed and managed, including review of the current status of regulations governing maritime transport of PDG.

***Step 2: Hazard identification*** – Provide answers to the question "*What has gone or can go wrong?"* Explore top events, transport hazards, causes and contributing factors, and the sequence of events that have led or can lead to the loss of containment and the involvement of dangerous goods.

***Step 3: Exposure and consequence analysis*** – Provide answers to the question "*What are the consequences?"* including other related questions, such as "Who/what are exposed to hazards of dangerous goods?" and "How are they exposed?" Explore the exposure and actual consequences of dangerous goods hazards to the risk receptors.

***Step 4: Likelihood estimation – quantification*** – Provide answers to the question *"How often?"* "*What is the likelihood*?" or "*How many/much*?" Quantify the risk and system elements, and if desirable and possible, identify and quantify their relationships. Employ statistical analysis techniques, which can perform summary and inference statistics. The likelihood (frequency/ probability) estimation is only one of the procedures.

***Step 5: Risk estimation and presentation*** – Risk estimation combines a) the likelihood (frequency/probability) and consequences, and b) the consequences and exposures to hazards of dangerous goods. The purpose of risk presentation is to reduce the large amount of information and provide a simple risk description that is useful for decision-making.

### Sensitivity analysis

For the purpose of prioritisation, the individual risks are ranked with respect to the likelihood and consequences/exposure i.e. is the Risk Index. The Management Index, which combines risk index and sensitivity (expressed as Risk Index x Sensitivity) provides further ranking for those risks that have an equivalent Risk Index. Although this step is not found in many traditional risk analyses, sensitivity analysis has become an important element of the process in some countries, for example the UK. However, sensitivity analysis involves cost benefits, risk perceptions and other non-technical aspects of risks as well, which may be outside the scope of the risk analysis stage. Furthermore, this analysis may constitute a large study in its own right. Therefore, this step may not necessarily be considered a constituent element of a particular risk analysis.

The framework (Figure 5.4) combines the key steps described above (excluding sensitivity analysis) and the integrated principal procedures or structures of the backward and forward logic analysis techniques employed in Fault Tree (FTA) and Event Tree (ETA) Analysis. Risk analysis may employ a wide range of combinations of specific risk analysis techniques, some of them are presented in Chapter 3, Vol. I, and Mullai, 2006b, include FTA and ETA techniques. Both these techniques can be employed for the analysis (identification or exploration and quantification) of a) hazards, causes and contributing factors, and b) consequences. Furthermore, in the risk analysis, the wide range of other advanced qualitative and quantitative data analysis methods, models or techniques can be employed to analyse system and risk elements and their relationships.

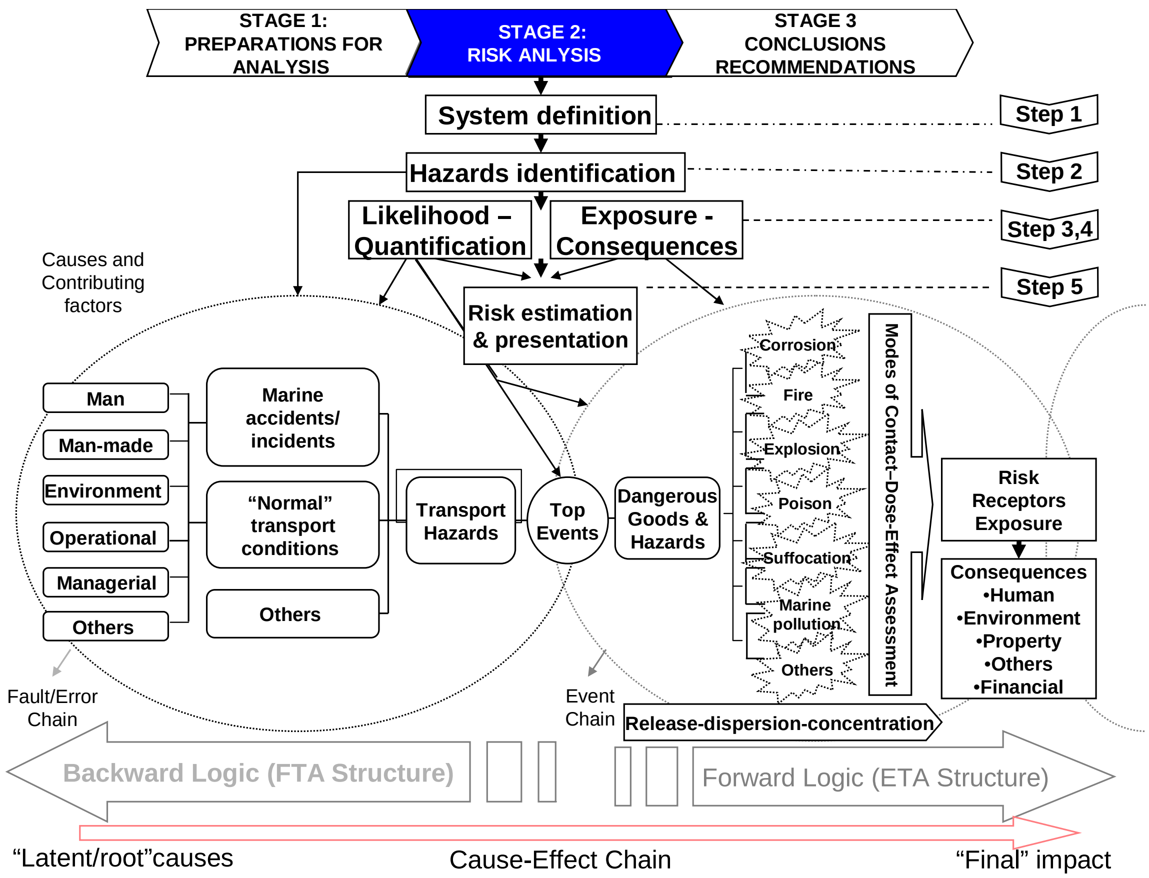


**Figure 5.4: The risk analysis framework**

The following section discusses in detail ***Stage 2*** and its steps/sub-steps of the risk analysis process as shown under the **highlighted area** in Figure 5.4.

## 5.2.1. Step 1 – System definition

*Tasks: Define and describe the system and related activities whose risks are to be analysed and managed. This includes the review and evaluation of the current "state-of-the-art" regulatory system governing the maritime transport system of packaged dangerous goods.*

This is an important step of the risk analysis whose purpose is to define and describe the constituent elements of the system and risks, and to provide necessary assumptions. This section will serve as the "groundwork" or the "point of reference" for the analysis of the risk and system elements, conclusions and recommendations. In this step, the relevant concepts are defined and described, based on which the system and risk elements have to be measured.

### 5.2.1.1. Maritime transport system of PDG

*Tasks: Define and describe the maritime transport system of PDG including other essential risk-related elements.*

Marine accident case histories and other related data contain many different complex concepts describing the maritime transport system and risk elements. These concepts will serve the purposes of analysis and measurement of the system and the system outcomes. The selection and precision of the relevant concepts will affect reliability and validity of the risk analysis. Therefore, the relevant concepts should be carefully selected, precisely defined and accordingly described in some detail. Some examples of relevant concepts to be selected, defined and described include:

- *Ships*: all types of ships carrying PDG, and other types of ships involved in marine accidents, or which interfere with maritime transport of PDG, including relevant data for these elements: types, sizes, flags/nationalities, ages and other properties.
- *Dangerous goods*: all categories of dangerous goods carried in packaged form, including: IMDG Code classes 1-9, dangerous goods "in limited quantities" such as passengers' personal effects, and other chemicals. The description could include classes and subclasses, hazards properties, and subsidiary risks.
- *Packaging/units*: types and forms of packaging and cargo transport units (CTU) by which dangerous goods are carried, including types/forms, materials, packaging group, and other related information on packaging and CTU.
- *Vessel traffic*: PDG and other traffics, for example passengers, oil and chemicals carried in bulk traffic, including types, numbers, and sizes of ships; amounts, numbers and sizes of shipments of PDG; and types of packaging and CTU.
- *Cargo/ships/port activities*: cargo loading, unloading, packing, stowing, securing, and documentation, navigation, manoeuvring and other maritime transport-related activities.
- *Maritime transport infrastructure*: the state of the navigation systems, canals, waterways, terminals/ports, equipment and warehouses.
- *Weather, sea conditions and other navigations hazards*: the force and direction of winds, the precipitation, the humidity, the temperature, the state and direction of the sea, currents, seawater properties, water depths, and other navigation elements.
- *Marine environment*: the fauna and flora of the marine environment and inland waters, resources and values, sensitive areas and coastlines.
- *Exposed population*: ship's crew/personnel, passengers, stevedores/workers on land, inspectors/surveyors, pilots and local community.
- *Properties and other activities ashore:* individual and common properties, business and other activities ashore.

The maritime transport system under consideration should be understood as a complex entity that is formed of humans, machines and the environment. It is important to identify the total system, system processes and other related activities. The system is divided into different levels of resolution. This means separating the transport system into its constituent parts or elements and defining and describing them. However, as a detailed risk analysis, and subsequently a detailed description of the system would be prohibitively expensive (HSC, 1991), the risk assessors and decision-makers should discuss the degree of detail of the analysis, the scope of the data available, and the potential need for additional data collection.

For more information about the maritime transport system see Chapter 3, Vol. I, and Mullai, 2006a.

#### 5.2.1.2. Regulatory system governing maritime transport of PDG

*Tasks: Review and evaluate the current "state-of-the-art" regulatory system governing maritime transport of PDG.*

### Current "state-of-the-art" regulatory system

*Task: Review the current "state-of-the-art" regulatory system governing maritime transport of PDG.*

The regulatory system governing the maritime transport system of PDG, which consists of a wide range of legal and non-legal instruments, is an important constituent element of the system (for more information see Chapter 3, Vol. I, and Mullai, 2006a). Like other modes of transport, maritime transport of dangerous goods, including such matters as technical, operational, safety and health and environmental protection aspects, is highly regulated. Regulations for designing, constructing and testing packaging/units and transport operations are generally based on the lessons learned from past accidents and the experiences of many experts around the world. Complying with the regulations provides a common level for the safety and marine environment protection in maritime transport of dangerous goods. Therefore, the current "state-of-the-art" regulations and safety technology should be reviewed. What comprises the regulatory system for the maritime transport of PDG? What is the current "state-of-the art"? What other appropriate safeguards are in place? These are some of the issues that should be dealt with in this section. In addition, the review of the regulations will also provide the basis for dealing with some important issues for the risk analysis and management.

### Evaluation of the regulatory system

*Task: Evaluate the "state-of-the-art" regulations governing maritime transport of PDG.*

Identify and describe regulations-related issues, some of which can be identified in the risk analysis process, including: Does the maritime transport system of PDG conform to good practices and established rules? How and to what extent have regulations-related issues contributed to the risks? How to enhance safety and health, marine environment and property protection in the future through improvements in regulations?

Other types of information and data that may be deemed relevant and important for the risk analysis can be explored and presented in this step.

### Analysis process

The previous step provided a conceptual framework and other relevant information. The remaining steps deal with the analysis process of the system and risk elements. The analysis process begins with hazards identification. However, prior to this, it is important to understand the chain of marine events and determine the top events from which the analysis process starts. This will further describe the elements of the model.

In order to have a better understanding of the analysis process, the model (see Figure 5.4) can be used as a guide. The graphical representation of the model allows easy visualization of the process.

### Understanding the chain of events

The risks of maritime transport of PDG are about marine events involving releases or involvements of dangerous goods. In order to understand these risks, it is, therefore, important to understand the complexity of these events in the first place. Case histories (see Chapter 4, Vol. I, HCB, 1986-2003, SMA, 1985-1999 and others) have shown that marine events involving PDG are generally generated and propagated in the form of a complex chain or network of events. This is an open cause-effect chain, in which the effects of one event, or combinations of events, may become the causes for another subsequent event or chain of events. For example, dangerous goods lost at sea can cause the contamination of the seawater and sediments, which can cause the contamination of fish. People can be poisoned by consuming the contaminated fish. The chain may "starts" with "latent or root" causes and "ends" with "final" consequences or effects. In between, it may difficult to distinguish causes from effects. The time span (timeliness) between the "root" cause and "final" consequence varies widely for individual events. This could vary from a few seconds or minutes (e.g. a massive explosion following an impact or fire) to several years (e.g. the spill of dangerous substances from corroded containers that have been poorly maintained for a long time), and even decades (e.g. marine pollutants getting into the food chain). For many individual events, the chain is short and simple. However, in many risk analyses, a large number of events are often taken into consideration, sometimes as many as hundreds or even thousands of events. Generally, the chains or networks are long and very complex.

## 5.2.2. Step 2 – Hazard identification

*Question: "What has gone or can go wrong?"*

*Tasks: Explore transport hazards, causes and contributing factors, and the sequence of events that have or can lead to failures of packages and subsequently to loss of containment and/or involvement of dangerous goods, which have actually caused or have the potential to cause undesired outcomes to the risk receptors.*

The analysis process usually begins with hazards identification, which is a vital component of the risk analysis (RSSG, 1992). The term "hazard identification" may take different meanings in different contexts. But in this report, the main purpose of hazard identification is to identify and describe the list of hazards and their causes and contributing factors. In this section, the term "hazard" is used to denote the situations or conditions and combinations thereof *that have the potential to cause damage to* containment and/or dangerous goods. It should not be confused with the term "hazards of dangerous goods." Case histories (case histories in Chapter 4, Vol. I, HCB 1986-2003 and other databases presented in Chapter 2, Vol. I) show that the maritime transport system of PDG is associated with a wide range of hazards, including physical or mechanical, climate or weather, chemical, electrical, electro-chemical, radioactive, biological and other hazards. Dangerous goods hazards, such as fire, explosion, and corrosion can cause and/or contribute to damage or deterioration of the packaging. Furthermore, many marine accidents and incidents have been attributed to the hazards, problems and faults in other parts of the supply chain. For example, this includes production of dangerous goods and packaging, packing, storage, handling in factories, storage sites, ports or terminals, and transport by other modes.

Maritime transport hazards and accidents are attributed to many different causes and contributing factors. However, the main categories include human, organisational, managerial, technical, operational and physical environment factors or conditions. The analysis should take a systems approach view, where the maritime transport system is considered as a very complex *socio-technical-environment* (*STE*) entity that is formed of humans and man-made entities operating in a physical environment. If sufficient quantitative data is available, the accidents, transport hazards and their causes and contributing factors that contribute most to the risks are identified.

There are different structured and formal analysis techniques available for conducting hazard identification, but they are not readily applicable for analysis of maritime transport hazards and causes and contributing factors. Therefore, as mentioned earlier, the principal procedures of backward/top down logic analysis employed in the Fault Tree Analysis (FTA) technique has been adapted for hazard identification. In these procedures, the wide range of qualitative and quantitative data analysis methods or techniques could be employed to explore and explain phenomena.

#### 5.2.2.1. Define top events

Whatever analysis approach or technique is employed, the risk analysis process begins at some point in the chain of events or somewhere else. In a risk analysis, it is customary to define one or a set of events, known as the “top” or “initiating” events[20], from which the analysis process starts. There is no unanimously accepted definition of what may constitute a top event. It varies across industries and sectors and, sometimes, it becomes a matter of the analyst’s choice. In shipping, for example, “marine events” such as grounding, collision, fire/explosion, machinery failure etc., as defined in several sources (see Mullai, 2006a), are generally taken as the top events. For road and rail transport, “turnovers”, “collisions”, “derailments” or “punctures or ruptures” of tank containers and other forms of packaging are some of the events selected as the top events, for which causes and consequences are identified and analysed. In order to explore the causes and consequences, analysis techniques are often employed for each type of event.

Given the vast range of types of dangerous goods and packaging, and the large number and complex combinations of events and conditions in maritime transport of PDG and other parts of the supply chain, the determination of top events becomes very difficult.

[20] Note: the terms “top event” and “initial event” are used in FTA and ETA respectively, and for the purpose of convenience the term “top event” is chosen.

Based on the case histories, the following events are defined as the top events for the purpose of the risk analysis in the maritime transport of PDG (see Figure 5.5):

1. *Breach of package:* This category includes ruptures, punctures, pierces or any other form of failure or damage that can lead to the release and/or involvement of dangerous goods or unsafe situations caused or affected by one or combinations of distribution/ maritime transport hazards and inherent faults of packages and packing. Large amounts of different types of dangerous goods are carried by sea in various types of packaging in liquid, gas or liquefied gas forms, for example oil products, LNG, LPG, and many corrosive, flammable, explosive and toxic liquids and gases. For many of these substances and materials, release is the necessary, but not sufficient, condition to come in contact and cause harm to people, the environment or property.
2. *Failures of packaging performance*: This category includes the failures or deviations of the packaging system to perform the intended functions that are due to inherent faults in design, construction, packaging material and packing procedures, but which are not necessarily caused or affected by distribution/ maritime transport hazards. For example, this category may include the release and/or involvement of dangerous substances and materials due to inherent design/construction/material faults (e.g. seals, valves or caps), inadequate sealing (e.g. in drums or bottles) or improper tightening of safety valves (e.g. in tanks).
3. *Other events – other than categories 1 and 2*: This category includes other events leading to release and/or involvement of dangerous goods or unsafe situations that are the result of deviations from the intended functions of packaging or transportation, but which are not covered by the above categories and for want of sufficient reasons can not be classified. For example, this category may include events involving materials of class 4, such as fires in cargoes of cotton or fishmeal, which may not necessarily involve any breach or failure of the package and the release of dangerous goods.

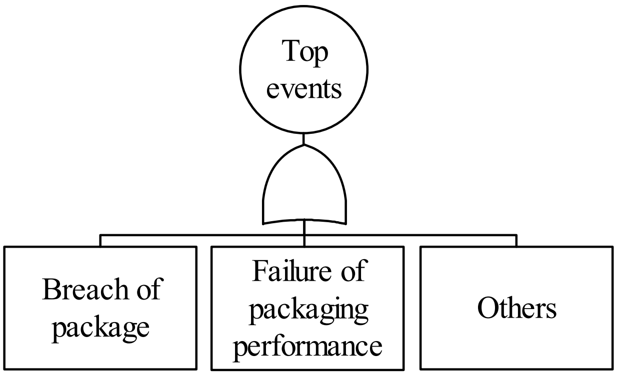


**Figure 5.5: Categories of top events**

Case histories have shown that dangerous substances have been released and/or involved or have come in contact with water due to one or combinations of the failures and conditions defined above. In the analysis process, it is important to take into consideration the following aspects:

- *Consider different levels of packaging*: Unlike the carriage of bulk dangerous cargoes, packaged dangerous goods are carried in different levels of packaging (e.g. bags/drums-pallets-containers); the breach or failure of one level may not necessarily involve the release of the containment.
- *Provide answers to the question*: Did transport hazard (e.g. forces, stresses or loads) values exceed the design and construction limits or conditions? For example, the packaging and cargo securing systems are designed and constructed based on the class societies and industry's standards. These standards are based on various analytical and calculation methods, large numbers of assumptions and approximations for each individual system (e.g. packaging, ship etc), static and dynamic forces, loading/ discharging conditions, weather conditions, and ship handling. The design and operational properties of the packaging system, the cargo securing system and other related systems can be developed as a conjoint branch in the fault tree.
- *Explore the breach/failure-release/involvement sequences of events*: The course of exposure and consequences for dangerous goods hazards is significantly affected by the sequences of events mentioned above.

The top events defined above can be used as the common joint points for both analysis procedures, i.e. the FTA and ETA procedures. In other words, both these procedures "spring" from a single set of top events. The top events "divide" the cause-effect chain into two main areas, namely: a) the "*cause or error*" chain consisting of events and conditions (i.e. hazards, causes and contributing factors) that can lead to the top events, which can be analysed by the backward/top down logic employed in the FTA technique; and b) the "*effect*" chain consisting of events and conditions following the top events, which can be analysed by the forward logic procedures employed in the ETA technique.

#### 5.2.2.2. Hazard identification by means of FTA

As a principal rule, the analysis begins with the "cause/error" chain. The diagram (Figure 5.4) shows that top events are generated and developed from left to right, whereas the analysis follows the reverse path, from right to left.[21] The analysis is accomplished by using "backward logic", asking questions like "Why?" "How can this happen?" or "What are the causes and contributing factors of this event or failure?" The purpose of this line of procedures is to identify and visually model those events and conditions that solely or in combination lead to the top events together with their logical relationships. The elements and their relationships constitute the FTA structure. The structure may be a graphical logic diagram showing how the packaging system can fail and dangerous substances can be released and/or involved. The model may contain numbers of branches developed at various sequential/ successive levels of

[21]Note: This may be considered as a left-right layout model, in which the generation and development of events are modelled from left to right, while the analysis follows the reverse path, from right to left. This layout format is chosen for the purpose of convenience. There are also other layouts, for example, right-left, bottom-up or top-down. The most common form is the top-down form.

resolutions. The analysis proceeds from the upper to deeper levels. At each level the above-mentioned questions are asked at the deeper levels until the underlying causes and contributors of events are "uncovered."

### Subdivide the system

In principle, the FTA and ETA techniques are based on the "division" of the system studied. This process defines the essential elements of the system, providing the structure of the trees. There are mainly three approaches for subdividing a system, namely hardware (equipment or technical), functional and hybrid approaches (USCG, 2001) (Figure 5.6). The choice of approach depends on the system being studied and the types and amounts of data available. The hardware approach focuses primarily on the identification of the failure of hardware items that make up a system's components or parts. This is generally used in a well-defined system in which hardware items can be identified. The functional approach focuses on the identification of functional or operational failures of the system. The third approach is a combination of the two first approaches, in which the analysis may begin with identification of the elements or components of the system, and then proceed with the functional failures in the system, or vice versa.

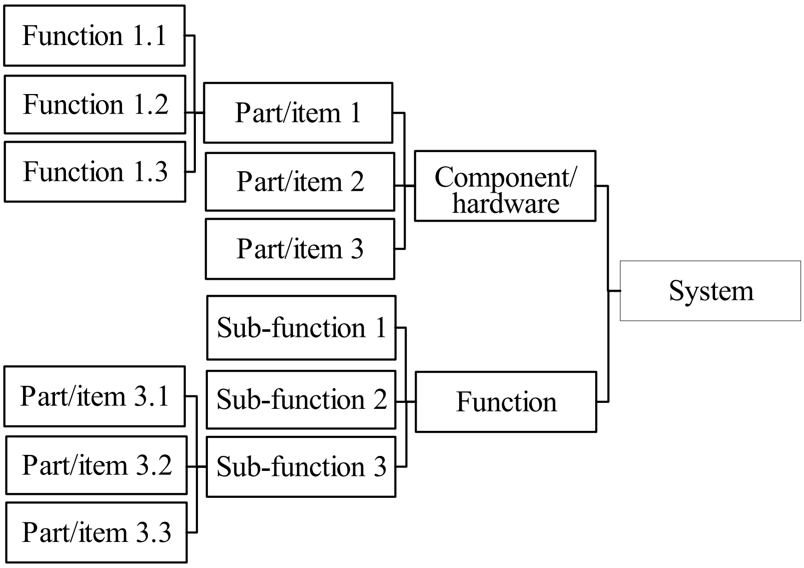


**Figure 5.6: System subdivision approaches (adapted after USCG, 2001)**

The division of a system by technical and functional properties alone is not sufficient for the risk analysis in the maritime transport system of PDG. One of the reasons is that this particular system, like many other systems, does not operate in isolation. Many things and phenomena related to the system are very complex and interrelated. The system is very dynamic, and its performance is affected by the physical environment in which it operates, such as weather/atmospheric and sea conditions and events associated with the ship operation. The fault tree can be structured based on the maritime transport system's components, events or conditions. The following provides the key elements of the fault tree structure and their levels of resolution, which are largely identified by examination and analysis of the empirical data.

1. *“Marine accidents/incidents”*: this category includes all marine accidents/incidents reported in statistics, as defined by the IMO, Lloyd’s Register of Shipping, and others (see Mullai, 2006a), such as: collision, contact, grounding, foundering, fire/explosion (excluding fire/explosion events caused by dangerous goods), listing/capsizing, hull/water tightness, ship missing, and machinery, excluding events in the categories 2 and 3.
2. *“Normal” transport conditions*: this is the “other” category of marine accidents/incidents (as defined in the above sources), such as dangerous goods/cargo spills or releases, loss overboard, damage, shifting; toxic and flammable/ explosive fumes or gases releases; and other accidents/incidents or near-misses.
3. *Other*: this category includes marine accidents/incidents that are not included in categories 1 and 2 and that for want of insufficient reasons, cannot be otherwise classified, such as criminal aggressions, wars or hostile acts, terrorism, hijacking, sabotage, arson or other deliberate acts related to maritime transport.

*Causes and contributing factors*: This category includes the causes and contributing factors of the marine accidents/incidents (categories 1 and 2). The list is endless, and the categorisation system varies across countries and industries. However, the main categories include: *human* or *man-made*, *environmental*, *operational*, *managerial*, and *other* factors. The main categories are further subdivided into subcategories. The main and subcategories are interrelated. Table 5.2 shows the main categories of causes and contributing factors and some examples:

**Table 5.2: Main categories and subcategories of causes and contributing factors of marine accidents – some examples**

| **Main categories** | **Sub-categories – some examples** |
|---|---|
| *Human* | Human factors related to dangerous goods activities and risks<br>• Performance<br>• Abilities/skills<br>• Behaviour<br>• Awareness<br>• Perception<br>• Education<br>• Training<br>• Experience |
| *Man-made* | • Hardware/technical<br>- Ship system<br>- Packaging system<br>- Cargo – dangerous goods system<br>- Cargo handling system<br>- Cargo securing system<br>- Search, rescue and recovery equipment and devices<br>• Dangerous goods regulations and standards related to |

| Main categories | Sub-categories – some examples |
|---|---|
| | - Maritime transport and other related activities<br>- Accidents/risks (people, environment and property) and response to dangerous goods<br>- System design and construction standards<br>- Safety and Quality Management System standards<br>- Maintenance standards<br>- Dangerous goods inspection standards<br>• Programmes<br>- Dangerous goods training programmes<br>- Dangerous goods/container inspection programmes<br>• Software<br>- Dangerous goods related software programmes<br>• Information and Communication Technology (ICT)<br>- Dangerous goods related ICT |
| *Environment* | • The physical environment<br>- Weather/atmospheric hazards<br>- Navigational hazards |
| *Operational* | • Dangerous goods/cargo related activities<br>- Cargo loading/discharging<br>- Cargo stowage<br>- Dangerous goods segregation and separation<br>- Transport units and container packing<br>- Dangerous goods communication<br>- Dangerous goods documentation<br>- Cargo securing<br>- Transport and caring<br>• Ship operations<br>- Navigation |
| *Managerial* | • System management<br>- Organisation/business management<br>- Crew management<br>- Ship system and operation management<br>- Cargo system and operation management<br>- Cargo securing and securing system management<br>- Regulatory system management |
| *Other* | Causes and contributing factors other than the above, for example:<br>- Business/economic, technical, environmental, social, and political factors. |

The design of data sampling and variables (marine accidents/incidents and their causes and contributing factors) will be largely dependent on: a) the quality and amount of the data available; b) data accessibility; and c) the classification system based on which marine accident/incident databases are designed and maintained.

The following section describes in some detail the principal procedures at each level.

### Define the FTA top structure – the first level of resolution

After the identification of the top events, the next step is to define the top or first level of resolution in the FTA structure. This concerns the identification of those conditions that most directly lead to the top events. For many situations, "*distribution/maritime transport hazards*" can be identified as the factors that, either solely or in combinations, most directly can lead to the top events, in particular for categories 1 and 3. The principal hazards include: *physical/mechanical, climate/weather, chemical, electrical, electro-chemical, radioactive, biological and other hazards* (see Figure 5.7). For category 2 of top events, which are events that are not necessarily due to maritime transport hazards (see Figure 5.5), the first level of resolution can be "bypassed." These events can be directly linked to the second level of events, that is "non-marine events" or "normal" transport conditions.

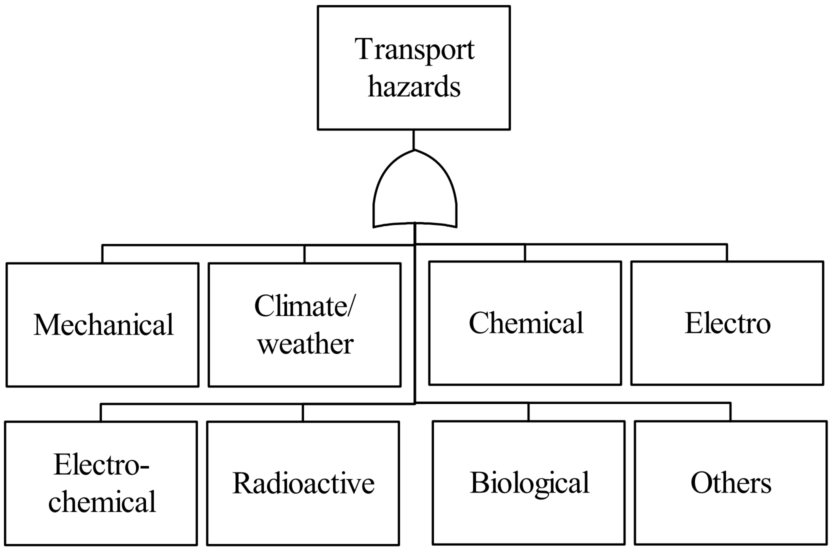


**Figure 5.7: The top structure – the first level of resolution: the principal transport hazards**

### The second level of resolution

The second level resolution consists of these main branches: a) "*marine accidents/incidents*"; b) "*normal*" transport conditions; and c) "*other*" category (see Figure 5.8). These categories of events are identified as the most direct conditions that may expose PDG to maritime transport hazards. Packages, for example, are exposed to damage from mechanical forces (e.g. impacts, crushings, vibrations, and frictions) exerted in the marine events, such as collision, contact or grounding. Packages are damaged not only due to hazards falling in the category of "marine events", but also due to hazards generated during transport related activities such as loading, discharging, packing, or stowing. The "*other*" category includes other events, such as deliberate acts.

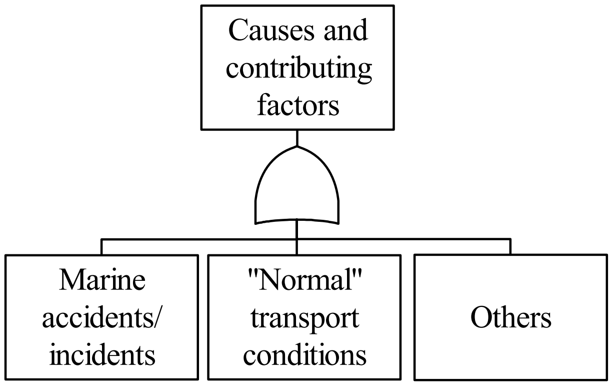


**Figure 5.8: The second level of resolution**

### Develop branches in successive levels of detail

The next logical steps are taken towards *the underlying actual or potential causes and contributing factors* of each category of the events in the second level of resolution. The analysis process continues at successive levels of detail until it is “completed.” Generally, the analysis is deemed “completed” when each branch of the fault tree has been explored and described reasonably exhaustively, and pursued to the lowest level of resolution deemed necessary by the analysts and/or decision-makers. However, this depends on many interrelated factors, including decision-making needs, time, resources and data available. The risk analysis should, in principle, contain enough detail to provide necessary and sufficient information and insights for decision-making. The analysis may begin with an upper limited level, and then add in one or more selected areas. As shown above, the third and other successive levels in the fault tree structure represent the causes and contributing factors of the categories of events in the second level, namely a) “*marine accident/incidents*” and b) “*normal*” transport conditions or “*non-marine accidents/incidents*”. The analysis may be primarily focused on the exploration and explanation of causes and contributing factors of the second category of events.

### 5.2.2.3. Other data analysis methods

The FTA technique is based on logical and sequential procedures as described in Chapter 3, Vol. I, and Mullai, 2006b. However, as experiences in data analysis have shown (see Chapter 4, Vol. I, and Mullai and Paulsson, 2002), given the large number of different types of events taken into consideration, the data and information availability and the system’s complexity, a “genuine” algorithm analysis cannot be expected. Things and phenomena are very complex and often interrelated, and perfect “fitting” into the structure of the tree is not always possible. Despite their common usage, techniques are limited in terms of accuracy and efficiency when dealing with large tree structures (Bartlett and Andrews, 2002). In order to make use of all data available and provide a better understanding of the system and phenomena (i.e. risks), various qualitative and quantitative analysis methods or techniques available could be employed, including those techniques that make use of more “relaxed” analysis procedures (see Chapter 3, Vol. I, and Mullai, 2006b). Marine events involving PDG are often attributed to combinations of many different factors. Therefore, a simple categorisation based purely on technical, procedural, organisational, environmental or human factors may not entirely be possible. In order to reflect the interrelations among categories, cross-references and analysis could be made. For example, technical problems can be explored and described (in text, tables or other formats) in the context of human, operational or environmental factors. For certain categories of problems or failures, the process of logical and sequential structuring would be a difficult and time-consuming task. Numbers of causes and contributing factors of marine events identified from (or grounded on) empirical data may not necessarily be "linked" to the structure of the tree, but rather dealt with and represented as separate categories. However, the analysis process may still follow the principles of the backward or top down logic (see Figure 5.9).

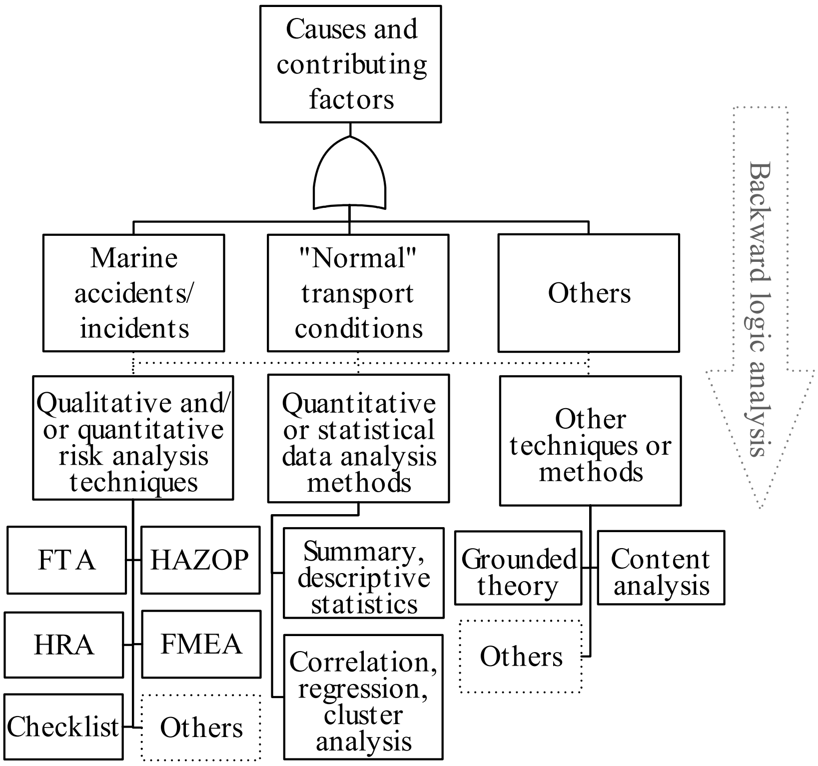


**Figure 5.9: Examples of analysis processes and techniques**

### 5.2.3. Step 3 – Exposure and consequence analysis

*Questions: What has or could happen after dangerous goods are released from their containments and/or are involved? What risk receptors are exposed to dangerous goods hazards? How are they exposed? What are the actual consequences?*

*Tasks: Explore exposure and actual consequences of dangerous goods hazards to the risk receptors.*

The exposure and consequence analysis concerns the identification of the nature and estimation of the extent of exposure and consequences caused by hazards of dangerous goods to the risk receptors. The key steps, which are important and relevant for both exposure and consequence analyses, consist of the identification of the list/inventory of dangerous goods carried in packaged form and their hazards, risk receptors, distribution or dispersion and concentration of DG, dose-effect relationships, and consequences including many contributing factors and conditions.

#### 5.2.3.1. Exposure analysis

*Tasks: Explore dangerous goods and their hazards that cause undesired outcomes for the risk receptors, nature/categories, and estimate the number or amount of risk receptors exposed to dangerous goods hazards.*

Risk measurement not only combines the frequency and the severity of the consequences as defined by the IMO (2002) in the FSA. Risk can also be measured as the combination of the consequences relative to the exposure, i.e. the number of risk receptors exposed. The exposed risk receptors (i.e. humans, the environment, and property) are the set of population that is potentially subjected to the effects of dangerous goods hazards (see Chapter 3, Vol. I, and Mullai, 2006a). In the transport of dangerous goods, one form of risk estimation is the measurement of the actual consequences relative to the exposure to hazards of dangerous goods, i.e. the ratio between consequences and exposures. This has become a legal requirement in some countries, for example, in the EU, the USA and other OECD countries (OECD, 2004). Therefore, the identification and measurement of the population exposed to hazards of dangerous goods is an important input to the risk analysis process.

The analysis may concern the past, present and anticipated exposures. The purpose is to provide answers to a number of important and relevant questions, including: What is the fate of dangerous goods once they are released from their containments? How could risk receptors be exposed to hazards of dangerous goods? What categories of, and how many, risk receptors are exposed to hazards of dangerous goods? The exposure analysis involves the following main interrelated steps:

##### *5.2.3.1.1. Dangerous goods and their hazards*

*Tasks: Explore the list/inventory of dangerous goods and their hazards that cause undesired outcomes for the risk receptors.*

##### Dangerous goods inventory

*Task: Explore the list/inventory of dangerous goods carried in packaged form by water for the time and location being studied that have been involved or have had the potential to be involved, including all classes and sub-classes of dangerous goods (classes from 1 to 9).*

It is also important to provide information related to dangerous goods and their properties, for example whether they are liquid, solid, gas, liquefied gas or a mixture. Information about physical and chemical properties of dangerous goods may include: solid - particle size; liquid – viscosity, volatility, boiling and freezing point or range; gas – density, lighter or heavier than air, vapour pressure; other properties such as flashpoint and explosive limits, solubility and pH, reactivity, electrical and heat conductivity, or the nature and concentration of combustion products. The extent of exposure/effects of hazards of dangerous goods depends largely on the size and type of shipments. Therefore, it is important to provide information on the amounts (in kg or tonnes) and types of dangerous goods, and type, number and levels of packaging or units in which they are carried (for details see Chapter 3, Vol. I, and Mullai, 2006a).

#### Dangerous goods hazards

*Task: Explore inherent hazardous properties of dangerous goods that have caused or have the potential to cause undesired outcomes for risk receptors.*

Goods/cargoes carried on board ships pose different risks in different ways, but the risk of maritime transport of PDG deals with the risks of dangerous goods posed *by virtue of their inherent hazards only*. The nature and magnitude of consequences and exposures and the sequence of events following the release/involvement of dangerous good depends very much on the types of their hazards. Large numbers of different types of dangerous goods possessing different hazards are carried in packaged form by water. Many dangerous substances possess more than one hazard. Based on the Globally Harmonized System of Classification and Labelling of Chemicals, hazards of dangerous goods are classified into two main categories: physical hazards and health and environmental hazards, for both substances and mixtures (see Mullai, 2006a). Given the large number of hazards and data available at hand, the analysis of the entire set of hazards posed by PDG would become time consuming and costly. The case histories (case histories in Chapter 4, Vol. I, HCB 1986-2003 and others) show that the major hazards of PDG, which could be primarily taken into consideration in the risk analysis, are toxic/poison, fire, explosion, and marine environmental pollution hazards. For example, some of the worst marine accidents in history involving PDG (e.g. catastrophic accidents in Canada, Halifax, 1917 and the USA, Texas City, 1947), have been attributed to fire/explosion hazards.

#### *5.2.3.1.2. Dangerous goods release-dispersion-concentration*

*Tasks: Explore sequences of events following the release, dispersion, concentration and/or involvement of dangerous goods that have caused or can cause consequences for the risk receptors.*

#### The fate of dangerous goods - package drift modelling

In many situations and for many types of dangerous goods, the fate of dangerous goods largely depends on the fate of the packages themselves. Many marine accidents, such as foundering or sinking, grounding, fire/explosion, and listing/capsizing, can involve losses overboard of PDG. The dispersion and concentration of dangerous goods are related to the drifting and/or sinking of packages. However, unlike bulk dangerous cargoes, the loss of PDG at sea or in contact with water may be neither sufficient nor necessary for dangerous goods to be spilt, dispersed and come in contact with risk receptors. At present, the data available provide little information concerning drifting of packages. Iceberg motions modelling, experiments and individual case histories can provide information necessary for modelling and forecasting packages (e.g. freight containers, tanks, drums) drifting in the sea.

PDG lost at sea present hazards to shipping and the marine environment. Package drift modelling can provide a useful tool for responsible authorities. In cases of cargo losses overboard, drifting models can enable the authorities to:

- Predict the movement and location of packages;
- Determine and inform about the dangerous area for navigation;
- Conduct effective search and recovery operations. An accurate prediction of package drifting may narrow the research area;
- Estimate the exposure and consequences of marine pollutants and other hazards to people, the environment and properties.

The drifting of packages is affected by a wide range of variables, including:

- *Package design, construction and operational properties*, e.g. material, shape, dimensions, mass, buoyancy, cross-sectional area, immersed fraction;
- *Weather/sea conditions*, e.g. wind direction and velocity, wave properties, integrated water current direction and velocity, vertical and horizontal profiles of the currents, water viscosity and density, atmospheric and sea level pressure, tides;
- *Topography*: water depth, sea/river bottom and coastal line topography etc.

### Dangerous goods release modelling

Based on release or emission modelling, the amount, duration and rate at which dangerous goods are released (e.g. toxic/pollutant substances) from the containment are explored and estimated. Modelling of dangerous substances releases could be based on the case histories, historical data of direct monitoring of releases or the use of computer models.

### Dangerous goods release on board ships

What has happened on board ships after the release/involvement of dangerous goods? The carriage of PDG on board ships, in particular today's large ships, is somehow different when compared to the carriage of dangerous cargoes in bulk and other activities in the supply chain. Dangerous goods are carried on board ships at different levels of packaging. Furthermore, the ship itself could be considered as a "large packaging" and "environment" consisting of numerous complex systems. The principles of the ETA technique can be adopted to explore the sequences of events involving PDG on board ships. The ETA technique may be an effective tool for modelling events' sequences, outcomes and their subsequent consequences resulting, for example, from a leak or rupture of a container with flammable and toxic liquids or liquefied gases on a ship's deck or in a hold. But it cannot provide sufficient information on the exposure and effects of toxic substances or marine pollutants, for example the dispersion and concentration of contaminants into environment and its habitats. Therefore, for that purpose, other models could be adopted from other environment or ecological assessment frameworks and other guidelines (USEPA, 1992; NOVA Chemicals Corporation, 2001; ACS, 1998).

### Dangerous goods dispersion and concentration

*Tasks: Explore dispersion and concentration of dangerous goods and/or hazards.*

Once they are released from their containments and/or are involved (e.g. flammable liquids or gases and explosives), many different types of dangerous substances/hazards travel through the media of transportation (water, air and land) undergoing complex processes and changes. For example, many toxic substances or pollutants are dispersed and concentrated into the environment in which they are released, such as water and air, whereas non-soluble substances released into the water simply move away from the source by means of currents and waves.

*Dangerous goods hazard ranges and amounts*. How do dangerous substances/ hazards move away from their sources? Dangerous substances and/or their hazards can move at different directions and reach different distances from the containment/ship at different levels of concentrations or intensity. In order to estimate the nature and extent of consequences and the exposure of risk receptors to hazards of dangerous goods, it is important to consider:

- The distance from the sources the substance/hazard can reach and expose risk receptors;
- The amount of substance/hazards present at different distances from the source, i.e. the level of concentration (e.g. toxic substances and marine pollutants) and intensity (e.g. heat or fire radiation, blast or shock waves from explosions) relative to time, distance, and direction from the sources of release.

The dispersion and concentration of chemicals are complex chains of processes. For example, marine pollutants are accumulated in biota (i.e. fauna and flora) directly or indirectly through the contaminated abiotic media (water and sediments). The contaminant can be taken up in a certain accumulation of factors by human or other living organisms throughout the food chain. The accumulation factor is the ratio of the concentration of a given contaminant, for example in biota, to that in an abiotic medium, e.g. biota to human. The dispersion and concentration are affected by many different factors that should be taken into account. Some of these factors include: the amount and types of dangerous substances involved; wind speed and direction; currents strength and direction; the state of the sea; wave direction and speed; water temperature, mass, and density/salinity; precipitation; ambient temperature and atmospheric pressure.

The dispersion and concentration of dangerous substances could be estimated in various ways and by different means including: real time monitoring, for example exposure measurement, instrumental monitoring, and observations; historical data; case scenarios; technical analysis, including mathematical/computer modelling, for example thermal flux, overpressure or bio-chain modelling.

Dispersion, concentration and intensity data are very limited for marine accidents involving PDG, as they are seldom reported. In-depth investigations of some case histories, however, may provide information on the distribution and concentration modelling for some dangerous substances released into the environment.

#### 5.2.3.1.3. Modes of contact - routes of exposure

*Task: Explore the ways and routes through which the dangerous substances and/or hazards come into contact and interact with the risk receptors.*

The risk receptors come into contact with dangerous goods hazards in different ways, including:

- *Human*: For example, people can come in contact with chemicals through inhalation, skin absorption, ingestion, pressure wave contact, flying objects/debris, radiant flux exposure, and other modes of contact. Living organisms can be directly and/or indirectly exposed to hazards of dangerous goods. A direct contact is, for example, the inhalation of toxic fumes or contact with corrosive substances, whereas an indirect contact is the oral intake of contaminated food and water.
- *Marine environment*: For example, dispersion and concentration of toxic substances and materials into water, sediments, biota, and land.
- *Property*: For example, surface, pressure wave, flying objects/debris, radiant flux exposure, and other modes of contact.

The risk receptors may come in contact with dangerous substances through one, or combinations, of the above routes of exposure. The routes of exposure play an important role in types and magnitudes of the consequences.

#### 5.2.3.1.4. Dose-effect assessment

*Task: Explore and assess dose-effect relationships.*

By virtue of their inherent hazardous properties, dangerous goods can cause different types and degrees of harm when in contact. This depends on a particular damage mechanism (dose-effect relationship). The biological, physical and chemical effects on risk receptors can only occur after a certain level of exposure (known as the threshold level[22]) is exceeded. A similar term for the threshold is the "endpoint", which is defined as the risk receptor values to be protected (USEPA, 1992). Endpoints are referred to as endpoint entities, properties and effects levels. For example, dichlorodiphenyltrichloroethane (DDT), which has been carried by ships in large quantities, including ships that in some cases are reported to have been lost at sea (HCB, 1986-2003), can cause thinning of eggshells of various avian species. This can subsequently lead to the reduction of a species' reproductive success. In such cases, the endpoint is the concentration of the chemical that causes sufficient thinning to impede reproductive success. Different organisms can react differently at the same level of exposure. The relationship between the dose level and the resulting incidence of fatalities, injuries or disease is affected by various interrelated factors and

[22] Threshold: a) a level or point at which something would happen, would cease to happen, or would take effect; b) the minimum intensity or value of a signal that will produce a response or specified effect (Collins Dictionary, 1992)

conditions such as duration, frequency, and level of exposure, and the physical conditions of the people exposed. Poisoning by inhalation, for example, is related to the amount of pollutant in the air, the amounts of the pollutant that each person inhales, breathing rates, duration of exposure and age of the persons exposed.

With respect to the exposure and consequences due to dangerous goods hazards, there are various established thresholds, including (NOVA Chemicals Corp, 2001): Lowest Observable Effect Level (LOEL) i.e. the smallest dose that causes any detectable effect; No-Observed Effect Level (NOEL) i.e. the dose at or below which no biological effects of any type are detected; No-Observed Adverse Effect Level (NOAEL); Threshold Limit Value (TLV), Maximum Allowable Concentration (MAC), Maximum Contaminant Level (MCL), Lethal Dose/Concentration for 50% of population (LD50 or LC50), odour threshold, overpressure threshold (e.g. 1 pound per square inch), and radiant energy flux threshold (e.g. 5 $kW/M^2/40$ seconds). The threshold level can be determined by using the technical analysis approaches provided in the respective guidelines, such as Emergency Response Planning Guide (ERPG) or U.S. EPA Consequence Analysis Guidance for boundaries. They are pre-determined by the responsible national or international authorities.

Some other relevant endpoints that may be considered in the analysis of risks to organisms from chemicals are (ACS, 1998) acute effects such as skin and eye irritation, respiratory and skin sensitisation, toxicity, carcinogenicity, mutagenicity, immunotoxicity, neurotoxicity, reproductive or developmental toxicity, and physical-chemical properties. Gender-bending chemicals, for example, are substances similar to estrogens, which if released into the environment can cause damage to the reproductive organs of creatures such as fish, birds and humans.

##### 5.2.3.1.5. Risk receptors exposure

*Task: Explore risk receptors that have been exposed and/or have the potential to be exposed to dangerous goods hazards.*

The sets of populations (or the “populations of concern”) that are actually affected or can potentially be exposed to hazards of dangerous good constitute the risk receptors. The main categories of risk receptors include: a) *human*: individuals, groups, societies; b) *the marine environment*: water, sediments, fauna and flora, land - shorelines and beaches, including also the air; c) *property*: individual, common, business properties, such as ships, cargoes, equipment, facilities and other assets at sea and ashore; and d) *others*: e.g. sea and land-based activities. As the study of the “entire” population may be practicably impossible, a representative sample population, which is the set of risk receptors selected for measurement, can be used to make inferences about the population. The exposure analysis may include any other element that may be deemed important and relevant for measuring the performance of the systems and their outcomes.

### 5.2.3.2. Consequence analysis

*Tasks: Explore the nature of actual consequences of dangerous goods hazards for the risk receptors.*

The main categories of the risk receptors and the nature of consequences to them include:

- *Human* – human health and safety – consequences of hazards of dangerous goods, such as death, injuries, acute or chronic illness and other health effects. The latter category consists of effects on humans as the result of exposure to pollution, evacuation, confinement, economic losses, and psychological or emotional effects (e.g. anxiety). Health effects could be due to uptake and accumulation of pollutants in the food chain.
- *The marine environment*: contamination of the water, sediments and effects on the biota (i.e. fauna and flora), including aesthetics (i.e. relating to beauty or taste) consequences. The latter category covers damage to marine environment values. As people perceive environmental values differently, highly perceived consequences may not necessarily be high from the ecosystem point of view.
- *Property*: damage and losses to individual, commercial or public properties.
- *Other*: this category may include effects and interruptions to maritime transport-related activities, businesses, communications, transport systems (e.g. navigation systems), water/sea related activities (e.g. fishing, water cultivation or agriculture), and other forms of implications and effects (e.g. legal or business implications).

The above categories of consequences are often interrelated. For example, human health problems may arise from contamination of the marine environment. Almost, all the above consequences can be directly and indirectly expressed or measured in terms of monetary units, i.e. the economic consequences. The consequence analysis should also take into consideration the actual and potential threats of dangerous goods in the future, for example threats of fires, explosions, contamination and marine environment pollution. The consequences for risk receptors can be related to or measured against other risks as well as system elements, such as hazards, causes and contributing factors, types/sizes of ships, packages and dangerous goods.

## 5.2.4. Step 4 – Likelihood estimation, evaluation, quantification

*Questions: "How often?" "What is the likelihood?" or "How many/much?"*

*Task: Quantify or evaluate system and risk elements.*

This step involves quantification of risk elements, including likelihood (frequency/ probability) estimates, statistical summary and inferences. In many situations, in particular in qualitative risk analyses that are based on a single or a few case histories, quantification of system and risk elements may be very limited, if not impossible. Therefore, in these cases risk elements, such likelihood and severity of consequences, are evaluated or benchmarked against relevant risk criteria available and experts' judgements. Identification and quantification of the system and risk elements are inseparable procedures. However, for the purpose of presentation, these procedures are presented under separated headings.

#### 5.2.4.1. Likelihood estimation

At this step the likelihood is estimated (DNV, 1995; Ertugrul, 1995). Regarding the risks of marine events involving PDG, depending on the amount and quality of the data available, the likelihood could be estimated for almost any risk and system element, including:

- *Top events*: for example, the likelihood of puncture, rupture or damage to packages, such as containers or tankers;
- *Causes and contributing factors*: for example, the likelihood of the hazards, causes and contributing factors leading to damage or failures of packages;
- *Dangerous goods hazards*: for example, the likelihood of ignition of a flammable liquid released onboard ships;
- *Consequences of dangerous goods*: for example, the likelihood of fatalities and injuries caused by specific hazards, such as fire, explosion, and toxic fumes.

Given the large number of risk elements and the sequences of marine events involving PDG, the compound likelihood may consist of a representative likelihood, for example the likelihood of a specific consequence (e.g. fatality) of a specific hazard (e.g. explosion) for a specific risk receptor (e.g. ship's crew) in a specific time period (e.g. in one year).

#### 5.2.4.2. Methods of estimation, evaluation and expression

There are various methods of estimating and expressing likelihood and severity of consequences, such as quantitative, semi-quantitative, and qualitative methods (see Mullai, 2006b). Quantitative methods are usually based on extrapolation of historical data, in which the likelihood and severity of consequences are expressed as numbers. Semi-quantitative methods employ both quantitative data and experts' judgements. For example, the likelihood is expressed as "less than", "greater than" or within a range of a specified likelihood. Qualitative evaluation is mainly based on comparison or benchmarking of the results of the risk analysis and criteria available, for example risk evaluation criteria of the IMO and the ISO. Furthermore, evaluation relies on experts' perceptions and judgments on the degree of compliance with guidelines, legal and technical criteria, for example guidelines on employees' exposure limits to dangerous goods hazards. Examples of qualitative evaluation and expression of likelihood and severity of consequences are: a) likelihood (Frequency Index – FI) – extremely remote, remote, reasonably probable, frequent; b) severity of consequences (Severity Index) – minor, significant, severe, catastrophic (IMO, 2002). Risk evaluation criteria vary among countries and industries. For more information about risk elements evaluation and risk criteria, see Mullai, 2006b.

#### 5.2.4.3. Other methods of quantification

The estimation of likelihood, which is one constituent element of the quantification or statistical analysis, is an important procedure in the risk analysis. However, a comprehensive risk analysis should not rely solely on the estimation of likelihood. The wide range of statistical analysis procedures can provide additional information. Further, they can also provide more precise results than qualitative (descriptive) analysis and likelihood estimation alone. The statistical inference procedures could be employed to identify the existence, and measure the directions and amounts, of the relationships among variables representing various concepts of the maritime transport system and risk elements. The consequences and exposures to dangerous goods hazards can be measured in terms of amounts or numbers, for example the number of fatalities, injuries or the sea area (in km or $km^2$) affected by marine pollutants, and relationships with other elements of the risks.

Quantification of the risk elements varies from very simple to highly complicated. Full quantification is usually resource intensive and quite complex. The quantification, which is primarily based on accident case histories, may be extended to those levels of resolution and risk elements for which data are available. Because of the limited amount of data and resources, a diverse group sample of risk receptors could be selected and studied in order to make inferences about the risks for the general population.

The quality of estimates varies widely, depending, inter alia, on the quality and amount of data, the methods employed and the judgements and assumptions of the risk analysis. Some characterizations of estimates include best estimate, conservative estimate (over-estimation) and its confidence limit, and Monte Carlo distribution of estimates reflecting the uncertainties of data.

The quantification may involve any system and risk element, but the key elements include a) transport hazards, causes and contributing factors, b) exposures and c) consequences.

#### 5.2.4.4. Quantification by means of FTA

With reference to the analysis (i.e. the identification and description) of hazards, causes and contributing factors of damage/breach of packages by means of the Fault Tree Analysis (FTA), after the tree structure has been explored the next step is its quantification. If necessary and possible, the quantification of the elements of the structure is performed to provide answers to the question "*How often*?" The FTA technique is mainly based on algorithm analysis, in which branches of the tree structure are quantified on the basis of historical data. Because of the complexity of the system and events associated with it, interrelations with other systems, and data available at hand, the analysis cannot always rely solely on the sequential and logical organisation. And if it does, the structure of the tree would be extremely time consuming, too long and very complicated. Therefore, in order to simplify things and make use of all available data and enhance further understanding of the risk and system elements, other forms of quantitative analysis can also be employed and combined. As mentioned earlier, statistical inference analysis can be performed to explore and measure the relationships among variables, for example the relationships between types of dangerous goods and human consequences.

#### 5.2.4.5. Exposure estimation

*Task: Estimate the size/extent of the risk receptors exposed to hazards of dangerous goods, along with the magnitude, duration, and spatial extent of exposure.*

The exposed risk receptors are those receptors that are bounded by the range of dangerous goods hazards. Table 5.3 shows the main categories of risk receptors and some examples of the measurement units of exposure.

**Table 5.3: Categories of risk receptors and some examples of measurements of exposure**

| Nr. | Category of risk receptors | Examples of measurement units of exposure |
|---|---|---|
| 1 | Human: individuals, groups, societies<br>• Ship's crew/personnel<br>• Passengers<br>• Others<br>• Shore personnel<br>• Local community | • Total number of people (all categories)<br>• Number of personnel on board all ships and ships carrying PDG only<br>• Number of passengers: all ships and cargo/passenger ships<br>• Number of shore personnel: all personnel and personnel involved in PDG activities<br>• Number of people ashore: around ports, waterways and sea transport routes |
| 2 | Marine environment<br>• Biota: fauna and flora<br>• Water<br>• Sediments<br>• Shore/coastlines | • Amounts/numbers: e.g. numbers of protected or sensitive sea areas exposed<br>• Tonnes/volumes of dangerous goods carried/handled<br>• Shorelines/inland waters exposed: km and miles<br>• Sea/inland waters areas exposed: $m^2$, $km^2$ and $mile^2$ |
| 3 | Property<br>• Ships<br>• Cargo<br>• Other properties | • Cargo/traffic: tonnes, tonnes/miles, shipments and shipment/miles, for a) all categories of cargoes/commodities and b) all and each class of PDG<br>• Ships: number, dwt or grt, ship/miles or km for a) all types of ships b) ships carrying PDG only<br>• Properties ashore: amount/number |
| 4 | Others<br>• Activities: transports, port and other activities | • Activities in hrs, days and weeks, e.g. transit time or working hrs in port, and other activities at sea and ashore |
| 5 | Financial exposure of one or combinations of the aforementioned categories | • Monetary units: price/value/cost of any of the mentioned categories |

In consideration of the legal requirements (see section 5.2.3) and the decision-maker's preferences, this step may become an important, but at the same time a time and resource intensive process. Table 5.3 shows that exposure of risk receptors can be measured in many different ways. However, the monetary unit may be assigned as the common unit of exposure for nearly all categories. Table 5.3 also shows that the exposure estimation largely involves a "simple" counting of different elements. In many countries, the exposure data are reported and recorded by different people in different databases. For example, the number of people (i.e. ship's crew/personnel exposure) employed in the Swedish merchant fleet and the number of licensed fishing vessels are recorded in the Swedish Seamen's Register and the Swedish National Board of Fisheries and Fishermen's Federation (see Table 5.1) respectively.

Any of the above measurements can be related to the time unit of exposure, which is usually taken as one year. Some other forms of time units are lifetime (expressed in hours or years), working lifetime (expressed in hours or years), total working hours per year, total working hours with dangerous goods per year and so on. Depending on the scope of the study, the extent of exposure may be estimated for risk receptors exposed to a) activity: e.g. maritime transport (en route or voyage time and port time) and other related activities; b) location: e.g. local, regional and national/international.

The number of people exposed at different distances from the site of release can be estimated with computer models using information from the census and maps. Some models can even estimate exposures for different places including indoor, outdoor, workplaces and other places. Demographic data, that is data about human populations, especially with reference to their size, structure, and distribution, for the ship's personnel, passengers, people working in ports and living in the vicinity of sea transport routes, waterways and around the port, could be used to estimate the human exposure.

The marine environment and all properties and activities ashore that are bounded by the dangerous goods hazards should be inventoried and possibly quantified for the risk analysis on a local, regional or national level. For the marine environment, which consists of both biota and abiotic media of the areas including seas, coastal waters, shorelines, and inland waters, identify all protected sites, and locally, nationally, regional or internationally designated sites and sensitive sites with their specific physical, ecological, social and economic features. Sites should be classified according to wildlife importance, vulnerability of seabirds to pollution, fishing, and well-being and economic benefit for the surrounding community, landscape and geology.

In the case of a risk analysis based on the exposure estimation, it would be difficult and resources consuming to collect exposure data. The review of many marine accident case histories and databases (see Chapter 4, Vol. I, and databases reviewed in this chapter) shows that exposure data are not adequately detailed, if not lacking, to support the risk analysis process of the marine accidents/incidents involving dangerous goods. Many databases mainly contain data on fatalities, injuries, property damage, and pollution. Exposure data could be collected from other databases, or through other data collection methods and techniques.

### 5.2.4.6. Consequence estimation

*Task: Estimate or evaluate the extent/magnitude of actual consequences of dangerous goods hazards to risk receptors including influencing factors.*

A single-event release of dangerous goods may be associated with one or combinations of hazards that can affect N or more numbers/amounts of different risk receptors to different degrees or magnitudes of severity. The severity of human consequences, for example, may vary from undetectable or insignificant effects, serious but recoverable injuries, irreversible and permanent severe health problems, or death. Similarly, the aquatic community in a marine environment will be affected in various ways. This is because the environment is comprised of a wide variety of organisms, with quite variable physiologies, and accordingly they have very different sensitivities and responses to different chemicals at different concentration levels.

Consequences are measured and expressed in quantitative, semi-quantitative, and qualitative terms. Table 5.4 provides some examples of parameters that can be used to measure the actual consequences of hazards of PDG for each specific risk receptor. Some of these parameters may serve as direct measurements, while others may simply serve as indicators, in particular in the absence of the former.

**Table 5.4: Risk receptors and examples of consequences and their measurements**

| Nr | Specific risk receptors | Specific consequences | Examples of measurement units: specific magnitude of consequence for specific risk receptors – due to hazards of PDG |
|---|---|---|---|
| 1 | Human<br>• Ship's crew/ personnel<br>• Passengers<br>• Others<br>• Shore personnel<br>• Local community | • Fatality<br>• Injury<br>• Other safety/ health effects | • Number of fatalities<br>• Number of injuries<br>• Number of people with other safety or health effects |
| 2 | Marine environment<br>• Biota: fauna and flora<br>• Water<br>• Sediments<br>• Shore/coastlines | • Pollution<br>• Losses | • Shore length contaminated/affected<br>• Area contaminated/affected<br>• Amount/number of biota contaminated/affected<br>• Amount/number of PDG lost at sea<br>• Concentrations of harmful substances in biota, water and sediments<br>• Ships affected: numbers, dwt/grt involved, e.g. sunken or grounded ships |
| 3 | Property<br>• Ships<br>• Cargo<br>• Other properties | • Damage<br>• Losses | • Ships affected: numbers, dwt/grt, e.g. total and constructed total loss<br>• All cargo/packages and PDG only: number/amount damaged or lost |

| Nr | Specific risk receptors | Specific consequences | Examples of measurement units: specific magnitude of consequence for specific risk receptors – due to hazards of PDG |
|---|---|---|---|
| | | | • Properties: number/amount of properties damaged, specific degree of structural damage |
| 4 | Others<br>• Activities: transports, ports, other activities | • Interruptions<br>• Others | • Interruptions or suspensions of activities: hrs, days or weeks<br>• Others: loss of business, goodwill etc. |
| 5 | One or combinations of the aforementioned categories | • Financial: losses, claims | • Monetary units: costs/losses/claims arising from the losses, damages or other implications related to any of the above categories due to hazards of PDG only |

An estimation based on the actual accident experiences is often preferable. But, for many events with very few or non-existent data, consequences are also estimated using some theoretical or mathematical models. The estimations may even derive from the experts' judgements. Thus, the quantification of consequences of pollutants in the marine community is difficult because the toxicity or environmental data (e.g. chronic and acute toxicity data) are limited.

Depending on the amount and quality of data, the consequences can be measured by non-metric and metric measurements, namely nominal, ordinal, and scale (interval and ration). The following are some examples.

- *Nominal*: the categories of the human consequences, for example, ship's personnel, passengers, shore personnel and local community; or the categories of the magnitude of human consequences, for example, fatality, injury, other safety and health effects;
- *Ordinal*: the magnitude of injury, for example, slight, moderate, serious and very serious;
- *Scale*: the number of fatality or injury, "N or more" fatality or injury, fatality or injury within these ranges "1-10", "10-100" or "100-1000", the magnitude of severity of injury/health problems, for example percentage of skin burn, percentage of reduction in respiratory capacity.

Elements of consequences can be related to each other and to other risk elements. The compound consequences may consist of individual consequences of specific hazards outcomes (e.g. fire, explosion, and toxic/poison) of specific magnitudes (e.g. number of fatalities or injuries per event) for specific risk receptors (e.g. human, environment and property). Because of the incompatibility among measurements of consequences, the compound consequences for all risk receptors can be measured and expressed in qualitative form.

The use of death and injury as the only parameters for measuring the severity of consequences may not be entirely appropriate. The hazards of dangerous goods can cause a wide variety of effects, for example nuisance (odour), irritation, incapacitation, irreversible effects, which are often not considered in the risk assessment of transport of dangerous goods. The usage of severity, irreversibility and magnitude as a measure of consequences may be considered appropriate in many situations. In the transport of dangerous goods, for the lack of such data, mortality and injury are used as the human consequence measurements. Some measurement units used in estimating the exposure and predicting the consequences are:

- Concentration of the substance that interacts with the risk receptor over a given specified time period (hours, days, or years), for example parts per million (ppm), $mg/m^3$, mg/kg, or ml/l for a specified time period;
- Overpressure delivered: for example, $grams/cm^2$;
- Energy flux delivered: for example, $KW/M^2/sec$.

In such cases, the magnitude of consequences is measured as the difference between the changed value and the "original" value or threshold. The marine environment contains different substances at various concentrations, i.e. the natural or background concentration (see Chapter 4, Vol. I). One approach of measuring the magnitude of the contamination of the marine environment would be to measure the difference between the values of concentration after the introduction of pollutants into the sea and the natural concentration.

As shown above (see Table 5.4), consequences to the risk receptors are calculated by different measurement units. For various reasons, consequences to individual, or combinations of, risk receptors should be measured by a common measurement unit. One of the commonest measurement units is a monetary unit, for example, U.S. $. Damages to the environment and properties are often measured in monetary units.

## 5.2.5. Step 5 – Risk estimation and presentation

*Tasks: Estimate or evaluate risks by combining the likelihood (frequency/ probability) and consequences, the consequences and exposures to dangerous goods hazards.*

### 5.2.5.1. Risk estimation

Depending on the data available and requirements of the decision-makers, risk characterization or estimation may combine either the likelihood and consequences or the consequences and exposures to dangerous goods hazards. Table 5.5 shows how the information is combined to characterise risks. Other similar terminologies often used interchangeably include risk estimation, risk calculation, or risk measurement. The term "combine" may be considered as a generic term. This term may encompass any procedure that may be needed to express the risks. The risk cannot always be estimated, calculated or measured by mathematical procedures, for example, by multiplying or dividing numbers.

**Table 5.5: Risk characterisation approaches**

| **Risks** | **= Likelihood x Consequences** | | | | **= Consequences/Exposures** | |
|---|---|---|---|---|---|---|
| Risk | Likelihood | Consequence | | | | Exposure |
| Individual risk | Individual likelihood | Individual consequences by | | | | Individual exposures |
| | | Risk receptors | Hazards | Types of consequences, severity | Location & activity | Population bounded by hazards of DG |
| | | • Human<br>• Marine environ.<br>• Property, activity | • Fire<br>• Explosion<br>• Toxic<br>• Corrosion<br>• Suffocation<br>• Infection<br>• Radiation<br>• Marine pollutants<br>• Others | • Fatality<br>• Injury<br>• Others health effects<br>• Chronic illnesses or diseases<br>• Pollution<br>• Losses<br>• Damages<br>• Others | • Local<br>• Regional<br>• National<br>• International<br>• Ships<br>• Waterways<br>• Ports<br>• En-route<br>• At port | •Risk receptor category<br>•Hazard type<br>•Location<br>•Activity |
| Aggregated Risk | Aggregated Likelihood | Aggregated consequence | | | | Aggregated exposure |

There are two main approaches commonly used for characterising risks, where: 1) the likelihood (i.e. frequency and probability) (F) is combined with consequences (C) ($R = f(FC)$); 2) the consequences are averaged over or divided by the exposed populations or the universe (E) ($R = f(CE)$), which are estimated for one year. The frequency can be estimated relative to a wide range of exposure measures, such as characteristics of dangerous goods shipments, the exposed population, means of transport, activities and many more. The ratio between the consequences and exposures is in itself the probability of the consequences that may be experienced by the exposed risk receptors. When data are available, the consequence and risk estimations, particularly for humans and the marine environment, should take into account the combination of the severity, persistence, and irreversibility of consequences and probabilities of each element.

The risks are characterised in quantitative and qualitative terms or a combination of both. In quantitative terms, for example, the human risks are expressed in some numbers of deaths and injuries over a lifetime or working lifetime in a population. Qualitative characterisations such as "low", "medium" and "high" are used whenever risk quantification is neither feasible nor necessary. The quantitative risk characterization may be deterministic, for example where a point estimate of exposure is compared to a point estimate of consequences, or probabilistic, where the distribution of exposure data is compared to the distribution of consequences data and risk is reported as the percent of people or species in the aquatic community expected to be affected.

The likelihood, consequences and exposures, and subsequently the risks themselves, can be related to any element (see Table 5.5) including risk receptors, types of hazards generated by dangerous goods, location, maritime transport components and activities. This allows the comparison of the adverse effects associated with different activities and components of the maritime transport system such as transport, handling, transport means, types of dangerous goods and packaging. The compound (overall or aggregated) risks consist of individual or specific risks, which can be expressed as follow:

(1) $\Sigma Ri = \Sigma f\,(FiCi)$; and
(2) $\Sigma Ri = \Sigma f\,(FiCiEi)$

Risk characterisation may not necessarily imply mathematical procedures. Given the wide range of different incompatible measurement units used to express likelihood, consequence and exposure, the compound or aggregated risk is not always a simple arithmetical sum of the individual risks.

The way in which risks are estimated and presented depends on many different factors, including the objective, scope and depth of the study, types and amounts of data being used, risk criteria available, preferences and requirements of the decision-makers, and the legal requirements, if any. In some industries and sectors, including the transport of dangerous goods, and countries, the risks are estimated and presented in accordance with established guidelines. For example, the American Institute of Chemical Engineers provides some commonly used risk measures and procedures for estimation of the human risks, including both societal and individual risks, for the chemical industry. These measures can be suitable for application in risk estimations for the maritime transport of PDG. Risks can be estimated in various forms, including these forms (CCPS, 1989):

- *The Fatal Accident Rate* (FAR) is the estimated number of fatalities per exposure hours, for example, 1,000 employees' (e.g. ship and shore personnel) working lifetimes (Lees, 1980).
- *The Average Rate of Death* (ARD) is the average number of fatalities that might be expected per unit time from all possible incidents (Lees, 1980). This is also known as the Accident Fatality Number (AFN).
- *The Individual Hazard Index* (IHI) is the FAR for a particular hazard, with exposure time defined as the actual time that a person is exposed to the hazard concerned (Helmers and Schaller, 1982).
- *The Mortality Index* (MI) or Number is used to characterise the potential hazards of toxic materials (Marshal, 1987).

The following are some types of risks and the way they are estimated:

***Individual risk:*** The American Institute of Chemical Engineers (CCPS, 1989) defines individual risk as the risk to a person in the vicinity of a hazard. Because of the limited data available, the risks are often estimated for fatalities and irreversible injuries. Individual risks are estimated for exposed individuals and groups of individuals at particular places, or the average number of individuals in an affected zone. Some individual risk measures are (CCPS, 1989):

- *Individual Risk Contour* shows the geographical distribution of the individual risks.
- *Maximum Individual Risk* is the individual risk to persons exposed to the highest risk in an exposed population.
- *Average Individual Risk* (exposed population) is the individual risk averaged over the exposed population.
- *Average Individual Risk* (total population) is the individual risk averaged over a predetermined population, without regard to whether or not all people in that population are actually exposed to the risks.
- *Average Individual Risk* (exposed hours/worked hours) is calculated for the duration of the activity.

***Societal risk:*** This is a measure of the risks to a group of people (HSC, 1991). It is often measured in terms of the sum of the frequency distribution of multiple casualty events at a local, national or regional level. In addition to frequency and consequence information, the social risk estimation requires a definition of the population at risk, such as the populations features (e.g. gender and age), the likelihood of people being present at a given location, for example, port/terminal, coastal waters, straits, and channels. The purpose of measuring the societal risks is to compare the estimated risk values against risk criteria.

***Injury risk:*** Another form of measuring and expressing human risk is the injury risk measure, but this is less applicable. Because of the lack of, and high degree of uncertainty related to, injury data, many risk assessments in transport of dangerous cargo (i.e. oil and oil products) have not taken injury risk measures into account. Another approach to measuring and expressing injury risk is to use the ratio of deaths to injuries.

***Risks (fatalities and injuries) per unit measure of the activity/system:*** For maritime transport of PDG it is possible to relate the detriment, which is the numerical measure of consequences, to a variety of measures of the activities or the system elements. For example, fatalities and injuries due to dangerous goods hazards can be expressed relative to one or combinations of the following:

- the total miles travelled
- the total number of transits
- the total number of vessel calls
- the total passenger/crew hours on board
- the total passenger/crew miles travelled
- the total tons or ton/miles of PDG;
- the total number of dangerous goods shipments/packages – all the above per unit of time, usually one year.

The working lifetime could be used as a unit of time for employee (crew) risks. Similar measurements can also be used for property and environmental risks.

#### 5.2.5.2. Risk presentation

The amount of data that is considered in a risk analysis could be very large. The purpose of risk presentation is to reduce this amount of data and provide a simple quantitative or qualitative risk description that is useful for decision-making (CCPS, 1989). There are various formats of risk presentation. Both risk estimation and presentation formats should be compatible with the risk criteria available. In other words, in order to facilitate risk evaluation, risks should be measured and presented in accordance with the risk criteria (similar forms and units of measurement) against which they will be compared or evaluated. Some risk presentation formats, which could be employed in the risks of PDG as well, are (CCPS, 1989):

- *Single number index:* e.g.1/100,000. Scientific notation (see Table 5.6) is generally used to present quantitative risk information.
- *Table.* Risks indices of both individual and societal risks are often presented in tables where the risks of various group sizes of affected people are tabulated. This form of presentation is easy to interpret. The human risks due to hazards of PDG only can be presented, for example, in the following group sizes of affected people (fatalities/ injuries): 1-10; 11-100, 101-1000, 1001-10,000.
- *Graph*: e.g. F-N (Frequency-Number) curve. This is a common form for presenting the societal risk measure. The curve is a plot of cumulative frequency vs. consequences, in which the severity of consequences is expressed as the number (e.g. fatalities) ranging over several orders of magnitude. This form is also used in presentation of the dangerous goods risks.
- *Map*: e.g. individual risk contour plot (i.e. "isorisk" lines) expressing risks vs. distance.

Table 5.6 shows an example of quantitative expressions of the risks. The human risks, including both individual and societal risks, could be expressed as the ratio of consequences and exposure (i.e. the probability) to dangerous goods hazards for a specific period of time, usually one year. The marine environment and property risks can be expressed and presented in a similar way. The probability may range from 0 to 1.0, where at 1.0 there is absolute certainty that an undesirable event will occur.

**Table 5.6: Risk measurement and presentation**

| Actual number | Scientific Notations | | Read as |
|---|---|---|---|
| 1/10 | $1x10^{-1}$ | 1E-01 | One in ten |
| 1/100 | $1x10^{-2}$ | 1E-02 | One in a hundred |
| 1/1000 | $1x10^{-3}$ | 1E-03 | One in a thousand |
| 1/10,000 | $1x10^{-4}$ | 1E-04 | One in ten thousand |
| 1/100,000 | $1x10^{-5}$ | 1E-05 | One in a hundred thousand |
| 1/1,000,000 | $1x10^{-6}$ | 1E-06 | One in a million |
| 1/10,000,000 | $1x10^{-7}$ | 1E-07 | One in ten million |

#### 5.2.5.3. Risk estimation and presentation by means of FTA

The Fault Tree Analysis (FTA) technique explores the actual and potential factors that lead to the top events. But, "What has or could have happened after packages with dangerous goods have been breached?" A complete picture of risks of marine events involving PDG will be thoroughly established through a systematic coverage of the sequential propagation of events. The ETA is an effective tool in determining how the failure of packaging can result in the release and/or involvement of dangerous goods, and how various factors and conditions affect the path of the chain of events. In addition, it can explore and, perhaps, quantify outcomes (e.g. fire, explosion, toxic etc.) and consequences (e.g. fatalities and injuries) of dangerous goods release and/or involvement.

The ETA consists of the following key steps (see Mullai, 2006b): a) define the system or activity of interest including physical/system and analytical boundaries and hazard identification; b) identify and list the initiating events; c) identify and list the lines of assurance and physical phenomena; d) determine event progression; e) event sequence outcomes – consequences and frequencies; f) summarize results - risk estimation and presentation. The first steps are in common with FTA, which is discussed in some detail in Mullai, 2006b. Based on examination and analysis of the empirical data, the key steps of ETA are further expanded and developed for marine accidents involving PDG.

***Identify and list the initiating events:*** The set of events considered for a risk analysis may contain multiple initiating events requiring multiple event trees. In order to simplify drawing, these events are categorized according to the lines of assurance. Initial events are usually listed on the left side of the tree. Depending on the type, purpose and boundary of the study, one or a set of events can be chosen as the top or initial events. In the latter case, events are grouped into categories. Individual and cumulative fatalities and injuries could be estimated for the events involving PDG categorised into a) "Marine events" such as collision, fire and explosion other than those caused by dangerous goods, grounding, machinery failure, and foundering, and b) "Non-marine events" that include all events other than events of category (a) such as spills and fire/explosion due to PDG.

***Identify and list the lines of assurance and physical phenomena:*** Defining the function of safeguards or lines of assurance is an important step in identifying their effectiveness. In maritime transport, they are specifically designed for detection and mitigation of the consequences of dangerous goods releases. The lines of assurance come in different forms including a) engineered systems, for example the packaging system, ship system, emergency response equipment and device systems, and b) administrative or personnel systems, such as emergency response teams and human detection through sensors. Physical phenomena, such as weather and sea conditions, influence the sequence of marine events. For example, immediate ignition or delayed ignition, dispersion characteristics and consequences of the release of flammable liquids onboard ships are significantly affected by different weather conditions. The list of lines of assurance and physical phenomena is placed across the top of the tree in the chronological order in which they affect the event progression.

***Determine event progression**:* At this step the logical progression of the event as it moves through the various lines of assurance is determined. This involves identification of the success (e.g. no spill or release, no ignition, no fire or explosion, no fatalities) and failure (e.g. spill or release, ignition, fire or explosion, fatalities) branches of each line of assurance and physical phenomena. The successes and failures are usually displayed in the upward branch and downward branches respectively. Some branch points may have more than two outcomes that may be displayed in numbers. But some branches may have only one outcome, in which case there would be a straight line through the line of assurance. This will occur when the conditional probability is 1.0 and the line of assurance does not affect the outcome because of some preceding success or failure of another line of assurance.

For example, in the case of rupture or damage to a tank container with a flammable liquid loaded on board the ship, the first branch event progression of the spill event may depict two potential paths forward, depending on whether or not the release ignites. If the spill ignites, three systems may be available in a ship to extinguish the fire, namely handheld fire extinguishers, the $CO_2$ system, and the seawater system. Successive branch points may depict the success or failure of each system. The upper branch in each case extends directly to the outcome because, once the fire is extinguished, there is no need for the remaining systems to operate.

The Fault Tree Analysis (FTA) and other analysis technique procedures can be employed to identify and analyse the causes and contributing factors of each system or subsystem (e.g. fire extinguishing systems) failure.

### Events sequence outcomes – frequencies and consequences

The construction of the event tree provides a picture of the progression of the events to each of the various outcomes, which for the marine events involving PDG consists of hazards of DG such as fire, explosion, toxic/poison, and marine pollution. Each event outcome may result in N or more consequences of various magnitudes, which are associated with a frequency. Both consequences and frequencies are estimated either qualitatively or quantitatively. The outcomes in an event tree are generally ordered from high frequency and low consequence to low frequency and high consequence. For independent sections, only the product of the probabilities may be required. Quantitative estimation of frequencies is accomplished by multiplying together the initiating event frequency and all probabilities from the branch points. When dependencies are encountered in the system failures and outcomes, it may only be desirable to perform estimations by means of new and more advanced assessment techniques based on the binary decision diagram (BDD) formulation of system failure logic; see for example these sources (Gulati and Dugan 1997; Dugan and Doyle 1996; Sinnamon and Andrews 1996; Rauzy 1996).

### Summarize frequencies and consequences - risk estimation and presentation

Risk analysis takes into consideration a set of marine events, where each event can generate numerous event sequences or scenarios associated with consequences and frequencies. Summarizing the consequences and frequencies in a separate table facilitates organization of the data for evaluation and presentation. Each event sequence may be marked with a number indicating the event tree for each scenario, e.g., the number 1.1 may show the first scenario from event tree 1, so 2.2 is the second scenario from event tree 2 and so on. The frequency and consequence information for each scenario is summarized in the subsequent columns.

When the number of events is small, a visual examination of these data may be sufficient to examine the risks. But when the number of events is large, the data may be presented in a format that can better facilitate understanding and decision-making. The F-N curve is a suitable format for quantitative risk presentation for large numbers of events; it plots the cumulative frequencies of events causing N or more consequences. The F-N curve can visually show the frequency of consequences (i.e. the risks) of dangerous goods hazards and compare them with available risk criteria. To plot the F-N curve, event scenarios are sorted from the highest to the lowest consequence. Then the frequency data are accumulated for each scenario. The x-axis plots the consequence, and the y-axis plots the cumulative frequency. Event scenarios with identical consequences will generate a vertical line on the F-N curve. In order to avoid the vertical lines, only the last data point for each consequence is plotted.

## 5.2.6. Sensitivity analysis

This step has been performed in a number of recent risk studies (see e.g. DETR, 1999). This analysis may go beyond the risk analysis that largely focuses on the technical aspects of risk issues. The sensitivity analysis takes into consideration many other socio-economic aspects of the risks (see Mullai, 2006b). This step may be a study in its own right. Therefore, this step need not necessarily be considered a constituent element of the risk analysis described in this chapter. However, depending on many factors described in this chapter, it would be up to the risk analysts and decision makers to decide on the scope of the risk analysis.

In this step, after the individual risks are estimated, for the purpose of prioritisation the risks are ranked with respect to likelihood, consequence, exposure and sensitivity. The rankings form the risk and management indexes, which are defined by the expressions provided below. The Risk Index determines the risk level, whilst the Management Index provides further ranking for those items that have equivalent Risk Indexes.

*Risk Index* = Likelihood x Consequence or Consequence / Exposure
*Management Index* = Risk Index x Sensitivity (DETR, 1999)

Management indexing can be employed in any type of risks. In marine environmental risk analysis, the purpose of the sensitivity analysis is to identify areas (coastal and sea areas) that are sensitive to marine pollution. Together with the pollution risk analysis, the sensitive analysis is used, for example in the UK, as a basis to establish Marine Environmental High Risk Areas (MEHRA) (DETR, 1999). In order to assess the environmental sensitivity of coastlines and waters, the first step is to identify all protected, designated or sensitive sites, which can be locally, nationally, regionally or internationally designated sites. Sensitivity classifications are developed to meet the special needs and characteristics of a country or region including specific physical, ecological, social and economic features. Sites are, for example, classified according to the following categories: wildlife importance, vulnerability of seabirds to pollution, fishing, well-being and economic benefit of the surrounding community, landscape and geology. This classification system is based on a variety of methods including laboratory and field studies and case histories of past pollution events.

The determination of the degree of sensitivity of coastal ecological zones and their habitats is an important element for any marine pollution contingency planning and prevention priorities. Each and every individual identified site is reviewed and assessed by various methods and techniques, including the judgement of bodies specialised in the marine environment. Marine environment sensitivity is then documented, and by using various advanced technologies, such as the geographical information system (GIS), an index mapping is created. Marine environment sensitivity mapping has recently become an essential part of the marine pollution prevention programme in a number of countries.

## 5.3. Stage 3 – Conclusions and recommendations

This is an important stage of the risk study (see the **highlighted are** in Figure 5.10). Based on the facts and the analysis, provide key concluding statements or remarks concerning risk elements – this is a synthesis of the entire risk study work. Synthesised information about the main elements of the risks should be provided, including transport hazards, causes and contributing factors, likelihood and the major contributors of events involving PDG, consequences due to hazards of dangerous goods, and the risks expressed in qualitative or quantitative form. Estimated risks may be evaluated against established risk criteria, if any, for example, whether the risks of PDG are negligible, acceptable or unacceptable.

One objective of the risk analysis is to develop recommendations for better management of risks. In this context, it is necessary to suggest risk management strategies and measures. The main categories of strategies and measures are shown in Chapter 3, Vol. I, and Mullai, 2006b. However, the results and recommendations form only one set of information considered by decision makers. Recommendations do not in themselves make a decision, but inform it, as many other factors are often taken into account in the decision-making process (see Mullai, 2006b). Recommendations suggested may undergo further scrutiny or study, including cost-benefits analysis.

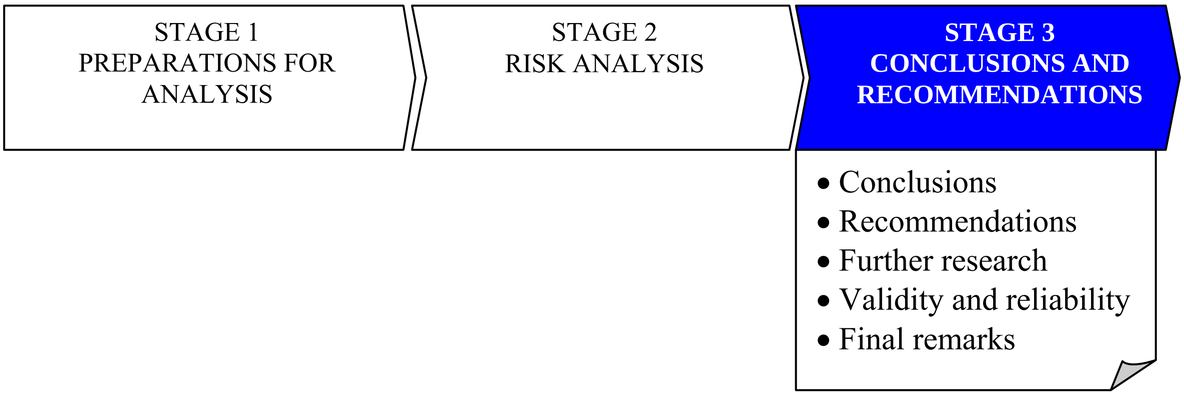


**Figure 5.10: Stage 3 – Conclusions and recommendations**

The concluding remarks can include important discussions concerning the validity and reliability of the study's results, contributions of the study, and suggestions for further research.

The risk analysis framework presented in this chapter is validated and demonstrated in practice in Chapters 1-7, Vol. II.

# 6. Reflections on Risk Analysis Framework Demonstration

*This chapter summarises the demonstration process of the risk analysis framework presented in Chapter 5, Vol. I. It also provides some reflections on the demonstration process.*

## 6.1. Framework demonstration

The following section briefly presents the experiences of and some reflections on the validating demonstration process of the risk analysis framework presented in Chapter 5, Vol. I. The framework is demonstrated step-by-step in practice in Chapters 1-7, Vol. II.

In order to demonstrate the risk analysis framework and for the reasons presented in Fig. 6.1 and Table 6.1, *several other datasets,* which are datasets other than those used in the framework development, are mainly collected from a wide range of U.S. data sources. The demonstration combines both qualitative and quantitative datasets and data analysis approaches (see Figure 6.1). Table 6.1 presents some advantages and disadvantages of the risk analysis approaches, which are explored based on the understanding gained in the demonstration process. The risk analysis that combines both qualiative and quantintative approaches provides numerous advantages, but it could become a very laborious and intensive process that requires considerable time and resources. The following are the main categories of datasets used in the framework demonstration:

**Qualitative data:** The qualitative datasets mainly consisted of *marine accident case histories* - the m/v "Santa Clara I" (SCI) accident and several other case histories collected from various sources. The m/v SCI case is a representative marine accident case of damage and losses overboard of PDG, including arsenic trioxide and magnesium phosphide, exposure of people to toxic substances, and pollution of the marine environment. The m/v SCI case consists of numerous materials, such as the investigation report of the USCG (U.S. DOT, 1992) and several articles or reports written by U.S.'s experts in the field (Whipple et al. 1993, McGowan 1993; Merrick 1993; Crokhill 1992). This case is one of the most detailed ones ever reviewed, and one of the best-known cases in the U.S. and, perhaps, in the world's maritime community. The initial intention was to demonstrate the framework by employing a qualitative analysis approach based on a representative marine accident case history, i.e. the "m/v Santa Clara I" accident case. Despite the fact that this was one of the most detailed case histories reviewed, the m/v SCI case accident history was insufficient to facilitate a complete demonstration of the framework. Therefore, other datasets were selected and collected.

**The quantitative/statistical data** included the following datasets:

- *Hazmat*[23] *incident data collected from the following hazmat incident databases*:
  - The U.S. Hazardous Material Information System (HMIS) database (U.S. DOT, 2005) containing: number of cases: ca. 186,000 incident cases; period: 1993-2004
    - Number of variables: 184;
  - The U.S. National Response Center (NRC) database (NRC, 2005): number of cases: 454,000 incident cases; period: 1990-2004; number of variables: 230
- *Other quantitative datasets:* a) Economic censuses: Commodity Flow Survey (CFS) - Hazmat Transportation Reports; b) population censuses (1990-2000) from the U.S. Department of Commerce and the U.S. Census Bureau; c) vessel statistics; d) other databases and data sources

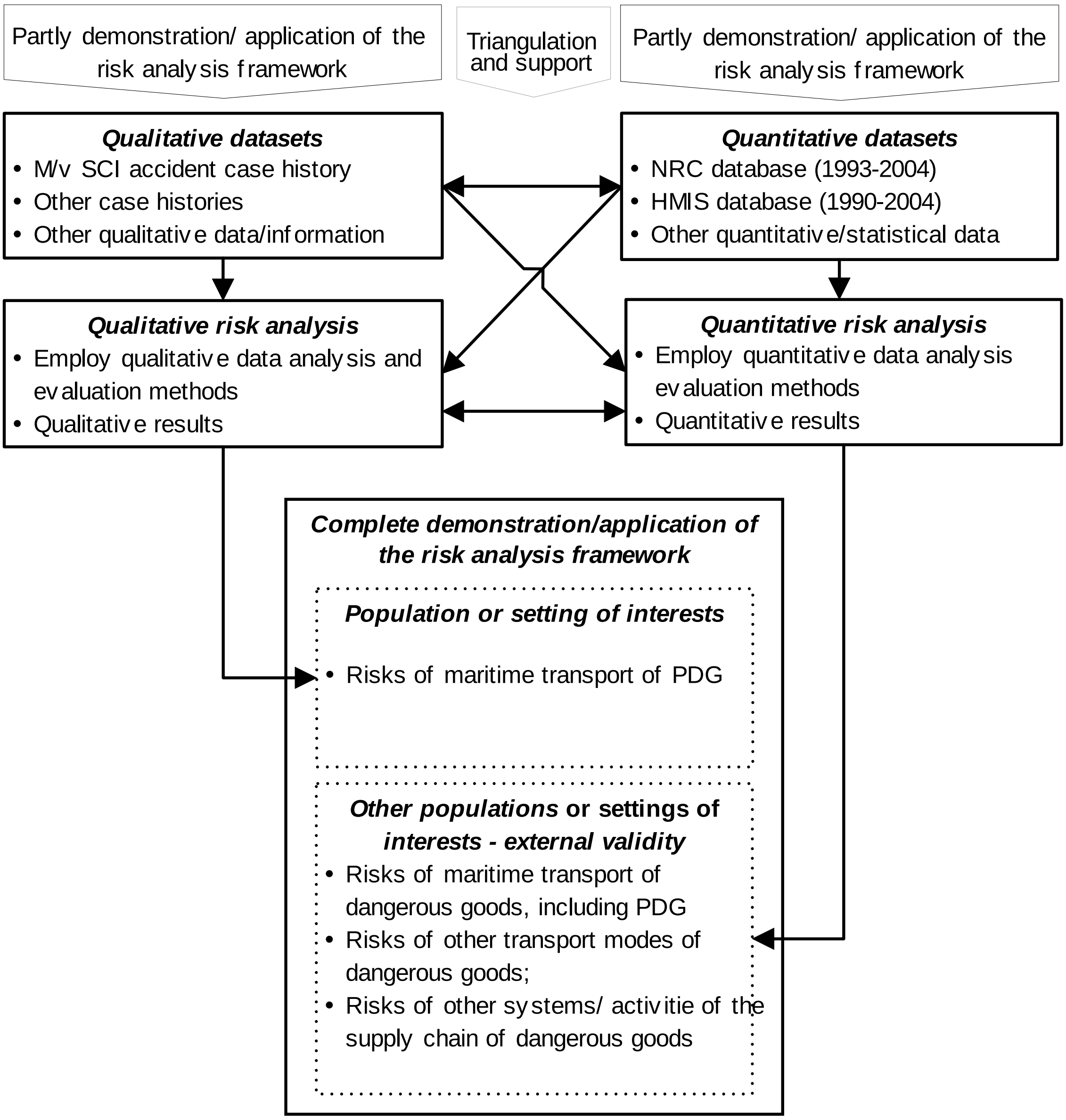


**Figure 6.1: Framework demonstration – datasets, analysis approaches and the scope**

[23] Hazmat means "hazardous materials", which is a term for dangerous goods commonly used in the U.S.

Given the large amount and diversity of the datasets used, the risk analysis carried out in Chapters 1-7, Vol. II, may be one the largest of its kind. Furthermore, given the large number and diversity of variables as well as the "uniqueness" of some variables (e.g. top events, packaging failures, transport hazards, human consequences – hospitalisation and evacuation, damage), some of the results presented in Vol. II may not be found elsewhere.

## 6.2. Reflections on framework demonstration

### 6.2.1. Tips for preparing for data analysis

The framework demonstration is largely based on the analysis of empirical data obtained from two hazmat incident databases, the NRC and HMIS databases. A thorough examination of both databases showed that they contain errors in data compilation. Both databases contain large numbers of datasets organised by year and variable that have to be merged into single datasets and prepare for analysis. In order to avoid errors during the data merging process, which might render datasets and, subsequently, the results of the risk analysis unreliable and invalid, it is important to:

- Become familiar with data merging processes and approaches;
- Examine the data carefully and thoroughly; learn more about datasets and variables prior to the data merging process;
- Determine the data merging approach prior to the data merging process;
- Exercise due diligence during the data merging process - check, check and re-check;
- Run preliminary analysis tests after the completion of the process;
- Review the merged datasets and make appropriate adjustments, if necessary;
- Make sure again that the datasets are correctly selected, transferred and merged.

### 6.2.2. Some adjustments and refinements in the framework

In this research, every reasonable effort has been made to provide a risk analysis framework that consists of relevant concepts and assist risk analysts to generate valid and reliable results. The validating demonstration showed that neither the m/v SCI accident and other case histories nor statistical data had the capacity to induce any significant change to the framework presented in Chapter 5, Vol. I. The framework presented in this chapter (Chapter 5, Vol. I) could be compared with its original version (see Mullai, 2004), which is the version prior to the demonstration. Unlike many frameworks or techniques presented in Chapters 1 and 3, Vol. I, and Mullai, 2006b, the framework is largely grounded on large amounts of diverse empirical data (see Chapter 4 and Appendix 2, Vol. I). It consists of conceptual categories and properties representing the system and phenomena and their relationships. Grounded theory is intimately linked to and derived from the data. Usually, grounded theory cannot be proved to be entirely wrong or dismissed by new or more data; it is destined to last despite inevitable modification or reformulating (Glaser and Strauss, 1967). Once a conceptual category or property is conceived, changes in evidence may not necessarily alter its clarity (Glaser and Strauss, 1967). Further, the results of the risk analysis that is facilitated by the framework (see Chapters 1-7, Vol. II) may have a higher degree of validity, reliability, completeness and detail than many other studies cited in Volumes I and II, including the individual and all data sources combined (i.e. the accident investigation report, articles or papers of conference proceedings and other sources) of the m/v SCI case history.

However, because of the huge amounts of diverse data, some of which are very unique for the transport of packaged dangerous goods/hazmat, used in demonstration of the framework, on the basis of the results of analysis, some adjustments or refinements have been made in the framework during and after the process of demonstration, such as:

- *Top events*: The HMIS database is a very large and specific (in many respects it is a very unique) database that record transport incidents involved packaged dangerous goods/ hazmat. The database contains many variables (with many variable types, labels and values) representing the system and risk elements that may not be found elsewhere. As shown in Chapter 4, Vol. II, the development of the framework is based on a large amount of marine accident cases, but not that large as the amount of incidents contained in the HMIS and NRC databases. The results of data analysis showed that there were more items or sub-categories in the categories of top events than those explored earlier (i.e. in Chapter 4, Vol. I). Consequently, some adjustments or refinements were made in the categories of top events. Some categories of damage or failures in the packaging components and areas were also added. But, this did not induce changes in the concept of "top events." On the contrary, the results proved and replicated the construct, and thereby strengthened its validity and reliability.
- *Transport hazards:* For the same reasons mentioned above, some sub-categories with in the categories of transport hazards were also explored and included. The results of data analysis also suggested that the top events are not always directly as the result of transport hazards, as defined. In many cases, release incidents are attributed to operational failures (e.g. improper or loose tightening of caps or other closure device). Subsequently, the relationships amount the constructs of "transport hazards", "top events" and "causes and contributing factors" were revised and refined.
- *Reorganising*: Some steps, sub-steps or procedures in the framework, for example those concerning exposures and consequences of hazmat incidents, are reorganized in a better and more logical manner in order to reflect the system and phenomena being studied.

Given the very nature of the human being (biology and behaviour – body and mind) and its surroundings and their interrelations, many products of scientific enterprises, including theories, statements of facts, explanations and predictions, frameworks, models, methods and many more, are not always and absolutely perfect. It may nearly always be possible to make further improvements, changes, modifications or adjustments, but the costs may outweigh the expected benefits. In many researches, just as in many human activities, a balance between the costs and benefits of improvements is usually required. Otherwise, it would be an uneconomic, if not counterproductive, enterprise for organisations and countries. Further, as mentioned earlier, the body of scientific knowledge is the product of many incremental contributions made by the consorted and collective efforts of many generations. For a wide range of interrelated reasons, some of them are mentioned in Chapter 2, Vol. I, many theories, frameworks, techniques, models or tools have been developed in the field of risk assessment and management as well as other fields of science. And many more are to come in the future. Thus, a collection of sixteen frameworks and thirteen techniques, which are developed for and employed in various systems, including maritime systems, are presented in Chapters 1 and 3, Vol. I, and Mullai, 2006b. Some of these frameworks and techniques are based on and serve the same systems or risk issues.

### 6.2.3. Some considerations when applying the framework

The application of the risk analysis framework and validity and reliability of results generated by its application could be constrained by a wide range of interrelated factors and issues. The following presents some important factors that could be taken into consideration when applying the risk analysis framework presented in Chapter 5, Vol. I, as well as when conducting risk analyses or study projects in general:

- *Classification or coding systems of the system and risk elements*: There are many complex and, to some extent, incompatible classification systems. Definitions and concepts described the system and risk elements vary across countries and industrial communities. Chapter 3, Vol. I and Mullai, 2006a, present some of the well-known classification systems, such as the IMO, the USCG and the Lloyd's Register of Shipping systems. However, the relevant and specific classification systems should be employed in specific cases. Thus, for the simple fact that the validating demonstration is mainly based on the U.S.'s incident data sources (see Chapters 1-7, Vol. II), the relevant U.S.'s classification systems are largely employed. Combining datasets from different data sources, countries or industries might be a problem. In such cases, efforts should be made to exercise due diligence in reconciling different systems and making appropriate adjustments.
- The risk analysis framework facilitates the risk analysis process – from preparations through data analysis and presentation of the results, conclusions and recommendations. However, some sub-steps or tasks simply cannot be demonstrated and presented in a risk analysis report. They provide guidelines that could be followed in the overall risk study or project process.
- *Complexity and dynamics of the system and risk elements*: In the risk analysis framework, considerable efforts have been made to describe the risk analysis process in a consistent and logical way. But, the system and phenomena (i.e. risks) associated with it consists of a large number of elements that are in very complex and dynamic relationships. Therefore, it has been very difficult to present everything in great detail in the framework. The framework contains the most relevant concepts that are presented in graphic and/or text formats. The key concepts are, however, presented in a graphic format.

- *Time, resources and data available - the scope of the study*: A detailed risk analysis may be prohibitively expensive (HSC, 1991). The risk analyst(s) should be well aware and informed about the time frame and resources available. At the early stage of the risk study, they should discuss in detail with the decision makers, project financiers or other relevant parties about the scope of the study, such as the breadth and depth, and the physical and analytical boundaries of the study. The scope of the study, in combination with other factors, will affect the entire process and results of the study. In a risk analysis, in particular analysis concerning dangerous goods risks/accidents, numerous difficulties and constraints may arise in finding and acquiring relevant data. Unlike in U.S. and some other countries, in many countries and organisation, the data issue may be a considerable barrier. Some issues concerning the risk-related data are: inaccessibility (data not for the public use), unavailability (countries or organisations lack data), a limited scope (only a few variables), different and incompatible data formats, limited quantity, inadequate poor quality, costs (very expensive to acquire) and the time frame required for collection and compilation of data.
- *Abilities, predispositions and skills of risk analysts*: The framework contains detailed guidelines for facilitating risk studies concerning the maritime transport of PDG as well as other systems. However, every risk study is, to some extent, "unique" in its own right, which require the ingenuity and creativity of the risk analysts. Consequently, the validity and reliability of the results of the risk study will depend very much on the abilities, predispositions and skills of risk analysts.

**Table 6.1: Advantages and disadvantages of qualitative and quantitative risk analyses**

| Method | Disadvantages/limitations | Advantages/benefits |
|---|---|---|
| **Qualitative risk analysis** | • Partial qualitative risk analysis in the field of interest – internal validity, i.e. maritime transport of PDG.<br>• Gaps in data, lack of or insufficient data.<br>• Limited or no data and method triangulations.<br>• Very limited or no quantification of the system and risk elements and their relationships.<br>• Limited or no exploration of certain concepts representing the system and risk elements – e.g. top events, transport hazards, types of incidents and causes and contributing factors. Consequently, a number of stages and steps of the framework could not be demonstrated at all, or could not be completely demonstrated. | • Provide a higher degree of detail in the analysis of a number of concepts.<br>• Explore a number of concepts that cannot otherwise be explored by means of quantitative data analysis.<br>• Provide explanations and support for the interpretation of the results of the quantitative data analysis.<br>• In certain cases, create a higher degree of confidence and more reliable explanations of phenomena and relationships to which quantitative data analysis may be neither applicable nor necessary. |

| Method | Disadvantages/limitations | Advantages/benefits |
|---|---|---|
| **Quantitative risk analysis** | • Partial quantitative risk analysis in the field of interest, i.e. maritime transport of PDG.<br>• A number of concepts cannot be explored at all, or cannot be completely explored.<br>• A number of stages and steps in the framework cannot be demonstrated at all, or cannot be completely demonstrated.<br>• Gaps, lack of or insufficient quantitative data.<br>• Data availability and accessibility constraints. | • Explore and quantify a number of important concepts of dangerous goods risks.<br>• Estimation of various types of dangerous goods risks.<br>• Provide various forms of risk presentations.<br>• Some results may have a higher degree of confidenceand generalisation compared to the results of qualitative analysis.<br>• Provide explanation and support for the interpretation of the results of the qualitative data. analysis. |
| **Combined risk analysis – quantitative and qualitative risk analysis** | • It could become a very laborious and intensive process, requiring considerable time and resources.<br>• Costs may outweigh benefits.<br>• Extra efforts, diligence, appreciation, skills and knowledge are required to employ and combine various types of datasets, data anlysis methods, and results. | • Provide a full demonstration of all stages, steps and sub-steps contained in the framework.<br>• Provide a higher level of exploration and quantification.<br>• Explore and quanitify the relevant concepts presented in the framework.<br>• Data and method triangulations.<br>• Fill gaps and extend data.<br>• Test thoroughly and enhance the validity and reliability of the framework and results generated by its application.<br>• Test and enhance, in particular, the external validity, i.e. framework application to other populations or settings of interest.<br>• Enhance understanding in the field of risks of maritime transport of PDG and other systems or activities in the DG/hazmat supply chain.<br>• Put dangerous goods/hazmat risks into perspective and compare them with risks in other systems. |

# 7. Conclusions and Recommendations

*This chapter provides concluding remarks on the research work, the research contributions to "academics" and "practitioners", and some areas for future research. Recommendations for improving risk methodology and human safety and health and the protection of the marine environment and property are also provided. The chapter concludes with some final remarks.*

## 7.1. Conclusions

Increasing largely amounts of different types of packaged dangerous goods (PDG) are carried by water through environmentally sensitive and residential areas. Unlike maritime transport of bulk dangerous cargoes, different types of PDG are carried together with non-dangerous goods and passengers onboard cargo/passenger ships. Case histories have shown that PDG have been involved in serious and very serious marine accidents. Some of the worst marine accidents ever recorded have involved PDG. In recent years, the issues of maritime transport safety and health and of protecting the marine environment have attracted increasing attention. The literature study showed that knowledge about the risks of the maritime transport of PDG is limited. Further, it also showed that, in recent years, increasing numbers of risk assessment frameworks have been developed in many areas, including those of human safety and health and the marine environment protection. For the shipping industry, these frameworks have mainly been developed for analysis/assessment of maritime risks in general and maritime transport of bulk dangerous cargoes in particular. The FSA is not intended for application in all circumstances. Despite extensive research, no specific risk analysis framework for maritime transport of PDG was found. Further, the study of many different frameworks, techniques and practices also showed that no single methodology has the capacity of dealing with all the problems and needs in shipping, including the analysis of risks in the maritime transport of PDG.

Against the above background, the objectives of this study were to: a) develop a risk analysis framework for maritime transport of PDG; b) enhance understanding of dangerous goods risks and provide recommendations for improving human safety and health and protection of the marine environment and property. In this study, considerable efforts have been made to achieve both objectives. Based on the literature study and the analysis of empirical data, a risk analysis framework (see Figure 7.1) is developed for application in the maritime transport system of PDG as well as other systems. The framework structure consists of three main stages. Each stage consists of a number of steps and sub-steps or tasks. The process is generally cyclic, and some activities can be performed simultaneously. The risk analysis process focuses on attempting to provide answers to the fundamental questions concerning the risks, known as the "the triple definition." These questions are: "What has gone and can go wrong?" "What are the consequences?" and "How likely is that to happen?"

The validating demonstration of the framework carried out in Chapters 1-7, Vol. II, has produced comprehensive knowledge in the field. Detailed lists of recommendations for improving risk methodology and human safety and health and protection of the marine environment and property are provided in Volumes I and II, and Mullai, 2006a and 2006b. The demonstration showed that the framework satisfies both valid and reliable conditions. The results of the study replicated the constituent components of the framework. Further, the results of this study may have a higher degree of validity and reliability than many other studies, including those cited in both volumes. The framework will assist, but not guarantee, risk analysts to generate detailed, valid and reliable results.

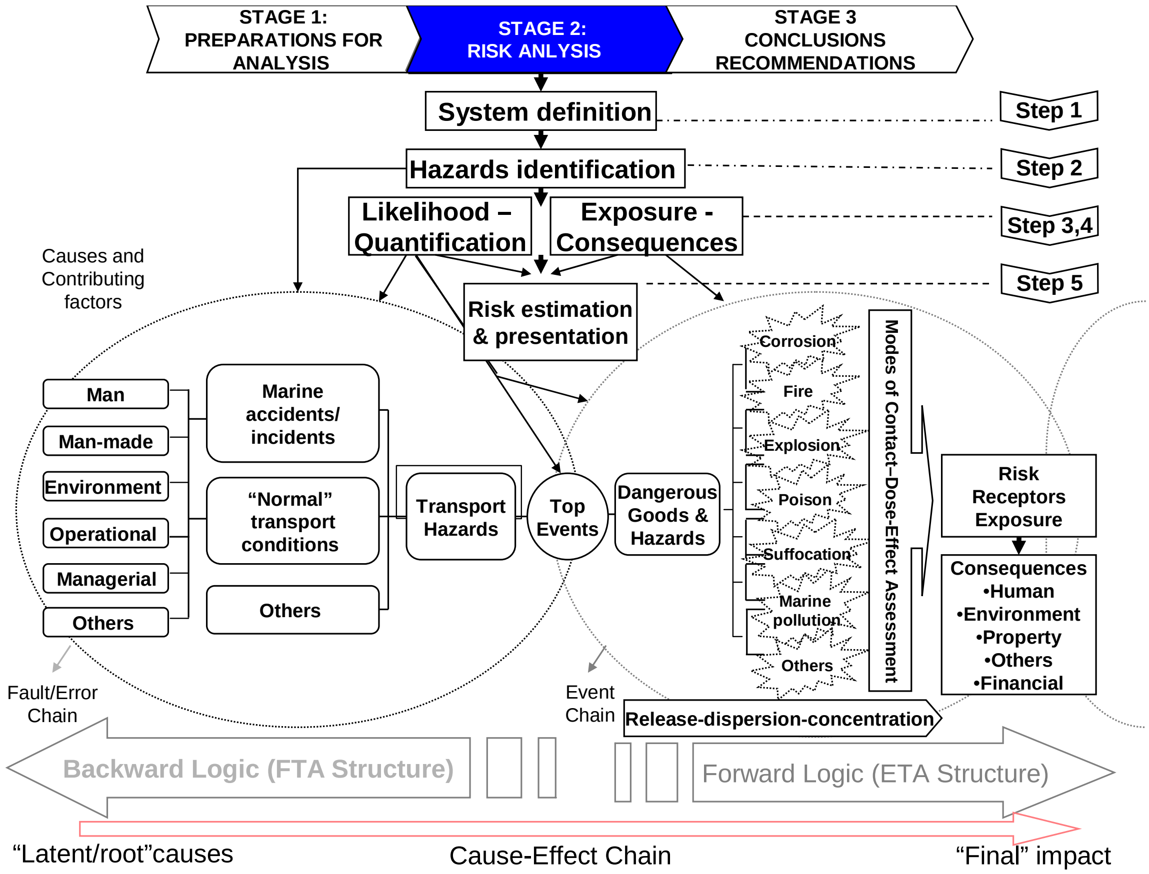


**Figure 7.1: Risk analysis framework (from Chapter 5, Vol. I)**

## 7.2. Research contributions

### 7.2.1. Theoretical and practical contributions

Figure 7.2 shows the main areas of the theoretical and practical contributions of this research to the communities of academics and practitioners. A detailed list of the relevant communities in the field is provided in, in Section 1.7 ("the Readership"), Chapter 1, Vol. I.

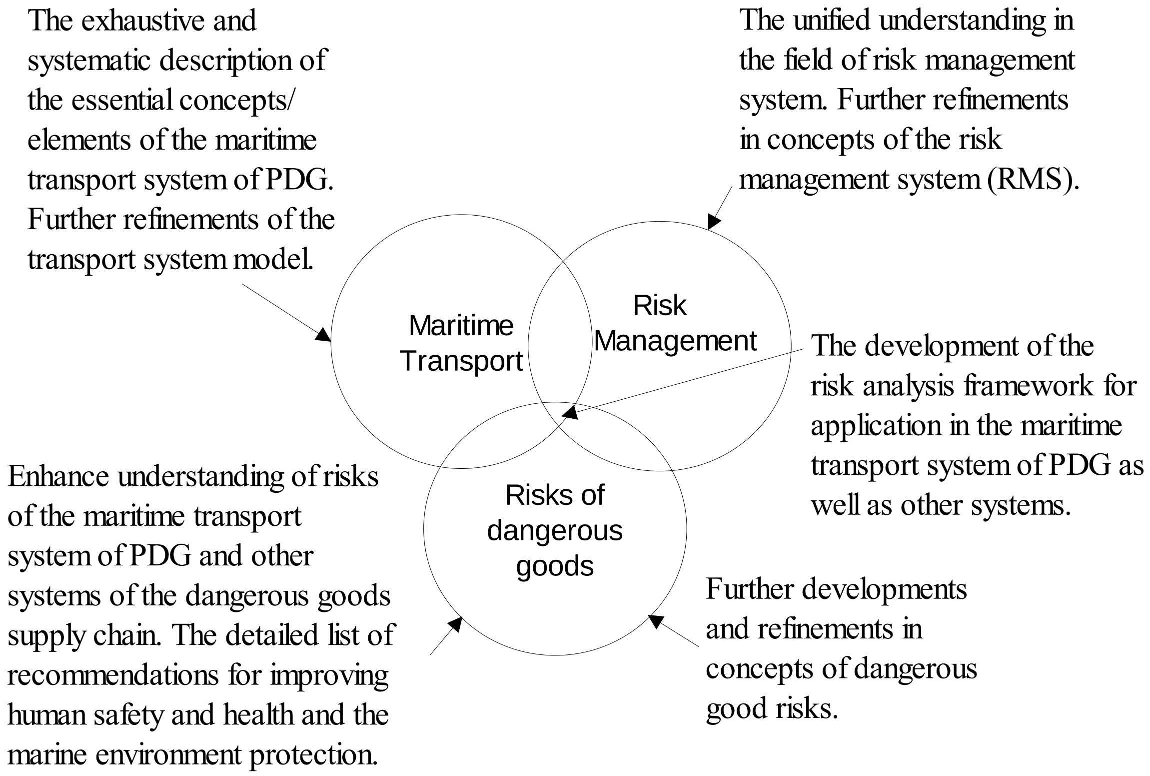


**Figure 7.2: Theoretical and practical contributions**

This study makes contributions to both communities of academics and practitioners in various forms. With reference to the "state-of-the-art" knowledge in the field explored in the literature study (see Chapters 1 and 3, Vol. I, and Mullai, 2006a, 2006b), attempts have been made to "fill a gap" in the literature in risk methodology and to enhance understanding of risks, which, in turn, may contribute to improving human safety and health and protection of the marine environment and property in the maritime transport of packaged dangerous goods and other systems and activities of the dangerous goods supply chain.

In the following section, the theoretical and practical contributions of this study are elaborated in some detail.

***The development of the risk analysis framework***: Given the research objective, one of the main (both theoretical and practical) contributions of this research is the development of a risk analysis framework (see Figure 7.1) that can be readily applied to the maritime transport system of PDG. By definition, the framework constitutes a theoretical contribution. To be a theory, a statement has to take the form of a universal statement that is not restricted to unique or particular circumstances, and it has to provide an explanation (Denscombe, 2002). Because of the high level of abstraction and the large amounts of diverse data used in the development and demonstration of the framework, the application of the framework is not confined to the domain of risks in the maritime transport system of PDG. The demonstration showed that the framework could facilitate the risk analysis process in other systems and activities of the dangerous goods supply chain. The framework consists of theoretical constructs and their relationships. It provides explanations of why and how the concepts representing the system and the risk elements are connected. The validating demonstration also showed that the framework has the capacity to facilitate the exploration and explanation of complex cause-effect relationships in the maritime transport system of PDG and risks associated with the system.

In order to comprehend the contributions made in this study, the risk analysis framework presented Chapter 5, Vol. I (see Figure 7.1) could be compared with other frameworks or modes presented in Chapters 1 and 3 and Mullai, 2006b. For the purpose of illustration, the following section compares the *risk analysis framework* (in Figure 7.1), including the *risk management system (RMS)* model (in Figure 7.4) with the *IMO Formal Safety Assessment (FSA)* (in Figure 7.3). Recalling briefly the FSA presented in Chapters 1 and 3, Vol. I, and Mullai, 2006b, the FSA is a methodology for assessing risks related to maritime safety and the protection of the marine environment and for evaluating the costs and benefits of IMO's options for reducing these risks (IMO, 1993, 1997, 2002). Since its first introduction, the FSA has been reviewed and refined several times by the IMO's main committees. In 2001, the IMO Guidelines for the FSA, which outline the FSA methodology as a tool, were approved. The FSA may be one of the most "authoritative" frameworks or methodologies in the shipping industry and beyond. The literature review (see Chapter 1, Vol. I) showed that the FSA has been applied or tested in several maritime-related risk studies (see Rao and Raghavan, 1996; EC, 1998a; Trbojevic and Carr, 2000; Lee et al., 2001; Lois et al., 2003).

Figure 7.3 shows the flow chart of the IMO's FSA methodology. Firstly, Step 1 "Hazard Identification" is not a separate step (as shown in Figure 7.3) but is rather the first step integrated into the risk analysis/assessment process (see Step 2, Figure 7.3), and several sources cited in both volumes do agree.

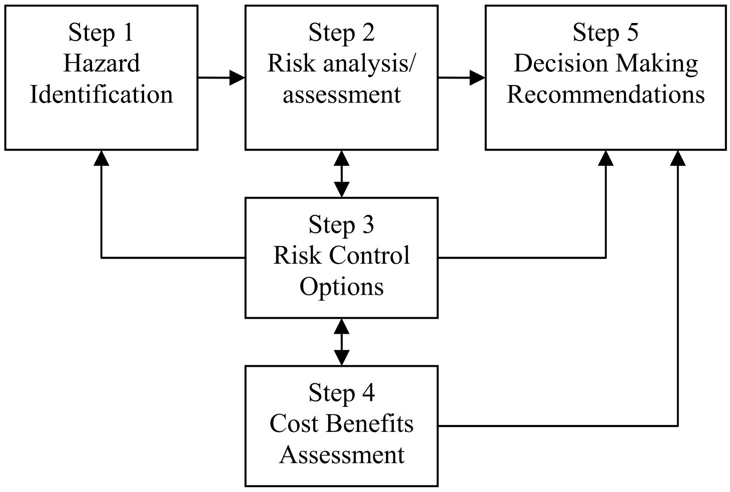


**Figure 7.3: Flow chart of the IMO's FSA methodology (IMO, 2002)**

Secondly, the steps shown in Figure 7.3, which are described in the IMO Guidelines for the FSA (IMO, 2002), are highly generic. According to the IMO Guidelines (IMO, 2002), the *FSA is not intended for application in all circumstances*. Therefore, as the extensive literature study showed, the FSA has been adapted, further developed, or simply applied or tested in several maritime-related systems or issues, but not in the maritime transport system of packaged dangerous goods. The thorough review of the guidelines showed that the FSA is not readily applicable to analysis the risks involving maritime transport of dangerous goods, including *packaged dangerous goods*. Thirdly, the FSA lacks essential concepts for representing and measuring the maritime transport system of dangerous goods and risks associated with it. Thus, the FSA does not contain some important concepts related to dangerous goods risks, such as "the list dangerous goods and their hazards" "release, dispersion and concentration" "routes of exposure" "dose-effect relationship" "risk receptors" "exposure" "aggregated consequences and risks" and many more.

During accident investigation or study numerous difficulties arise, including difficulties in the identification of the data, the determination of the scope of the study, documentation and presentation of the findings, and the development of recommendations (Hollnagel et al., 2006). The risk analysis framework combines both the high level of abstraction and the high degree of specific details. The framework specifically deals with dangerous goods risks encompassing relevant concepts, guidelines, principles and other valuable information, some of which are not found in the FSA as well as other frameworks or models presented in Chapters 1 and 3, Vol. I, and Mullai, 2006b. The framework brings the extensive personal experience gained in this and other studies and some of the world's best experiences, practices and knowledge in the field. The framework could assist the risk analysts to overcome the difficulties and constrains that may arise during accident/risk studies.

The risk analysis framework (see Figure 7.1) is an integral part of the risk management system (RMS) model (see Figure 7.4). These two models/frameworks, which would complement each other in a wider process or project, will facilitate the risk assessment and management processes. This, in turn, will contribute to improving human safety and health, and protection of the marine environment and property in the maritime industry. Furthermore, they will assist the relevant authorities and organisations in the development and changes and evaluation of regulations and risk management strategies and measures.

***Enhance understanding of the risks of maritime transport of PDG and other systems***: Accident prevention relies to a great extent on a proper understanding of the hazards, so that the appropriate risk management strategies and measures can be put in place to safeguard those who are potentially endangered (Thomson, 1999). The framework provides a blueprint for preparing and performing risk studies. It attempts to provide answers to numerous questions concerning the risk analysis process, such as when, why, what and how to prepare and perform a risk study? The answers to these questions will enhance understanding of dangerous goods risks. The framework will assist risk analysts in dealing with different situations arising in a dangerous goods-related risk study or project.

Risk analyses vary widely in terms of their degree of detail and complexity. In order for the framework presented in this study to have a wider scope of application, every reasonable effort has been made to develop a framework that will facilitate any type of analysis – from the simplest qualitative to the most comprehensive quantitative risk analysis. Then, it will be up to the risk analysts and decision makers themselves, under the specific conditions that may arise (see Chapter 5, Vol. I), to determine the level of analysis. The demonstration (see Chapters 1-7, Vol. II) showed that this risk analysis framework has the capacity to facilitate both qualitative and quantitative risk analyses.

Choosing the right technique for the right situation, data, system or activity is very important. With respect to the ability to prevent accidents, selection of the right method or techniques may be as important as analysis outcomes (Brown, 1993). Chapter 3, Vol. I and Mullai, 2006b, present a list of some of the world's best-known risk management and analysis/ assessment (sixteen) frameworks and (thirteen) techniques to choose among. Based on the experiences of the best-know organisations in the field (e.g. the USCG and the HSE) as well as personal research experience, frameworks and techniques are evaluated and some of their merits are presented. The combined application of some data analysis techniques are demonstrated in practice in the risk analysis in Vol. II.

This study intends also to contribute to improving human safety and health and the protection of the marine environment and property (i.e. practical contributions) by means of improving risk methodology (i.e. theoretical and practical contributions). A better methodology can contribute to a better understanding of the risks by generating more detailed, valid, reliable and relevant knowledge. In turn, a better understanding may contribute to more informative and, hopefully, better decision-makings. The implementation of improved risk methodology has proven in practice to yield benefits. For example, as mentioned in Mullai, 2006b, in the U.S., 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). However, the development of a risk assessment tool in itself will do nothing to control risks, unless the results generated by it are used as the basis for a risk management plan that generates measures to ensure that the risks conform to technical, societal or legal requirements (Carson and Mumford, 2005).

The validating demonstration of the framework (see Chapters 1-7, Vol. II) is a comprehensive analysis of dangerous goods risks. The analysis combines large amounts of diverse qualitative and quantitative datasets, including the merged datasets from the HMIS and NRC databases. Some of the valuable risk-related information contained in this report might not be found elsewhere. Furthermore, given the size and diversity of the datasets, this study may be one of the largest of its kind.[24] Efforts have been made to explore and present comprehensive knowledge of the field from large datasets by combining qualitative and statistical data analysis learning techniques. A part of the huge amount of data contained in both U.S.'s hazmat incidents databases[25] are highly "condensed" or aggregated into smaller manageable information pieces that would enable exploration and prediction of the phenomena, i.e. risks. The information generated in this study will assist the relevant authorities and organisations in their decision making processes.

The risk estimation and presentation (see Chapter 6, Vol. II) may serve as prediction and explanation tools. Thus, given the representativeness, the amount (i.e. the sample size) and the diversity of data, both types of risk estimations and presentations: 1) the FN curves of the human (fatality, injury, hospitalisation and evacuation) risks, the environment and property damage (in $) risks and environmental risks of the maritime transport system and other systems of the transport and the supply chain (see Figures 6.6~6.17, Chapter 6, Vol. II); and 2) diagrams of vessel, transport and aggregated

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[24] Compare the results of this study with other studies in the field, including (Haastrup and Brockhoff, 1991; Römer et al., 1995; Chee et al., 1994; Donk and Rijke, 1995; Rao and Raghavan, 1996; Trbojevic and Carr, 2000; Wang and Foinikis, 2001; Lee et al., 2001; Giziakis and Giziaki, 2002) and many other studies cited in both volumes of this thesis. The SPSS programme, which is widely used in Lund University, is one of the best-known and the most advanced programme for statistical data analysis available for public use. The 2005 version of the SPSS programme, which is used in this study for merging and analysing datasets contained in both aforementioned databases, is the first version that has the capability to handle unlimited numbers of cases and variables. The earlier versions have been limited to a number of 1500 cases.

[25] A part of the information provided in Vol. II of this thesis is the "essence of essence" (only ca. 50 A4 paper size written in both sides) of the huge amount of the empirical data used in the validating demonstration process. The amount, as well as the value, of the empirical data contained in both U.S.'s databases (HMIS and NRC databases) are equivalent to the following: a) ca. 642,000 A4 paper (210x297mm) (or 1,284 packets of 500 A4 paper each) paper size written in both sides (one incident case history is ca. one A4 paper, if not more, written in both sides); b) ca. 192,600 m A4 paper in length (297mm ~ 0.3m); c) ca. 38,443$m^2$ A4 paper (ca. 16.7 A4 paper per $m^2$); d) ca. 3,075kg A4 paper (ca. 80g/ $m^2$); e) ca. U.S. $ 64.2 million worth (assuming administrative costs for compiling and maintaining incident records U.S. $ 100 per incident case).

supply chain risks measured as the ratios of consequences and incidents averaged over respective exposed populations (see Figures 6.18~6.25, Chapter 6, Vol. II), may serve as powerful tools, for example, comparison, evaluation, prediction and explanation of risks in the maritime transport system, other modes of transport and other systems of the dangerous supply chain.

On the basis of the results and understandings gained in this study, detailed recommendations for improving human safety and health and the protection of the marine environment and property are provided in Chapter 7, Vol., Mullai, 2006a and 2006b, and Appendix 3, Vol. II. The results of risk estimations and presentations presented in Chapter 6, Vol. II, may serve as the basis for further studies and for the development or improvement of risk evaluation criteria in the field. Further, in organisations, countries and regions where the relevant data are inexistent or inadequate, the results and experiences from some of the world's best data sources – i.e. the U.S. data in terms of quantity, quality, diversity scope and accessibility – brought in this study may inspire the relevant organisations or institutions to establish risk-related data systems, collect and compile data, perform comprehensive quantitative risk analyses on a regular basis, and establish fact-based risk evaluation criteria in the field.

It is essential to identify the physical, chemical, toxic and ecotoxic phenomena and processes that occur in connection with accidents involving dangerous goods (Thomson, 1999). Based on the combination of the empirical data analysis and an extensive literature study, the risk analysis (see Chapters 1-7 and Appendix 2, Vol. II) explores (i.e. adds to the body of knowledge) the hazardous properties of arsenic trioxide and magnesium phosphide and the processes (i.e. release, dispersion, concentration, modes of contact etc.) that occurred in connection with the m/v SCI accident.

From an economic perspective, this study may contribute to cost savings for both academics and practitioners concerned with the maritime transport system of PDG. As mentioned earlier in Chapter 1, Vol. I, risk studies are generally very time-consuming enterprises, and both labour and resource intensive. The costs are often quoted as a big barrier, especially as far as comprehensive analyses are concerned. For example, a detailed risk assessment in the chemical industry can cost up to $8 million (OECD, 2000). Considerable time is spent on the identification of the relevant data sources, data collection and analysis, organisation and presentation of the results. On the basis of the understanding gained in this and other research projects (see Mullai and Paulsson, 2002) and the experiences of some of the best practices in the world, the framework provides valuable specific information, principles and guidelines that will *make the risk study more effective and efficient*. The application of this framework may yield savings in time and money. This, in turn, may encourage the relevant authorities and organisations and scientific communities to conduct more systematic and comprehensive risk analyses on a regular basis with lesser efforts and amount of resources.

Dissemination of the detailed information generated in this study may prevent fatal events and injury (i.e. a practical contribution). Saving just one human life, including savings in costs arising due to fatality or injury compensations, would be a worthy contribution. In some developed countries the costs of a fatality, including medical costs, lost productivity capacity, human costs or value of a statistical life and other costs, vary between less than $ 1 to 3.7 million in the U.S. (Trawen et al., 2000) In the shipping industry the proposed value of GCAF (Gross Cost of Averting a Fatality) for injuries and ill health is $ 1.5 million (IMO, 2004c).

A better understanding of risks would also contribute to a better selection and implementation of the most effective and efficient risk management strategies and measures for the prevention and mitigation of marine environment pollution, emergency responses and salvage operations. Case histories have shown that mitigation and ship and/or dangerous cargo salvages are very specialised, time and labour intensive and expensive operations. Cargo and other properties, personnel injuries and pollution claims have been ranked, in that order, as the top risk categories by value, accounting for more than 80 % of the total claims paid by UK P&I Club in 1998 (P&I Club, 1998). The pollution claims represented only 5% of the total number of incidents, but accounted for approximately 20% of all the claims by value. Further, the results of this study showed that the costs of environmental damage, including cleanup, decontamination and other costs, accounted for more than a half (ca. 54 %) of the total costs incurred due to transport incidents reported to the HMIS database during the period 1993-2004, excluding human consequences. The consequences of dangerous goods incidents are very expensive. In particular, the pollution of the environment has become very expensive. Thus, a better understanding of how to prevent such incidents may result in cost savings for the practitioners concerned, including carriers, shippers and other parties.

The courses of events concerning chemical release, dispersion and concentration, modes or routes of contacts with chemicals and the dose-effect mechanism are explored in some details in this study, but not in other studies cited in both volumes. Understanding these events will enable the responsible authorities to respond effectively and efficiently in cases of incidents involving dangerous goods, which could save human lives and prevent or avoid extensive damage to the environment and property. Thus, in the case of the m/v SCI, by understanding the probable courses of events and the gravity of the situation, the U.S. responsible authorities avoided escalation of the events and their consequences by taking immediate and effective responsive actions. Furthermore, the catastrophic consequences of some of the world's worst marine accidents have largely been attributed to the lack of understanding of the courses of events involving dangerous goods and hazardous properties of dangerous goods.

The research contributions also include the efforts made to provide a better understanding and refine concepts in the research areas (i.e. theoretical contributions), as shown in Figure 7.2, namely: *maritime transport*, *risks of dangerous goods* and the *risk management system*.

***Enhance understanding in the field of maritime transport***: The theoretical model of the transport system (see Mullai, 2006a), which is used as a point of reference for defining and describing the maritime transport system of PDG, does not adequately represent the system. The model lacks certain important concepts (e.g. the regulatory system), and certain relationships are incomplete or incorrect. Chapter 3, Vol. I, and Mullai, 2006a provide a systematic and exhaustive definition and description of the system, which will enhance understanding of the maritime transport system of packaged goods and contribute to further improvements of the model. This part of the thesis will provide risk analysts with the information they need to understand the large number of diverse, often incompatible, definitions, concepts and classification systems. This may assist risk analysts in making better-informed decisions in the selection and usage of the relevant definitions, concepts and classification systems. This also applies to other constituent parts of the Frame of Reference (see Mullai, 2006a, 2006b).

***Enhance understanding in the field of dangerous goods risks***: The literature study showed that there is no general agreement on the concepts of risks. These concepts are defined and used in different ways. Based on the understanding gained in this study, attempts have been made to enhance understanding of the field. The essential constituent concepts in the field of dangerous goods risks are defined and described in a detailed and systematic manner (see Mullai, 2006a.

***The Risk Management System (RMS) model***: The literature study showed that numerous institutions or organisations share misconceptions concerning the essential concepts in the field. In Chapter 3, Vol. I, and Mullai, 2006b, based on the study of some of the world's best practices and frameworks in the field, efforts have been made to *provide a unified understanding of the field of the risk management system*. Figure 7.4 presents the key elements (phases, stages, steps and sub-steps) of the risk management system, which are defined and described in detail in Mullai, 2006b. As mentioned earlier, in combination with the risk analysis framework (see Figure 7.1), the RMS model will facilitate the risk assessment and management processes.

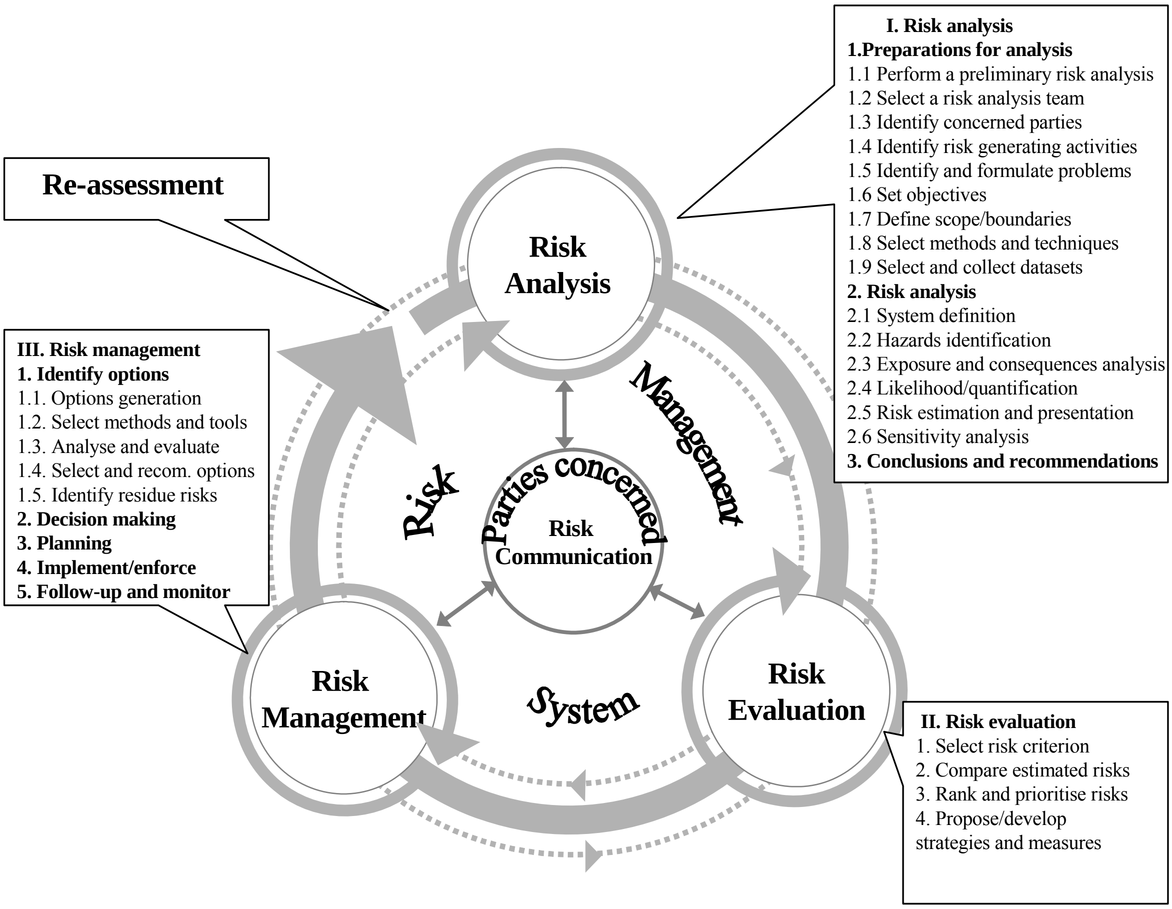


**Figure 7.4: Components of the Risk Management System (RMS) (from Chap. 3, Vol. I)**

### 7.2.2. Dissemination of the results of the study

#### Presentation

Some results of this study are presented in several meetings, including:

- Stockholm/Norrtälje (Sweden) workshop (May, 2006) organised by the Swedish Coast Guard and the DaGoB project office with all project partners.
- St. Petersburg (Russia) conference (December, 2006) organised by the Finnish Ministry of Transport, the Finnish Consulate in St. Petersburg and the DaGoB project office with all project partners and Russian representatives from the ministry of transport, port and other industries and authorities.
- Malmö (Sweden) conference (April, 2007) organised by the DaGoB project office and Lund University with all project partners and other participants, including the department of fire protection, Lund University, SSPA Swedish AB (Gothenburg, Sweden) and World Maritime University (Malmö, Sweden).

#### Distribution

Two publications (Mullai, 2006a and 2006b) are distributed to all participants in the Malmö conference (April, 2007). Both publications are also available in the website of the DaGoB project. As part of the WP (work package) four of this project, which concerns dissemination and transfer of research results including publications, the

DaGoB project office arranged (June, 2007) a dissemination seminar in Brussels in cooperation with the Finland European office.

## 7.3. Future research areas

Continuous improvement, refinement, invention and development of new and more advanced knowledge, methods, techniques or tools in all fields, including the maritime transport of dangerous goods, are important tasks in science. Many different factors that shape the needs for research works are implicitly and explicitly addressed in detail in Chapter 5, Vol. I. The following are some interrelated factors that affect future research:

- *System dynamics*: the maritime transport system of PDG is constantly changing.
- *System constituent elements*: the maritime transport system of PDG consists of a large number of different elements or subsystems in a very complex interrelationship. Certain properties of the system and risks are specific for specific countries or local conditions.
- *Interconnections with other systems*: the maritime transport system of PDG is an integrated element of the maritime transport system and maritime-related industries in general, the transport system and the chemical supply chain.
- *New and changing risks*: system changes and new technological developments may be associated with new and changing risks.
- *Data*: new types and larger amounts of data may become available.
- *Resources*: more resources may become available.
- *Methodology*: new and more advanced frameworks, techniques, tools or models may become available.
- *Concern*: increasing concern among the public and other interests.

One or combinations of the aforementioned factors may make the future researches in the field of risks of maritime transport of PDG relevant, important or necessary.

Risk management encompasses a wide range of activities. Risk analysis is a very important activity, whose principal objectives are to supply decision makers with information and tools. A generic objective may consist of a number of specific objectives (see Chapter 5, Vol. I). This study addressed risk methodology and issues. The future risk studies may address the same and other related aspects or issues, for example technical, operational, educational and training aspects. Volume II contains results from the analysis of data collected for the U.S. sources concerning risks and systems in the U.S. Other studies may deal with the same issues, but for the specific conditions of organisations, locations, countries or regions. Volumes I and II and Mullai, 2006a and 2006b provide detailed recommendations, which implicitly and explicitly suggest areas for future researches. The following may be two important future research areas:

***Designing a model for quantifying marine incident data***: The risk analysis process relies very heavily on the marine incident case histories. The review of many accident databases (see Chapters 1 and 3, Vol. I) indicates that the Hazardous Cargo Bulletin (HCB) database may be considered a good public data source, which, in combination with other sources, can be used as a data source for the risk analysis in the maritime transport of PDG. This database, which covers a period of two decades, contains some relevant categories of data concerning accidents involving maritime transport of PDG. The case histories are collected from some of the most well-known and reliable maritime information providers and maritime interests (e.g. the USCG, the NRC and Lloyd's List). The case histories are presented in a narrative format (see Appendix 3, Vol. I). Furthermore, the HMIS and NRC databases also contain a large number of different variables (approx. 180 and 230 respectively) representing system and risk elements. In order to quantify the incident data and thereby facilitate the risk analysis process as well as organise the analysis results in a better way, a model (a tool) is therefore needed.

***Performing a comprehensive risk analysis in maritime transport of PDG***. Risks of maritime transport of dangerous goods have become growing concerns. This has been partly due to the increasingly large amounts of many different types of dangerous goods carried by water through large populated areas. The literature study (see Chapter 1, Vol. I) has shown that many studies have largely focused on the risks of major marine accidents involving bulk dangerous cargoes such as oil, oil products, liquefied gases, and some chemicals. In this study, considerable efforts have been made to enhance understanding of risks of maritime transport of packaged dangerous goods as well as other systems and activities of the dangerous goods supply chain based largely on the U.S. data sources. However, it is important and relevant to perform thorough quantitative risk analyses in the field for specific organisations (e.g. large shipping lines involved in container traffic), locations, countries and regions. The risk analysis framework presented in this thesis can serve as a facilitating tool in the risk analysis process.

Detailed lists of future research questions and areas are provided in Mullai, 2006a and 2006b.

## 7.4. Some results and recommendations

The following are some results and recommendations:

- ***Improve the quality of data***: Risk analysis is hampered by the fact that the data that is intended to enable decision makers to make informed decisions is often inadequate. In many countries, reliable data on amounts and types of dangerous goods shipments and parties, including dangerous goods manufacturers, shippers, freight forwarders and carriers, are still lacking. The responsible authorities may not always receive reports on all types of dangerous goods accidents. In many cases, the reports received may be incomplete and inaccurate.

- ***Harmonize and integrate databases***: The review of a large number of databases showed that the degree of detail and the coverage of databases vary considerably. Dangerous goods accidents are recorded in many different organisational, national, regional or international databases. In order to share experiences and common issues, databases should be harmonized and integrated.

- ***Analyse thoroughly and make use of container/CTU inspection results***: In many countries, container/CTU inspection programmes are in place. Inspections records should be systematically analysed and the results should be used in a risk analysis. These results will assist risk analysts and the responsible authorities in identifying trends in maritime transport of PDG. Furthermore, they will allow the authorities to identify the shippers, carriers and others parties that have failed to comply with relevant regulations most frequently and seriously.

- ***Share risk-related data and research results***: Many risk-related datasets from different databases are confidential and cost money to acquire. In many countries, maritime administrations and rescue services maintain separate databases that may capture similar data, but they may not "talk" to each other. In order to gain better understanding and reduce risks, cooperation and an exchange of information about marine accidents among the authorities responsible in different countries, communities, industries and sectors should be enhanced. Case histories have shown that marine accidents involving dangerous goods affect many parties involved in maritime transport of PDG and beyond in many different ways. Human safety and health, and the protection of the marine environment and property are shared responsibilities of all parties concerned. Therefore, all parties concerned should also share risk-related data and research results. The benefits of free sharing and dissemination of data and research results will offset any short-term financial gain.

- ***Advanced technological solutions*** could be employed to capture and record the wide range of risk-related data in the field. For example, these may include technological solutions for collecting data on chemical/oil spills, transport/vessel traffic and dangerous goods traffic, climate/ weather conditions, the state of the environment and many more. In 2002, Mullai and Paulsson (2002) suggested the installation of fixed or movable devices for sensing the presence of chemicals and changes in the water content in the Öresund sea area (i.e. the sea area between Sweden and Denmark). These devices would enable detection of illegal or deliberate oils and chemicals discharges into the sea. In addition, such devices would deter illegal discharges as well as provide on-line assessment of the sea water content. The statistical incident data (NRC, 2005) show a large number (ca. 14%) of incidents reported are “unknown sheen and spills”, which may also include illegal or deliberate discharges. These types of devices are installed in the Neva River in St. Petersburg, Russia.[26]

[26] This is according to a Russian speaker, who described the system in a conference in St. Petersburg, Russian, in 2006, organised by the DaGoB Project office, Finish Ministry of Transport and Finish Consulate, in which the author of this thesis also participated. According to the speaker, the system is effective in preventing and mitigating oil and chemical spills.

- ***Record and compile other types of data than incident data***: Data generated from reporting and monitoring ships carrying dangerous goods, search and rescue operations, marine environment pollution response and monitoring operations in territorial waters and across national borders should be systematically collected and compiled in databases.

- ***Make decisions on the basis of risks and cost benefits***: Modern risk management should recognize the important role that rigorous and systematic risk analyses plays in risk-related decision-making, in particular decisions characterized by a high degree of uncertainty and requiring large amounts of resources as well as socially and politically sensitive decisions. Policy and legislative decisions should be primarily based on comprehensive technical risk analyses rather than on one single specific case. In principle, decision-making should be based on risk and cost-benefit analyses, and not on hazards (causes and contributing factors) or consequences alone. In order to prioritize the appropriate risk strategies and measures, the risks should first be technically analysed and estimated. A risk index could be used to rank hazards against risk elements. The risk strategies and measures affecting hazards with higher risk indexes are, in principle, most desirable - "large benefits for little efforts." However, "inexpensive" risk measures can be enacted regardless of the significance or the impact of variables. In addition, decisions should not be made on the estimated risks on the basis of one form of risk measurement only. In many situations, risks cannot be properly estimated and presented by using the consequence/ likelihood or consequence/ exposure estimation approach alone. Different risk estimations and presentations may provide different results.

- ***Employ advanced risk analysis methods***: The literature review has shown (see Chapters 2 and 4, Vol. I) that marine risks or accidents studies have often taken a simplistic view of the phenomena involved. Risks or accidents are largely analysed by means of simple analysis approaches – single case histories, qualitative analysis, a few variables, and summary statistics. Risk analysis should employ more advanced and complex data analysis methods, including multivariate quantitative analysis. Analysts should avoid overlooking some elements of the system and risks and unnecessarily scrutinising some others.

- ***Exercise due diligence in defining system and risk elements***: There is a lack of common agreement on the definition of many terms, for example marine accidents and incidents, consequences and causes. Given the number and diversity of datasets, definitions and concepts (see Chapter 3, Vol. I, and Mullai, 2006a, 2006b), analysts may run into the risk of committing errors that will affect the results of the risk study. "Minor" errors may even render the entire study unreliable and invalid.

- ***Improve the harmonization of relevant definitions and concepts***: The report showed (see Chapter 3, Vol. I, and Mullai, 2006a, 2006b) that terms, definitions and concepts (classification or coding systems) in the field are numerous and diverse and, to some extent, incompatible. Terms are sometimes misleading because risk concepts are interrelated, and different words are often used to describe the same thing. Choosing among terms may often be a matter of taste, not meaning. Ambiguous terminologies give rise to confusion and misunderstandings. Variation makes it difficult to understand and compare risks and the practices of risk management. Therefore, some definitions and concepts deserve better harmonization. Efforts should be made to build a more coherent and unified view of risks and the practices of the risk management system. However, perfect harmonization may not be expected, as some differences may not be resolved even in a long-term perspective. In many countries, data collection and compilation in databases are based on the established classification or codification systems. Any change in the current systems, regardless of how significant it might be, would require an enormous effort in order to adjust the earlier data records to the change in the system and to the data generated after the change. If no appropriate adjustments have been made, a change may render many years, or even decades, of recording data less useful, if not useless. In this study, many different systems of definitions and concepts have been explored and presented. In order to enhance the generalizability of the framework and avoid any misdirection, a particular system has generally neither been chosen nor suggested. This is left open, so that risk analysts can carefully select for themselves which system to use.

- ***Further improve marine accident reporting systems***: Reporting systems are vital in providing important information for risk analyses. Experiences from other industries and sectors, for example the aviation industry, show that systematic reporting and recording of incidents, including near misses, are very important for risk analysis and management.
  - Promote and design reporting and questioning systems, rather than blaming the culture.
  - Integrate local, regional and national incident reporting schemes.
  - Conduct periodic studies and reviews of accidents and incidents.
  - Integrate dangerous goods traffic and other risk-related data.

**Some specific recommendations for Sweden**:

- *Further improve the SMA database* contents and structure, as suggested below.
  - Collect and record data concerning the following variables:
    - Type and amount of cargoes/substances involved and/or carried on board at the time of accident.
    - Type and numbers of packages involved and/or carried on board at the time of accident.
    - Types of vessel traffic: for the Öresund area, for example, the following categories of vessel traffic are proposed: a) north-south bound; b) one or more Öresund port-south bound; c) one or more Öresund port-north bound; d) east-west bound.
    - Categories of the events subsequent to an initial event.
    - More descriptive information on marine accidents.
    - More data on the consequences of marine environment pollution.
    - Integration of container/CTU inspection results.

    - Better harmonization of the SMA classification systems with international organizations or authorities, for example the IMO, LRS and USCG systems.
    - Employ more advanced data analysis approaches, methods, frameworks or tools.
    - Create systems that integrate risk-related databases, data analysis and evaluation methods, risk studies or project results.
- *Develop the concept of national aggregated risks*: Integrate maritime risk-related data, data analysis results and evaluations with, for example, those of:
    - Risks of other modes of transport, such as road, rail, air.
    - Risks of different types of systems, activities and miscellaneous phenomena.
    - Types of risks, including technical, natural, human, environmental, property, businesses, social, internal/external etc.
    - Location: counties.
- *Develop compounded risk criteria* for an estimation, presentation and evaluation of national aggregated risks.
- *Develop the concept of regional aggregated risks*: Maritime risks and other types of risks do not recognise borders. It would be in the best interests of Sweden to promote and establish a common, regionally integrated system that would enable a collection of risk-related data, analyses and evaluations of regional maritime risks on a regular basis.

Recommendations for improving risk methodology and human safety and health and protection of the marine environment and property are provided in Chapter 7 and Appendix 3, Vol. II, and Mullai, 2006a, 2006b.

## 7.5. Final remarks

This study makes contributions to the scientific and practitioners communities. The main contribution consists of: a) the *development of a risk analysis framework* for application in maritime transport of PGD, including the risk management system (RMS) model; and b) on the basis of a comprehensive risk analysis, *enhancing understanding of the risks* of maritime transport of packaged dangerous goods and beyond, and providing recommendations for *improving human safety and health and protection of the marine environment and property*. The framework is both theoretically and empirically grounded. Because of the high level of abstraction of numerous constituent concepts, and the similarities and interconnections between, on the one hand, the maritime transport system of PDG and the risks associated with it and, on the other hand, other systems and risks, the framework has a wider field of application. The risk analysis framework will facilitate the risk analysis process in the maritime transport system of packaged dangerous goods and beyond. Its application will generate detailed, valid and reliable results that will assist concerned parties to further improve human safety and health and the protection of the marine environment and property. This research also contributes to enhancing understanding of the field and refining some important concepts in the main research areas, namely the maritime transport system, risks and the risk management system. Finally, the results of this research may serve as inspirations or the basis for future studies in several research areas.

# APPENDIXES

## Appendix 1: The list interviews, communication and documents

| Name | Position/organisation | Documents |
|---|---|---|
| Arne Lundberg | Port of Ystad, former mariner/captain | • Documents about the port |
| Börje Mark | Port of Trelleborg, port captain | • Documents about the port |
| Lennart Andersson | VTS Malmö, the head of department | • Vessel traffic statistics – Öresund/port of Malmö |
| Others | Port of Trelleborg: TT Line - personnel responsible for the carriage of dangerous good<br>Port of Ystad: custom personnel, personnel responsible for container/CTU inspections | • Container/CTU inspection report |
| Sölve Arvedson | Former mariner, Swedish Board of Investigation, rector of the World Maritime University (WMU) | • Numerous accidents case histories and accident investigation reports |
| Theodor Sampson | Former US Coast Guard personnel, professor at the World Maritime University (WMU) | |
| Björn Loonström | Swedish Coast Guard (SCG) Headquarters, Karlskrona | • Numerous accident case histories and accident investigation reports |
| Preben Jakonsen | Captain, Chief for Drogden VTS, Denmark | • Marine accidents/indents database – Drogden VTS, Denmark |
| José Anselmo | Coordinator of Waterborne Sector R&D, EC, Directorate Transport and Energy, Waterborne Transport R&D Programme | |
| Per Sefenson | Maritime Safety, EC, Directorate Transport and Energy, Waterborne Transport R&D Programme | • Summary of the “State-of-the-art” papers: databases, accident investigations in EU |
| Fernando Pardo | Captain, professor at the World Maritime University (WMU) | • Accident investigation/study report – m/v “Cason” case |
| Johan Horck | Former mariner, lector at the WMU | • Documents on cargo lashing and securing on ships<br>• Numerous other documents |
| Thomas Fagö | Räddningstjänstchef (Rescue Service Agency), Sweden | |

## Appendix 2: The list of some marine accident case histories involving PDG

| Nr. | Case | Sources |
|---|---|---|
| 1 | M/v "Ariadne" – August 24, 1985 | • IMO (International Maritime Organisation) (1986) Focus – Hazards of dangerous goods<br>• Heare S.F., Rohrer W., and Humphrey A.M. (1986) M/v "Ariadne" Incident. The Hazardous Material Spills Conference Proceedings, 1986<br>• SERI (Swedish Environment Research Institute) (1988) Hazard Assessment of Toxic Materials from a Shipwreck: The Case of the Ariadne in Mogadishu Harbour, Somalia.<br>• Nerland L. (1985) Mission Report on the "Ariadne" Incident. The International Maritime Organisation<br>• Looström B. (1997) Grounding of container ship loaded with chemicals, Swedish Coast Guard H.Q. |
| 2 | M/v "Burgenstein" – January 10, 1977 | • GWSD (German Waterways and Shipping Directorate) (1977) The m/v "Burgenstein" case 1977. The Waterways and Shipping Directorate North, Special Federal Unit for Maritime Pollution Control, Cuxhaven, Germany<br>• Looström B. (1991) The m/v "Burgenstein" Case, Abstract, Marine Chemical Accidents, Swedish Coast Guard H.Q. |
| 3 | M/v "Cason" – December 5, 1987 | • IMO (International Maritime Organisation) (1996) Focus – Hazards of dangerous goods<br>• IMO (International Maritime Organisation) (1987) The m/v "Cason" case: Experiences and findings in connection with the casualty involving the m/v "Cason"<br>• Pedro F. (1988) Report on analysis of a marine accident involving dangerous goods: the m/v "Cason" |
| 4 | M/v "Cavtat" and "Lady Rita" – July 14, 1974 | • Tosco G. (1978) The m/v "Cavtat" case. Inspettorato Centrale per la /Difensa, del Mare Ministro della Marina Merchantile Italy<br>• Tiravanti G. and Boari G. (1979) Potential Pollution of a Marine Environment by Lead Alkyls: The m/v "Cavtat" Incident, Environment Science & Technology Journal<br>• Tiravanti G., Rozzi A. and Dall'Aglio M. (1980) The m/v "Cavtat" Accident Evaluation of Alkyl Lead Pollution By Simulation and Analytical Studies. Pergamo Press Ltd. UK<br>• Looström B. (1979) The loss of m/v "Cavtat" and the salvage of its dangerous cargo, Maritime Chemical Accidents, Swedish Coast Guard H.Q. |
| 5 | M/v "Cita" – March 26, 1997 | • IMO (International Maritime Organisation) (1997) Casualty Analysis Database. The Sub-Committee on Flag State Implementation<br>• MARS (Major Accident Reporting System) Database (1997), MAIB Official Report |

| Nr. | Case | Sources |
|---|---|---|
| | | • DETR (Department of the Environment, Transport and the Regions, UK) Publications Sale Centre, Unit 21 Goldthorpe Industrial Estate, Goldthorpe, UK |
| 6 | M/v "Dana Optima" - January 13, 1984 | • IMO (International Maritime Organisation) (1984) Loss and salvage of drums containing dinoseb. Report submitted by Denmark, Maritime Environment Protection Committee, MEPC 21/INF 2 |
| 7 | M/v "Dutch Navigator" – April 27, 2001 | • HWNA (Hazard World News Archive) (2001) UK chemical strike team musters for Avonmouth container incident, June 2001, http://www.existec.com, 2001 |
| 8 | M/v "Grand Camp" - April 16 and 17, 1947 | • Pandanell M. (2002) Texas (USA) City Fire Department, the Texas City Disaster, http://www.local1259iaff.org, 2002 |
| 9 | M/v "Grim" - October 4, 1997 | • MARS (Major Accident Reporting System) Database (1997) Groundings in Finland. Report of the Finnish Government |
| 10 | M/v "Hamburg Star" | • Dickey A. (1997) Alert after vessel loses containers. Lloyd's of London Press. Ltd., UK |
| 11 | M/v "Heng Shan" – August, 2001 | • HWNA (Hazard World News Archive) (2001), Cargo ship fire in Manzanillo, Mexico, October, 2001, http://www.existec.com, 2001 |
| 12 | M/v "Herald of Free Enterprise (HFE)" – March, 1987 | • Lovinski Ch.N. (1997) "Herald of Free Enterprise" Incident. Hazardous Cargo Bulletin, July 1997, pp. 19<br>• Ford T. and Lord R. (2001) Better alarm management, Loss Prevention Bulletin; Vol. 162, No. 1 |
| 13 | M/v "Jala Padmu" - 1944 | • Looström B. (1991) Explosion in Bombay, India, 1944, Abstract, Maritime Chemical Accidents, Swedish Coast Guard H.Q. |
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## Appendix 3: Hazardous Cargo Bulletin (HCB) Incident Log

The HCB Incident Log provides reports on incidents involving dangerous goods in the following systems: a) road, rail, air transports; b) marine/inlandwaters transport; c) miscellaneous, e.g. chemical plants, warehouses, oil fields, oil depots, pipelines etc. The Incident Log for the marine/inlandwater incidents contains the following categories of data/ variables: time (date, month and year), location (country, port and others), the name of the vessel, substance, details of the incident and the source (see table below – extraction from 2004).

| Date | Location | Vessel | Substance | Details | Source |
|---|---|---|---|---|---|
| 01-01-2004 | Walton County, Florida, USA | Jeanie | Diesel oil, gasoline | Tug pushing two s/h barges to Murphy Oil terminal in Freeport ran aground out of the channel; both barges grounded, ruptured, spilling 20,000 bbl (3180 cubic metre) diesels, 20,000 bbl gasoline. | NRC |
| 01-01-2004 | Porto Torres, Sardinia, Italy | Panam Serena | Benzene | Explosion during discharging of benzene cargo from chemical tanker (10,050 dwt, built 2003); vessel destroyed, fire spread to shore side facilities; two crew killed. | Bloom-berg |
| 08-01-2004 | Hayannis Harbor, Massachu-setts, USA | Katama | Propane | Road tanker with 10,000 gal/38 cubic metre propane overturned on ferry from Hyannis to Nantucket in rough seas; ferry returned to Hyannis for assistance; no leakage reported. | DNT |
| 12-01-2004 | Durban, South Africa | Un-known | Bunker oil | Spill of some 20,000 litres marine fuel oil from disused bunkering point in Durban marine; spill mostly contained within marina and 15,000 litres recovered. | Lloyd's List |
| 15-01-2004 | Columbia River, Oregon, US | Other | Trans-former oil/ PCBs | At least 1300 gallons transformer oil tainted with PCBs leaked from US Army Corps of Engineers facility at Dalles Dam after cooling pipe fractured in cold weather. | Seattle Times |
| 16-01-2004 | Bohai Gulf, China | Li Da Zhou no 18 | Diesel oil | Tanker (2,000 dwt) with 1,000t diesel cargo caught fire 112 km south-west of Yingkou; crew took to lifeboats but three | Fairplay |

| Date | Location | Vessel | Substance | Details | Source |
|---|---|---|---|---|---|
| | | | | died of exposure; fire extinguished by response tug. | |
| 18-01-2004 | La Voute/ River Rhone, France | Barges | Benzene | Two barges, one with 2,300 cubic metre benzene, hit pilings of railway bridge over river Rhone; cargo lightered; tugs used to prevent excess pressure on bridge; one crew lost. | Hint |
| 21-01-2004 | Kelly Point, Oregon, US | CF Starlight | Marine fuel oil | Tank barge (2,700 grt, built 1982), with 700 cubic metre marine fuel oil, grounded in Columbia River; vessel boomed while cargo was transferred; no pollution reported. | Lloyd's List |
| 23-01-2004 | Hallaniyat Island, Oman | Metin KA | Ethanol | Chemical tanker (5,500 dwt, built 1974) with 4,500 t cargo ethanol from Karachi for Turkey, grounded in shallow waters after navigation error; no spill; ship lacked correct charts. | Lloyd's List |
| 28-01-2004 | Kavkaz, Russia | Un-known | Crude oil | One ton of oil (crude) spilt to Kerch Strait between Azov and Black Seas during of tanker at Solvalub terminal; vessel not boomed and skimmer immediately available. | Fairplay |
| 31-01-2004 | Kimbe, Papua NG | Antares | Palm oil cargo and heavy fuel oil bunker | Chemical tanker (29,500 dwt, built 1984) spilt 60 t heavy fuel oil bunkers during loading of palm oil cargo; spill due to operational error as fuel was transferred between tankers. | Lloyd's List |
| 02-02-2004 | La Reunion, Australia | MSC Vietnam | Nitric acid | Nitric acid leaked from drums aboard containership unloading boxes at eastern port enroute Australia to Saudi Arabia; captain requested permission to offload leaking box. | Hint |
| 03-02-2004 | Wicomico River, Maryland, US | VB33 | Gasoline | Barge with 26,000 bbl (4,100 cubic metre) gasoline grounded while at anchorage at Shark Fin Shoal after ice floe caused anchor to drag; barge refloated without spill on rising tide. | NRC |

| Date | Location | Vessel | Substance | Details | Source |
|---|---|---|---|---|---|
| 04-02-2004 | Newark, New York, US | KTC90 | No 6 fuel oil | Crack found in hull of barge by inspectors at BP Marine; barge had 77,000 bbl (12,250 cubic metre), no 6 fuel oil already loaded; crack above both waterline and cargo line; no spill reported. | NRC |
| 07-02-2004 | Milford Sound, New Zealand | Milford Monarch | Diesel oil | Up to 14,000 litres diesel spilt from passenger vessel; spill mostly contained in basin but some reached sound; vessel's operator suspected sabotage after water hose found in tank. | NZCity |

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