ADVANCED RISK MANAGEMENT IN OFFSHORE TERMINALS AND MARINE PORTS

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ABSTRACT

This research aims to propose a Risk Management (RM) framework and develop a generic risk-based model for dealing with potential hazards and risk factors associated with offshore terminals' and marine ports' operations and management. Hazard identification was conducted through an appropriate literature review of major risk factors of these logistic infrastructures. As a result in the first phase of this research a Fuzzy Analytical Hierarchal Process (FAHP) method was used for determining the relative weights of the risk factors identified via the literature review. This has led to the development of a generic risk-based model which can help related industrial professionals and risk managers assess the risk factors and develop appropriate strategies to take preventive/corrective actions for mitigation purposes, with a view of maintaining efficient offshore terminals' and marine ports' operations and management. In the second phase of the research the developed risk-based model incorporating Fuzzy Set Theory (FST), an Evidential Reasoning (ER) approach and the IDS software were used to evaluate the risk levels of different ports in real situations using a case study. The IDS software based on an ER approach was used to aggregate the previously determined relative weights of the risk factors with the new evaluation results of risk levels for the real ports. The third phase of the research made use of the Cause and Consequence Analysis (CCA) including the Fault Tree Analysis (FTA) and Event Tree Analysis (ETA) under a fuzzy environment, to analyse in detail the most significant risk factors determined from the first phase of the research, using appropriate case-studies. In the fourth phase of the research an individual RM strategy was tailored and implemented on the most significant risk factor identified previously. In the last phase of the research and in order to complete the RM cycle, the best mitigation strategies were introduced and evaluated in the form of ideal solutions for mitigating the identified risk factors. All methods used in this research have quantitative and qualitative nature. Expert judgements carried out for gathering the required information accounted for the majority of data collected. The proposed RM framework can be a useful method for managers and auditors when conducting their RM programmes in the offshore and marine industries. The novelty of this research can help the Quality, Health, Safety, Environment and Security (QHSES) managers, insurers and risk managers in the offshore and marine industries investigate the potential hazards more appropriately if there is uncertainty of data sources. In this research with considering strategic management approaches to RM development the proposed RM framework and risk-based model contribute to knowledge by developing and evaluating an effective methodology for future use of the RM professionals.

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ABBREVIATIONS

ABS	American Bureau of Shipping
ADB	Asian Development Bank
AHP	Analytical Hierarchy Process
AIRMIC	Association of Insurance and Risk Managers
ALARM	National Forum for Risk Management in the Public Sector
ALARP	As Low As Reasonably Practicable
BC	Before Christ
BSc	Bachelor of Science
CALM	Catenary Anchor Leg Mooring
CBA	Cost Benefit Analyses
CCA	Cause Consequence Analysis
CCTV	Closed Circuit TV
CIS	Commonwealth of Independent States
CSI	Container Security Initiative
C-TPAT	Customs-Trade Partnership Against Terrorism
CW	Chemical Weapon
DETR	Department of the Environment, Transport and the Regions
DfT	Department for Transport
DG	Dangerous Goods
DNV	Det Norske Veritas
D-S	Dempster-Shafer
ER	Evidential Reasoning
ETA	Event Tree Analysis
EUC	European Union Commission
FAHP	Fuzzy Analytical Hierarchy Process
FBR	Faulty Behaviour Risk
FCCA	Fuzzy Cause and Consequence Analysis
FEAHP	Fuzzy Extended Analytical Hierarchy Process
FETA	Fuzzy Event Tree Analysis
FFP	Fuzzy Failure Probability
FFTA	Fuzzy Fault Tree Analysis
FMADM	Fuzzy Multi-Attribute criteria Decision-Making
FMEA	Failure Mode and Effect Analysis
FNIS	Fuzzy Negative Ideal Solution
FPIS	Fuzzy Positive Ideal Solution
FPS	Fuzzy Possibility Scores

FPSO	Floating, Production, Storage and Offloading units
FSA	Formal Safety Assessment
FST	Fuzzy Set Theory
FSU	Floating Storage Unit
FTA	Fault Tree Analysis
FTOPSIS	Fuzzy Technique for Order Performance by Similarity to Ideal Solutions
GAO	United States Government Accountability Office
GDP	Gross Domestic product
HAZID	HAZard IDentification
HAZOP	HAZard and OPerability
HRA	Human Reliability Analysis
HSE	Health and Safety Executive
HSE-MS	Health, Safety and Environment Management System
IAHP	International Association of Harbours Pilots
IDS	Intelligence Decision System
ILO	International Labour Organisation
IMO	International Maritime Organisation
IRM	Institute of Risk Management
ISMS	Integrated Safety Management System
ISO	The International Organisation for Standardisation
ISPS	International Ship and Port facility Security Code
IT	Information Technology
KPI	Key Performance Indicator
LNG	Liquid Natural Gas
LPG	Liquid Petroleum Gas
MADA	Multi-Attribute Decision-Analysis
MADM	Multi-Attribute Decision-Making
MSc	Master of Science
OHSE	Offshore Health and Safety Executive
PFSO	Port Facility Security Officer
PHA	Preliminary Hazard Analysis
PMSC	Port Marine Safety Code
PRM	Port Risk Manager
PSPOT	Petrochemical Sea Ports and Offshore Terminals
P&I	Protection and Indemnity
QRA	Qualitative Risk Analysis/Assessment
RM	Risk Management
Ro-Ro	Roll on Roll off cargoes
SOLAS	Safety of Life at Sea
SRD	Safety and Reliability Directorate
SRFT	Security Risk Factor Table

SRM	Security Risk Management
STA	Security Threat Analysis
SVA	Security Vulnerability Analysis
TFN	Triangular Fuzzy Numbers
TLP	Tension Leg Platform
TOPSIS	Technique for Order Performance by Similarity to Ideal Solution
UNCTAD	United Nations Conference on Trade and Development
USCG	United State Coast Guard
VTMS	Vessel Traffic Management System
VTS	Vessel Traffic Service

CHAPTER 1: INTRODUCTION

1.1. AN OVERVIEW OF THE RISK MANAGEMENT

The principle of Risk Management (RM) may be traced to 2250 BC when the Babylonians established a principle called Bottomry as a method of handling the risks associated with international trade (Trenerry, 1926). One of the earliest records of RM is the marine insurance arrangements that were drawn up by Phoenician traders more than 3000 years ago (Brown, 1998). Indeed both individuals and firms have been informally dealing with risk for thousands of years. Yet, regardless of the occurrence of risk in society, academic interest in the area of RM has only begun quite recently. In fact the "birth" of the discipline can largely be traced back to only the late 1950s and early 1960s, since it was not until this time that a formal definition of "corporate RM" was developed or indeed widely accepted (Snider, 1991; Williams *et al,* 1995).

In earlier definitions the main purpose of the RM was its insurance buying function in order to avoid the "pure risk" e.g. piracy, theft, storms etc. Pure risk exists when there is uncertainty as to whether loss will occur. No possibility of gain is presented by pure risk – only the potential for loss. Other examples of pure risk include the uncertainty of damage to property by fire, flood or the probability of premature death caused by accident or illness (Trieschmann *et al,* 2001). Furthermore, pure risks were typically seen as being non-business risks in that they were more an unfortunate by-product of a firm's manufacture of goods and services rather than an integral part of the production process (Carter and Crockford, 1974; Mehr and Hedges, 1974). In contrast to pure risk, "speculative risk" exists when there is uncertainty about an event that could produce either a profit or loss. Business ventures and investment decisions are examples of situations involving speculative risk (Trieschmann *et al,* 2001). In other words it is mostly involved with business related risks and decision making processes.

However, during the end of 20th century and at the beginning of the 21th century research into corporate RM started to move along away from emphasising the importance of the insurance buying and pure risk avoidance. There are new emergent reviews of the development in both practical interest and academic research into the field of RM which have been carried out by the era researchers. However they have introduced two key insights to facilitate the RM development. The first one is the achievement of integrated RM as "when RM is integrated (or embedded) into all of the functions and processes within the organisation" (AIRMIC, 1999). This addresses not just insurable pure risks but also all other types of related risks (i.e. speculative risks) that a firm, corporation or organisation can face e.g. country risks, business risks, organisational risks, operational risks, etc. The second one is "taking a strategic management approach to RM development" (Johnson and Scholes, 2002; CFO research Service, 2002). In this respect Williams *et al,* (1995) define RM as: "a general function that seeks to identify, assess, and address the causes and effects of uncertainty and risk on an organisation". They then go on to say that "the purpose of RM is to enable an organisation to progress toward its goals and objectives in the most direct, efficient, and effective path".

Eventually as per AIRMIC, ALARM and IRM (2002) RM "is a central part of any organisation's strategic management. It is the process whereby organisations methodically address the risks attaching to their activities with the goal of achieving sustained benefit within each activity and across the portfolio of all activities. The focus of good RM is the estimation and treatment of these risks". They explain RM should be a nonstop and developing practice which runs all through the organisation's strategy and the implementation of that strategy. It should address systematically all the risks surrounding the organisation's activities at earlier periods, in present and particularly in the future. Moreover, RM must be integrated into the culture of the organisation with an effective policy and a programme led by the most senior management. As per IRM (2002) "RM must translate the strategy into tactical and operational objectives, assigning responsibility throughout the organisation with each manager and employee responsible for the management of risk as part of their job description. It supports accountability, performance measurement and reward, thus promoting operational efficiency at all levels".

1.2. RESEARCH BACKGROUND

1.2.1. Earlier concepts

As Bureau of Transport Economics (2000) explains infrastructures (i.e. marine ports and terminals) are essential elements for the operation of every country's economy that can affect their cost structures, industry competitiveness and living standards. They then express the fact that still the importance of marine ports does not tend to be acknowledged by general public. Following the aforementioned statement, Helmick (2001) explains that the general public in USA are unappreciative of the key role of marine ports and terminals as conduits enabling products to be available for their consumption. In addition Young (2001) discusses that "sea ports affect almost everything that people come into contact with on a daily basis, yet marine ports do not have the same recognition with the general public as airports".

While the general public and government in many countries are in fact unaware of the economic contribution and the regional impact of their ports and terminals, as is discussed previously by Helmick (2001) and Young (2001), research and the subsequent improvements in four related areas (operational, organisational, economical and business) of sea ports and marine terminals have been occurring for many years. Although in respect of the mentioned areas many efforts have been carried out by different researchers over the recent years, leading international organisations and bodies such as United Nations Conferences on Trade and Development (UNCTAD), World Bank, European Commissions and Asian Development Bank which are the main places where there have been strong tendencies to carry out research concerning marine ports and terminals for many years.

In respect of the operational improvements perspectives of the marine ports and terminals UNCTAD (1976), World Bank (2001) and Marlo and Casaca (2003) express that performance indicators are important factors in determining the efficiency of the sea ports and marine terminals. For the purpose of the safety and pollution prevention improvements of ports in 1993, UK Marine Safety Agency (MSA) proposed to the International Maritime Organization (IMO) that Formal Safety Assessment (FSA) could be applied to ensure a strategic oversight of safety and pollution prevention (Trbojevic and Carr, 2000). In another attempt UNCTAD (2006) discusses factors which influence the improvement of the security related issues within marine ports. In respect of the port safety and container revolution Fabiano *et al,* (2009) explain the factors that can affect occupational accident frequency in ports and terminals. Regarding offshore terminals the UK Health and Safety Executive (HSE) has focused comprehensively on health, safety and environmental related matters particularly from the time when the Piper Alpha disaster took place in 1988.

Relating to the organisational improvements perspectives, for ports and terminals Thomas (2001) for example, has researched organisational and institutional relationships within container terminals and others have examined the port privatisation, ports operational/management structure and the industrial relationships with employees, including stevedores (UNCTAD, 1996; World Bank, 2001). As sea ports become more concerned with performing a linking role in the international trade and transportation chain, research emerging on how this relationship should be managed and facilitated by new information technologies has been conducted (Lee *et al,* 2000). Frankel (2001) for instance, in reviewing technological opportunities for container terminals, explains how new technology enables sea ports to integrate cargo transfer into individual customer logistical requirements.

In respect of the economic (macro and micro) related issues and perspectives for ports and terminals, UNCTAD (1996) and World Bank (2001) have examined the macro-economic purposes and contributions of the ports and terminals, their value for the trade, and how competitiveness among ports and terminals can impact the economies of the different countries. For example Goss (1990a) explains how having efficient sea ports can raise the gross domestic product of a nation. On the other hand at the micro-economical level, Palmer (1999) concentrates on the efficiency of the port facilities and operations in order to improve their competitive positioning. In respect of port productivity and efficiency which will influence and improve the competitiveness of the ports and terminals, others such as World Bank (2001), Wang *et al* (2007) and Huang *et al* (2008) have carried out different investigations.

With reference to the business related perspectives of the ports and terminals, Malchow and Kanafani (2001) have discussed the factors that influence marine port selection by shipping lines and other customers by applying a generic multinational model. Other business related studies about marine ports and terminals include reviews of the development of sea ports via case studies, with respect to the individual port and terminal bases, as well as regional and national levels (e.g. UNCTAD, 1985; Xiaobin and Sum, 1995; Mak and Tai, 2001; Beresford, 2004)

In the past, the above areas of the research may have been sufficient, but now, dynamic and enforced changes occur in marine ports' and offshore terminals' economical, business, operational and organisational related environments. The prompt is refocusing on the marine ports and offshore terminals studies, in order to include the recently emergent RM-related issues taking into consideration both externally and internally driven elements e.g. pure and speculative risks. This view has been steadily increasing and evidenced, for example, in the changes to the UNCTAD from 1996 to 2006. UNCTAD (2006) is used to describe the initial development of a security risk assessment and management framework which is capable of reflecting the logistics scope of transport networks. But before 2006 the focus was mostly on the development, management, commercial, operational and organisational issues of the ports and terminals. Another example is GAO's case which recently has focused on the ports' RM topic. GAO (2006) has stressed "further refinements needed to assess risks and prioritise protective measures at marine ports and other critical infrastructures". In UK also, DETR (2000) has required all marine ports to perform risk assessment of their marine operations in order to put into practice the safety management system.

1.2.2. Recent researches and their contribution to RM

Currently RM related studies such as ISPS Code (2003) represent a very small proportion of the investigations corresponding to the offshore terminals' and marine ports' operations and management issues. Issues contained within the four major areas mentioned in the previous section still tend to dominate the offshore terminals and marine ports research as is evident in the most major maritime related academic journals such as Journals of: Marine Science and Technology, Offshore Engineering, Offshore Technology, Marine Policy, Maritime Policy and Management, Maritime Economic, Maritime Economic and Logistics, Marine pollution Bulletin, Transport Management, Transportation Research, Research in Transportation Economics and Environmental Impact Assessment Review. Moreover they can be evident in many non-maritime related academic journals such as Journal of: Hazardous Materials, Economics and Business, Production Economics, Operational Research, World Development, Cleaner Production, Commerce on Line, Productivity Analysis, Industrial Economics, Computers, Industrial Engineering, Fuzzy Sets and Systems, Expert Systems with Applications, Applied Soft Computing, Reliability Engineering and System Safety and International Journal of Business Continuity and Risk Management. UNCTAD, EUC, World Bank, ADB, HSE, DNV, ABS etc also conduct research on the same mentioned backgrounds.

Currently ports' and terminals' RM related studies are evident only in a few journals such as Journal of Hazardous Materials. Trbojevic and Carr (2000) show an established risk based methodology which can be used for safety improvements in marine ports. Tsai and Su (2005) in the Journal of Marine Policy have explained about a new risk assessment method used for assessing five East Asian ports situated in different countries. In another attempt, and in Journal of Maritime Policy and Management, Banomyong (2005) explains about the impact of port and trade security initiatives on maritime supply chain management.

In respect of nations and governments for the purpose of the RM-related subjects, countries such as USA, UK, Canada, Norway, Australia and New Zealand are pioneers in RM issues by developing their own specific RM guidelines and standards. Most of the produced RM standards by these governments are used in areas such as: Norwegian Petroleum Directorate, US Offshore Oil Production Industry, US Coast Guard, US Nuclear Regulatory Commission, US Department of Defence, US Department of Energy, US GAO, UK HSE, UK Ministry of Defence, UK DfT (i.e. DETR superseded by Department for Transport in 2002), UK Marine Coastguard Agency and International Maritime Organization (IMO) in London (ABS, 2003 and HSE, 2010).

However in respect of the offshore terminals and marine ports RM-related topics except the work reported in the journals mentioned earlier, appears to have been little interest until recently. As the DETR (2000), World Bank (2001), UNCTAD (2006), GAO (2007) and, HSE (2010) claim, there exist risks in ports and terminals, all of which require attention in respect of their hazards identification, assessment and management if they are going to remain responsive to the strategic needs and future challenges.

In this regard recently GAO (2007) regarding managing risks in ports explains that US ports and waterways handle more than 2 billion tons of domestic and import/export cargo annually, and more than 95 percent of US international trade moves by water. As such, ports are a global gateway to world markets and significant engines in the US economy. However, as significant as they are, almost every main US port faces one or more types of natural catastrophe with potentially devastating effects. Ports located in the Eastern seaboard and the Gulf Coast encounter the prospect of hurricanes, and ports on the West Coast are in locations that are extremely vulnerable to earthquakes. Losing a main port, even for a short duration e.g. a number of weeks, could have a national economic impact, making successful improvement a worry not only for the local area but also for the central government. Therefore it is important to have disaster planning and recovery programme in ports and ultimately to conduct the RM for ports.

Similar sentiments are expressed by UNCTAD (2006) in respect of the 11th September attack on the US in 2001 as well as about International Ship and Port facility Security (ISPS) Code which came into force in 2004 by the IMO. In their conclusions they introduced an "initial security risk assessment and management framework capable of reflecting the logistics scope of the transport networks. The document also reviewed existing approaches to measuring transport security compliance costs and funding schemes adopted by industry and governments in order to finance the costs of security regulations".

The World Bank in 2001 presented an analytical framework for assessing the risks confronting port operators and with the goal of identifying principles for the equitable sharing of each risk between the public and private sector parties involved.

Moreover in the UK as a consequence of the Sea Empress disaster in Milford Haven in 1996, the Port Marine Safety Code (PMSC) was introduced in the UK in March 2000, necessitating all ports to perform risk assessment of marine operations in order to execute the safety management system (DETR, 2000). Following this regulatory requirement in the US, UK and New Zealand many ports in the same year carried out the risk assessment processes in order to meet the PMSC's requirement.

In the offshore industry, safety and risk-based subjects mainly relate to the legislation and safety acts principally in response to disasters involving significant loss of life. These can include the destruction of a fixed offshore gas production platform (e.g. Piper Alpha installation in the UK waters in 1988) or the destruction of an offshore oil and gas production terminal (e.g. Bombay High North Platform in 2005). Mather (2004) stated that the Piper Alpha incident has caused a fundamental change in the way the industry was both certified and regulated. Regulatory bodies and legislators such as HSE and Department for Transport (DfT) in UK require all offshore companies (operators, contractors etc) involved in offshore operations, logistics and engineering must carry out and have valid documents called Safety/HSE Cases and Reports prior to starting any task. This demonstrates that a comprehensive Quantitative Risk Assessment (QRA) methodology involving use of different techniques has been utilised prior to carrying out any offshore activities. The mentioned document confirms that all the potential hazards for the intended operations are identified, assessed and mitigation measures along with an appropriate emergency response plan in place for immediate use and/or formal investigations. These documents must be approved by legislators before any operation starts and finally they can be used as evidence or will be checked in court as a testimony in a court case. They will be used in courts to prove and show that an ultimate safety related due diligence has been exercised for the intended operations in order to protect operators' or contactors' liabilities against potential raised claims.

In another case, ports and terminals have received exceptional attention by GAO's report in 2006 as marine ports are broadly viewed as indicating attractive terrorist targets, in part because of their importance to the economy. As GAO expressed more than 95 percent of US's overseas trade (and 100 percent of certain products, such as foreign oil) is transported in vessels. The estimated economic effects of a successful attack and resulting shutdown of this system could cost billions of dollars. Ports in addition symbolize attractive targets since they contain countless vulnerability. In total, the US's 300 plus ports have more than 3,700 cargo and passenger terminals. Chemical factories, oil refineries, power plants, and other facilities are often located in port areas and add another set of possible targets. Roads cross many ports, allowing access by land as well as by water, and the number of people working in or travelling through ports is significant.

Nevertheless it seems that there are some moves by governments and international bodies towards RM for managing mostly the pure risks that offshore terminals and marine ports may encounter. Presently for the purpose of dealing with speculative risks (i.e. business related ones) arguments and efforts are generally rare.

By viewing the above facts and arguments the discipline of RM (especially those relating to speculative and business related risks) is still developing.

1.3. JUSTIFICATION FOR THE RESEARCH

As mentioned in the previous section, there have been some moves toward RM to avoid the pure risks but at the moment the moves toward managing the speculative risks are very slow (i.e. risks which are linked directly to the business function and decision making processes within the offshore terminals and marine ports). This trend reveals the fact that in the offshore and port industry there is a lack of a coherent framework with which to understand the RM decisions in offshore terminals and marine ports especially for the purpose of their operations and management.

On the other hand, the problem facing port RM professionals is a lack of research upon which to base their activities, a general lack of a model that approximates the RM realities of the field and confusion over terminology, approaches and methods in the discipline. There is a distinct need for some form of a generic model which can highlight the issues facing RM professionals such as risk managers, emergency managers, QHSES managers, Human Resource (HR) managers, production managers, site control managers, Safety officers, port facility security officers, port state control officers etc.

Adesola and Baines (2005) state that business environments are complex. Logistics related activities (e.g. offshore terminals and ports' operations) are undergoing swift and major changes motivated by such pressures as customer expectations, new technologies, and increasing global rivalry. As a result, many business processes within firms which are mainly logistics providers are dynamic and constantly changing. In order to carry on in such environments, logistics practitioners are forced to frequently modify and improve their business processes to react quickly to changes.

Figure 1.1 depicts major pressures that are being exerted on offshore terminals and marine ports (Ward, 2005). Uncertainty, for example, may be caused by complexity in marine transport business along with its regulatory regimes, rapid change of technologies, increasing and changing demand of customers, increasing pressures from other competitors (neighbouring ports and terminals), and scarcity of resources (e.g. financial incentives for port development and cheap labour etc). The uncertain environment may contribute to bad experiences and increasing demands for better performance. It is shown in Figure 1.1 that much of the pressure for RM in sea ports and offshore terminals originates from bad experiences: heavy commercial losses, major accidents, terrorist attacks, natural disasters, and so on. Bad experiences are also a key driver of developments in the marine related regulatory environment (i.e. port/harbour or offshore authority regulations, health and safety legislations etc). Eventually these developments can lead to increased demand for insurance. Bad experiences also can stimulate demand for insurance and reduce the profitability of insurers. Together, these factors encourage ports' and terminals' managers as well as insurers to become more proactive in enhancing their own RM practices ultimately leading to the development of the best RM practices.

Figure 1.1: Pressures toward RM in offshore terminals and marine ports
Source: Modified from Ward (2005)

In fact in both theoretical and empirical research on offshore terminals' and marine ports' RM is only beginning to emerge and the important contribution of RM on these facilities appears yet to be appreciated.

Therefore, at the substantive level, there exists a gap in knowledge about the usage of RM during the offshore terminals' and marine ports' operations and management. Similarly, at the academic level there is a need for more practical research to find out the justification for existence of the RM and different methods for its (i.e. RM) proper implementation on these logistics infrastructures particularly with due regard to the potential requirements in the near future.

1.4. RESEARCH QUESTIONS

In order to ensure that the research objectives are met and for the purpose of providing a base for activities in this research, the following questions have been generated:

- What are the hazards or sources of risks and uncertainties associated with offshore terminals and marine ports and how can they be identified?

  Based on the definition of the hazard (i.e. anything to cause harm to people, the environment, property, plant, products, reputation etc.) there are different types and categories of hazards or risk factors that can put any offshore terminal and/or marine port in danger. Furthermore while there are different methods and techniques for hazard identification there are a number of common features of importance.

- How can the identified hazards or risk factors be prioritised and ranked?

The prioritisation of hazards or risk factors is fundamental to analysis of them. There are a number of ways in which this can be done and these will vary depending upon the risk factors under consideration and the particular methodology being employed.

- What are the most appropriate and useful tools for evaluating the risk factors in real situations (e.g. port-to-port comparisons) and how can they be used?

  For application of any specific risk-based model (identified and ranked risk factors) on offshore terminals or marine ports (e.g. for the purpose of their audit, port-to-port or offshore terminal-to-offshore terminal risk evaluation etc due to the characteristics of RM) there will be a need of using human judgements and to use knowledge based decision support systems. Previously, the risk evaluations were all based on the knowledge of managers. Now there are numerous techniques and software tools for decision support systems that can be used in this regard.

- What are the most appropriate and useful tools to analyse the causes and consequences of the most significant identified risk factors and how can they be used?

  There is a need to carry out cause and consequence analysis on any individual risk factor. It must be investigated for potential causes. The investigation should not be limited only to identify the causes already known. The investigation must be carried out for potential causes which may lead to loss in future but has not happened yet. Additionally it must be ensured that all the effects are identified, taking into consideration the ones which have previously occurred. Therefore careful analysis is needed to ensure that all the known/unknown causes and effects for each individual risk factor are high-lighted. There are different tools and techniques to do this.

- Individually for any of the most significant risk factors, how can a separate RM methodology and strategy be mapped and implemented?

  Different RM methodologies and approaches can be implemented on any organization such as offshore terminals and marine ports. On a detailed level the same is applicable on any individual risk factor. This is possible provided that the identified risk factor is properly investigated by a competent person or authority and furthermore an appropriate RM strategy and methodology is mapped and implemented on the individual risk factor in question.

- How can the identified hazards or risk factors be mitigated and controlled?

  After risk factors were identified and assessed in order to complete the RM cycle it is appropriate by using a proper decision making tool or technique to select the best available strategies in order to manage and control the hazards.

1.5. RESEARCH AIM AND OBJECTIVES

1.5.1. Research aim

This research aims to propose a RM framework and develop a generic risk-based model for dealing with potential hazards and risk factors associated with offshore terminals' and marine ports' operations and management in order to choose the best proposed alternatives (control options) to mitigate risk factors.

1.5.2. Research objectives

Having defined the aim of the research, a number of objectives were developed in order to meet the described aim. These objectives were as follows:

- To conduct an intensive literature search in order to identify sources of risks and uncertainties associated within offshore terminals and marine ports.

- To propose a risk-based framework and research methodology for identification, assessment and management of the potential risk factors.

- To propose a novel risk prioritisation, evaluation and analysis approach to evaluate the levels of the identified risk factors.

- To propose an appropriate decision making tool for evaluating the proposed alternatives (control options) in order to mitigate the previously identified and assessed risk factors.

- To examine the proposed model by the use of various test cases and case studies in different stages of the model.

1.6. ACHIEVEMENT OF THE RESEARCH

The achievement of the research is the development of an advanced generic RM model enabling industrial professionals to identify, assess and mitigate the risk factors and sources of uncertainties existing in offshore terminals and marine ports.

Another research deliverable is to demonstrate the theory of the strategic management approach to the RM development and to reveal the implementation of the principle of the RM integration into all of the functions and processes in offshore terminals and marine ports. The proposed RM model is intended to provide a practical tool for RM professionals in the application and study of the RM processes in offshore and marine industries.

1.7. RM FRAMEWORK OF THE RESEARCH

RM framework like strategic management is an ongoing process that identifies, assesses and mitigates hazards and risk factors in which any company or industry is involved and sets goals and strategies to mitigate all existing and potential sources of uncertainties and then even can reassess each mitigation strategy regularly to determine how they have been implemented and whether they have succeeded or need replacement by a new set of strategies to meet changed circumstances or new environment. Figure 1.2 in this research depicts a RM framework designed for managing hazards and risk factors associated within offshore terminals' and marine ports' operations and management.

In first section of RM framework hazard identification was conducted through an appropriate literature review of major risk factors of these logistic infrastructures.

As a result in the first phase of the risk assessment (i.e. second section of RM framework) a Fuzzy Analytical Hierarchal Process (FAHP) method was used for determining the relative weights of the risk factors identified via the literature review. This has led to the development of a generic risk-based model which can help related industrial professionals and risk managers assess the risk factors and develop appropriate strategies to take preventive/corrective actions for mitigation purposes, with a view of maintaining efficient offshore terminals' and marine ports' operations and management. In the second phase of the risk assessment section the developed risk-based model incorporating Fuzzy Set Theory (FST), an Evidential Reasoning (ER) approach and the IDS software were used to evaluate the risk levels of different ports in real situations using a case study. The IDS software based on an ER approach was used to aggregate the previously determined relative weights of the risk factors with the new evaluation results of risk levels for the real ports. The third phase of the risk assessment section made use of the Cause and Consequence Analysis (CCA) including the Fault Tree Analysis (FTA) and Event Tree Analysis (ETA) under a fuzzy environment, to analyse in detail the most significant risk factors determined from the first phase, using appropriate case studies. In the fourth phase of the risk assessment section an individual RM strategy was tailored and implemented on the most significant risk factor identified previously.

In the last section of the RM framework and in order to complete the RM cycle, the best mitigation strategies were introduced and evaluated in the form of ideal solutions for mitigating the identified risk factors.

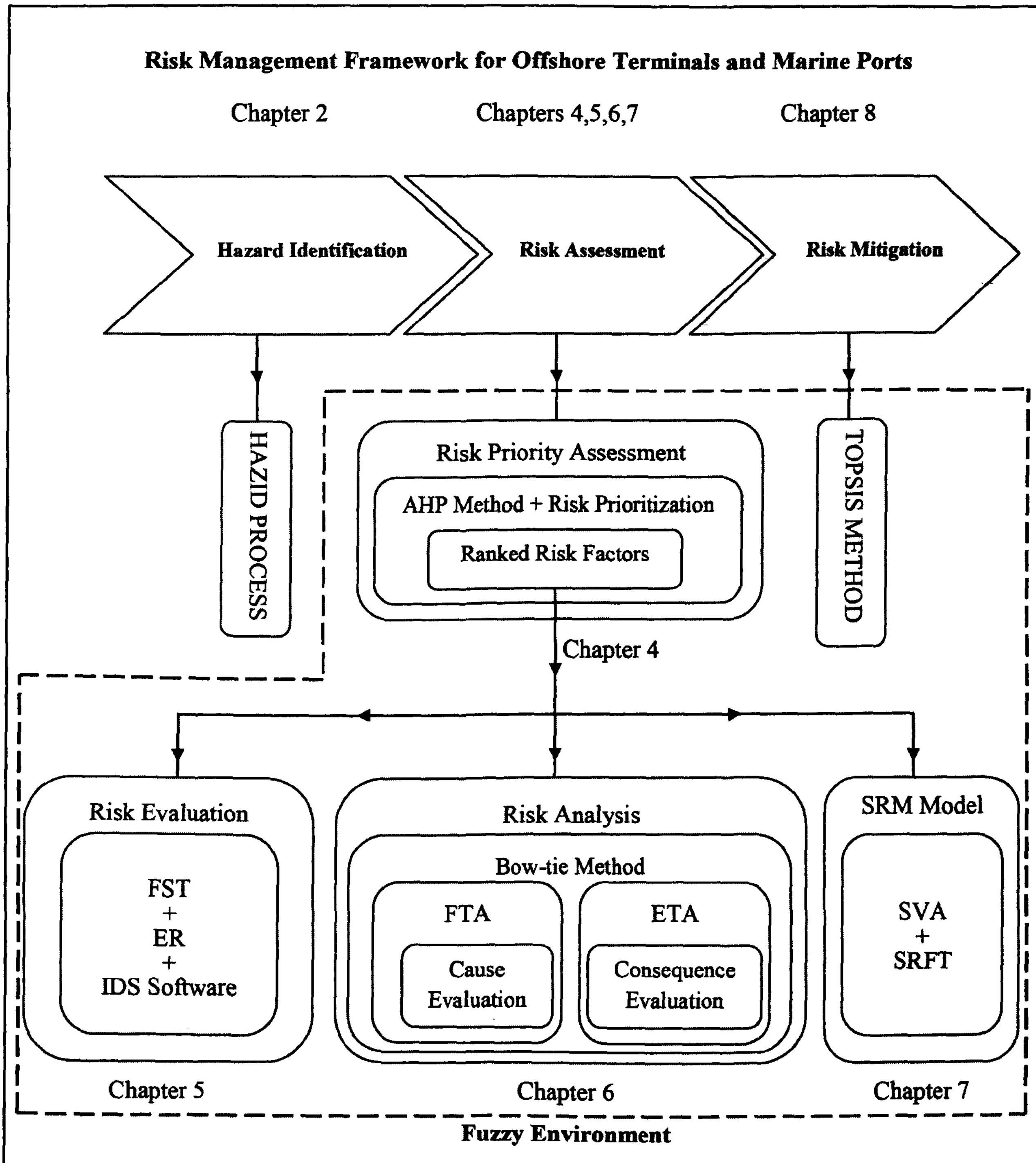


Figure 1.2: RM framework for offshore terminals and marine ports

1.8. THESIS STRUCTURE

This thesis has followed a common research and reporting structure as follows:

Chapter 1 corresponds to research background and explains the earlier concepts and recent researches and their contribution to RM. Justification for the research was explained and then research questions were generated to ensure that the research objectives are met. At the end RM framework and structure of the thesis were explained.

Chapter 2 is literature review and used to identify major externally and internally driven sources of uncertainties. Hazard identification was carried out using the documents and references from the different offshore, marine and logistics related sources.

Chapter 3 is methodology chapter. In order to cope with the identified risk factors an appropriate research methodology was defined. The proposed research methodology was used to analyse and handle each phase of the defined RM framework.

Chapter 4 is first phase of the risk assessment section of the RM framework. An FAHP method is used for determining the relative weights of the risk factors identified via the literature review. This will led to the development of a generic risk-based model.

Chapter 5 in second phase of the risk assessment including the developed risk-based model incorporating FST, has used an ER approach and the IDS software to evaluate the risk levels of different ports in real situations using a case study.

Chapter 6 in third phase of the risk assessment has used the CCA including the FTA and ETA under a fuzzy environment, to analyse in detail the most significant risk factors determined from first phase of the risk assessment.

Chapter 7 in the fourth phase of the risk assessment has tailored and implemented an individual RM strategy on the most significant risk factor identified from first phase of the risk assessment.

Chapter 8 is the last section of the RM framework and in order to complete the RM cycle, the best mitigation strategies were introduced and evaluated in the form of ideal solutions for mitigating the identified risk factors.

Chapter 9 explains conclusions and contribution to knowledge in RM of offshore and marine industries. Additional suggestions for the further research were recommended.

CHAPTER 2: LITERATURE REVIEW

2.1. INTRODUCTION

Managing risk is one of the main intentions of firms working internationally (Ghoshal, 1987). However, the present forms of the handling of risk and uncertainty in the international management literature differ in their use. Miller (1991) defines the most important uses of the term "risk" are in reference to unforeseen variation or negative variation (i.e. "downside risk") in business outcome variables e.g. revenues, costs, profit, market share etc. Managers generally relate risk with negative results (March and Shapira, 1987). The perception of risk as performance variance is broadly utilized in finance, economics, and strategic management. With either the variance or negative variation accepting, "risk" refers to variation in business outcomes or performance that cannot be predicted in advance (Miller, 1991).

Taking a corporate strategy perspective of RM engages the maximum challenge for uncertainty identification, not least because the factors capable of influencing performance are so many. To conduct any analysis of sources of uncertainty tractable at a business level needs sources to be broken down into broad categories or areas which taken together, entirely cover the range of uncertainties facing the organisation. These categories then serve as prompt lists for identifying sources of uncertainty in more detail (Ward, 2005).

The simplest kind of framework may be just a list of major categories such as the examples shown in Table 2.1.

Table 2.1: Simple frameworks for categorizing sources of risks.

Example 1 (OGC, 2002)

Strategic / commercial risks

Economic / financial / market risks

Legal, contractual and regulatory risks

Organisational management / human-factors

Political / societal factors

Environmental factors / Act of God (force majeure)

Technical / operational / infrastructure risks

Example 2 (PricewaterhouseCoopers, 2004)

External factors: economic and business; natural environment; political; social; technological.

Internal factors: infrastructure; personnel; process; technology.

As Miller (1991) explains again, the brand "risk" has also frequently been assigned to factors either external or internal to the firm that impact on the risk experienced by the firm. In this sense, "risk" essentially refers to a source of risk. Some general examples of risk referring to risk sources are terms such as "political risk" and "competitive risk". Such terms link irregularity in firm performance to specific vague environmental components.

In some form of enhanced models business perception frameworks present an illustrative structure to add supporting sense for the categories of uncertainties identified. A diagrammatic framework provides a richer perspective of sources of uncertainty both in terms of the construction and scope of sources included (Ward, 2005). An example of this kind of framework is shown in Figure 2.1.

Figure 2.1: A corporate framework of areas of uncertainty

Source: Adapted from Ward, (2005) and AIRMIC, ALARM, IRM Standards, (2002)

Ward (2005) expresses the other business perspective frameworks classify sources of risk in hierarchical structures. For example, Arthur Andersons Business Model (reproduced in full in ICAEW, 1999) assigns business risks into three main types of environment, process and information for decision-making. Process uncertainties are divided into operations, empowerment, information processing technology, integrity and financial. These classes are then further divided to help a more detailed analysis.

Another example is Ernst and Young's Risk Universe based on four first level categories of: operations, financial, strategic and knowledge, followed by more detailed second and third level divisions of these categories into narrower (but still broad) areas of uncertainty (Mottershead and Godfrey, 2001).

Such hierarchical structures can differ considerably in the categories adopted at each level, and it can be difficult to make a convincing case for one structure over another. In practice companies might choose to develop their own hierarchical structures, knowing particular features of their line of business (Ward, 2005). An example of a hierarchy structure for different sources of risks and uncertainties for an organization or a firm within the industry i.e. offshore terminals and marine ports are fully explained and illustrated for the purpose of this thesis in Chapter 4.

As the focus in this thesis will only be on RM in offshore terminals and marine ports it is therefore necessary first to review and argue the existing risk-based literature in the marine industry as a whole and then narrow it down and concentrate merely on the RM of offshore terminals and marine ports.

2.2. A BRIEF LITERATURE REVIEW ON MARINE INDUSTRY

In order to review the risk-based issues in the marine industry it is useful to discuss them according to the existing sectors. Obviously these sectors can extend from inland terminals or dry ports inside coastal or land locked states up to the other locations beyond the oceans. Figure 2.2 simply illustrates these sectors in the marine industry.

Figure 2.2: Segments in the marine industry

Source: Khan *et al* (2002), Maclachlan (2004) and ICS (2007)

In the process industry shown in Figure 2.2, process operations are the most hazardous activities next to the transportation and drilling operations on onshore or offshore oil and gas platforms. Past incidents of onshore and offshore oil and gas activities have shown that a minor hazardous situation in the process operation might develop a catastrophe. This is a main worry particularly in offshore platforms and terminals whether in the form of fixed and/or mobile structures due to the scarcity of the space and compact geometry of the process area, less ventilation, and difficult escape routes (Khan *et al*, 2002). In the onshore sector, a refinery plant located near a coast line or within a marine port area can be engaged with marine related activities such as transportation of the oil products by pipelines or tanker ships via oil terminals. Therefore it will be categorised under the marine industry sector and the whole complex can be called petrochemical sea port.

In the offshore sector of the process industry there are many types of floating production systems and units e.g. Floating, Production, Storage and Offloading (FPSO) units i.e. large, permanently moored oil tankers that have oil and gas processing facilities mounted onto their decks. Oil from subsea wells is piped on board the FPSOs through flexible flow-lines, and is processed before being stored in the FPSOs' cargo tanks. Processed oil or gas can then be discharged, through flexible hoses, into offloading oil or gas tanker vessels through tandem or double banking operations. Processed oil or gas can be transferred from FPSOs to onshore base destinations though offshore pipelines. Normally FPSOs are employed in areas of deeper water such as Gulf of Mexico, West Africa, Australia and Brazil (Mather, 2009). Among the various installations/jackets or rig/vessel types (e.g. fixed or mobile drilling jack up units, semi-submersible drilling/pipe laying units, drilling ships/barges) used in the offshore/process industry in this chapter, only FPSOs were included due to their double nature of being an offshore processing facility, and also a vessel. As it is considered to be an offloading terminal, it replaces a conventional platform in its entirety. However as it is evident the process industry can extend from a plant refinery and be connected through onshore and offshore (subsea) pipelines to floating platforms or units such as a FPSO moored in the middle of the sea.

Various sources (ABS, 2003; OCIMF, 2004 and Maclachlan, 2004; Mather, 2009; UKHSE, 2010 and Sutton, 2010) there is literature in the offshore industry which mainly relates to the legislation and safety acts such as Mineral Working Act (MWA) 1971, Health and Safety at Work Act (HSWA) 1974 and Statutory Instrument (SI) Number 289 in 1974 in UK. All of them have discussed comprehensively the issues such as safety cases and safety reports; Safety Management System (SMS); Formal Safety Assessment (FSA); Health, Safety and Environment (HSE); ISPS Code; Safety Case Regulations; Quantitative Risk Assessment (QRA); the concept of As Low As Reasonably Practicable (ALARP) in judging the level of acceptable risk. Moreover in onshore process sectors, risk-based process activities and safety aspects are discussed mainly under integrity management, safety and reliability management or engineering (Sutton, 2010). None of the mentioned concepts have described specifically at a holistic level about a generic or even specific RM methodology or framework which consequently could encompass all the concepts. Conversely phrases such as hazard, safety, security, reliability, disaster, emergency and crisis frequently discussed in the mentioned concepts also can all be categorised under a unique phrase i.e. 'risk'. However other phrases such as identification, assessment, evaluation, analysis, mitigation, control, audits, inspection, review and reports can be considered as subcategories for a unique phrase i.e. 'management'. Therefore using a phrase of 'RM' alone can justify all these scattered impressions.

In the logistics industry (as shown in Figure 2.2) sea ports are a major component of the maritime industry and have an important role to play in world trade, international logistics and global supply chains. In respect of the modern sea ports presently there are two main dimensions: ports as trade gateways and corridors, and ports as logistics and distribution centres (ICS, 2007). In the present situation, the ocean freight transport commerce has changed its structure as a result of the new trends and preconditions that came with the introduction of the container and the rise of intermodality (Jarzemskis and Vasiliauskas, 2007). Therefore the major troubles sea ports encounter today, as a result of growing containerised trade, are lack of speed at sea port terminals and increasing congestion on the access routes serving their terminals (Woxenius *et al*, 2004). Furthermore in many places around the world, bimodal and trimodal inland terminals (barge, rail, and road) have become inherent parts of the transport systems, mainly in areas having a high dependence on trade. In this respect marine based transport growth is slowly spreading to inland sides after a phase that concentrated on the expansion of sea port terminals and maritime shipping networks. There are many rationales for this growing attention. The complication of modern shipment distribution and the amplified focus on intermodal transportation solutions and capability issues appear to be the key driving factors. In addition ESCAP (2009) explains the massification (i.e. economies of scale through larger volumes) of the flows in networks, through a concentration of cargo on a limited set of sea ports of call and associated trunk lines to the hinterland. This has also shaped the right conditions for nodes to emerge along and at the end of these trunk lines. These nodes in the hinterland networks of sea ports have been referred to as dry ports, inland terminals, inland ports, inland hubs, inland logistics centres, inland freight villages etc. As a result inland terminals have become an intermodal and freight distribution unit that comes into three major functional categories. They can be marine barge terminals serviced from deep-sea ports, intermodal rail terminals connected to gateways and distribution centres linking supply chains. In addition inland ports are commonly integrating terminals (rail, barge or in rare cases both) with distribution centres in operational characteristics mainly associated with satellite terminals or load centres. The above mentioned facts justify and support the inland terminals or dry port concept as an integrated part of a marine industry and logistics system in maritime business especially for port customers and users (shippers, shipowners, agents, freight forwarders, exporters and importers) to outsource their functions which will need a lot of territory with the cheaper hinterland locations.

As discussed for the process industry, in port sectors there also exists literature on different legislations about health, safety, the environment and security issues for ports and terminals as shown in Table 2.2. Most of them address security, health, safety and environmental protection topics rather than the risk itself. On very rare occasions, development of the RM for the purpose of sea ports and terminals has been specifically discussed, for example by GAO (2006 and 2007), UNCTAD (2006) and UK HSE (2010).

Table 2.2: Summary of existing literature about health, safety, environment and security issues in port sectors.

Sources of Literature	Health	Safety	Environment	Security
Health & Safety at Work Act (1974)	•	•	•	
SOLAS Convention (1974)	•	•	•	
UNCTAD (1976)	•	•	•	
MARPOL Convention (1978)			•	
Pilotage Act (1987)	•	•	•	
Dock Regulation (1988)	•	•	•	
Port Act (1991)	•	•	•	
UNCTAD (1993)	•	•	•	
Trbojevic and Carr (2000)	•	•	•	
DETR (2000)	•	•	•	
PMSC (2001)	•	•	•	•
ISPS Code (2003)				•
UNCTAD (2006)	•	•	•	•
GAO (2006) and (2007)	•	•		•
ICS (2007)	•	•	•	•
World Bank (2007)	•	•	•	•
DNV (2010)	•	•	•	•
UK HES (2010)	•	•	•	•

In Figure 2.2, international shipping is a highly competitive industry that provides a crucial service for society through the economic carrying of goods and passengers by merchant ships between sea ports, terminals, offshore structures and units etc via inland waterways such as canals, channels, rivers and open seas. As there are many stakeholders, it is essential to have agreed and shared regulations. For example, shipping is a capital-intensive industry and shipping companies require funding of their operations. This finance largely comes from banks that derive their own finance from loans and the investments of their shareholders. Banks and their shareholders need a rule-based system to protect their risks. Similarly the carriage of cargo depends upon well-tested contracts and proficiency, which in turn are used to determine the outcome of an insurance claim in the event of loss or damage. Mariners are also obliged by contracts of employment and ship-owners have liabilities to make available seaworthy ships for the trades. Not only does this cover the physical condition of the vessels but the human factor, the manning and qualifications of the crew, navigational equipment, fire safeguard, lifesaving ability and overall watertight integrity of the vessel. Ships have to enter and work in ports. They require pilots, stevedores, shipyards and dry docks; they need services, stores, bunkers and water. Mariners always become visitors with immigration and health controls, which are somewhat broadly dissimilar in the different countries they visit. Customs also have a direct interest on ships, their cargo, crew and passengers for custom duties, smuggled goods and drugs. Therefore, there is an understanding that shipping is used for many purposes. However there are other challenges such as new regulations. For example, the ISM Code does not yet have a body law tested in court about the commercial effects of mismanagement and administrations. Therefore analysis of specific clauses may require accurate definitions. Operators, nevertheless, have to handle and run their vessels and ships' captains above all have to be responsive to their legal responsibilities (Maclachlan, 2004).

In the shipping industry and based on the available literature from several sources (ABS, 2003; Maclachlan, 2004; ICS, 2006; NE P&I Club, 2008) rules and regulations or safety and security issues have been discussed in detail. Among them there are topics such as marine insurance, associated with Hull and Machinery (H&M), Protection and Indemnity (P&I), Freight, Demurrage and Defence (FD&D), war risk, security risk and strike insurances. Additionally in this regard there are international organisations such as IMO and International Labour Organization (ILO); Conventions e.g. SOLAS 1974 and MARPOL 73/78; ISM and ISPS Codes; Collision avoidance regulations and International Maritime Dangerous Goods (IMDG) Code. They mostly emphasize on health, safety, environmental protection and security issues. Some of them, such as the Collision avoidance regulations are designed for the purpose of preventing the risk of collision. Insurance covers are normally used to transfer burden of risks from assureds to insurers. In fact there is a lack of development and integration of the RM perception within the shipping industry as well. Traditionally in shipping industry the concept of RM is only limited to marine insurance covers and issues such as claim handling.

2.2.1. Lessons to be learnt from accidents

Ultimately in terms of legislation in practice, the offshore and marine industry has suffered a lot and in the past and produced some disjointed, conflicting regulations, mainly in response to disasters involving considerable loss of life, culminating in the destruction of the Piper Alpha installation in UK waters in 1988. Based on Mather (2004) the Piper Alpha tragedy proved to be the catalyst for a radical change in the way the industry was both certified and regulated. The explosion accident on 20 April 2010 on board the Deepwater Horizon, which was an offshore drilling platform working on a well one mile below the surface of the Gulf of Mexico, has led to a major oil spill (TNYT, 2010).

Lack of compliance with safety practice and mistakes in proper inspections has been found as main root causes for both the cases above. Still no one has argued strictly for lack of complying with a generic or any specific RM methodology.

2.3. EXISTING RM METHODOLOGY FOR MARINE INDUSTRY APPLICATIONS

Based on the above summaries it can be seen that there are different risk-based expressions and eventually all are used in these three sectors of the marine industry to identify, assess and mitigate the impact of risk factors that are threatening the marine industry. Furthermore there are many regulatory bodies and other responsible individuals internationally involved in the industry whose main purposes are to avoid and prevent potentials for different hazards or risk factors and/or to take preventive and corrective actions. More or less all of them are trying to manage or control existing or probable hazards and somehow by using the risk-based related terms and application of some mitigation methods are trying to justify that they were involved in a RM related processes but eventually none of them are using a generic or a holistic RM methodology or framework. This cannot be seen even in regulatory applications. Whereas it can be seen its advanced form, as the QRA method or even the FSA methodology produced by the IMO applicable in offshore and shipping industries in the offshore side of the oil, gas and process industries for the purpose of safety cases to identify, assess and mitigate the hazards associated with the whole operations. The first one uses the words "quantitative risk assessment" but utilises hazard identification, risk evaluation and risk mitigation phases within its methodology. These steps are the ones used in a RM methodology. In the second one i.e. "Formal Safety Assessment" the steps are also hazard identification, risk assessment, risk mitigations, cost/benefit analysis and recommendation respectively which justify being steps of a RM methodology. Moreover many participants in the marine industry are still not well familiar with a RM framework, its proper definition and methodology.

Furthermore, as discussed in Chapter 1, it is a key issue that RM is embedded and integrated into the functions of the organisations as well as the decision of taking a strategic management approach within organisations. In order to overcome all the mentioned insufficiencies in marine industry applications e.g. offshore terminals and sea ports, a holistic and generic framework for RM has been introduced in Chapter 3. This reinvention in the marine industry can be an optimum solution to cover all the mentioned deficiencies. The dictionary typically defines "holistic" as dealing with wholeness rather than focusing on its parts or different sides or viewpoints. In fact the term of "holistic" RM can be used in the simple sense for the management of all sources of risks (Hopkin, 2002). Miller and Waller (2003) clearly regard this as a necessary part of their view of integrated RM as they state: "the essence of integrated RM is consideration of the full range of uncertain contingencies affecting business performance". However, in its proper sense, "holistic" implies a systemic perspective, which recognises system properties that are distinct from the properties of system components. In this sense, holistic RM would imply recognition and management of interactive effects between organisation activities and associated risks (Ward, 2005). In another instance linking the concept of enterprise-wide, holistic and integrated approaches Deloach (2000) defines enterprise-wide RM as: "a truly holistic, integrated, forward looking and process oriented approach is taken to manage all key business risks and opportunities – not just financial ones – with the intent of maximising shareholders value for the enterprise as a whole". Therefore a clear understanding of the terms in RM is important and a clear methodology essential to ensure for a strong framework. For this reason prior to discussing of different phases of RM it is better first to have a clear view of the meaning of the following terms:

- Hazard: is something with the potential to cause harm to people, property, the environment, business etc (Sutton, 2010).

- Risk: is defined as "a measure of human injury, environmental damage or economic loss in terms of both the incident likelihood and the magnitude of the injury, damage or loss" (CCPS, 2000).

- Risk Management: is a central part of any organisation's strategic management. It is the process whereby organisations methodically address the risks and sources of uncertainties attaching to their activities with the goal of achieving sustained benefit within each activity and across the portfolio of all activities (IRM, 2002).

- Offshore Terminals: relate to offshore installations/platforms/rigs in the form of offshore fixed or floating units engaged in the oil and gas explorations and exploitations. Fixed units are defined as all bottom-fixed structures, but excluded Tension Leg Platforms (TLPs), Floating, Production, Storage and Offloading units (FPSOs), Floating, Storage Units (FSUs) and production jack-ups rigs even while they are "fixed" throughout their production stage and therefore are classified as "fixed installations" by the UK's Health and Safety Executive (HSE) under the Safety Case Regulations. However these units are defined and reported under floating units which are defined as semi-submersibles, jack-ups, ships, barges, FSUs, FPSOs, TLPs etc engaged in drilling, accommodation, production and storage (Oil and Gas UK, 2011).

- Marine Ports: are areas of land and water including facilities, destined mainly for receiving vessels, loading, unloading and storage of cargoes, receiving and delivering the cargoes to land transport means. They may also include activities of firms (e.g. freight forwarders, shippers, exporters, importers and petrochemical, oil and gas companies, refineries etc) linked to the sea-borne trade (ICS, 2007).

2.3.1. Hazard identification

The first phase in any RM process is hazard identification (World Bank, 2007; GOA, 2007; UNCTAD, 2006; IRM, 2002 and DETR, 2000). "Hazard identification should be approached in a methodical way to ensure that all significant activities within the organisation have been identified and all the risk factors flowing from these activities are defined" (IRM, 2002). Although in general terms many firms, organisations and government bodies are using the phrase of "hazard identification" as the first phase in their RM processes but more particularly in engineering and industrial sectors (e.g. offshore and marine industries) as it is discussed by (ABS, 2000, Pillay and Wang, 2003; Wang and Trbojevic, 2007) the phrase of "HAZID" (i.e. HAZard IDentification) is used instead of the first one. HAZID is a general term used to describe an exercise whose goal is to identify hazards (risk factors) and the associated events that have the potential to result in a significant consequence. For example, a HAZID of an offshore terminal or offshore petroleum facility may be conducted to identify potential hazards which could result in consequences to personnel e.g. injuries and fatalities, environmental oil spills and pollution, and financial assets e.g. production loss/delay. The HAZID process can be applied to all or part of a marine port, an offshore facility, a vessel or it can be implemented to examine operational procedures for organisations. Depending upon the system being evaluated and the resources accessible, the process used to conduct a HAZID can differ (ABS, 2003). As ABS (2000) and Dickson (2003) explain that Literature Search, Physical Inspection, Organizational Charts, Flow Charts, Check-lists, What-if Review, Safety Audit, Hazard and Operability Study (HAZOP) are hazard identification methods.

As an example in offshore terminals and marine ports mainly in oil, Liquefied Natural Gas (LNG) and/or Liquefied Petroleum Gas (LPG) import and export terminals HAZOP is the best solution for hazard identification purposes. HAZOP is a structured way of examining the planned or existing process operation. The objective of a HAZOP study is to identify problems that may represent risk to personnel or equipment, or prevent efficient operations (Lassen, 2008). Based on ABS (2000) literature search is one of the HAZID techniques used to express an exercise whose goal is to identify hazards and associated events that have the potential to result in a major effect. As Saunders *et al*, (2007) have explained the benefit of literature search is to save time as the required risk-based data is previously searched and available, and also it is less costly than other techniques. It is also likely to be of higher-quality, and the data can be used in conjunction with the other qualitative and quantitative methods.

2.3.2. Risk evaluation

Risk evaluation involves the development of an overall estimation of risk by gathering and integrating information about scenarios, frequencies and consequences, and it is one major component of the whole RM process of a particular enterprise. In the process of risk evaluation, both qualitative and quantitative techniques can be used (Krishna *et al*, 2003). However as ABS (2003) discusses the word risk itself specifically is the product of "frequency" with which an undesirable event is anticipated to occur and the "impact" of the event's outcome. In other words risk is composed of two parameters, frequency and impact; i.e. risk is equal to frequency multiplied by impact. Due to the highly subjective nature and lack of information, it is usually difficult to determine risk parameters precisely. A reasonable and suitable way to express these parameters is to use qualitative verbal expressions (i.e. linguistic variables) especially during experts' judgments. To estimate the occurrence frequency, for example, one may often use such verbal expressions as very low, low, medium, high and very high. In addition to estimate the consequence impact also one may often use such linguistics variables as slight, minor, moderate, critical and catastrophic. A variety of other techniques has been used for risk evaluation and analysis including Preliminary Hazard Analysis (PHA), Failure Modes and Effects Analysis (FMEA), Fault Tree Analysis (FTA), Event Tree Analysis (ETA), Cause-Consequence Analysis (CCA), Human Reliability Analysis (HRA) of which some are qualitative and some are quantitative techniques (CCPS, 1992; Lees, 1996; Dickson, 2003, ABS, 2003 and Sutton, 2010). As Dickson (2003) explains these techniques have all been developed in the industrial setting, normally in response to some practical business problems.

2.3.3. Risk mitigation

IRM (2002) explains that "risk treatment is a process of selecting and implementing measures to modify the risk". Risk treatment includes as its major element, risk control/mitigation, but extends further to, for example, risk avoidance, risk transfer, risk financing, etc. Obviously as discussed previously marine insurance is one of the methods and strategies used extensively in the marine industry for risk mitigation purposes. Another example for risk mitigation in the process industry is Safety Integrity Level (SIL) that is a measure of the availability of protection layer or barrier. Protection layers include Basic Process Control System (BPCS), critical alarms and human intervention, Safety Instrumented Functions (SIF), physical protection and emergency response. All these mitigate the frequency of occurrence of the potential unwanted end-consequence or mitigate the impact the end-consequence represents (Lassen, 2008). All statutory regulations, classification societies' rules, IMO Conventions and Codes are typical examples of strategies used for the purpose of risk mitigation. There are also many other analytical tools for carrying out the cost-benefit analysis or for selecting the best strategy if there are more strategies for risk mitigation purposes. Among these methods, the most popular ones recently used by researchers were Analytic Hierarchy Process (AHP) which can be used either for prioritisation in order to rank the risk factors or be used as a decision making tool to select the best solutions for mitigating the risk factors (Golec and Taskin, 2007), Analytic Network Process (ANP) (Yuksel and Dagdeviren, 2007), Axiomatic Design (AD) (Kulak and Kahraman, 2005), and TOPSIS (Kahraman *et al*, 2007). A variety of different strategies can be utilized depending on whether to take preventive or corrective actions during the risk mitigation phases of the RM cycles, i.e. whether to proceed toward proactive or reactive RM approaches, there could be different strategies to be utilised.

As an example in order to carry out RM and complete the execution cycle properly, after hazard identification and risk assessment phases, by using the concept of As Low As Reasonably Practicable (ALARP) in judging the level of acceptable risk, a risk factor itself will be judged and if it is not acceptable by application of the mitigation strategies it must be controlled and managed. However the utilised strategies in the mitigation phases must be monitored in order to know whether they have reduced the risk factors to an acceptable level or not. For example if by measuring the amount of ALARP over time it was evidenced that the used strategies were not effective, then the utilised strategies must be changed. To enable this, SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis can be used. A SWOT analysis is a popular tool for analysing internal and external environments in order to attain a systematic approach and support for a decision situation (Kotler, 1988; Wheelen and Hunger, 1995). In a SWOT analysis the internal and external factors are referred to as strategic factors and summarised within the SWOT analysis. Additionally the final goal for any strategic planning process, of which SWOT is an early stage, is to develop and adopt a strategy resulting in a good fit between internal and external factors. SWOT can also be used when a strategic alternative emerges suddenly and the decision context relevant to it has to be analysed. If used correctly, SWOT can provide a good basis for successful strategy formulation (McDonald, 1993).

2.4. EXISTING HAZARDS IN OFFSHORE TERMINALS AND MARINE PORTS

The literature review presented in this thesis is used to identify hazards and conduct the HAZID phase of the RM for the purpose of offshore terminals and marine ports. As discussed before in marine industry offshore terminals and marine ports may become exposed to externally (e.g. country and business) or internally (e.g. organisational and operational) driven sources of risks and uncertainties at any time. Through an appropriate hazard identification process (i.e. literature review), the mentioned sources of risks and uncertainties will be investigated through the following sections.

2.4.1. Country risks

Given the increasingly inclusive nature of investment ranges, knowing country risk is very important (Claude, 1996). A critical assessment of country risk is necessary because it reflects the capability and compliance of a country to service its financial commitments. Many risk rating agencies use different techniques to verify country risk ratings, combining a range of qualitative and quantitative information regarding alternative measures of economic, financial and political risks into associated composite risk ratings (Hoti and McAleer, 2004).

As an example for managing the country risk which may affect the corporate business activities internationally, CBB (2008) explains, although the particulars of the country RM programme will differ among licensees, depending upon the nature and complexity of the licensee's international activities, a comprehensive RM programme for a country should entail:

- A sufficient country risk assessment process.
- Methods to identify and measure country risk exposures.
- Suitable and effective monitoring and control procedures.
- Stress management and testing and contingency planning.

In another instance SEB (2006), a merchant banking in Europe in order to investigate country risk factors which normally are used by its clients and traders for doing business and investment purposes, as an example the country of Mexico has been compared with the country of Russia. As it is shown in Figure 2.3 these countries have been compared against each other in respect of the five different risk factors as are depicted on the radar type chart. This kind of chart will be used in Chapter 5 in order to facilitate the required analysis. The depicted risk factors for these countries are also compared with an average (blue line) which was defined for the Emerging Market (i.e. Average EM) countries. Key ratios shown in Figure 2.3, illustrate the economical and financial indices for Mexico in 2006.

Figure 2.3: An illustrative example of country risk analysis
Source: Based on SEB Merchant Banking (2006)

As per ICRG (2001) country risk refers to the risk of investing in a country, dependent on changes in the business environment that may negatively influence operating profits or the value of investments in a specific country. For example, financial factors such as currency controls, devaluation or regulatory changes, or stability factors such as mass riots, civil war and other potential events contribute to companies' operational risks.

Evaluating country risks is a critical exercise when choosing sites for international business, mainly if investment is to be undertaken. Certain risks can be managed through insurance, hedging and other types of financial planning, but other risks cannot be controlled through such financial devices. Some of these latter risks may be measured in a risk return analysis, with some countries' risks requiring higher returns to justify the higher risks. The study of country risks is also essential in order to expand alternative scenarios: Uncertainty may remain, but it can be transformed into planned uncertainty, with no surprises and with contingency plans in place. As a result in every country corporations may deal with a unique set of country risks (Conklin, 2002).

Country risk is sometimes also referred to as political risk. In this context it refers to the unwanted events resulting from government policies or actions, and for this purpose political risk assessment is a broader view of the influences of government policies and actions on selected industries or corporations (Fitzpatrick, 1983; Simon, 1984; Cosset and Suret, 1995; Rodrigue *et al*, 0211). However country risk is a more general term, which generally only refers to risks affecting all companies operating within a particular country.

With due regard to the above statements it has been pointed out that although political risk assessment has long been practiced by multiple nation enterprises for a broad review of the influences of government policies and actions, it has been rarely seen for port reviews (Fitzpatrick, 1983; Simon, 1984; Cosset, 1995 and Sur *et al*, 1995). Nevertheless, it is believed that the port business environments are associated not only with micro-port policies, but also with macro-economic and political practices of the host nations. As Tsai and Su (2005) explain in this highly competitive environment, complete understanding of the overall political influences appears to be increasingly valuable for carriers' (i.e. shipping lines) decisions. In addition, it is essential for a host government to perceive and recover its port environments.

Governmental actions and policies, involving a parent country, a host country and overall international relationships, are seen as factors that can be lead to the political risk of business environments (Nigh, 1986). However, government actions or policies have multiple aspects. The most common classification is to divide political risk into two categories: micro-risks and macro-risks, depending on whether the risk factors affect selected/overall industries (Robock and Simmonds, 1983). Micro-risks represent the risks resulting from the political changes that influence only a selected field of business activity or foreign enterprises; while macro-risks represent those resulting from political changes that influence enterprise. The classification of micro and macro risks presents an understandable structure to methodically identify risk factors (Friedmann and Kim, 1988).

With respect to port projects the World Bank (2007) explains that the port operator is subject to the full range of national legal, economic, social, and political influences that determine the stability of the nation in which the project is located. This must be investigated in detail, as this environment generates variety of risks, typically referred to as "country risks."

Until now there have been no country RM studies on the port review, except the one Tisa and Su (2005) carried out in order to develop a port-to-port comparative risk assessment model (see Chapter 4). In their study they conducted a case study of the political environment evaluations for five East Asian counties (i.e. sea ports): Hong Kong, Singapore, Busan (South Korea), Kaohsiung (Taiwan) and Shanghai (China). Their empirical case concluded that the mentioned country's political risk was a strong indicator for the business environments of the host ports.

Although for the purpose of country risk factors, ICRG (2001) rating comprises 22 variables in three subcategories of risk namely political, financial and economical risk but in previous country RM literatures, the factors were split into three categories: government policies, political and social systems, and macro-economic practices (Killer, 1992; Zhi, 1995; Alon and Martin, 1998). Of these, government policy is frequently divided to further categories in order to reflect its broad range of characteristics (Tisa and Su, 2002). As Tisa and Su (2005) explain considering the nature of the carriers' business as an important and main factor in port business, government policies was subdivided into the three main items of port development policy, port management policy and foreign enterprise policy. The first two of these categories i.e. port development policy and port management policy specifically will influence the global carrier business, while the third one i.e. foreign enterprise policy indicates the host nation's general attitudes towards foreign enterprises. These three sub-divided government policies, together with the other two factors identified earlier, i.e. political and social systems, and macroeconomic practices, are considered to be used as the main five risk factors which eventually can shape sub-framework of country risks. Tisa and Su (2005) for evaluation of the mentioned risk factors in their investigation have used AHP method i.e. an Analytical Process Approach but for the purpose of this research and under the fuzzy environment a fuzzy AHP method i.e. FAHP will be utilised (see Chapter 4).

2.4.1.1. Macro-economic practices

Oxelheim and Wihlborg (1987) have explained that macro-economic uncertainty is a broad concept encompassing fluctuations in the level of economic activity and prices. Miller (1992) has categorized the macro-economic uncertainties into five divisions such as inflation, changes in relative prices, foreign exchange rates, interest rates and terms of trade. Tisa and Su (2005) with respect to the macro-economic risks for ports in the host countries have categorised them into four main issues of economic invigoration, stability in interest and foreign exchange rates, GDP growth and balancing of national saving and debt.

Some researchers have examined previously the economic purposes and contributions of offshore terminals and marine ports, value of trade and how these facilities can impact on a nation's economy (Goss, 1990a; Struyf and Vebreke, 2000). For example, Goss (1990a) explains how having efficient sea ports can raise the GDP of a nation. Furthermore Alderton (1999) and Marti (1990) express that often this literature will admire the benefit of the sea port sector to regional and national economic development in terms of being an economic multiplier.

In another instance World Bank (2001) discussed uncertainties in the port industry which relates to fluctuations in exchange and interest rates, non-convertibility of the local currency into foreign currency and non-transferability. This risk is higher in those countries where political condition is highly unstable, the economy is weak and government policy does not attract Foreign Direct Investment.

Exchange rate risk (i.e. variability in the value of the project or amount of loan resulting from unpredictable fluctuation in the exchange rate has become a supreme consideration of the private operator, if a guarantee cannot be obtained from the government or central bank of the host country. Optimal risk allocation principle – to assign risk to the party best able to manage it - does not work out for exchange rate risk in port finance. Operators can pass on some or all of the risk to a third-party by contractual arrangement (e.g. swap contract) (Desai, 2005). Figure 2.4 gives a general idea how a port authority or private operator can reduce or mitigate monetary risk through a swap contract.

Figure 2.4: Swap Contract
Source: Desai (2005)

Monetary risks such as interest and foreign exchange rates can be hedged or eliminated in different ways. Off-shore account with approval of local authority can eliminate whole risk raised through non-convertibility or non-transferability of local currency. However, where the operator cannot obtain authorization for off-shore account, guarantee for convertibility or transferability from the government or the central bank of a host country would be the best approach against monetary risk (World Bank, 2001). With respect to the balancing of national saving and debt as previously discussed by Hoti and McAleer (2004) assessment of country risk is essential because it reflects the capability and compliance of a country to service its financial commitments.

2.4.1.2. Political and social systems

Relating to the social and political system risks affecting the ports in the host country Tisa and Su (2005) have categorised them into four main issues of political stability, government efficiency and incorruption, social stability and internationalisation. Political uncertainty is generally associated with major changes in political regimes (Shubik, 1983 and Ting, 1988). Political uncertainty reflects the threats and opportunities linked with probable or real changes in the political system. Political volatility can result from a war, revolution or other political disorder. Democratic changes in governments or heads of state are another reason of political ambiguity that has not been widely recognized in the political risk literatures (Miller, 1992). Policy uncertainty refers to the instability in government policies that impact the business community (Ting, 1988). Some authors (e.g. Agmon, 1985; Bunn and Mustafaoglu, 1978) do not distinguish between political and policy uncertainties but use the term "political risk" to encompass both of these uncertainties.

Desai (2005) explains that political risks have financial, operational, security and reputational impacts. Corruption, bureaucracy, political shift, terrorism, legal and regulatory irregularities can be primary sources of political risks. Political risk is one of the significant risks involved in offshore and port projects. Furthermore it is expressed that the political risks arises from the unforeseen actions, decisions or inactions of a offshore/port authority or public entity. Here, inaction implies clearly the non-compliance of the contract by the offshore and port authorities or governments. Moreover overestimation of government actions may result in expropriation, nationalisation, and inefficiency in applying legal systems. Political risk appraisal is always a complex matter and there are no means, hedging or guarantees that eliminate risk entirely. In this respect and as an example the following corruption index compares the most corrupt and the cleanest countries with each other.

Table 2.3: Countries corruption index

Source: Based on Alderton (2008), Berlin Transparency International Group survey.

As explained above, political risk arises from non-compliance of the contract by the offshore/port authority or government, the efficiency of contractual commitments of such parties depends on the reliability of applicable laws and regulations. Legal systems must be formed on the basis of international rules and regulations. As an appropriate legal system is not enough for managing political risk, an operator may call for the involvement of multinational organisations such as the World Bank, Asian Development Bank, International Finance Corporation etc. The presence of such multinational organisations in port project forces the government to avoid imposing any measures that put the project in jeopardy. Other approaches for protecting against political risk are financial involvement of sponsors or lenders of host country, guarantee from export credit agents (World Bank, 2001).

Regarding social uncertainty as Miller (1992) discusses it is generated from the beliefs, values, and attitudes of the residents that are not reflected in existing government policy or business practice. It also results from the difficulties inherent in predicting the probability of collective action and the direction of such action when people are faced with discrepancies between their own values and those embodied in the institutions impacting their lives. Eventually it can lead to political and policy uncertainty and would be characterized by social unrest, riots, demonstrations, or small-scale terrorist movements. If such movements subsequently develop into threats to the government, political instability can occur. The reason for separating the political and social dimensions of general environmental uncertainty is that they relate to two separate stake holder groups: government and society at large (Freeman, 1984).

As Desai (2005) explains social risk is very often based on the quality (efficient, skilled, well-educated and trained etc) of the labour force, national law regarding the labour force, interference of labour unions in port operations and management. In many countries, a special importance has been given to dock workers under national law that increases the cost for port operation. Port authority or private operators may sustain a loss in terms of cost of unemployment payment, retraining etc while reforming the workforce. Whenever labour cost becomes too costly and raises port/terminal tariff, ship owners or shippers will try to avoid the port and use a neighbouring port. Weak labour forces can be responsible for low production level, high damage level and theft due to high interference of labour union, and strike.

In another case internationalisation is the same geographical expansion of trade and industry activities over a national country's borderlines. The term began to be used when the event slowly replaced imperialism as the central organisation principle framing cross-border relations between market economies started in the 1920s. The economic internationalisation process accelerated after World War II and appeared supreme until the early 1970s, when a new phenomenon of globalization began to appear (Gjellerup, 2000). Internationalisation is a phenomenon researched seriously over the last few decades from several viewpoints, including: international management, strategic management, organisation theory, marketing, small business management etc. Issues like the growth in global activities, international management and decision-making, and factors getting advantage or disfavouring internationalisation have been studied for both large as well as small businesses (Ruzzier, 2006). Tisa and Su (2005) in their port related studies have found the internationalisation as one of the macro country risk factors.

2.4.1.3. Foreign enterprise policy

As per Tsai and Su (2005) regarding the foreign enterprises policy risks affecting the ports in the host country, they have categorised them into three issues of trade restriction, tax incentives and capital and remittance controls.

As mentioned in the previous section for political and social system, policy uncertainty was referred to as instability in government policies that impact the business community (Ting, 1988). In respect of foreign enterprises policy Miller (1992) explains that some of the most related types of government policy uncertainties are unforeseen financial reforms, price controls and changes in the level of trade barriers. Even when policies do not transform, managers may be unsure as to the government's obligation to enforcing existing statutes. Multinational firms face government policy uncertainties in their home country as well as in the host countries.

2.4.1.4. Port development policy

As per Tsai and Su (2005) development policy for sea ports indicates the host government's idea for ports' organisational pattern, liberalisation and internationalisation degree, industrial potential in adjacent areas, and position of port relative to other intercontinental ports within a nation.

With reference to the port organisational pattern, liberalisation and internationalisation degree as UNCTAD (1993) explains subjects such as privatisation and commercialisation are the main topics. These subjects are contemporary because of the reforming of the international economic situation. In this regard over the last decade, there has been a universal trend of institutional reforming in the public sector. In some developed and developing countries, it has taken the form of commercialisation or privatisation of public enterprises. Based on UNCTAD (1995) in the former Russia and the former socialist countries in Eastern Europe and Asia, steps have been taken to change their centrally planned economies into market economies. Globalisation of manufacturing and national and global competition have been major driving factors for these changes. In the past, political decisions have transferred certain economic activities to the public sector. Now, market forces are increasingly being allowed to drive the entire national economy, which often involves institutional changes, away from public enterprise entered economies.

As UNCTAD (1995) explains obviously in order to develop the liberalisation and internationalisation degree of the port, methods such as deregulation and decentralisation are useful ones. Additionally these methods will ease the port privatisation and commercialisation processes as well as they will recover the port competitiveness factors. As a competitive environment is built, benefits accrue quickly to the users. Labour-related deregulation is in numerous cases, the most vital part of the port reform. In France, for example, ignoring some labour laws which had allowed dockers a special employment status and updating others, has brought positive results in some French ports, such as the ports of Dunkirk and Rouen.

Industrial potential in neighbouring areas and port positioning relative to other international ports within a same nation are also other competition factors which will influence the host country's vision during drafting and composing their port development policies (Tisa and Su, 2005).

2.4.1.5. Port management policy

As per Tsai and Su (2005) port management policy indicates the country's approach toward private financing policy of port infrastructure and equipment, port due and charge policy, efficient operation policy, and port customs practices.

In this respect as per UNCTAD (1995) port management policies are aimed to grant the users with the lowest transport charge, or best logistics cost, which includes not only the charges paid by them to the port but also their own operating expenses incurred while in port.

In offshore terminals and marine ports the significant changes are obviously not only the physical changes, such as the replacement of the berth by the terminal as the operational unit, but also the institutional changes as autonomous corporate bodies, namely offshore/port authorities and offshore/port operators, are now a standard feature in ports around the world. As explained in a previous report, (UNCTAD, 2006) port authorities are resorting to strategic planning to survive in a competitive environment through the use of cost leadership and service differentiation, in general, and strategic pricing in particular. Further, these port authorities are improving their managerial capabilities by implementing concepts, such as total quality-control, and relying on management tools, such as port pricing (UNCTAD, 2005). Perhaps the degree of the impact of competition on these corporate bodies can be measured by the increased reference made to clients instead of users.

In another instance Alderton (2008) in respect of port management objectives explains that in the past, few ports and terminals seem to have had clear and explicit management objectives. However, the adoption of the ISM Code and the development of quality management by ports in the early 1990's, will have caused the minds of port/terminal boards to focus on this problem and come up with a variation of the following:

Ways of minimising costs:

- Minimise payments by users in the port, including ships' time at a port.
- Minimise users' total through transport costs.
- Minimise port costs.

Maximise of benefits:

- They maximise benefits to the owners of port.
- They maximise benefits to the town, region or country.

2.4.2. Business risks

PricewaterhouseCoopers (2004) has classified the business risk factor among the externally driven uncertainties which can impact any corporation. In another instance OGC (2002) categorized the commercial and strategic risks among the other risk factors that could be accounted as sources of uncertainties in a corporation. As it can be seen from the framework depicted in Figure 2.1, Ward (2005) has demonstrated areas of uncertainty within a corporation. Along with the externally driven risks or sources of uncertainties in a corporation, significant strategic uncertainty factors were competition, industry change and customer change/demand ones. IRM (2002) also has mentioned the same factors in the framework of their RM standards.

2.4.2.1. Competition factors

Over the past 20 years, competition among ports and terminals around the world has increased dramatically, owing to several factors such as the increased competition in liner and tramp shipping, the development of inland transport networks, deregulation of inland transport operators and facilitation of transport procedures. The greatest engine of change has been the unitisation of general cargo which now moves in containers or on pallets. The outcome is the predominance of intermodal transport, over sea and land transport, and its reduced costs. Increased competition has forced port managers to give priority to users' needs and to assess their added value received from port services and facilities. This value is related to the increase in value of the cargo as a result of its being moved from its place of origin to its destination (UNCTAD, 1995; Cullinane *et al*, 2002; Estache *et al*, 2002 and Drewry, 2005).

The World Bank (2007) explains that five forces will act together to shape the competitive landscape facing port authorities and port service providers:

- The rivalry among existing competitors.
- The threat of new competitors.
- The potential for global substitutes.
- The bargaining power of port users.
- The bargaining power of port service.

These features will influence ports of all sizes, driving needs for port development, service enhancement, pricing decisions, and other management actions. Winners and losers will appear in the global port sector, largely dependent on how port managers strategically position themselves in the evolving competitive landscape.

Furthermore as Alderton (2008) has discussed a recent survey of the Atlantic market indicates that the traditional approaches to explain inter-port competition, including the hinterland concept, are not particularly importers' perspectives as shown in Table 2.4.

Table 2.4: Port competition factors

Source: Alderton (2008)

Although the port environment in general has become more and more competitive, it differs between regions and places depending on the extent to which these factors have impacted the nature of the port environment. In this context, the following key elements influencing the ports' competitiveness have been proposed based on the existing literatures (ADB, 2000; Peters, 2001; Tongzon and Heng, 2005; UNESCAP, 2005; Cargo News Asia, 2006; WCL, 2006; World Bank, 2007; ICS, 2007 and Alderton 2008; Yap and Notteboom, 2011).

- Port (terminal) efficiency.
- Landside accessibility.
- Cargo handling charges.
- Logistics and Value added services.
- Port Reliability.
- The depth of water.
- Port/terminal location.
- Shipping frequency.
- Adequate services (Ship repair, bunker and supply).
- Quick response to ports' users need.
- Adaptability to the changing market environment.

2.4.2.2. Industry change factors

Since the environment in which marine ports operate has been transformed considerably, ports are affected by a variety of new forces driving global competition, including the far reaching unitisation of break bulk cargo, the rise of mega-carriers, the market entry of logistics integrators, the formation of network connections between port operators, the growth of inland transport networks etc (Notteboom and Winkelmans, 2001a, b). The previous section introduced the major players and competitors of the container trade which were taken into consideration. Now the most important challenges and changes which are occurring in the port industry are explained as follows (Juhel, 2001; Slack, 2001; Drewry Shipping, 2002; ICS, 2005 and World Bank, 2007; Yap and Notteboom, 2011):

- Fluctuation in shipping industry.
- Consolidation among ocean carriers.
- Potential for global substitutes for port/terminal users.

2.4.2.3. Customer change factor

In the following section other risk factor affecting the business environment of the ports and terminals are discussed.

- Increase in ship's size.
- Change in customer demand on type of cargoes e.g. bulk, Ro-Ro and container.
- Change in variety of products and services in ports and terminals.

Over the last decade, technological development has accelerated the vessel dimension in such a way that seems to have no limit on the vessel size. This uncertainty in vessel size creates more challenges for ports. Larger ship needs new large dock gantry cranes and extensive dredging that involves a huge investment. Therefore, to establish new facilities anticipating new size dimension is a quite risky task (Slack, 2001). In another case as WCL Consulting Inc. (2006) explains in order to achieve economies of scale, ocean carriers are deploying larger capacity vessels (e.g. 10,000+ TEU post-Panamax vessels) and at the same time rationalising their direct port calls by load centring at fewer "Hub" and "Transhipment" ports. Other risk factors mentioned in this section are fully discussed in Chapter 1 in support of Figure 1.1.

2.4.3. Organisational risks

In respect of the organisational risks shown in Table 2.1, organisational management and human resources are categorised as sources of risks and uncertainties that a corporate or a firm may become exposed to (OGC, 2002).

Akerboom and Maes (2006) have explained that a general set of job and organisational characteristics which may raise different organisational and worker outcomes, is not a new idea. For example, models of healthy organisations take note that organisational performance and workers' health and welfare can be promoted by a common set of qualifications (Shoaf *et al*, 2004). In the same manner, Zacharatos and Barling (2004) have explained that the management of safety is no different from the management of organisational performance, and therefore many of the determinants of organisational performance are likely to affect organisational safety as well. In order to comprehend the significance of the organisational factors which may affect any firm or company, it is better to look at Figure 2.5.

As shown in Figure 2.5, incidents are always preceded by a certain combination of technical, human and/or organisational failures. In particular the definition of organisational failure plays an important role on majority of existing processes leading to accident which are explained by Vuuren (1998). Regardless of rising communal, industrial and scientific attention in the organisational causes of incidents, the idea of organisational failure is still only partially understood by researchers and hardly recognized by organisations (Vuuren and Van der Schaaf, 1995).

To some extent arbitrarily, but after reading and analysing hundreds of accident scenarios, the following general failure types are summarised and classified into three groups (Wagenaar *et al,* 1990):

a) "Physical environment: design failures, missing defences, hardware defects, negligent housekeeping, and error enforcing conditions".
b) "Human behaviour: poor procedures, lack of training".
c) "Management: organisational failures, incompatible goals, lack of communication".

Figure 2.5: A simple model of incident causation
Source: Based on Van der Schaaf (1992)

While these failure categories are formed through human action, they are not called 'unsafe acts'. They are not immediately followed by a disaster; however they create inviting circumstances for unsafe acts to occur (Vuuren, 1998).

As per OGC (2002) the following categories are some of the aspects that can be considered as a starting point in any organisation for identifying the main areas risk in relation to programmes:

- Lack of clarity over roles and responsibilities.
- Management incompetence.
- Poor leadership.
- Key personnel who have inadequate authority to fulfil their roles.
- Inadequate corporate policies.
- Lack of support to business processes.
- Operational procedures-adequate and appropriate.
- Inadequate or inaccurate information.
- Poor staff selection procedure.
- Indecision or inappropriate decision making.
- Professional negligence.
- Performance failure (people or equipment).

In the following section organisational related risk factors or sources of uncertainties in the offshore terminals and marine ports that are faced by the different maritime related organisations will be investigated. Based on the existing literatures (UNCTAD, 1998; ISO, 2002; Oakland, 2002; ICS, 2007; BPM, 2010; DNV, 2010 and Marianos *et al*, 2011) organisational related risk factors are mainly discussed under heading of factors such as organisational structure, management, quality process, human resource, key performance indicators.

2.4.3.1. Organisational structure

Schein (1985) defines three organisational problem areas that cover the problems encountered by consultants in the area of organisational development. His division of problem areas is based on what he perceives as the three main themes in organisational science. The first theme is the structure of an organisation and deals with problems about how to divide tasks, authority, responsibilities, and resources to make the organisation function as efficiently as possible. The second theme deals with interpersonal relations between people working in the organisation. Finally the third theme deals with the strategy of an organisation.

ICS (2007) explains that it is difficult to generalise as to the best organisational structure for a modern port, but a typical structure can be found in UNCTAD (1996). Moreover UNCTAD (1985) expressed that the selection of an appropriate form of port administration is a matter of port policy rather than part of the preparation of a specific port development plan. The basic system of port administration, whether it is to be an autonomous or a centrally directed administration should be determined by the national ports authority. However, there are certain organisational elements of the administration which are the responsibility of the local port authority. A check-list of these elements is given by UNCTAD shown in Table 2.5. Organisational structure of the port is the first elements among others which must be taken into consideration.

Table 2.5: UNCTAD Check-list

Organisational elements needed in a port administration
1. Organisational structure.
2. Administrative procedures.
3. Costs analyse and control.
4. Tariff structure.
5. Consignment documentation and customs procedures.
6. Electronic data processing and telecommunications systems.
7. Data collection, analysis and dissemination procedures.
8. Staffing and manning policies.
9. Staff selection procedure.
10. Training programmes.
11. Marketing and public relations (including the education of potential users of a proposed new facility).

Source: UNCTAD (1996)

2.4.3.2. Management

Management acts as individuals considering and communicating decisions. They promote the need to develop and improve the organisation and to set targets (Oakland, 2002). Regarding management failures Alderton (2008) has stated the following reasons as main contributing factors:

- Lack of direct authority to effect remedial action.
- Qualification required by the job for senior managers.
- Lack of adequacy in upgrading knowledge.
- Lack of continuity in senior manager's positions.

2.4.3.3. Quality process

International standard encourages the implementation of a process approach when developing, executing and improving the efficiency of a quality management system, to improve customer satisfaction by meeting customer needs. The application of a system of processes within a company, jointly with the identification and connections of these processes, and their management, can be called "process approach" (ISO, 2000). Alderton (2008) in respect of the insufficiencies observed in the ports' and terminals' clearance procedures and documentation summarizes them as follows:

- Late arriving documents.
- Faulty document.
- Outmoded documentation requirements and processing methods.
- Outmoded clearance facilities for vessel and cargo.
- Importers allowed ordering shipments without sufficient funds to take delivery on arrival.

2.4.3.4. Human resources

With the introduction of the Formal Safety Assessment (FSA) in the IMO decision making process concerning new rules, and the recent tanker disasters resulting in extensive oil spills, the public tension for improving safety conditions in port, offshore and shipping industries has increased (Trbojevic and Carr, 2000). Taking into account that some types of safety report (case) regulations related to marine operations have not been recognized, and that the port, offshore and shipping industries are at the beginning of safety rules which are already in use in other industries. A step wise methodology for safety expansions for example in sea ports has been developed by Trbojevic and Carr. In their first step, during HAZID phase they found out the main risk parameters in their port dynamic risk model. Organisational and human risk factors were among the main parameters. On the other hand they found that the main elements leading to organisational risk factors were poor management practices, lack of ship specific knowledge and poor vessel maintenance. In respect of human risk factors poor decision making, poor judgement, lack of knowledge and poor communication were noted as main factors. In addition as per quality management standard's requirements, ISO 9001 (2000), the Code 4.2 (human resource) explains that the employees performing the tasks which can affect the product quality shall be capable on the basis of proper education, training, skills and experience.

2.4.3.5. Key performance indicators

Based on PWHC (2007) "Key Performance Indicators (KPIs) mean factors by reference to which the development, performance or position of the business of the company can be measured effectively". Additionally Oakland (2002) expresses that the KPIs, tell the organisations whether they are moving towards or away from the mission, or remaining stationary. ICS (2007) explains that performance indicators are tools or instruments that allow port managers to measure port or terminal performance, and take corrective decisions to improve it when and where it is needed. Then ICS explains that an indication of port/terminal performance is important and will become increasingly so as ship size continues to grow, competition increases and capital intensity of port investment rises.

As per ICS port/terminal operations performance can be considered under three broad categories:

- Physical performance refers to the output of existing assets and facilities. The performances of the port can be calculated as a whole or the performances for each set or group of facilities (berths, yards, cranes, sheds, storehouses and labour force), can be considered.
- Quality performance is a factor of competition which may exceed the price of port services in importance. Port reliability, flexibility and application of rules are all included in the quality of port services.
- Financial performance is described as the profit and loss contribution of each category of port operation and service.

2.4.4. Operational risks

Frost *et al* (2001) explain that operational integrity in corporate level generally encompasses the management of operational risks stemming from inappropriate cultural environments, lack of management supervision, errors, malice, fraud, poor health and safety and environmental compliance failures, physical disasters, and poor internal controls. Furthermore they express that the consequences of not managing operational risk properly go beyond direct financial losses. Failure at the level of operational continuity can lead to what organisations fear most, that is, a loss of reputation among the public at large and their shareholders. As Davidson (2003) explains operational risk addresses the risks associated with carrying out operations. Included here are matters such as running an assembly line, managing an office, and operating a computer facility. Risk arises when events occur that threaten operations in some way. For example if a factory experiences a power failure, its assembly lines will stop, and it will be unable to produce its manufactured products on schedule.

Furthermore Frost *et al* (2001) explain that while Operational Risk Management (ORM) practices in some industry sectors are well established – such as those in the nuclear power and air transportation industries – the need for a systematic approach to ORM is only now starting to enter into the wider business consciousness. One of the most immediate business drivers for taking ORM more seriously now than in the past is demonstrated by those organisations that have suffered catastrophic failure because of poor ORM.

As per OGC (2002) the following categories are some of the aspects that can be considered as a starting point in any organisation for identifying the main areas risk in relation to programmes:

- Safety being compromised.
- Inadequate incident handling.
- Breaches in physical security/information security.
- Pollution incidents.
- Failing to meet legal or contractual obligations.
- Human error/incompetence.
- Residual maintenance problem.
- Failure to control IT effectively.

In the following section impact of the above mentioned areas of risk and sources of uncertainties in the offshore terminals and marine ports under the heading of operational risk factors with the existing literatures are discussed.

2.4.4.1. Port safety related risk factors

The Ports and Waterways Safety Act of 1972 urged the U.S. Coast Guard (USCG) to retain an "acceptable level of safety" in the ports and waterways of the U.S. The law launched a clear, but subjective, goal for the Coast Guard's historic waterway management function. The awareness of this goal implied the capability to determine and to quantify together the intensity of risk in any waterway and the risk reduction value of safety involvements such as aids to navigation systems, pilotage, and vessel traffic systems. A George Washington University/Virginia Commonwealth University team was asked to build up a computer based set of techniques that could be used by the USCG to consider the Vessel Traffic Management (VTM) necessity for each of the most important Ports and Waterways in the U.S. (Harrald and Merrick, 2000). As a result they used the fleet composition, traffic conditions, navigational conditions, waterway configuration, potential consequences of transporting dangerous goods and subsequence lack of not using VTM systems as main risk factors for the purpose of their model in order to measure the safety risk levels of their ports for the mentioned factors. By the use of expert judgements and an AHP method which will be explained in Chapter 4 they became able to evaluate and measure the levels of the U.S. ports' safety risk factors. For the purpose of this research the same model will be used as one of the subset frameworks of the operational risk model but instead of the AHP method it will be evaluated by the use of a Fuzzy AHP method (see Chapter 4).

Two separate port risk assessment workshops were conducted for the port of Morgan City, LA, USA, in April 2000 and port of Coos Bay in September 7, 2000. In both the workshops same risk factors, models, methods and tools were used in order to evaluate the levels of the same risk factors for the mentioned ports (PRA, 2010).

In respect of meeting safety standards in ports the Port Marine Safety Code (PMSC) has been designed and published in March 2000 by the DfT Ports Division. It aims to establish an agreed national standard for port marine safety and a measure by which harbour authorities can be held accountable for their legal powers and duties to run their ports and harbours safely (PMSC, 2001). It is noted that there is no known literature on this topic related to Iranian ports such as used in the case studies later in this research.

2.4.4.2. Security related risk factors

In support of RM issues during the operations, logistics and supply chain security of the ports and terminals Bichouet *et al* (2007) in the Lloyd's practical shipping guide explained that the concept of RM in ports continues to be overwhelmingly associated with operational risks such as security. In their argument they have categorised the port security related risk factors into the following major sections:

- People Safety: Partners, customers, and service providers.
- Asset Protection: Facilities, goods, products, and information.
- Profitability: Cash, e-commerce, and royalties.

UNCTAD (2006) on its debate towards a supply chain risk assessment framework has explained that some of the central aspects of the risk assessment and their meaning in the context of the maritime supply chain security can be highlighted in a form of the following three sources of risks:

- Environmental: uncertainties arising from external sources such as terrorist or environmental risks.
- Organisational: internal uncertainties arising within the supply chain such as strikes or production failures.
- Network-related: referring to the uncertainties arising from the interactions between organisations in the supply chain.

In the present maritime security regime, there is a tough highlighting on environmental and organisational risks and small spotlight on network-related vulnerabilities.

2.4.4.3. Pollution related risk factors

As Goulielmos (2000) explains marine pollution has received much attention by International Maritime Organization (IMO) (ESCAP, 1992), United Nations Conference on Trade And Development (UNCTAD, 1993), United Nations (1994, 1996), Comité Maritime International (CMI), International Navigation Association i.e. Permanent International Association of Navigation Congress (PIANC) used to be called in 1991, World Bank (Davis *et al*, 1990) etc. IMO has, in particular, dealt with transport, handling and storage of dangerous substances in offshore terminals and marine ports.

Advanced ports particularly those of the third generation have emerged as parts of the logistics chain (Goulielmos, 1998). The passive role of ports against anything was coming from sea towards the onshore and from shore side towards the sea has changed (Pronk, 1993), but their strategic position connecting sea and land makes them the best eyewitness for the pollution initiating from land, ships and from the ports themselves.

Additionally Goulielmos (2000) explains that the consideration has not been paid to the ports environment at all. The port environment is endangered by ports' hinterland, ports' activities and operations, and ships activities. Ports pollution may also result from ship accidents, accidents in ports (Goulielmos and Pardali, 1998), land activities, ship bunkering, noises, garbage, dust, dredging, port maintenance, ship air pollution, traffic congestion, sewage etc. The focus of the international community is mainly on ports' visitors i.e. the ships, because of the well-known marine accidents. Regardless of this, the issue of material dredging from ports has been addressed as early as 1975 (London Dumping Convention) and pollution of the sea from oil and the facilities for waste reception in ports and offshore terminals, as early as in 1973 (MARPOL 73/78, The International Convention for the Prevention of Pollution from ships). The issue of oil pollution in emergency situations in ports has been addressed since 1990 (Convention of Oil Pollution Preparedness, Response and Cooperation). Figure 2.6 presents the extent of the pollutions generated in ports.

Figure 2.6: Port Pollution and its causes.
Source: Goulielmos (2000), constructed from UNCTAD (1993)

As Goulielmos (2000) explains on the basis of an IAPH (International Association of Ports and Harbours) survey, filled in by 183 ports, the critical areas were three:

- Dangerous materials.
- Water pollution.
- Dredging and dumping of dredged waste.

The third factor is connected to port expansion or conservation.

In this regard IAPH suggested that the following principles should be applied during the environmental policy making of the ports:

- Limit sea (from ship, land, dredging) and air pollution (dust, noise).

- Use Environmental Impact Analysis (E.I.A.) in port development.
- Prevent risk of major accidents (Vessel Traffic System (VTS), emergency plans, and dangerous goods).
- Manage waste and discharge (recovery, collection, recycling, supervised disposal areas).
- Create quality areas.
- Regulate against pollution.

Lloyd's List has tabulated the most ship incidents (e.g. grounding, bunkering, collision, etc) that have occurred in ports world-wide which have caused the major pollution claims. The effect will vary greatly from port to port according to the particular physical features and situation of the port (Alderton, 2008).

2.4.4.4. Contract related risk factors

World Bank (2007) explains that legal risks with respect to port projects take place in association with the lack of accuracy in and the prospect of changes in the legislation and regulations overriding the project. It must be assumed that a set of rules exists at the time the project is initiated. The risk of changes in legislation or regulations can be initiated from the probability that condition in effect at the time of the agreement may change at a later date.

Sharp (2009) expresses that in the offshore industry an oil company may lose a specific contract for supply of hydrocarbons to a designated market for commercial, political and operational reasons. For example such loss can result from a major operational damage or an accident which has happened to an offshore terminal. In this case there may be a delay in a contract (made between the contractor and operator) for reconstruction of the damaged parts or rectifying and repairing the faults as a result of the major damage or accident. As a result of delay the oil company using the terminal having had contract with oil importers in the market will face financial loss.

2.4.4.5. Human related risk factors

As per Soares and Teixiera (2001) one of the oldest data banks that is frequently the basis for the majority of studies of worldwide information is operated by Lloyds. In respect of marine accidents, it is not shocking that around eighty percent of shipping accidents are caused by human factors. Therefore it has motivated interest in increasing methodologies that take into custody the nature of human errors in marine accidents and store them in data bases for additional numerical study as reported in Kristiansen *et al* (1999). They have mentioned pilots', ship's officers' and shore personnel error as main contributors for the human errors related risk factors. In another instance North of England P&I (Protection and indemnity) Club (2008) has reported the pilot's, ships' officers and crew and shore personnel's e.g. stevedores errors as the main categories of the human errors contributing to the major mentioned marine losses.

In another case Otterland and Roos (1960) have explained human factors that contributed to shipwrecks and other accident to ships; they have distributed the accidents by different type of employee such as deck officers, marine engineers, remaining crew and ratings, pilots, persons in other ships and persons on shore.

Again in another investigation which was made by Liu *et al* in 2005. The negligent causers in marine accidents found to be employees such as master, chief mate, chief engineer, second mate, pilot, third mate and second engineer. Moreover according to the UK P&I Club (2010) human error costs the maritime industry $541m a year. From their own analysis of 6091 major claims (over $100,000) spanning a period of 15 years, the Club has established that these claims have cost their members $2.6bn, 62% of which is attributable to human error. From this 62% (human error), 30% was contributed to the deck officers error, 15% was belonged to crew error, 8% to pilot error, 7% to shore person error and 2% was belonged to engineer officers error.

HFW (2002) during its incident investigation and analysis of offshore and maritime incidents (accidents and near-misses) has found that eighty percent or more of them involve human error. Furthermore in the maritime system human resource could include the ships' crew, pilots, dock workers, VTS operators etc. The performance of these people dependents on many characters, both inherent and learned. HFW, during their investigations found that the factors such as: people Knowledge, Skill, ability, alertness, judgement, decision making, safety culture, performance, crew competent, training and communication are the most significant factors that may cause organisational failure through the accidents.

2.4.4.6. Technical risk factors

As per Alderton (2008) inadequate maintenance policies will result in high proportion of equipment being out of service due to the following reasons:

- Absence of preventive and running maintenance.
- Lack of qualified maintenance personnel.
- Lack of adequate stocks of spare parts.
- Insufficient standardization of equipment types.

As per ICS (2007) ports and terminals also require engineering skills to undertake the maintenance and development of the fabric of the port/terminal structure in areas such as civil engineering, offshore engineering, hydrographic surveys, mechanical, marine and electrical etc works. As a part of the marine services, dredging and maintenance of port/terminal infrastructures, navigational aids, IT and equipment are among the main technical factors that will help the port/terminal to overcome its own short comings and remain competitive. For example in respect of IT Brancheau *et al,* (1996) explain that in a current survey between IT consultants in the U.S. constructing a responsive IT infrastructure to carry existing applications whilst remaining responsive to change is rated as the number one main issue. In this regard thus, it is not astonishing that Port of Singapore Authority (PSA) placed importance on structuring a flexible and extensible IT infrastructure as its third victory factor. A high-quality IT infrastructure strengthens the competitive positioning of business plans for any company (Broadbent and Weill, 1997). Furthermore, a flexible IT infrastructure is essential to offer long-term support for a business strategy that can swiftly react to changing environmental conditions (Eardley *et al*, 1997).

2.5. SUMMARY

This chapter has reviewed the theory and literature on RM and parent disciplines with the primary aim of identifying the boundaries of knowledge and describing the research problem. The chapter has thoroughly discussed the theory, practice and research developments into RM in offshore terminals and marine ports. It has also examined the literature on different and significant risk factors and their relationship with offshore terminals and marine ports. The parent and related disciplines examined included country, business, organizational and operational related risk factors. The review has uncovered several practices and problems related to the management of hazards and risk factors within offshore terminals and marine ports.

Summing up, alternative approaches that clearly incorporate subjectivity and empirical knowledge have to be addressed for an effective modelling and analysis of risk factors in general, and offshore terminals' and marine ports' country, business, organizational and operational related risk factors in particular. Recent developments in the field of RM create great potential for the development of decision support systems and knowledge based systems. Due to the characteristics of RM, emphasis on human judgement, a knowledge based decision support system seems to be an appropriate methodology. Several techniques for decision support systems development and uncertainty encoding procedures are available and can be used in this regard.

CHAPTER 3: RESEARCH METHODOLOGY

3.1. INTRODUCTION

The aim of this chapter is to describe how the research was conducted in order to fulfil the aim and objectives. The aim of this research is to develop a RM framework for identifying, analysing and managing risk factors affecting offshore terminals and marine ports. The research is, therefore, a typical management study since it aims to enhance the practice of RM in offshore and marine industries. The development of the RM framework requires that relevant knowledge be elicited from experts who are working in the related fields. However the process of knowledge acquisition is complex, lengthy and tense with difficulties. After introducing a generic RM framework, this chapter will discuss the different research strategies and the choice of the most appropriate ones for the present study. The chapter deals with the whole issues of research design, namely research perspectives, research types, research methods, sampling selection, data collection and analysis techniques. The data collection methods adopted namely experts' judgements, are discussed briefly here and at length in the next chapter.

3.2. A GENERIC RM FRAMEWORK

Figure 3.1 provides an illustrative view of a generic RM framework proposed for the purpose of this research upon which the research methodology will be directed.

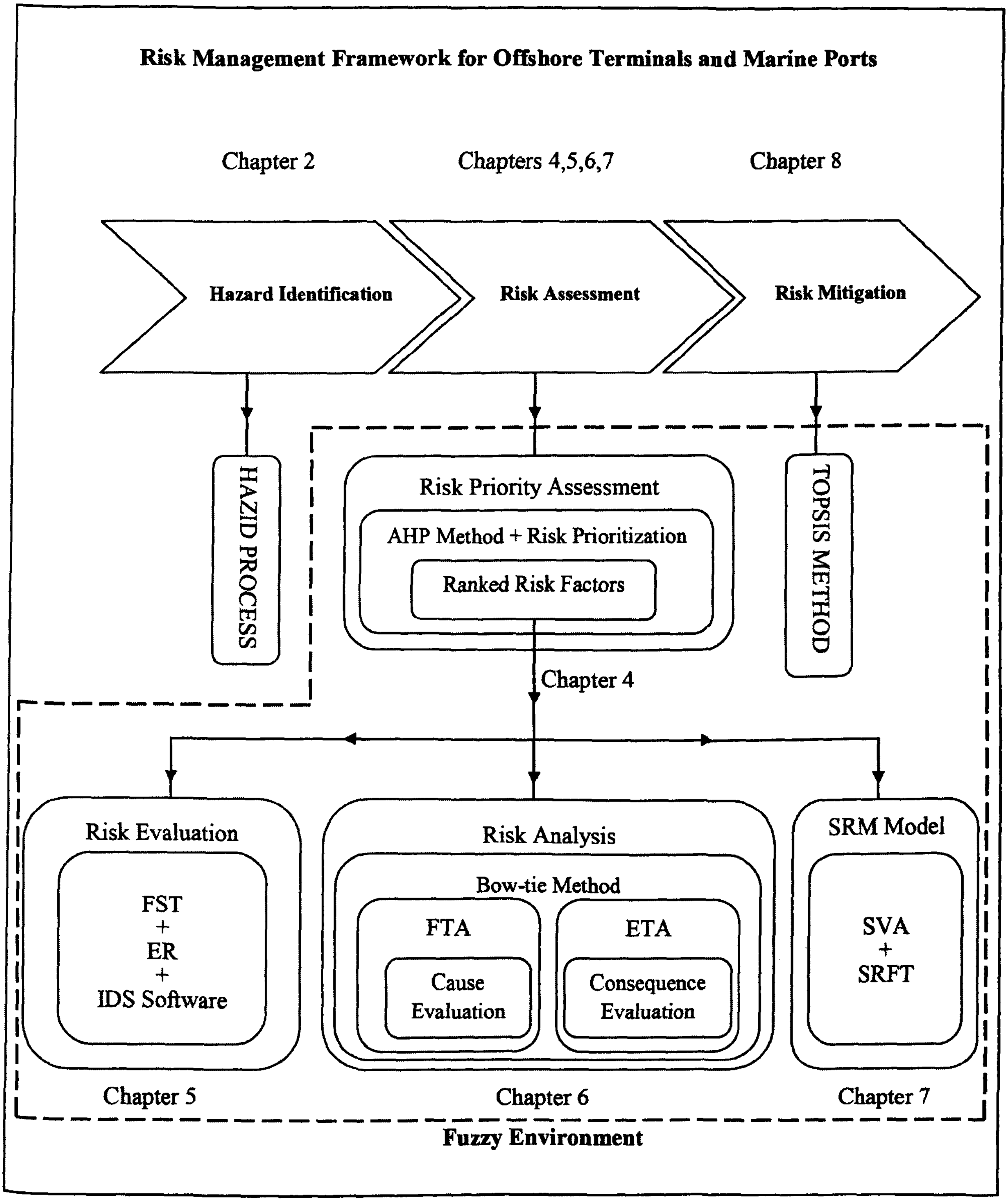


Figure 3.1: RM framework for offshore terminals and marine ports (copied from Chapter 1)

3.2.1. Hazard identification phase

The risk-based framework in this research comprises the review of literature (i.e. Chapter 2) on the existing risk factors or in other word hazard identification i.e. HAZID process to develop a risk-based hierarchical model similar to clusters in order to conduct the rest of the RM processes easily and in a clear manner as are shown in Figure 3.1.

3.2.2. Risk assessment phase

The identified hazards or risk factors from Chapter 2 will be assessed and weighted in this phase and then they will be prioritised and ranked using a designed hierarchical model, a FAHP method and experts' judgements which are fully explained in Chapter 4.

In Chapter 5 by using FST and an ER approach a new risk-based model will be implemented on three Iranian ports to show the applicability of the model during the port-to-port risk assessment. For this purpose the formerly designed hierarchical risk-based model, from Chapter 4 along with the new experts' evaluation results from the three Iranian ports while using the ER approach under fuzzy environment will be fed into the IDS software. As a result IDS will compute and rank the ports as per their risk index.

In Chapter 6 the most significant risk factors or hazards prioritised previously in Chapter 4 will be analysed in depth by the use of bow-tie method while using the FTA and ETA techniques under fuzzy environment. This will allow investigation of the causes of the most significant risk factors by FTA in addition to investigating their feasible consequences using ETA. As a result this will help to study individual risk factors in depth and to issue comments by experts, auditors, surveyors and investigators about lessons to be learnt and to give advice on how to avoid their recurrence.

In Chapter 7 of the research a separate RM strategy will be implemented on the significant risk factors to show the capability of the RM frameworks that can take into custody any of the risk factors exclusively. For this reason apart from the generic RM framework defined for the whole thesis (i.e. hazard identification, risk assessment and risk mitigation phases shown in Figure 3.1) a separate individual RM framework in the form of a robust individual strategy using a SRFT and SVA technique will be designed for the foremost revealed risk factors.

3.2.3. Risk mitigation phase

In Chapter 8 in order to mitigate the identified risk factors several alternatives (control options) will be proposed with the use of Fuzzy TOPSIS device (i.e. a decision making tool). The proposed alternatives will be gauged and ranked as per their priorities while using experts' judgements to see which one has more strategic importance.

Apart from the HAZID process all the other phases in this research will be conducted under fuzzy environment. Fuzzy environment has been used to deal with the vagueness of the data collected during the course of research. This process will ensure the cycle of the RM used for the purpose of offshore terminals and marine ports is complete. Full details about fuzzy theory will be explained in Chapter 4.

3.3. DESCRIPTIONS AND IDEAS LINKED TO RESEARCH DESIGN

3.3.1. Research methodology

The topic of research methodology and its procedures lies at the central part of every research study. Research methodology is concerned with the philosophical and theoretical foundations upon which the research is conducted in order for the knowledge yielded to be acceptable (Edum-Fotwe *et al*, 1996). As a result, research methodology has to describe the justification for the particular techniques or techniques s used in a research.

3.3.2 Research techniques

Techniques, alternatively, are methods and tools by which information is collected, evaluated and presented. Although sometimes they are used interchangeably; data collection techniques and data collection methods are considered different ideas in this research. A technique is defined as a systematic and orderly approach taken towards the collection of data so that information can be obtained from those data. A method is step-by-step process that can be followed in order to gather data and analyse them to find information. A technique tells how to do something rather than what is being done (Yin, 2009).

3.3.3 Research design

Research design can be described as the basic research plan or strategy, as well as its fundamental reason that aims to permit the viability and validity of the research. Basically, research designs, plans or strategies seek to respond questions such as how, why, who, when, where, how much, how many in order to provide explanations, descriptions, classifications, associations, relationships and causalities. Selecting an appropriate research methodology is a difficult task and involves, among others, not only setting a very clear definition of the aim and objectives to be achieved, research questions or hypothesis, but also an understanding of data collection methods and techniques, type of data, data sources, measurement instruments and data analysis strategies. There are close linkages between research questions, methodology, data collection techniques, type of data and data analysis and they cannot be treated in isolation. Yin (1994) considered this logic link as a sequence of evidence. There are many research methods and data collection techniques ranging from experiments, surveys, case studies, historical, questionnaire, interviews, experts' judgements and observation, to video and photography. Some of these methods are more suitable to certain research studies than to others. Nevertheless, no single method fits all research questions and research situations. Each design provides answers to a specific set of questions. Therefore, the best approach is one that is essential to the kind of questions the research wishes to answer, taking into account the extent to which it complies with reliability and validity criteria. Many times research is conducted by combining several methods since the different methods are not mutually exclusive. In addition, there is no straight forward set of rules that can be followed when selecting a specific method for one set of circumstances and another method for another set of circumstances. The following sections present two main research methods namely quantitative and qualitative as well as data collection methods and techniques used for the purpose of this research.

3.4. SAMPLING SELECTION

Collection of qualitative data in a research or study is to get a deeper understanding of a fact, as the significance of detailed data becomes inevitable. Saunders *et al.* (2009) have discussed the advantages of samples, and advised that selecting a sample allows the author to limit the amount of data that he/she wishes to collect, and only focus on a sub-group, as opposed to all possible cases.

Experienced professionals involved in the management of the offshore terminals and marine ports were chosen to be the sample population as they would be aware of the importance of hazards and risk factors they are involved with. Due to their ability to compare and define which hazards or risk factors have the higher impact on the operations and management of the offshore terminals or marine ports, they were the most suitable participants in this research. The reason behind conducting the test cases and case studies in the next chapters is that the experts used in this thesis have related and adequate educations, skills and experiences from the field (for more details about experts see Chapter 4). This provides a unique opportunity that will enhance the validity of the data collected, in terms of allowing a comparison between offshore terminals and marine ports. The Iranian Hormozgan Port Authority in Port of Shahid Rajaie was chosen to collect data due to the convenience of not being too far from the first case study location in Chapter 5.

The sample size of this thesis was six experts described in Chapter 4 and three experts for the remaining chapters, consisting of managers from Iranian offshore terminals or marine ports. This sample size was considered acceptable for this study. Saaty (2001) stated that just a small sampling size (<10 responses) was necessary if the data collected were gathered from the experts. This is due to that fact that professionals should share consistent belief and thus diminish the need for a huge sample size (see Chapter 4).

Convenience sampling method was used in this research. It is "convenience" because the researcher has privileged knowledge of offshore terminals and marine ports from his previous experiences as a Master Mariner. Convenience sample is also used due to easy access to the research case study area which is based in Iran where the researcher is from.

3.5. METHODOLOGY FOR DATA COLLECTION AND ANALYSIS

This section describes the process of data collection used in the thesis along with justification and analysis of the data gathered.

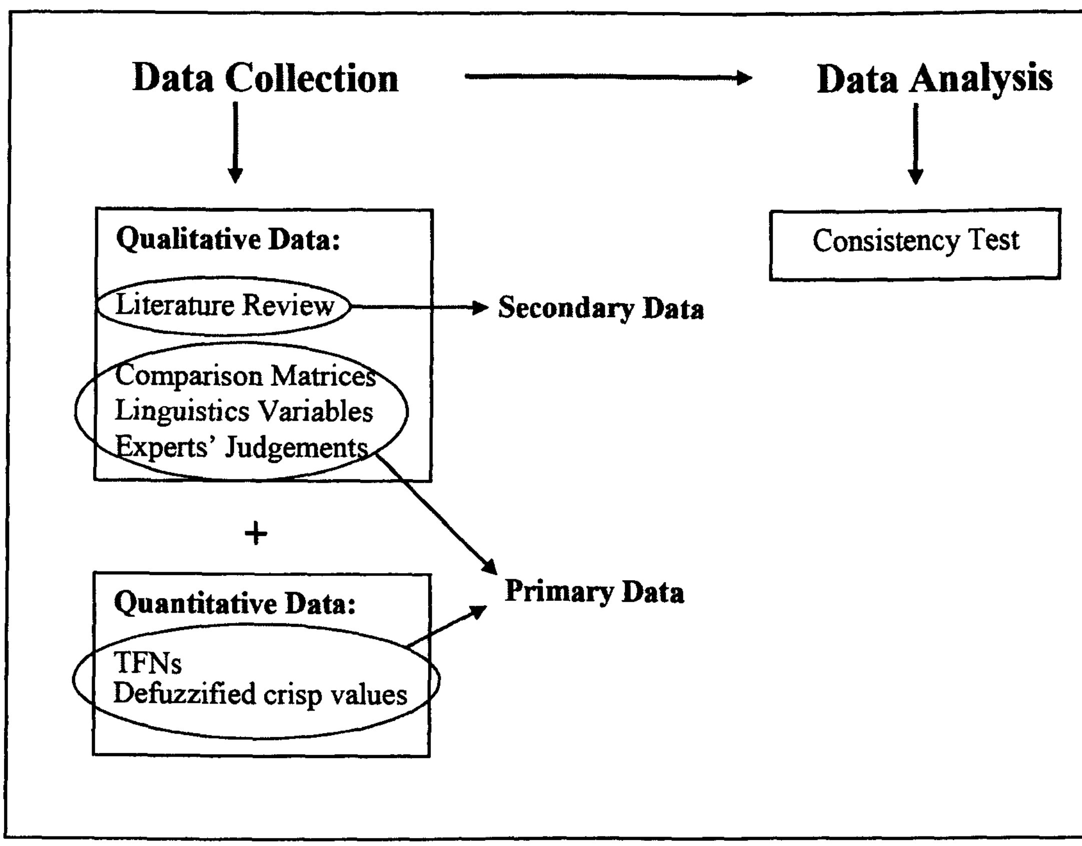


Figure 3.2: Methodology for data collection and analysis

The choice of data collection method should be in line with the research questions and its aim and the objectives (Saunders *et al,* 2009). Two types of data collection methods have been used in this thesis. Primary data collection involves collecting new data, whereas secondary data collection concerns the collection of existing data. These methods in the form of qualitative and quantitative data have been categorised and depicted in Figure 3.2 and are fully explained in the forthcoming sections.

3.5.1. Data collection

A well-structured methodology, based on experienced should enable organisations to take full advantage of the findings. A methodology is based on research and consultancy (Rigby, 1969).

In this thesis the research problem was to explain and provide a generic model and perhaps to justify RM processes in offshore terminals and marine ports. Due to scarcity of the research done in this area, to understand the research problem it is required to use an approach involving the use of multiple methods. Such an approach can entail qualitative and quantitative methods to gather and examine the data.

Naslund (2002) has pointed out limitations of using the quantitative research methods alone and argues for the integration of qualitative techniques as well in order to enhance the current power of quantitative logistics research.

As a result, qualitative research methods can be associated with face-to-face contact with people in the research setting, together with verbal data and observations. Qualitative data can also be collected in a number of forms, with methods ranging from the collection of evidence through interviews, which may be recorded and later transcribed; semi-structured interviews with crucially placed organisational personnel; personal correspondence with organisations; questionnaire survey; use of published and unpublished documents; literature reviews. Finally qualitative data can even be collected through experts' judgements.

Using the qualitative methods alone has a number of limitations. Stacey (1969) enumerates two problems specific to qualitative work in a particular participant observation. First, the full meaning of the data may not be grasped and temporary conditions can easily be taken to represent normal ones. Second, bias from the theoretical framework adopted and the data selected by the researcher, can also more easily creep into a study dependent only upon qualitative work (Jick, 1979). Additionally Swartz and Boaden (1997) also discuss that the quantitative method alone can never indicate the richness of social phenomena. Thus it is required to combine methods to do this, using quantitative data to help simplify phenomena and look for patterns, while qualitative methods provide the means to account for those patterns in ways which resonate with our experience of the phenomenon.

As it was discussed in Chapter 2 risk factors associated with offshore terminals and marine ports in the form of qualitative data were identified through the HAZID process i.e. literature review. As it is mentioned in Chapter 2 and based on Saunders *et al*, (2007), the advantage of literature review is that it saves time since it has already been collected, and it is also less expensive than other methods. It is also likely to be of higher-quality, and the data can be used in conjunction with the data collected through other qualitative methods such as experts' judgements.

In this thesis through conducting literature review in Chapter 2 various types of risk factors were identified in the first phase of the qualitative data collection. In the second phase the identified risk factors will be used during experts' judgements through utilising a FAHP method. Full explanations and discussions in respect of the nominated experts for the AHP and FAHP methods are explained in Chapter 4.

On the other hand, based on Eldabi *et al*, (2002) quantitative research places emphasis on procedure and statistical measures of validity. It relies on the measurement and analysis of statistical data to determine relationships between one set of data to another. It focuses on individuals. For example, a survey questionnaire or a comparison matrix is given to individuals as discrete objects of enquiry.

In this thesis data collected in the form of qualitative linguistics variables which were used during the experts' judgements will be transformed into quantitative data as per procedures explained in Chapter 4. The obtained quantitative data in this research are all in the form of Triangular Fuzzy Numbers (TFNs) that will be used for further calculations and analysis which in final stages of data analysis eventually will be defuzzified and transformed into a crisp value as fully mentioned in Chapter 4.

3.5.2. Data analysis

The collected data as explained in the previous sections must be further analysed prior to be used in other stages of the research. Analysing collected data needs specific strategies and techniques in order to produce a high quality analysis (Yin, 2009).

In this research data was gathered thought experts' judgements with the use of making several pair-wise comparisons as will be described in Chapter 4. Based on Saaty (1980) an important consideration for this process is the consistency of the pair-wise judgements provided by the decision maker. Therefore in order to ensure that the gathered data are reliable and consistent, an additional test called consistency test will be carried out on the data collected (see Chapter 4).

3.6. CONCLUSIONS

This chapter has explained and presented the various research designs in an effort to lay down the basics for the research. It has presented the main philosophical views behind the research methodologies. Different research perspectives, research types, data collection methods, data collection techniques and data sources were explained. The chapter explains in detail the reasons behind the selection of research methods and techniques for the present study. The next chapter will go on to discuss the issues of sample design (i.e. decision matrices), measuring instruments (i.e. pair-wise comparisons) and data analysis (i.e. consistency tests) details. Furthermore the next chapter presents the review of the theory and literature in the context of fuzzy sets and numbers.

CHAPTER 4: RISK PRIORITY ASSESSMENT

4.1. INTRODUCTION

Offshore terminals and marine ports play an important role in world trade, international logistics and global supply chain management. Their operations are associated with a high level of uncertainty because they operate in a dynamic environment in which hazards may cause possible accidents. This chapter discusses recently emergent RM-related issues taking into consideration the externally and internally driven elements e.g. pure risks (i.e. uncertainty of damage to property by fire, flood or the prospect of premature death caused by accidents) and speculative risks (i.e. risks which are linked directly to the business function, decision making processes and management). To overcome the problem this chapter will propose a generic risk assessment model which is based on a RM framework to priorities and detect the critical hazards that can lead to catastrophic damages to terminals and ports. The proposed model uses a FAHP method to determine the relative weights of the risk factors identified during the offshore terminals and marine ports operations and management. A test case is examined to illustrate the applications of the proposed methods. This can help port professionals and port risk managers develop appropriate strategies and take preventive/corrective actions in later stages for mitigating risks toward a successful offshore terminals' and marine ports' operations and management.

4.2. METHODOLOGY FOR RISK ASSESSMENT IN OFFSHORE TERMINALS AND MARINE PORTS

A generic FAHP-based risk assessment model is proposed for determining and assessing the levels of risk factors. The proposed model is a key part in the RM framework for offshore terminals and marine ports. The schematic diagram of the proposed FAHP-based risk assessment model is illustrated in Figure 4.1.

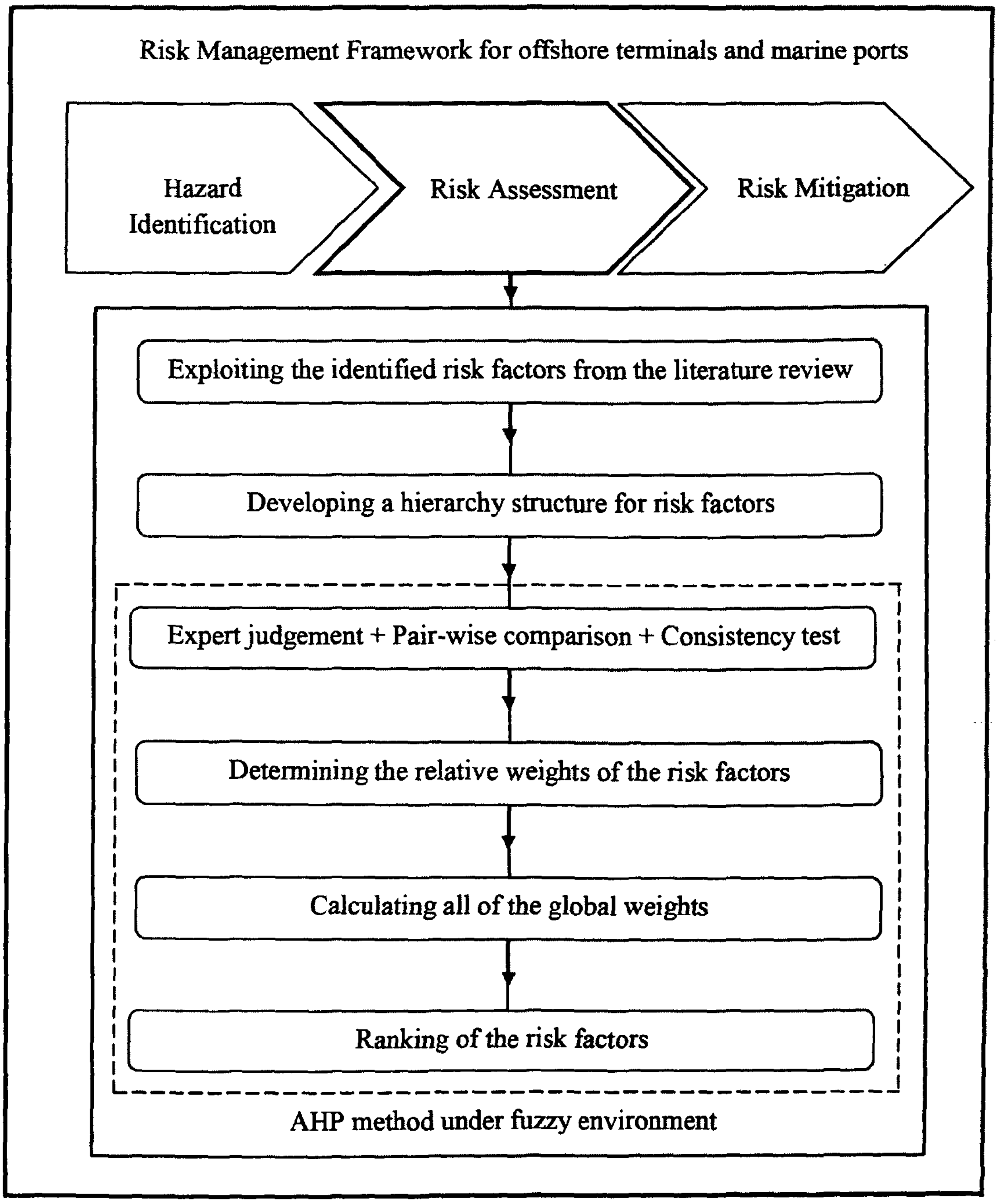


Figure 4.1: A generic Risk Assessment Model for offshore terminals and marine ports

The proposed FAHP-based risk assessment model will be implemented on offshore terminals and marine ports during risk assessment phases via carrying out the following steps:

Step 1: Exploiting the identified risk factors (hazards) in offshore terminals and marine ports. The identified risk factors are obtained through HAZID process.

Step 2: Developing a generic hierarchical structure based on the risk factors obtained in previous step. The risk-based hierarchy is structured in such a way that the title of the "sources of risks and uncertainties in offshore terminals and marine ports'' is the main goal and is placed on the top of the hierarchy labelled main goal. Country and business risks from externally driven environments plus organisational and operational risks from the internally driven environments are placed under Level 0. Sub-risk factors are placed under Level 2 and finally the sub sets of Level 2 subs are gathered under Level 3 risk factors.

Step 3: By use of the experts' judgment and opinions, the significance of the risk factors structured hierarchically in Step 2 (i.e. Level 1, Level 2 and Level 3 risk factors) will be explored. These judgements will be carried out in the form of the pre-defined linguistics variables which have been explained in the previous sections of this chapter. The linguistic variables then will be transformed into the TFNs and will be made ready for the pair-wise comparisons. Moreover a consistency test will be conducted on the comparison matrices in order to ensure that experts' judgements and pair-wise comparisons were reasonable.

Step 4: By use of the experts' judgements and pair-wise comparison matrices the local weights of the risk factors in Level 1, Level 2 and Level 3 will be determined.

Step 5: Determination of global weights for the risk factors in Level 3. The global weights for Level 3 risk factors will be calculated directly by multiplying the local weights of the Level 1, Level 2 and Level 3 risk factors.

Step 6: At the end the risk factors will be ranked directly as per their numerical priorities in order to show their significance.

4.3. RISK ASSESSMENT IN OFFSHORE TERMINALS AND MARINE PORTS

The key phase of any RM framework or cycle is the risk assessment phase to evaluate the identified hazards or risk factors (USCG, 2010; UKHSE, 2010; UNCTAD, 2006; ABS, 2003; IRM, 2002; IMO, 2002; PMSC, 2001; USDOD, 2000; USDOE, 1994 and USNRC, 1986). In this regard ABS (2000) explains that the competence to make sensible decisions is crucial to a successful business scheme. Furthermore in today's complex world, business decisions are rarely straightforward or easy. For this purpose risk assessment is typically applied as an aid to the decision-making process. There are a variety of qualitative and quantitative risk assessment methods which are used for different situations and in various industries. However before carrying out a risk assessment phase there is a need to effectively produce a generic model for the purpose of assessing the identified risk factors (hazards). Haimes (2002) argues if the adage, "To manage risk, one must measure it with appropriate metrics," constitutes the compass for RM, then modelling constitutes the road map that guides the analyst throughout the journey of risk assessment. However risk assessment of offshore terminals and marine ports is a new and challenging task as much of the available data is highly uncertain and vague, and many of the mechanisms may not be fully understood. As a result, a methodical approach is needed to handle quantitative and qualitative data when new knowledge and data become available. In this chapter a Fuzzy AHP method based on Chang's (1996) extent analysis will be used for assessing the identified hazards or risk factors.

4.4. A CATEGORIZATION OF UNCERTAINTIES BY DEVELOPING THE HIERARCHY

Review of a wide range of literature on uncertainty and RM from previous chapters served to identify the specific uncertain components i.e. risk factors. The identified risk factors need to be classified for an efficient assessment as included in the following section.

Many different classifications of risk factors have been developed over the years, however, based on different literatures most of them have considered the source factors (e.g. country, operational, organisational, business etc) as the most important criteria. In addition to the source criteria, there have been other forms of classifying risk factors, which take different perspectives. In this regard based on Balo and Price (2003) it is usual to categorise risk factors into dynamic/static, corporate/individual, internal/external, positive/negative, acceptable/unacceptable and insurable/non-insurable.

As offshore terminals and marine ports are critical logistics infrastructures they are under constant pressure from the externally and internally driven sources of risks and uncertainties. Externally driven sources of risks mean that the basis and root cause of risk factors which are exerted on a specific offshore terminal and marine port is from outside of the port's or offshore terminal's physical sphere. Like country or business risk factors, their original sources are not within the port under debate. For instance a related decree planned and ratified in the Parliament of a country will put the facilities under direct legal responsibility to compel the decree. Another example is business related risk factors e.g. offshore terminals' reliability factors that will lead an offshore terminal customer (oil exporter/importer, shipping company etc) to use the most reliable operators' terminals. Therefore the main root cause of this risk factor that originates from the competition dynamic and created by other operators' terminals can be tracked among external elements. On the other hand for case of the internal sources of risks and uncertainties like operational (safety, human error, pollution) or organisational (management, quality issues, human recourse management) risk factors, their root causes can be tracked within the physical sphere of the nominated facility under analysis.

For the purpose of offshore terminals and marine ports the main goal is to assess the identified risk factors. Based on the above discussion they can be properly classified into the external (e.g. country and business risks risk factors) and internal (e.g. organizational and operational risks risk factors) categories.

In maritime business offshore terminals and marine ports are used by different customers and users (shippers, shipowners, agents, freight forwarders, oil/gas companies, exporters, importers etc) who need to outsource their functions in a safe and reliable port/terminal with cheaper services and hinterland locations. Therefore for a port or an offshore terminal user, a vigilant assessment of target countries in order to decide whether or not to use the intended ports and offshore terminals within those countries is necessary. As it is discussed in the previous chapter country risk factors will cause businesses' unwanted consequence as a result of the uncertain and unexpected governmental policies or actions. Insufficient and incorrect actions and decisions in any country can destabilise the country socially, politically and financially. For example unexpected government policy can have significant effect on port/terminal pricing, taxes on cargo, port/terminal dues, cargo charges etc. Additionally insufficient government actions can exert social pressures on port/terminal and dock workers welfares and as a result it may lead to strike. As another example an oil importer will not use exporters' offshore terminals or petrochemical ports whose country is under United Nations' sanctions for its oil and gas products. Consequently these circumstances will put a port or an offshore terminal user in danger by using products and services of the related ports or offshore terminals. It can be noted that as the origin of the country risk factors which affect a port/offshore terminal are from outside of the port/offshore terminal itself i.e. the country under question, then from this point of view they can be regarded as external sources of risks categories.

During selecting the site of business in any port/offshore terminal their users will make sure that the selected place is the best one for their business applications. For example competitive advantage factors such as port/terminal efficiency or depth of water are factors which a ship-owner of a mega container ship or a very large oil tanker must consider before sending his/her ship to that port or offshore terminal. In any port shippers, freight forwarders, exporters and importers will check the ports' landside accessibility as a competitive advantage factor while transporting their goods and to see if they can use port services through their landside accessibility. Good quality bunkers, stores and repair facilities are other types of competitive factors which port/terminal users will take into consideration before selecting a site for their business. For instance a bad quality bunker will put seaworthiness of a ship under question and may even cause a severe damage to the ships' engines at any moment. Port location, shipping frequency and port's/offshore terminal's reliability are also other factors with which users may gain benefits if the choice is decided through a rational decision making process. As it can be seen this type of selection or business related decision making processes for a port user is not only confined to one port's boundaries. It is comparison of one port for example for its specific services like charges for handling of one container to load or discharge with other ports in vicinity for the same services. Thus again as such risk factors relate to the outside of a port's sphere they will be classified under an external category of the sources of risks and uncertainties for the purpose of offshore terminals' and marine ports' operations and management. Business risk factors have been discussed fully in the previous chapter.

However in terms of internal categories, based on the literature review conducted previously, factors such as organizational risk factors can affect different processes and performance of a port or an offshore terminal. Factors such as performance indicators (e.g. financial, operational and quality performance indicators) allow port/terminal managers to assess their ports and offshore terminals performance, and take corrective decisions and actions to recover the problems accordingly. Mismanagement in a port/terminal and any negligence during human resource management within an offshore terminal or a port are also other types of internally driven sources of risk factors. For example port directors or port security managers play pivotal roles in managing the complex interrelationships of the port users necessary to increase the productivity, while simultaneously generating a safe and secure port environment. For this purpose there is a need for developing a generic hierarchy for understanding the relationship between risk and vulnerabilities in offshore terminals and marine ports, and specific ways in which their users can help to reduce the risk factors associated with those vulnerabilities. Nevertheless paying attention to human resource management is a key factor in managing an organisation like a port. All personnel e.g. pilots, gantry cranes' men, security officers, port state control officers, terminal managers and stevedores must be properly trained, assessed and qualified. Even their health, safety, environmental and security awareness should be continuously investigated and monitored when planning for the future. Organisational structure of the offshore terminals and marine ports must be checked to ensure that adequate links and relationships are established between different departments and sections. By the use of a proper quality management system, sources of uncertainties while loading oil or gas from an offshore terminal or when bunkering in a port environmental and safety aspects must be taken into consideration. Additionally in respect of a product such as dry-docking a ship, consideration must be taken to see if the material used during a repair or overhauling are standard and personnel doing the job are qualified. As a part of quality process, for example, port state control officers under ILO and IMO Conventions can check the safety and living condition of the ships' personnel. Additionally they can check stevedores' work conditions while working on board of the visiting vessels within the related ports or offshore terminals. As it can be seen if anything goes wrong with the ships' personnel or stevedores when working on board it will affect the ports'/terminals' loyalty and its organisation. Customer satisfaction and complaints are also important indicators or elements that can contribute to assessing the quality process of a facility.

Among the other internal sources of risks and uncertainties, source criteria like operational risk factors (e.g. safety, security, pollution, human error etc) are the main sources of the pure risks as it was discussed in Chapters 1 and 2. They can, however, be avoided by deployment of the incentives such as insurance covers. The main aim here is how to eliminate or avoid them from happening in practice professionally. Any type of operational risk factors can have a disastrous effect on operation of a port or an offshore terminal. A large tanker ship entering a harbour may collide with break water at the entrance of a port as a result of a pilot's error. As a matter of fact this will lead to safety problems. It may result in pollution and oil spills, grounding or collision with other vessels or eventually can be a source of fire or explosion that would threaten the safety of the port, other vessels and the tanker ship itself all at the same time. For example in the case of the Sea Empress disaster in Milford Haven mentioned in Chapter 1, 72,000 metric tons of crude oil was released when oil tanker Sea Empress went aground a kilometre of the entrance of Milford Haven in UK. This caused disastrous and devastating impact on the environment (DETR, 2000). Another example which can be referred is the case of the offshore terminal, Bombay High North Platform (2005) in which a crewman on the support vessel Samudra Suraksha injured his finger. Then the decision was taken to transfer him to the Platform for medical attention, in bad weather and high waves where the control of the vessel was lost. The vessel collided with risers on the Platform, causing explosions and eventually destruction of the whole site. 11 people were confirmed dead and 11 people were reported missing. Bombay High North Platform was destroyed, Vessel Samudra Suraksha sunk, one helicopter destroyed, and 100,000 bbl/day production lost for several weeks. After the investigation the key contributor found was the failure to assess risk of routine activities in abnormal conditions (ORD, 2009).

Nowadays many offshore terminals and marine ports face tough governmental security regulations and business efficiency demands. Security has become a compelling essential which many port/terminal users are frustrated with. Maritime businesses and port interests responsible for the movement and storage of cargo, as well as cruise lines and ferry operations responsible for the safe transportation of paying passengers, understand the need for security and have spent a lot of money to enhance their own security after the September 11, 2001 terrorist attacks. New international, national, state, and local laws and regulations were forged in the result of September 11, 2001 which demanded a lot of security compliances in and around port facilities and throughout the maritime industry. In respect of security issues as it is a new challenge the ports' security officers must review relevant government regulations and industry conventions to fully appreciate the standards that most port facilities must develop and adhere to.

Nevertheless by taking into consideration the externally (e.g. country and business risk factors) and internally (e.g. organisational and operational risk factors) driven sources of risks and uncertainties in offshore terminals and marine ports, they cannot be assessed or managed except to be set as a hierarchy of priorities in a complex problem.

Forman and Gass (2001) express, in order to design a hierarchy, that one must set the appropriate levels, which will simplify the solution of the perceived problem. Anderson *et al*, (2008) explain that the first section in AHP is to develop a graphical demonstration of the problem in terms of the main goal, the criteria to be used, and the decision alternatives; such a graph depicting the hierarchy for the problem. For this purpose hierarchies structured hereafter are based on Figure 4.2 which illustrates a basic hierarchical structure for different sources of risks and uncertainties of an organisation or a firm within the industry.

Figure 4.2: Hierarchical structure for sources of uncertainties within a corporation.
Source: Based on Zhang and Patrick (2007)

It can be seen in Figure 4.3, that as the main sources of risks and uncertainties under debate in the thesis are "offshore terminals and marine ports". The same phrase has been attached as a main goal. Then external and internal driven sources of risk classification as discussed in detail in Section 4.4 are positioned in Level 0. Country/business and organizational/operational categories are located under Level 1. Subsets of the country, business, organizational and operational risk factors are under Level 2 and finally subsets of these subsets are categorised under Level 3 risk factors.

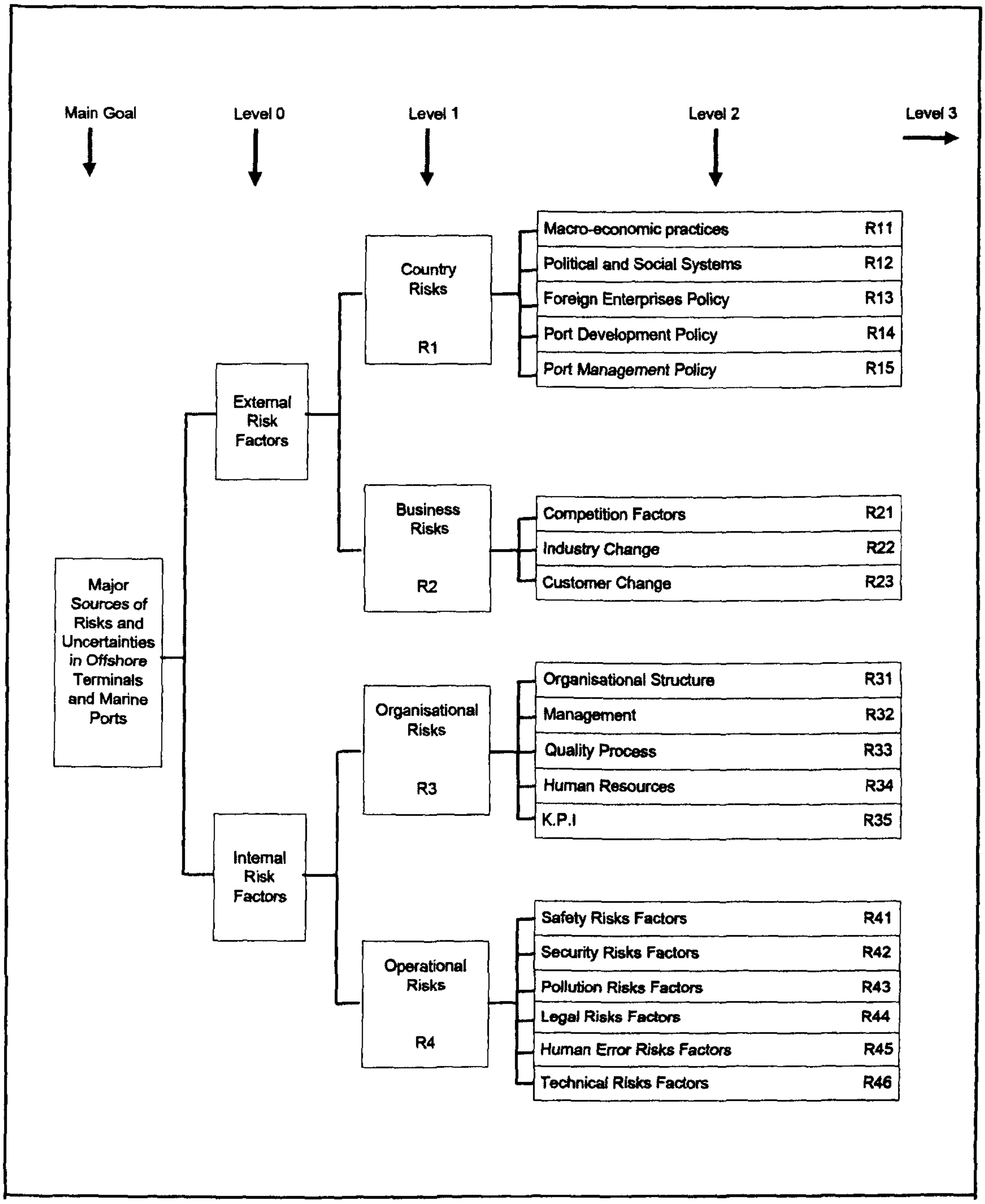


Figure 4.3: Main hieratical structure of risk factors in offshore terminals and marine ports

Figure 4.4: Country risks hierarchy for offshore terminals and marine ports
Source: Tsai and Su (2005)

Figure 4.4: Country risks hierarchy for offshore terminals and marine ports
Source: Tsai and Su (2005)

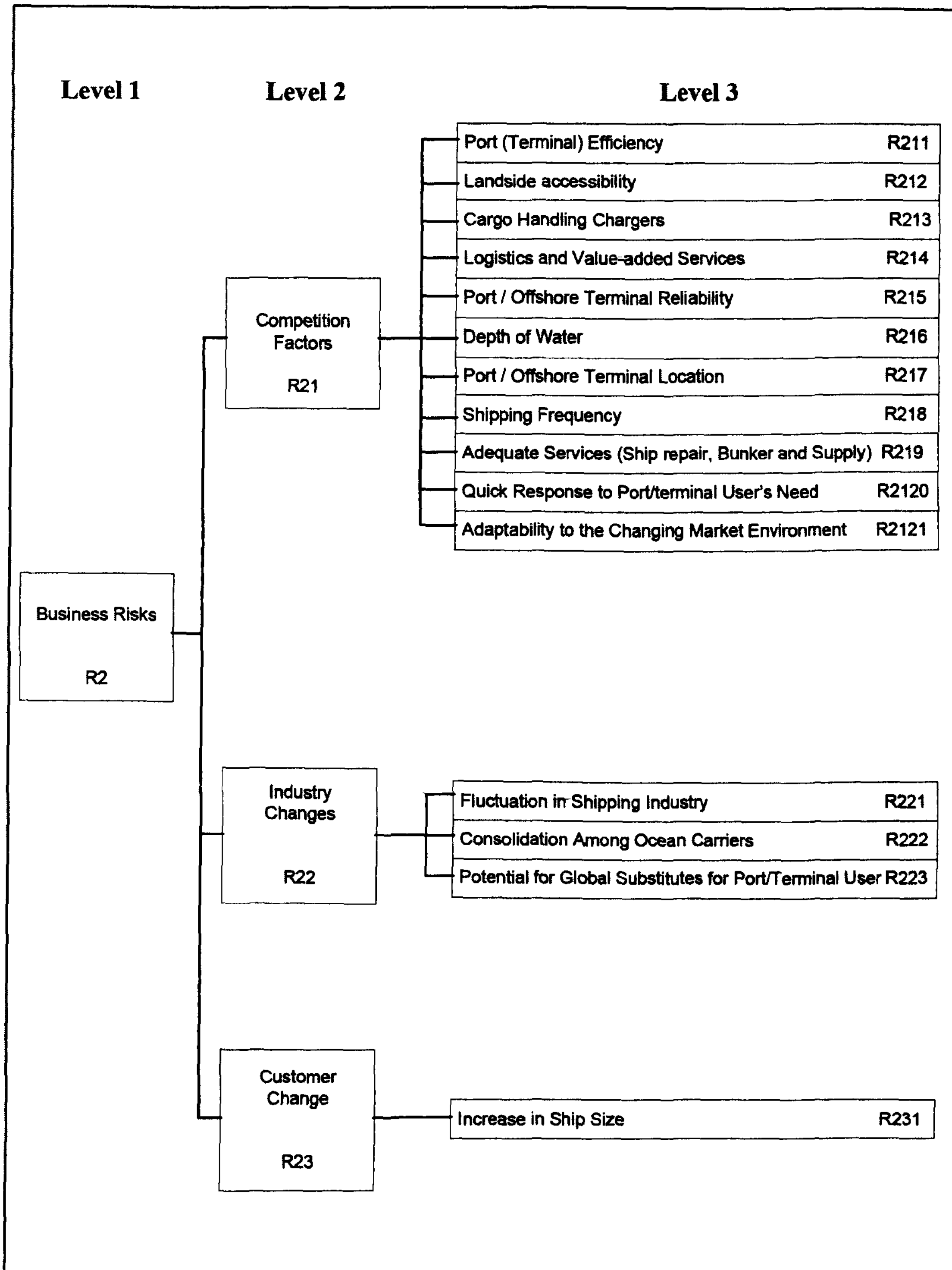


Figure 4.5: Business risks hierarchy for offshore terminals and marine ports

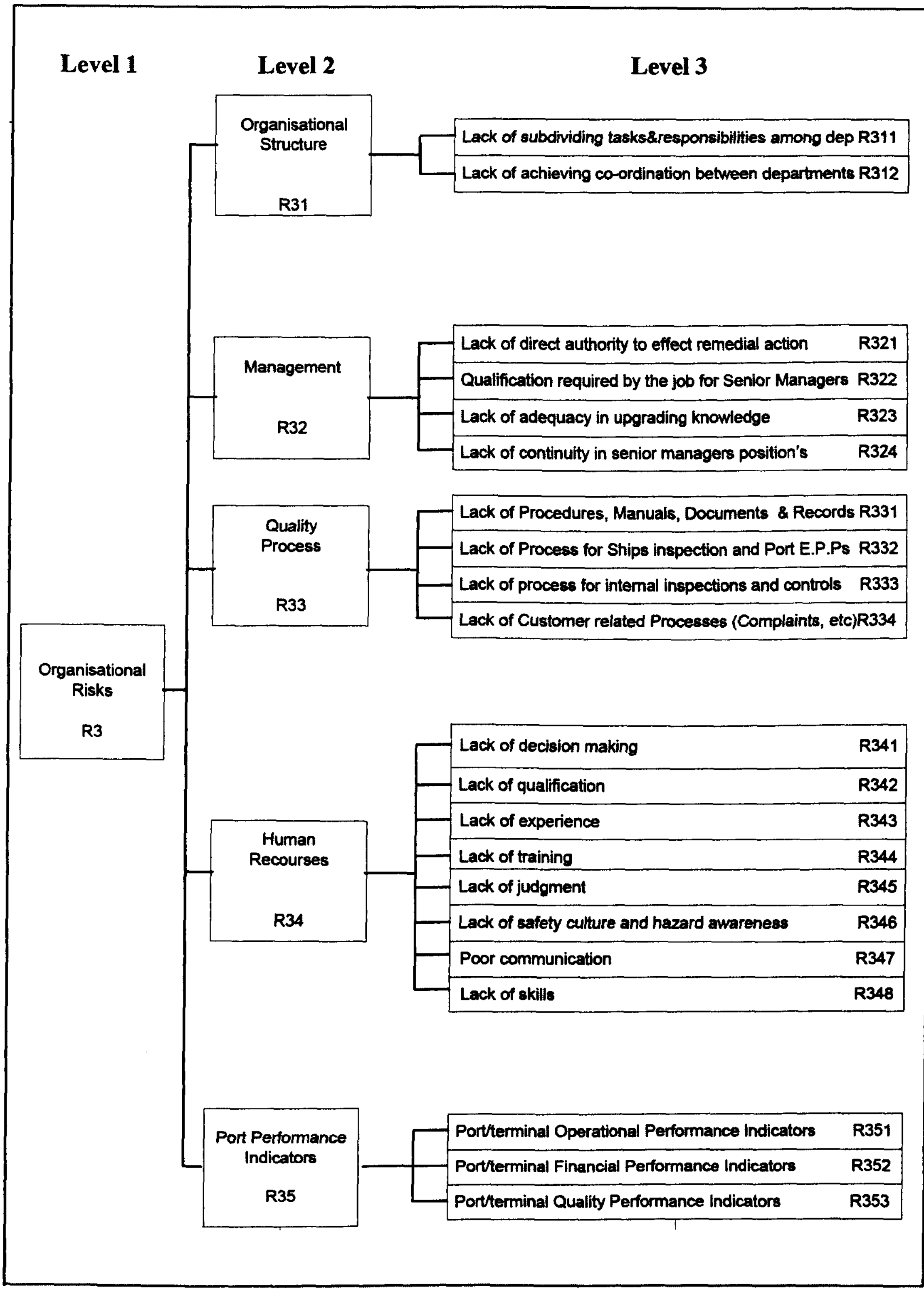


Figure 4.6: Organisational risks hierarchy for offshore terminals and marine ports

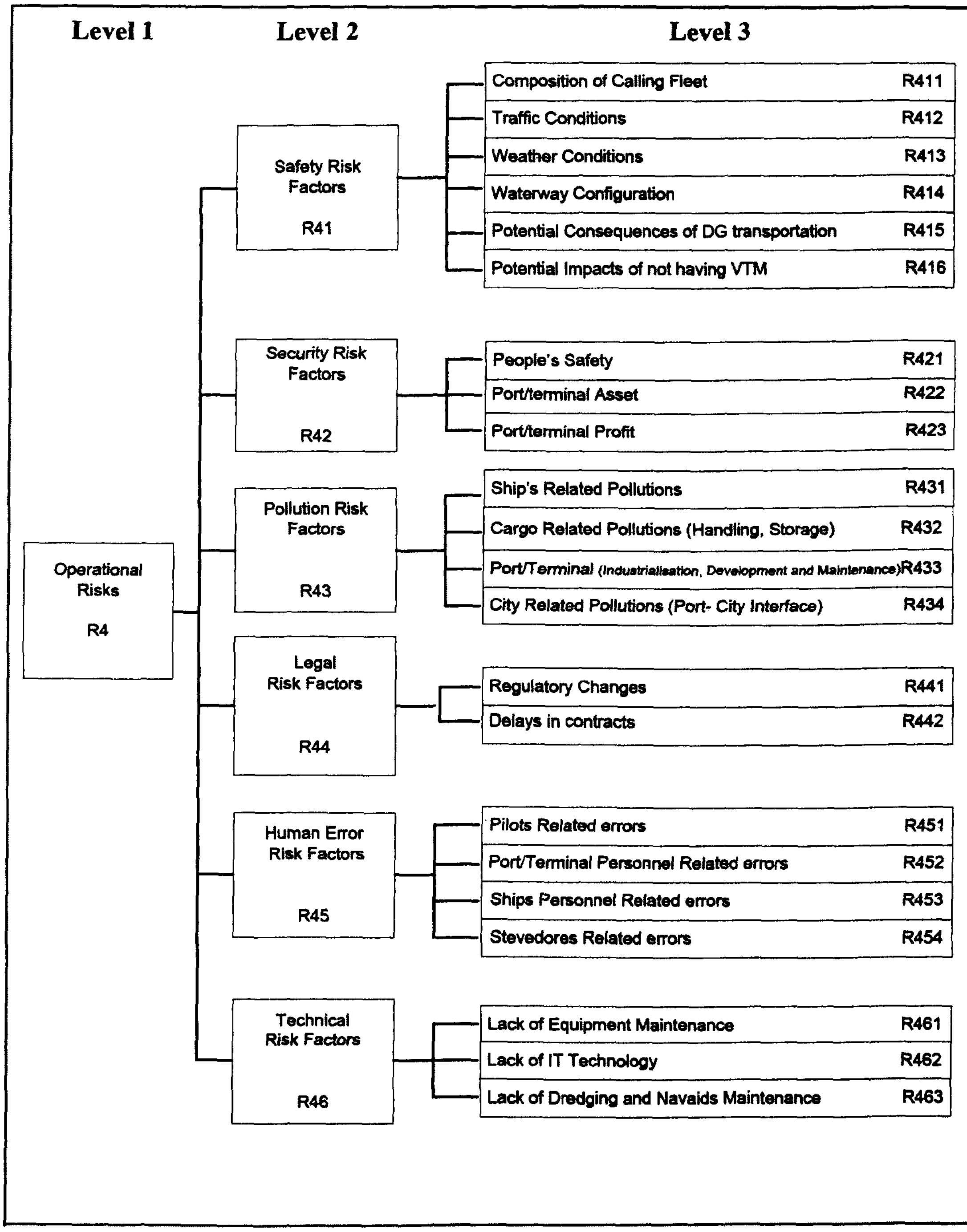


Figure 4.7: Operational risks hierarchy for offshore terminals and marine ports

4.5. DECISION MAKING UNDER UNCERTAINTIES

In solving various real-world decision making problems, it is necessary to handle uncertainties efficiently and effectively. There are some factors which cause uncertainties in decision-making situations. Some of the reasons are problem complexity, ill-posed questions, imprecision in computations, ambiguity in data/knowledge representation, problems in input interpretations, and noise (Keller and Tahani, 1992). This makes the decision making process extremely difficult and therefore there is a need for a systematic and comprehensive approach to support decision making (Saaty, 2001). Rule-based expert systems have been used for handling uncertainties. Generally, the expert systems are based on classical logic and developers need to add special methods for handling uncertainty. Some of the methods used for handling uncertainty in expert systems include heuristic approaches, probability theory, possibility theory and fuzzy logic theory (Murtaza, 2003). Among these methods fuzzy logic offers a more natural way of handling uncertainty. A considerable amount of research work has been performed in the areas of the fuzzy logic process (Takagi and Hayashi, 1991).

4.5.1. Fuzzy logic (sets and numbers)

Originally Fuzzy Set Theory (FST) was introduced by Zadeh (1965) to deal with vagueness of human judgement, which was oriented to the rationality of uncertainty due to ambiguity or vagueness. A major contribution of FST is its potential for demonstrating vague data. A fuzzy set is a set of objects with a range of grades of membership. Such a set is characterised by a membership (characteristic) function, with each object having a membership degree ranging between 0 and 1. The theory also allows mathematical operators and programming to apply to the fuzzy domain. Furthermore a fuzzy set is an extension of a crisp set. Crisp sets only allow full membership or non-membership at all, whereas fuzzy sets allow partial membership (Balli and Korukoglu, 2009).

On the other hand fuzzy numbers are the particular classes of numbers. A fuzzy number is a fuzzy quantity M that corresponds to a generalisation of a real number *r*. Intuitively, M(x) should be a measure of how well M(x) "approximates" *r* (Nguyen and Walker, 2000). A fuzzy number M is a convex normalised fuzzy set. A fuzzy number is characterised by a given interval of real numbers, each with a grade of membership between 0 and 1. It is possible to use different fuzzy numbers according to the situation and in practice triangular and trapezoidal fuzzy numbers are used (Klir and Yuan, 1995). In applications it is often suitable to work with Triangular Fuzzy Numbers (TFNs) due to their computational ease, they are useful in supporting illustration and information processing under a fuzzy environment (Ertugrul and Karakasoglu, 2007). A TFN i.e. $\tilde{M}$ is shown in Figure 4.8.

Figure 4.8: A Triangular Fuzzy Number (TFN), $\tilde{M}$
Source: Based on Chang (1996)

In this section, prior to the exploration of the FAHP method, the rationale for the FST will be briefly reviewed through the following definitions that will be used in this research hereafter. As depicted in Figure 4.8 a FTN is denoted simply as (l, m, u). The parameters l, m and u respectively denote the smallest possible value, the most promising value and the largest possible value that describe a fuzzy event.

A tilde '~' will be placed on top of a character if the character corresponds to a fuzzy set. TFNs are defined by three real numbers, shown simply as (l,m,u). The parameters l, m and u, respectively, signify the smallest possible value, the most promising value, and the largest possible value that describe a fuzzy event (Kaufmann and Gupta, 1985). Their membership functions can be defined as follows:

$$\mu_{\tilde{M}(x)}= \begin{cases} 0, if\ .x \leq l \\ \frac{x-l}{m-l},\ if\ .l < x < m \\ 1, if\ .x = m \\ \frac{u-x}{u-m}, if\ .m < x < u \\ 0, if\ .x \geq u \end{cases} \tag{4.1}$$

Figure 4.9: The intersection between M_1 and M_2
Source: Based on Zadeh (1965) and Chang (1996)

There are various operations on TFNs. However, some of the main operations used in this study are illustrated here. Assume, two positive TFNs $\widetilde{M}_1 = (l_1, m_1, u_1)$ and $\widetilde{M}_2 = (l_2, m_2, u_2)$ are real numbers as are depicted in Figure 4.9. The distance measurement $d(\widetilde{M}_1, \widetilde{M}_2)$ is identical to the Euclidean distance (Chen, 2000). Then under fuzzy environments their basic operations such as addition i.e.$\oplus$, multiplication i.e. $\otimes$ and their inverse can be depicted as follows (Yang and Hung, 2007):

$$\widetilde{M}_1 \oplus \widetilde{M}_2 = (l_1, m_1, u_1) \oplus (l_2, m_2, u_2) = (l_1+l_2, m_1+m_2, u_1+u_2) \qquad (4.2)$$

$$\widetilde{M}_1 \otimes \widetilde{M}_2 = (l_1, m_1, u_1) \otimes (l_2, m_2, u_2) = (l_1 \times l_2, m_1 \times m_2, u_1 \times u_2) \qquad (4.3)$$

$$\widetilde{M}_1^{-1} = (l_1, m_1, u_1)^{-1} \approx (1/u_1, 1/m_1, 1/l_1) \qquad (4.4)$$

Other algebraic operations such as change of sign and subtraction with fuzzy numbers can be found in (Zimmermann, 1996 and Kahraman, 2001).

4.6. ANALYTICAL HIERARCHICAL PROCESS (AHP)

One commonly used method for deciding among the complex criteria structure in different levels is Analytic Hierarchy Process (AHP), which was developed by Saaty (1980). The AHP is based on the subdivision of the problem in a hierarchical form. In reality, the AHP helps to put in order the reasonable analysis of the problem by dividing it into its single elements; the analysis then supplies an aid to the decision makers who, making several pair-wise comparisons, can appreciate the influence of the considered elements in the hierarchical structure. AHP can also give a preference list of the considered alternative solutions (Bentivegna *et al*, 1994; Roscelli, 1990; Saaty, 1980; Saaty and Vargas, 1990). As explained in Anderson *et al*, (2008) the first phase in AHP is to develop a graphical illustration of the problem in terms of the main goal, the criteria to be used, and the decision alternatives. This graph illustrates the hierarchy for the problem. Figure 4.2 previously showed a sample of a risk-based hierarchy for different sources of risks and uncertainties of an organisation or a firm to be used in any industry.

At the next stage, based on Anderson *et al*, (2008) the decision maker indicates a preference for each decision alternative based on each criterion. A mathematical process is used to synthesize the information on the relative importance of the criteria and the preferences for the decision alternatives to provide an overall priority ranking of the decision alternatives.

To set up priorities using AHP, preferences between alternatives are determined by making pair-wise comparisons. These comparisons are made using a preference scale (Taha, 2003). The standard preference scale used for AHP is 1 to 9 scale which lies between "equal importance" and "extreme importance" (Sarkis and Talluri, 2004). In AHP, Saaty (1980) suggested a scale of relative importance from 1 to 9 for making subjective pair-wise comparisons shown in Table 4.1.

Table 4.1: 9-point intensity of relative importance scale

Source: Based on Saaty (2008)

Therefore, if the importance of one factor with respect to the second is given, then the importance of the second factor with respect to the first is the reciprocal. Ratio scale and the use of verbal comparisons are used for weighting quantifiable and non-quantifiable elements (Pohekar and Ramachandran, 2004).

Nevertheless in order to determine the priorities as Anderson *et al*, (2008) explained there is a need to construct a matrix of the pair-wise comparison ratings as depicted in Equation 4.5. As Torfi *et al* (2010) discussed a comparison matrix involves the comparison in pairs of the elements of the constructed hierarchy. The aim is to set their relative priorities with respect to each of the elements at the next higher level.

$$A = \begin{array}{c} \\ C_1 \\ C_2 \\ \vdots \\ C_n \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nn} \end{bmatrix} \end{array} \quad (4.5)$$

The factors $\{x_{ij}\}$ can be interpreted as the degree of preference of *i*th criterion over *j*th criterion. It appears that the weight determination of criteria is more reliable when using pair-wise comparisons than obtaining them directly, because it is easier to make a comparison between two attributes than make an overall weight assignment.

Subsequently as is explained before using the pair-wise comparison matrix, there will be a need to calculate the priority of each alternative in terms of its contribution to the overall goal. This aspect of AHP is referred to as synthesization. The exact mathematical procedure required to perform synthesization is beyond the scope of this chapter. However, Anderson *et al*, (2008) and Karahalios (2009) argue that the following three-section procedure provides a good approximation of the synthesization result:

(1) Sum the values in each column of the pair-wise comparison matrix.
(2) Divide each element in the pair-wise comparison matrix by its column total; the resulting matrix is referred to as the normalized pair-wise comparison matrix.
(3) Compute the average of the elements in each row of the normalized pair-wise comparison matrix; these averages provide the priorities for the criteria in order to rank the alternatives.

Nevertheless a key section in AHP is making several pair-wise comparisons as previously described. Based on Saaty (1980) an important consideration in this process is the consistency of the pair-wise judgements provided by the decision maker. Based on Saaty (2008) and Karahalios (2009) consistency is fully explained as follows:

The basis of the AHP is the completion of an $n \times n$ matrix (x_{ij}) at each level of the decision hierarchy. This matrix A is of the form $a_{ij} = 1/x_{ij}$, $x_{ij} > 0$, where x_{ij} is an approximation to the relative weights (w_i/w_j) of the n alternatives under consideration (Harker, 1987). Given the $n(n-1)/2$ approximations to these weights which the decision maker supplies when completing the matrix, the weights $w = (w_i)$ are found by solving the following eigenvector problem (Saaty, 1977):

$$A\,w = \lambda_{max}\,w \tag{4.6}$$

where λ_{max} is the principle eigenvalue of the matrix A.

Saaty (1977) used the Perron root theorem, which states that there is one largest real positive eigenvalue for the matrix A with positive entries whose associated eigenvector is the vector of weights. This unique vector is normalized by having its entries sum to a unit. Thus, the activities in the lowest level of a hierarchy have a vector of weights with respect to each criterion in the next level derived from a matrix of pair-wise comparisons with respect to that criterion (Saaty, 1994). In an arbitrary random reciprocal matrix, A there exist some i, j and k for which $x_{ij}x_{jk} \neq x_{ik}$. Then the average of normalized columns of the reciprocal matrix provides a good estimate of the eigenvector (Vargas 1982):

$$w_i = \frac{1}{n}\sum_{j=1}^{n} \frac{x_{ij}}{\sum_{k=1}^{n} x_{kj}} \; ; \qquad \text{where } i = 1, 2, \ldots, n \tag{4.7}$$

When the numerous pair-wise comparisons are evaluated, some degree of inconsistency could be expected to exist in almost any set of pair-wise comparisons. The AHP method provides a measure of the consistency for pair-wise comparisons by introducing the Consistency Index (CI) and Consistency Ratio (CR), which can be calculated by using Equations 4.8 and 4.9 (Ung *et al*, 2006). The λ_{max} is the maximum average of the values or the maximum eigenvalue of an $n \times n$ comparison matrix and is calculated by Equation 4.10 (Vargas, 1982). RI is the random index for the matrix size, n and depends on the number of items being compared and is shown in Table 4.2 (Saaty, 1994). If CR is valued less than or equal to 0.1 then a consistency is indicated and the pair-wise comparisons are reasonable. However, this value is arbitrary and has not been proved mathematically. This is the reason that Saaty suggested that CR value could be near 0.2 and any attempt to reduce this value will not necessarily improve the judgement. Furthermore, in real life it is often very difficult to achieve this value mainly due to the disagreement of experts (Dadkhah and Zahedi, 1993; Wedley, 1993).

$$CI=\frac{\lambda max - n}{n-1} \tag{4.8}$$

$$CR=\frac{CI}{RI} \tag{4.9}$$

$$\sum_{i=1}^{n} x_{ij}w_i=\lambda_{max}w_j \; ; \qquad \text{where } i=1, 2, \ldots, n \tag{4.10}$$

Table 4.2: Average random index value

Source: Based on Saaty (1994)

Saaty (1980) proposed AHP as a decision aid to help solve unstructured problems in economics, social and management sciences. Among the different contexts in which the AHP can be applied, mention can be made of the creation of a list of priorities, the choice of the best policy, the optimal allocation of resources, the prevision of results and temporal dependencies, the assessment of risks and planning (Saaty and Vargas, 1990).

Although the AHP is supposed to capture the expert's knowledge, the traditional AHP still cannot really reflect the human thinking style (Kahraman *et al*, 2003). As Kulak and Kahraman (2005) explain in most of the real-world problems, some of the decision data can be precisely assessed while others cannot. They also explain humans are unsuccessful in making quantitative predictions, whereas they are comparatively efficient in qualitative forecasting. Furthermore Leung and Chao (2000) also have emphasised that in essence, the uncertainty in the preference judgments will give rise to uncertainty in the ranking of alternatives as well as difficulty in determining consistency of preferences.

For the purpose of risk assessment there are many methods such as AHP (Saaty, 1980), set theory (Ferreiros, 2007), graph theory (Wanger and Neshat, 2010), risk matrix (Marszal and Scharpf, 2002), etc which can be used for prioritisation of risk factors i.e. criteria. They enable the users to find relative weights of the risk factors and eventually to rank them in order to find the most significant ones. Among these methods AHP is probably the most simple, calculations are easy and its advantage is not only to determine relative weights of the risk factors but also it can be used as a decision making tool to select the best alternatives for different criteria. In a very brief sentence AHP method it cannot be only used to determine relative weights of the risk factors and rank them but also is a very useful and simple decision making tool.

As Wang and Chen (2007) express the traditional AHP method is problematic in that it uses an exact value to express the decision maker's opinion in a comparison of alternatives. Moreover the AHP method is often criticized due to its use of unbalanced scale of judgments and its inability to adequately handle the inherent uncertainty and imprecision in the pair-wise comparison process (Deng, 1999).

To overcome all these shortcomings, FAHP was developed for solving the hierarchical problems. Decision makers frequently find that it is more convincing to give interval judgments (i.e. ranges of values) than fixed value judgments. This is because decision makers are not usually capable of explicitly presenting their preferences in a comparison process (Kahraman *et al*, 2003).

4.7. FUZZY ANALYTICAL HIERARCHICAL PROCESS (FAHP)

The FAHP method can be observed as an advanced analytical technique developed from the traditional AHP. In other words FAHP is a synthetic extension of classical AHP method when fuzziness of the decision maker is considered. Despite the convenience of AHP in handling both quantitative and qualitative criteria of multi-criteria decision making problems based on decision maker's judgments, fuzziness and vagueness existing in many decision-making problems may contribute to the inaccurate judgments of decision makers in conventional AHP approaches (Bouyssou *et al*, 2000). Many researchers have studied the fuzzy AHP which is the extension of Saaty's theory in 1980, confirming that fuzzy AHP shows a relatively more sufficient description of this kind of decision making process compared to the traditional AHP methods (Ozdagoglu and Ozdagoglu, 2007).

Moreover in multipart systems, the experience and judgment of humans are represented by linguistic and vague patterns. Therefore, a much better representation of this linguistics can be developed as quantitative data; this type of data set is then refined by the evaluation methods of FST. On the other hand, the AHP method is mainly used in nearly crisp (non-fuzzy) decision applications and creates and deals with a very unbalanced scale of judgment. Therefore, the AHP method does not take into account the uncertainty associated with the mapping (Cheng *et al*, 1999). The AHP's subjective judgment, selection and preference of decision-makers have great influence on the success of the method. The conventional AHP still cannot reflect the human thinking style. Avoiding these risks on performance, the fuzzy AHP i.e. a fuzzy extension of AHP, was developed to solve the hierarchical fuzzy problems (Ozdagoglu and Ozdagoglu, 2007).

There are many fuzzy AHP methods proposed by various authors. The earliest work in fuzzy AHP appeared in Van Laarhoven and Pedrycz (1983) which compared fuzzy ratios described by triangular membership functions. Buckley (1985) determined fuzzy priorities of comparison ratios whose membership functions are trapezoidal. They extended Saaty's AHP (1980) to deal with the imprecision and subjectivity of the pair-wise comparison process using fuzzy utilities represented by fuzzy numbers. Their fuzzy utilities need to be ranked to prioritise the concerned alternatives. This ranking method can be quite complex and may produce unreliable results (Chan and Kumar, 2007).

Mikhailov (2004) proposed a fuzzy preference programming method to derive optimal crisp priorities, which are obtained from fuzzy pair-wise comparison judgments based on α-cuts decomposition of the fuzzy judgments into a series of interval comparisons. However, although fuzzy preference programming method claimed its superiority over some of the existing fuzzy prioritisation methods the mathematical complexity involved may restrict its practicability (Dagdeviren and Yuksel, 2008).

Chang (1992, 1996) introduced a new extent analysis approach for the synthetic extent values of the pair wise comparison for handling fuzzy AHP. The proposed method with extent analysis is simple and easy to implement to prioritise decision variables as compared with the conventional AHP (Chan and Kumar, 2007).

Chang (1996) introduced a new approach for handling FAHP, with the use of triangular fuzzy numbers for pair-wise comparison scale of FAHP, and the use of the extent analysis method for the synthetic extent values of the pair-wise comparisons. Chang *et al*, (1999) discussed their proposed theory and methodology on the extent analysis and applications of the FAHP.

Kahraman *et al*, (2003) utilised Chang's extent analysis in their FAHP methodology for the purpose of the multi-criteria supplier selection problems. By using the extent analysis in their study Kahramana (2004) provided a multi-attribute comparison of catering service companies in Turkey. Ertugrul and Karakasoglu (2006) proposed the use of extent analysis in their FAHP to select the best supplier for a textile firm in Turkey. Chan and Kumar (2007) used the FAHP based on extent analysis to tackle the different decision criteria like cost, quality, service performance and supplier's profile including the risk factors involved in the selection of a global supplier in their business scenario. The extent analysis was used by Dagdeviren and Yuksel (2008) for developing a FAHP model to determine the level of Faulty Behaviour Risk (FBR) in work systems.

Naghadehi *et al*, (2009) used extent analysis to develop a fuzzy model to select the best possible underground mining method. Whilst doing so they took subjective judgments of decision makers into their consideration. FAHP was used in determining the weights of the criteria by decision makers. In their study rankings of the methods were determined by AHP. Another attempt Celik *et al*, (2009) applied the FAHP methodology, based on extent analysis for shipping registry selection in the Turkish maritime industry. Balli and Korukoglu (2009) used the extent analysis in the operating system selection while using FAHP and Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) methods. Finally, Ertugrul and Karakasoglu (2009) exploited the extent analysis and used the FAHP and TOPSIS methods in their study for performance evaluation of Turkish cement firms.

For the purpose of this research the extent FAHP is utilised, which was originally introduced by Chang (1996). Let X = $\{x_1, x_2, x_3, \ldots, x_n\}$ an object set, and G = $\{g_1, g_2, g_3, \ldots, g_n\}$ be a goal set. Each object is taken and extent analysis for each goal performed respectively. Therefore, m extent analysis values for each object can be obtained, with the following signs:

$$\tilde{M}_{gi}^{1}, \tilde{M}_{gi}^{2}, \ldots\ldots\ldots\ldots\tilde{M}_{gi}^{m}, \qquad i = 1, 2, \ldots\ldots, n,$$

where $\tilde{M}_{gi}^{j}$ $(j = 1, 2, \ldots, m)$ are TFNs. The sequences of Chang's analysis can be given in the following sections (Chang, 1996):

Firstly: The value of fuzzy synthetic extent with respect to the i th object is defined as:

$$S_i = \sum_{j=1}^{m} \tilde{M}_{gi}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} \tilde{M}_{gi}^{j} \right]^{-1}; \tag{4.11}$$

To obtain $\sum_{j=1}^{m} \tilde{M}_{gi}^{j}$, perform the fuzzy addition operation of m extent analysis value for a particular matrix such that:

$$\sum_{j=1}^{m} \tilde{M}_{gi}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j \right) \tag{4.12}$$

and to obtain $\left[\sum_{j=1}^{n}\sum_{j=1}^{m}\tilde{M}_{gi}^{j}\right]^{-1}$, perform the fuzzy addition operation of

$\tilde{M}_{gi}^{j}$(j= 1, 2,..., m) values such that:

$$\sum_{i=1}^{n}\sum_{j=1}^{m}\tilde{M}_{gi}^{j} = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i\right) \tag{4.13}$$

and then compute the inverse of the vector above, such that:

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m}\tilde{M}_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right) \tag{4.14}$$

Secondly: As shown in Figure 4.8 $\tilde{M}_1 = (l_1, m_1, u_1)$ and $\tilde{M}_2 = (l_2, m_2, u_2)$ are two TFNs, the degree of possibility of $\tilde{M}_2 = (l_2, m_2, u_2) \geq \tilde{M}_1 = (l_1, m_1, u_1)$ defined as:

$$V(\tilde{M}_2 \geq \tilde{M}_1) = \sup_{y \geq x}\left[min\left(\mu_{\tilde{M}_1}(x), \mu_{\tilde{M}_2}(y)\right)\right] \tag{4.15}$$

and can be equivalently expressed as follows:

$$V(\tilde{M}_2 \geq \tilde{M}_1) = hgt\left(\tilde{M}_1 \cap \tilde{M}_2\right) = \mu_{\tilde{M}_2}(d) \tag{4.16}$$

$$= \begin{cases} 1, & \text{if} \quad m_2 \geq m_1 \\ 0, & \text{if} \quad l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & \text{otherwise} \end{cases} \tag{4.17}$$

As shown previously Figure 4.9 illustrates Equation 4.17 where d is the ordinate of the highest intersection point D between μ_{M_1} and μ_{M_2}. To compare $\tilde{M}_1$ and $\tilde{M}_2$, we need both the values of: "$V(\tilde{M}_1 \geq \tilde{M}_2)$" and "$V(\tilde{M}_2 \geq \tilde{M}_1)$"

Thirdly: The degree of possibility for a convex fuzzy number to be greater than k convex fuzzy $\widetilde{M}_i$ (i=1, 2, k) numbers can be defined by:

$$V(\widetilde{M} \geq \widetilde{M}_1, \widetilde{M}_2, \ldots \widetilde{M}_k) = V[(\widetilde{M} \geq \widetilde{M}_1) \text{ and } (\widetilde{M} \geq \widetilde{M}_2) \text{ and} \ldots \text{and } (\widetilde{M} \geq \widetilde{M}_k)]$$

$$= \min V(\widetilde{M} \geq \widetilde{M}_i), \quad i = 1,2,3,\ldots,k \tag{4.18}$$

Assume that $d(A_i) = \min V(S_i \geq S_k)$ for k = 1,2,…,n; k ≠ i. Then the weight vector is given by:

$$W' = (d'(A_1), d'(A_2), \ldots \ldots d'(A_n))^T \tag{4.19}$$

where A_i is *i*th element and $d'(A_1), \ldots, d'(A_n)$ are priority weights calculated by Equation 4.18 before their normalisation.

Fourthly: Via normalisation, the normalised weight vectors are:

$$W = (d(A_1), d(A_2), \ldots \ldots, d(A_n))^T \tag{4.20}$$

where W is a non-fuzzy number.

In this chapter, it has been decided to use Chang's extent analysis method because the sections of this approach are easier than the other fuzzy AHP approaches. This method uses the TFNs as a pair-wise comparison scale for deriving the priorities of the factors (i.e. risks) and sub-factors (i.e. sub-risks). In addition TFNs are used for pair-wise comparison matrices. The rationale for using a TFN is that it is instinctively simple for the decision makers to use and compute. Furthermore, models using TFNs have produced to be a successful way to formulating decision problems where the existing information is subjective and inaccurate (Zimmerman, 1996; Chang *et al*, 2002; Kahraman *et al*, 2004 and Chang *et al*, 2007).

Experts usually use the linguistic variable to assess the importance of a criterion over the other criterion or even to rate the alternatives with respect to various criteria. Table 4.3 illustrates the idea of the Fuzzy Multi-Attribute Criteria Decision-making (FMACD) and it has been intentionally transformed the existing linguistic values to TFNs i.e. Equal, Weak, Fairly Strong, Very Strong, Absolute along with their intermediate values between them. The purpose of the transformation process is two-fold: firstly to illustrate the proposed FMACD method and secondly to benchmark the empirical results using other precise value methods in the later analysis (Yang, 2007). Moreover Ma *et al*,

(2007) and Karahalios (2009) highlighted the following issues when using linguistic variables:

(1) Experts need to select linguistic terms for presenting their opinions by their preference. It is not demanded that all experts must use the same linguistic terms.
(2) It is not required for all linguistic terms to be placed symmetrically and to have total order. Therefore experts and decision makers have more independent right to present their opinions.
(3) Each linguistic term should be treated as a whole and the only concern is on its determinacy and consistency.

Among the commonly used fuzzy numbers, triangular and trapezoidal fuzzy numbers are likely to be the adoptive ones due to their ease in modelling easy interpretations. Ross (1985) and Anoop *et al* (2006) explain it is known that for engineering applications, to reduce the computational complexity, fuzzy sets with triangular or trapezoidal form are most commonly used. Both triangular and trapezoidal fuzzy numbers are applicable to the present study; however, this study uses TFN for FAHP application due to its easiness in use. In addition, modelling using TFNs has demonstrated to be an effective way for formulating decision problems (Chang and Yeh, 2002; Chang, Chung, and Wang, 2007; Kahraman, Beskese, and Ruan, 2004; Zimmerman, 1996).

In practical applications, the triangular form of the membership function is used most often for representing fuzzy numbers (Ding and Liang, 2005; Kahraman *et al*, 2004; Karsak and Tolga, 2001; Xu and Chen, 2007). TFN can adequately represent the mentioned fuzzy linguistic variables, thus, it is used for the analysis hereafter. As is depicted in Table 4.3, TFNs: N_1, N_3, N_5 and N_9 are used to represent the pair-wise comparison of decision variables from "Weak Strong'' to "Absolute'', respectively and TFNs N_2, N_4, N_6, N_8 represent the middle preference values between them. Figure 4.10 shows the membership functions of the TFNs, $N_i = (l_i, m_i, u_i)$, where i =1, 2, ..., 9 and l_i, m_i, u_i are the lower, middle and upper values of the fuzzy number N_i respectively (Chan and Kumar, 2007).

During the calculations whenever it is supposed to carry out a pair-wise comparison between the same criterion e.g. to compare criterion C_1 with C_1, C_2 with C_2 etc obviously the result is equal to 1 in which its converted TFN will be (1,1,1). Figure 4.10 shows the level of consistency that exists among the values derived from Table 4.3. In this research intermediate values also will be used hereafter.

Table 4.3: Linguistic Values and TFNs.

Source: Adopted from Chan and Kumar (2007)

Figure 4.10: Fuzzy triangular membership functions.
Source: Adopted from Chan and Kumar (2007)

As stated in Zhao and Govind (1991) in order to defuzzify the TFNs with the use of the techniques developed by Sugeno in 1985 it is required to add together their converted linguistics' variables and then divide them by three in case of the triangular numbers to get their average (i.e. centre of area defuzzification technique). For the fuzzy numbers a defuzzification process follows to obtain crisp numbers. Based on Wang and Parkan (2006) and Karahalios (2009) the method to calculate the crisp number for a TFN, is to compute the centre of the fuzzy number's triangular area shown in Figure 4.11.

Figure 4.11: The Defuzzification of a TFN
Source: Based on Wang and Parkan (2006) and Karahalios (2009)

As different experts have different impacts on the final decisions and results i.e. global weights of the risk factors, logically these weights can be changed by the experts, on the basis of their experience, knowledge and expertise (Zeng *et al*, 2007). Moreover absolute impartiality of expert knowledge is difficult to achieve but an important consideration in the selection of experts is whether to use a heterogeneous group of experts (e.g. both scientists and workers) or a homogenous group of experts (e.g. only scientists). The effect of differences in personal experience on expert judgement is assumed to be smaller in homogenous group compared to a heterogeneous group. A heterogeneous group of experts can have an advantage over a homogenous group through considering all possible opinions. However, criteria to identify experts are based on (1) a person's period of learning and experience in a specific domain of knowledge, thus influencing his or her judgmental and analytical behaviour, and (2) the specific circumstances in which experience is gained, e.g. in theoretical or practical circumstances (Ford and Sterman, 1998) and Karahalios (2009). Therefore different experts will have different weighting factors in the calculations during pair-wise comparisons.

4.7.1. Procedure for developing questionnaire survey and selecting experts

A variety of text books and recommended guidelines have been reviewed before the construction of the questionnaire survey. From these sources three important issues were discovered:

a) The questions in a survey should be simple, clear and appropriate for the level of the participants i.e. experts (Houtkoop-Steenstra, 2000).
b) The personal details of participants such as education and age may reveal different schools of thought (Bradburn and Sudman, 1979).
c) The structure of a questionnaire should be developed in different parts each targeting a part of the research goals (Frazer and Lawley, 2001).

A sample copy of this questionnaire is shown in Appendix I. Its aim is to collect experts' opinions with regard to the importance of the risk factors affecting offshore terminals' and marine ports' operations and management.

As discussed in Chapter 3, section 3.3.3 the questionnaire was constructed in twenty three parts each one referring to a part of the hierarchical structures shown for Level 1, 2 and 3 risk factors in figures depicted in Section 4.4. In the first section of each part personal details of the experts were included in order to verify their age, academic and industrial background. These data can be used afterwards for the evaluation of each expert's proficiency. The second section of each part is asking from each expert to evaluate in a scale of ten numbers the predefined linguistic terms including intermediate numbers and equal value as can be used for experts' everyday life. These linguistic terms are used by the experts in their answers in the rest of the questionnaire. The third section of each part of the questionnaire included example questions concerning the expertise of the experts in the industry. The expert should choose a set of pair- wise comparison to indicate the extent with which a risk factor is more important than another in a pair. The fourth section of each part is a matrix to be duly marked as per experts' judgements. Finally these matrices will be used by the researcher to collect, calculate and analyse data gathered in later stages.

For the purpose of this research all questionnaire survey forms were made in A4 papers and then they were sent to the nominated experts in Iran in the form of attachments to emails. It took near two and half months to obtain feed backs from experts as they were very busy with their managerial tasks. To carry out an optimum expert judgement in this chapter, six experts have been selected to carry out the judgement process in order to test the proposed model, methodology and the illustrated hierarchies.

All experts have their Bachelor i.e. BSc and Master i.e. MSc degrees in maritime related fields. In addition each has served as a harbour pilot previously for no less than 5 years in different Iranian ports and offshore terminals namely ports of Shahid Rejaie, Bandar Mahshahr and Assaluyeh along with offshore terminals of Cyrus, Soroosh and Lavan in Persian Gulf. Additional information in respect of the mentioned offshore terminals and marine ports are available in MDB and PMO (2011). Each expert has near 15 years' experience on offshore terminals' and marine ports' operations and management. The experts had different managerial positions in different operational fields (port administration/harbour and offshore authorities; marine Quality, Health, Safety, Environmental and Security departments; offshore oil and gas explorations; emergency management units; port and offshore terminal development; commercial, legal and insurance departments) in Iran.

The main factor in selecting these experts was based on their expertise that they have contributed in the fields related to the risk factors as illustrated in Figure 4.3. For this reason these experts will have equal weights in respect of each other regarding the comparison matrices. The experts were asked to compare the significance of the provided risk factors with each other.

4.8. TEST CASE

For the purpose of this research and in order to justify the proposed methodology for risk assessment of offshore terminals and marine ports the following test case will be conducted.

Now with the use of experts' judgments and the introduced FAHP method, the local and global weights for all of the risk factors will be calculated in this section. These calculations are carried out in fulfilment of the discussed steps of the generic risk assessment model introduced in this chapter. Final results are shown in Tables 4.8, II.19, II.20 and II.21. For the purpose of this section as shown in Tables 4.4, 4.5, 4.6 and 4.7 only comparison matrices for Level 2 risk factors have been calculated. Calculations for the rest of the eighteen pair-wise comparison matrices for Level 3 risk factors are available in Appendix II. Furthermore, since experts have decided to equally distribute the weights among the risks factors associated in Level 0 shown in Figure 4.3, therefore in this regard their relative weight for each risk factor is 0.25 and this is used during the calculations, because it has no effect on global weights of the Level 3 risk factors.

Nevertheless before carrying out the calculation hereafter and as it was discussed previously in Section 4.6 of this chapter an important consideration which should be taken into account during the pair-wise comparision is the consistency of pair-wise judgments provided by the decision makers. In addition also as it was discussed if CR i.e. Consistency Ratio become less than 0.1 in a specific matrix then pair-wise comparision for the matrix under calculations can be considered reasonable. In this regard as the calculations here in this research are based on the FAHP method, before carrying out the consistency tests it is necessary to defuzzify the TFNs in order to obtain the crisp values. The procedures for consistency tests and defuzzifications have been explained before in Sections 4.6 and 4.7. Although the exact and full mathemetical computation of the consistency ratio is beyond the scope of this chapter, an approximation of the ratio can be obtained with little difficulty. However all the pair-wise comparision matrices have been tested for the amount of their consistency ratio and all CRs were less than 0.1 which are considered reasonable. For the purpose of this chapter CRs along with full consistency tests' calculations for all of the Level 2 comparision matrices while using Equations 4.5, 4.6, 4.7, 4.8 and 4.9 have been calculated seperately and are shown along with the FAHP calculations for the related matrices in the following sections (Level 3 comparision matrices CRs are shown in Appendix II):

Table 4.4: Level 2 Country Risks – Calculating local weights

Country Risks	(MP)	(PSS)	(FEP)	(PDP)	(PMP)	Local Weights
Macro-economic Practices (MP)	(1,1,1)	(2,3,4)	(2,3,4)	(3,4,5)	(1/5,1/4,1/3)	0.312
Political and Social Systems (PSS)	(1/4,1/3,1/2)	(1,1,1)	(1/5,1/4,1/3)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	0.061
Foreign Enterprise policy (FEP)	(1/4,1/3,1/2)	(3,4,5)	(1,1,1)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	0.052
Port Development Policy (PDP)	(1/5,1/4,1/3)	(2,3,4)	(3,4,5)	(1,1,1)	(1/5,1/4,1/3)	0.204
Port Management Policy (PMP)	(3,4,5)	(1/5,1/4,1/3)	(3,4,5)	(3,4,5)	(1,1,1)	0.371

In Level 2 comparision matrix (5×5) for the country risk factors (R1) i.e. Table 4.4 the following results are obtained: $\lambda_{max} = 5.380$ CI = 0.095 RI=1.12 CR=0.085 < 0.1

Country Risks	(MP)		(PSS)		(FEP)		(PDP)		(PMP)		Priority
(MP)	1	0.17	3	0.27	3	0.25	4	0.42	0.25	0.12	0.24
(PSS)	0.33	0.06	1	0.09	0.25	0.21	0.33	0.03	0.33	0.16	0.11
(FEP)	0.33	0.06	4	0.36	1	0.08	0.25	0.03	0.25	0.12	0.13
(PDP)	0.25	0.04	3	0.27	4	0.33	1	0.11	0.25	0.12	0.18
(PMP)	4	0.68	0.25	0.02	4	0.33	4	0.42	1	0.48	0.40
	5.91		11.25		12.25		9.58		2.08		

Country Risks	(MP)		(PSS)		(FEP)		(PDP)		(PMP)		Priority
(MP)	1	0.24	3	0.33	3	0.39	4	0.68	0.25	0.02	1.6
(PSS)	0.33	0.07	1	0.11	0.25	0.03	0.33	0.05	0.33	0.012	0.3
(FEP)	0.33	0.07	4	0.44	1	0.13	0.25	0.04	0.25	0.09	0.7
(PDP)	0.25	0.06	3	0.33	4	0.52	1	0.17	0.25	0.09	1.1
(PMP)	4	0.96	0.25	0.02	4	0.52	4	0.68	1	0.38	2.5

with the use of Equations 4.5, 4.6, 4.7 λ_{max} can be obtained as follows:

$\frac{1.6}{0.24} = 6.6$, $\frac{0.3}{0.11} = 2.7$, $\frac{0.7}{0.13} = 5.3$, $\frac{1.1}{0.18} = 6.1$, $\frac{2.5}{0.40} = 6.2$; $\lambda_{max} = \frac{26.9}{5} = 5.380$

furthermore with the use of Equation 4.8 CI can be obtained as follows:

$CI = \frac{\lambda max - n}{n-1}$; $CI = \frac{5.38-5}{5-1} = \frac{0.38}{4} = 0.095$.

Finally with the use of Equation 4.9 and Table 4.2 (to get the related average random index value) CR can be obtained as follows:

$CR = \frac{CI}{RI}$, RI=1.12; $CR = \frac{0.095}{1.12} = 0.085$.

From Table 4.4, synthesis values in respect to main goal are calculated as per Equation 4.11 of the extent analysis and are depicted as follows:

S1 = (8.2, 11.25, 14.333) ⊗(1/55.831, 1/44.749, 1/34.15) = (0.147,0.251,0.419),

S2 = (4.7, 5.916, 7.333) ⊗(1/55.831, 1/44.749, 1/34.15) = (0.084,0.132,0.125),

S3= (4.65, 5.833, 7.166) ⊗(1/55.831, 1/44.749, 1/34.15) = (0.083,0.130,0.210),

S4= (6.4, 8.5, 10.666) ⊗(1/55.831, 1/44.749, 1/34.15) = (0.115,0.190,0.312),

S5= (10.2, 13.25, 16.333) ⊗(1/55.831, 1/44.749, 1/34.15) = (0.183,0.296,0.478).

These fuzzy synthesis values are compared with each other by using Equation 4.17 of the extent analysis as follows:

V(S1≥S2)=1, V(S1≥S3)=1, V(S1≥S4)=1, V(S1≥S5)=0.840;

V(S2≥S1)=0.364, V(S2≥S3)=1, V(S2≥S4)=0.633, V(S2≥S5)=0.163;

V(S3≥S1)=0.342, V(S3≥S2)=1, V(S3≥S4)=0.613, V(S3≥S5)=0.140;

V(S4≥S1)=0.730, V(S4≥S2)=1, V(S4≥S3)=1, V(S4≥S5)=0.549;

V(S5≥S1)=1, V(S5≥S2)=1, V(S5≥S3)=1, V(S5≥S4)=1.

Then priority weights are calculated by using Equation 4.18 of the extent analysis as follows:

$d'(C1)$ = min (1, 1, 1, 0.840) = 0.840,

$d'(C2)$ = min (0.364, 1, 0.633, 0.163) = 0.163,

$d'(C3)$ = min (0.342, 1, 0.613, 0.140) = 0.140,

$d'(C4)$ = min (0.730, 1, 1, 0.549) = 0.549,

$d'(C5)$ = min (1, 1, 1, 1) = 1.

$W' = (0.840, 0.163, 0.140, 0.549, 1)$

Collected priority weights are shown in vector W'. Finally after normalisation of these values as per Equation 4.20 of the extent analysis, priority weights in respect to the main goal will be calculated as follows for each criterion in Table 4.4:

$W = (0.312, 0.061, 0.052, 0.204, 0.371)$

Table 4.5: Level 2 Business Risks – Calculating local weights

Business Risks	**(CF)**	**(IC)**	**(CC)**	**Local Weights**
Competition Factors (CF)	(1,1,1)	(1,2,3)	(2,3,4)	**0.566**
Industry Change (IC)	(1/3,1/2,1)	(1,1,1)	(1,2,3)	**0.357**
Customer Change (CC)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,1,1)	**0.080**

In Level 2 comparision matrix (3×3) for the business risk factors (R2) i.e. From Table 4.5 the following results are obtained:

$\lambda_{max} = 3.066$ CI = 0.033   RI=0.58   CR=0.057 < 0.1

Business Risks	**(CF)**		**(IC)**		**(CC)**		**Priority**
(CF)	1	0.55	2	0.57	3	0.50	0.54
(IC)	0.5	0.27	1	0.28	2	0.33	0.29
(CC)	0.33	0.18	0.5	0.14	1	0.17	0.16
	1.83		3.5		6		

Business Risks	**(CF)**		**(IC)**		**(CC)**		**Priority**
(CF)	1	0.54	3	0.58	3	0.48	1.6
(IC)	0.33	0.27	1	0.29	0.25	0.32	0.88
(CC)	0.33	0.17	4	0.14	1	0.16	0.47

with the use of Equations 4.5, 4.6 and 4.7, λ_{max} can be obtained as follows:

$\frac{1.6}{0.54} = 2.9, \quad \frac{0.88}{0.29} = 3.4, \quad \frac{0.47}{0.16} = 2.9;$ $\lambda_{max} = \frac{9.2}{3} = 3.066$

furthermore with the use of Equation 4.8 CI can be obtained as follows:

$CI = \frac{\lambda\, max - n}{n-1}$; $CI = \frac{3.066-3}{3-1} = \frac{0.066}{2} = 0.033.$

Finally with the use of Equation 4.9 and Table 4.2 (to get the related average random index value) CR can be obtained as follows:

$CR = \frac{CI}{RI}$, RI=0.58; $CR = \frac{0.033}{0.58} = 0.057.$

From Table 4.5, synthesis values in respect to main goal are calculated as per Equation 4.11 of the extent analysis and are depicted as follows:

S1= =(4, 6, 8) ⊗ (1/15.5, 1/11.333, 1/7.916) = (0.258,0.529,0.010),

S2= =(2.333, 3.5, 5) ⊗ (1/15.5, 1/11.333, 1/7.916) = (0.150,0.309,0.632),

S3= =(31.750, 37.952, 44.334) ⊗ (1/15.5, 1/11.333, 1/7.916) = (0.102,0.162,0.316).

These fuzzy synthesis values are compared with each other by using Equation 4.17 of the extent analysis as follows:

V(S1≥S2)=1, V(S1≥S3)=1;

V(S2≥S1)=0.630, V(S2≥S3)=1;

V(S3≥S1)=0.136, V(S3≥S2)=0.530.

Then priority weights are calculated by using Equation 4.18 of the extent analysis as follows:

$d'(C1) = \min(1,1) = 1,$

$d'(C2) = \min(0.630, 1) = 0.630,$

$d'(C3) = \min(0.135, 0.530) = 0.135.$

$W' = (1, 0.630, 0.135)$

Collected priority weights are shown in vector W'. Finally after normalisation of these values as per Equation 4.20 of the extent analysis, priority weights in respect to the main goal will be calculated as follows for each criterion in Table 4.5:

$W = (0.566, 0.357, 0.080).$

Table 4.6: Level 2 Organisational Risks – Calculating local weights

Organisational Risks	(OS)	(M)	(QP)	(HR)	(PPI)	Local weights
Organisational Structure (OS)	(1,1,1)	(1,1,1)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1/3,1/2,1)	**0.161**
Management (M)	(1,1,1)	(1,1,1)	(1/4,1/3,1/2)	(1,2,3)	(1/3,1/2,1)	**0.122**
Quality Process (QP)	(2,3,4)	(2,3,4)	(1,1,1)	(2,3,4)	(1,2,3)	**0.353**
Human Resource (HR)	(1,2,3)	(1/3,1/2,1)	(1/4,1/3,1/2)	(1,1,1)	(1/3,1/2,1)	**0.118**
Port Performance Indicators (PPI)	(1,2,3)	(1,2,3)	(1/3,1/2,1)	(1,2,3)	(1,1,1)	**0.246**

In Level 2 comparision matrix (5×5) for the organisational risk factors (R3) i.e. Table 4.6 the following results obtained: $\lambda_{max} = 5.440$ CI = 0.110 RI=1.12 CR=0.098 < 0.1

Organisational Risks	(OS)		(M)		(QP)		(HR)		(PPI)		Priority
(OS)	1	0.11	1	0.13	0.3	0.12	0.5	0.05	0.5	0.11	0.11
(M)	1	0.11	1	0.13	0.3	0.12	2	0.23	0.5	0.11	0.14
(QP)	3	0.33	3	2.50	1	0.41	3	0.35	2	0.44	0.81
(HR)	2	0.22	0.5	0.06	0.3	0.12	1	0.11	0.5	0.11	0.12
(PPI)	2	0.22	2	0.26	0.5	0.20	2	0.23	1	0.22	0.23
	9		7.5		2.4		8.5		4.5		

Organisational Risks	(OS)		(M)		(QP)		(HR)		(PPI)		Priority
(OS)	1	0.11	1	0.14	0.3	0.24	0.5	0.06	0.5	0.11	0.66
(M)	1	0.11	1	0.14	0.3	0.24	2	0.24	0.5	0.11	0.84
(QP)	3	0.33	3	0.42	1	0.81	3	0.36	2	0.46	2.38
(HR)	2	0.22	0.5	0.07	0.3	0.24	1	0.12	0.5	0.11	0.76
(PPI)	2	0.22	2	0.28	0.5	0.41	2	0.24	1	0.23	1.83

with the use of Equations 4.5, 4.6 and 4.7, λ_{max} can be obtained as follows:

$$\frac{0.66}{0.11} = 6, \quad \frac{0.84}{0.14} = 6, \quad \frac{2.38}{0.81} = 2.9, \quad \frac{0.76}{0.12} = 6.3, \quad \frac{1.38}{0.23} = 6; \qquad \lambda_{max} = \frac{27.2}{5} = 5.440$$

furthermore with the use of Equation 4.8 CI can be obtained as follows:

$$CI = \frac{\lambda max - n}{n-1}; \quad CI = \frac{5.440-5}{5-1} = \frac{0.44}{4} = 0.110.$$

Finally with the use of Equation 4.9 and Table 4.2 CR can be obtained as follows:

$CR=\frac{CI}{RI}$, RI=1.12; $CR=\frac{0.110}{1.12}=0.098$.

From Table 4.6, synthesis values in respect to main goal are calculated as per Equation 4.11 of the extent analysis and are depicted as follows:

S1=(2,916, 3.333, 4.5) ⊗(1/44.5, 1/31.999, 1/21.748) = (0.065,0.104,0.207),

S1=(3.583, 4.833, 6.5) ⊗(1/44.5, 1/31.999, 1/21.748) = (0.080,0.151,0.299),

S1=(8, 12, 16) ⊗(1/44.5, 1/31.999, 1/21.748) = (0.180,0.375,0.736),

S1=(2.916, 4.333, 6.5) ⊗(1/44.5, 1/31.999, 1/21.748) = (0.065,0.135,0.300),

S1=(4.333, 7.5, 11) ⊗(1/44.5, 1/31.999, 1/21.748) = (0.097,0.234,0.506).

These fuzzy synthesis values are compared with each other using Equation 4.17 of the extent analysis as follows:

V(S1≥S2)=0.730, V(S1≥S3)=0.091, V(S1≥S4)=0.821, V(S1≥S5)=0.458;

V(S2≥S1)=1, V(S2≥S3)=0.347, V(S2≥S4)=1, V(S2≥S5)=0.709;

V(S3≥S1)=1, V(S3≥S2)=1, V(S3≥S4)=1, V(S3≥S5)=1;

V(S4≥S1)=0.730, V(S4≥S2)=0.932, V(S4≥S3)=0.333, C(S4≥S5)=0.672;

V(S5≥S1)=1, V(S5≥S2)=1, V(S5≥S3)=0.698, V(S5≥S4)=1.

Then priority weights are calculated using Equation 4.18 of the extent analysis as follows:

$d'(C1)$ = min (0.730, 0.091, 0.821, 0.458) = 0.458,

$d'(C2)$ = min (1, 0.347, 1, 0.709) = 0.347,

$d'(C3)$ = min (1, 1, 1, 1) = 1.

$d'(C4)$ = min (0.730, 0.932, 0.333, 0.672) = 0.333,

$d'(C5)$ = min (1, 1, 0.698, 1) = 0.69.

W'= (0.458,0.347,1,0.333,0.698)

Collected priority weights are shown in vector W'. Finally after normalisation of these values as per Equation 4.20 of the extent analysis, the priority weights in respect to the main goal will be calculated as follows for each criterion in Table 4.6:

$W = (0.161, 0.122, 0.353, 0.118, 0.246)$

Table 4.7: Level 2 Operational Risks – Calculating local weights

Operational Risks	(SRRF)	(SRRF*)	(PRRF)	(LRRF)	(HERF)	(TRRF)	Local Weights
Safety Related Risk Factors (SRRF)	(1,1,1)	(1/3,1/2,1)	(1,1,1)	(2,3,4)	(1/3,1/2,1)	(1,2,3)	**0.186**
Security Related Risk Factors (SRRF*)	(1,2,3)	(1,1,1)	(2,3,4)	(2,3,4)	(1,2,3)	(2,3,4)	**0.297**
Pollution Related Risk Factors (PRRF)	(1,1,1)	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)	(1/3,1/2,1)	(1,2,3)	**0.178**
Legal Related Risk Factors (LRRF)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)	(1/3,1/2,1)	(1/3,1/2,1)	**0.007**
Human Error Risk Factors (HERF)	(1,2,3)	(1/3,1/2,1)	(1,2,3)	(1,2,3)	(1,1,1)	(2,3,4)	**0.243**
Technical Related Risk Factors (TRRF)	(1/3,1/2,1)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,2,3)	(1/4,1/3,1/2)	(1,1,1)	**0.089**

In Level 2 comparision matrix (6×6) for the operational risk factors (R4) i.e. From Table 4.7 the following results are obtained:

$\lambda_{max} = 6.148$ CI = 0.029 RI=1.24 CR=0.024 < 0.1

Operational Risks	(SRRF)		(SRRF)		(PRRF)		(LRRF)		(HERF)		(TRRF)		Priority
(SRRF)	1	0.16	0.5	0.17	1	0.13	3	0.19	0.5	0.11	2	0.17	0.15
(SRRF*)	2	0.32	1	0.34	3	0.38	3	0.19	2	0.43	3	0.26	0.32
(PRRF)	1	0.08	0.3	0.10	1	0.13	3	0.19	0.5	0.11	2	0.17	0.13
(LRRF)	0.3	0.05	0.3	0.10	0.3	0.04	1	0.06	0.3	0.06	0.3	0. 26	0.10
(HERF)	2	0.32	0.5	0.17	2	0.25	3	0.19	1	0.22	3	0.26	0.23
(TRRF)	0.5	0.08	0.3	0.10	0.5	0.06	3	0.19	0.3	0.06	1	0.09	0.10
	6.3		2.9		7.8		16		4.6		11.3		

Operational Risks	(SRRF)		(SRRF)		(PRRF)		(LRRF)		(HERF)		(TRRF)		Priority
(SRRF)	1	0.15	0.5	0.16	1	0.13	3	0.3	0.5	0.11	2	0.20	1.05
(SRRF*)	2	0.30	1	0.32	3	0.39	3	0.3	2	0.46	3	0.30	2.07
(PRRF)	1	0.15	0.3	0.10	1	0.13	3	0.3	0.5	0.11	2	0.20	0.99
(LRRF)	0.3	0.04	0.3	0.10	0.3	0.04	1	0.1	0.3	0.07	0.3	0. 03	0.23
(HERF)	2	0.30	0.5	0.16	2	0.26	3	0.2	1	0.22	3	0.30	1.44
(TRRF)	0.5	0.08	0.3	0.10	0.5	0.06	3	0.2	0.3	0.07	1	0.10	0.62

with the use of Equations 4.5, 4.6 and 4.7, λ_{max} can be obtained as follows:

$$\frac{1.05}{0.15} = 6.66,\ \frac{2.07}{0.32} = 6.46,\ \frac{0.99}{0.13} = 7.61,\ \frac{0.38}{0.10} = 3.8,\ \frac{1.44}{0.23} = 6.26,\ \frac{0.61}{0.10} = 6.10; \quad \lambda_{max} = \frac{36.89}{6} = 6.148$$

furthermore with the use of Equation 4.8 CI can be obtained as follows:

$$CI = \frac{\lambda\, max - n}{n-1}; \quad CI = \frac{6.148-6}{6-1} = \frac{0.148}{4} = 0.029.$$

Finally with the use of Equation 4.9 and Table 4.2 (to get the related average random index value) CR can be obtained as follows:

$$CR = \frac{CI}{RI},\ RI = 1.24; \quad CR = \frac{0.029}{1.24} = 0.024.$$

From Table 4.7, synthesis values in respect to main goal are calculated as per Equation 4.11 of the extent analysis and are depicted as follows:

S1=(5.666, 8, 11) ⊗(1/67, 1/47.998, 1/32.164) = (0.085,0.167,0.342),

S2=(9, 14, 19) ⊗(1/67, 1/47.998, 1/32.164) = (0.134,0.292,0.591),

S3=(5.583, 7.833, 10.5) ⊗(1/67, 1/47.998, 1/32.164) = (0.083,0.163,0.326),

S4=(2.416, 2.999, 4.5) ⊗(1/67, 1/47.998, 1/32.164) = (0.036,0.062,0.140),

S5=(6.333, 10.5, 15) ⊗(1/67, 1/47.998, 1/32.164) = (0.095,0.219,0.466),

S6=(3.166, 4.666, 7) ⊗(1/67, 1/47.998, 1/32.164) = (0.047,0.097,0.218).

These fuzzy synthesis values are compared with each other using Equation 4.17 of the extent analysis as follows:

V(S1≥S2)=0.625, V(S1≥S3)=1, V(S1≥S4)=1, V(S1≥S5)=0.826, V(S1≥S6)=1;

V(S2≥S1)=1, V(S2≥S3)=1, V(S2≥S4)=1, V(S2≥S5)=1, V(S2≥S6)=1;

V(S3≥S1)=0.984, V(S3≥S2)=0.598, V(S3≥S4)=1, V(S3≥S5)=0.805, V(S3≥S6)=1;

V(S4≥S1)=0.344,V(S4≥S2)=0.025,V(S4≥S3)=0.361,V(S4≥S5)=0.223,V(S4≥S6)=0.726;

V(S5≥S1)=1, V(S5≥S2)=0.820, V(S5≥S3)=1, V(S5≥S4)=1, V(S5≥S6)=1;

V(S6≥S1)=0.655, V(S6≥S2)=0.301, V(S6≥S3)=0.672, V(S6≥S4)=1, V(S6≥S5)=0.502.

Then priority weights are calculated by using Equation 4.18 of the extent analysis as follows:

$d'(C1) = \min(0.625, 1, 1, 0.826, 1) = 0.625$,

$d'(C2) = \min(1, 1, 1, 1, 1) = 1$,

$d'(C3) = \min(0.984, 0.598, 1, 0.805, 1) = 0.598$,

$d'(C4) = \min(0.344, 0.025, 0.361, 0.223, 0.726) = 0.025$,

$d'(C5) = \min(1, 0.820, 1, 1, 1) = 0.820$,

$d'(C6) = \min(0.655, 0.301, 0.672, 1, 0.502) = 0.301$.

$W' = (0.625, 1, 0.598, 0.025, 0.820, 0.301)$

Collected priority weights are shown in vector W'. Finally after normalisation of these values as per Equation 4.20 of the extent analysis, priority weights in respect to the main goal will be calculated as follows for each criterion in Table 4.7:

$W = (0.186, 0.297, 0.178, 0.007, 0.243, 0.089)$

4.9. RESULTS AND DISCUSSIONS

Table 4.8 illustrates the final results estimated for the operational risk factors (i.e. an essential base for further investigations and developments in Chapters 5, 6 and 7) through the proposed FAHP methodology. The final results for the country, business and organisational risk factors are depicted in Appendix II.

Table 4.8: Level 3 Operational Risks – Global weights and rankings

Level 1 Risk	Level 2 Risks	Local Weights	Level 3 Risks	Local Weights	Global Weights	Rankings
Operational Risk	Safety Related Risk Factors (SRRF)	(0.186)	Composition of Calling Fleet (CCF)	(0.048)	(0.0089)	18
			Traffic Conditions (TC)	(0.340)	(0.0632)	6
			Weather Conditions (WC)	(0.099)	(0.0184)	15
			Waterway Configuration (WC*)	(0.398)	(0.0740)	5
			Potential Consequences of DG Transportation (PCDGT)	(0.027)	(0.0058)	20
			Potential Impacts of not having VTM (PIVTM)	(0.088)	(0.0168)	16
	Security Related Risk Factors (SRRF*)	(0.297)	People's Safety (PS)	(0.670)	(0.1989)	**1**
			Port Asset (PA)	(0.274)	(0.0813)	4
			Port Profit (PP)	(0.056)	(0.0166)	17
	Pollution Related Risk Factors (PRRF)	(0.178)	Ship Related Pollutions (SRP)	(0.496)	(0.0877)	**3**
			Cargo Related Pollutions (CRP)	(0.178)	(0.0316)	12
			Port/terminal Related Pollutions (PRP)	(0.220)	(0.0389)	10
			City Related Pollutions (CRP)	(0.106)	(0.0187)	14
	Legal Related Risk Factors (LRRF)	(0.007)	Regulatory Changes (RC)	(0.693)	(0.0055)	21
			Fraud in Contracts (FC)	(0.307)	(0.0024)	22
	Human Error Risk Factors (HERF)	(0.243)	Pilots Related Errors	(0.498)	(0.1210)	**2**
			Ships Personnel Related Errors	(0.161)	(0.0390)	9
			Port/terminal Personnel Related Errors	(0.189)	(0.0459)	8
			Stevedores Related Errors	(0.152)	(0.0369)	11
	Technical Related Risk Factors (TRRF)	(0.089)	Lack of Equipment Maintenance (LEM)	(0.078)	(0.0069)	19
			Lack of IT Technology (LITT)	(0.566)	(0.0503)	7
			Lack of Dredging and Navaids Maintenance (LDNM)	(0.356)	(0.0316)	13

After pair-wise comparisions and global weights' calculations using Level 2 and Level 3 risk factors as an example the final results for the operational risk factors i.e. R4 can be discussed in this section. The most significant risk factors (i.e. peoples' safety, pilots' errors and ships' pollutions) among all in respect of their effect to the offshore terminals and marine ports are marked under the rankings column in Table 4.8. These types of operational risk factors are the most significant ones that are determined to affect the offshore terminals and marine ports. Therefore these risk factors need to be analysed and eliminated precisely during the future works.

As it can be seen in Table 4.8 among Level 2 risk factors security related risk factor has got the highest importance and among its sub risk factors in Level 3 the risk factor of people's safety has been found to be the most significant one. It is evident between people's safety, assets and profit priority is always with peoples safety. Ports, offshore terminals and ships are vulnerable to abuse by third parties. A greater potential threat to an offshore terminal or a port is that of terrorist activity, a threat which has been heightened by the attack on the World Trade Centre on September 11, 2001. This will endanger the poeoples' safety in offshore terminals and marine ports. Maritime business and port interests responsible for the movement of cruise lines and ferry operations responsible for the safe transportation of passengers understand the need for security and have spent a lot of money to enhance their own security after the September 11 terrorist attacks. New international, national, state, and local laws and regulations were forged as a result of the September 11, 2001 tragedy demanding a lot of security compliances in and around port facilities and throughout the maritime industry.

In Table 4.8 along with Level 2 risk factors human error risk factors have the second highest importance and among its sub risk factors in Level 3 the risk factor of pilot related error has been found to be the most significant one. With reference to the marine accidents (FEL, 1993; BTC, 2002; DNV, 2002; Lees, 2005; NE P&I Club, 2008 and MAIB, 2010), it is not surprising that approximately eighty percent of shipping accidents are caused by human factors. Although in terms of human related errors the errors caused by of deck officers, ships crew or port personals are more regular than pilots' errors, but consequences or impacts of the errors committed by pilots especially within the port areas are very severe. As it was discussed before an accident such as collision of a ship with break water or another nearby ship at entrance of a port as a result of a pilot's mistake may lead into catastrophic tragedies. Therefore it has motivated interests in developing methodologies that can capture the nature of human errors in marine accidents and store them in data bases for further statistical study as reported in Kristiansen *et al,* (1999) and (Kristiansen, 2005). In their reports they have mentioned pilots as one of the main contributors for the human errors related risk factors. In order to manage this risk factor, ABS (2000)'s methodological applications such as root cause analysis or human reliability analysis are found useful.

It can be seen from Table 4.8 that between Level 2 risk factors pollution related risk factor has got the third highest importance and amongst its sub risk factors in Level 3 the risk factor of ship related pullutions has been found to be the most significant one. As it can be seen from Table 4.8 there are different causes of pullotion in offshore terminals and ports' boundries but as it has been explained previously the impact of the ships related pollutions especially to both marine environment and coast/land side are greater and in many cases are catastrophic. The example of such claims is the case of Deepwater Horizon (i.e. an offshore drilling platform) in Gulf of Mexico which had led to a major oil spill. Moreover in offshore terminals and marine ports pollution may result from ship accidents, land activities, ship bunkering, noises, garbage, dust, dredging, port maintenance, ship air pollution, traffic congestion, sewage and others. The attention of international community has been concentrated mainly on ports' visitors (i.e. the ships), because of the well-known marine accidents. Nevertheless there are solutions which address this risk factor such as marine insurance, proper compliance with the related international conventions and regulations (e.g. MARPOL Convention and HSE Regulation) by offshore terminals, marine ports and ships.

In addition the developed risk-based model in this chapter is used to evaluate and analyse the risk factors associated with offshore terminals and marine ports. By using the developed risk-based model risk managers can obtain a broad view of the risk factors in offshore terminals and marine ports. The proposed risk-based model is suitable for comprehensive risk assessments. It can be adopted by different users in the offshore and marine industry. The developed risk-based model can be simply established at various hierarchical levels according to the needs of users and existing data. It can be used in different offshore terminals and marine ports. The risk-based model is designed based on general point of view, which covers the general features of different offshore terminals and marine ports and can be used in any particular application. It can measure risk factors by considering numerous risk factors. It can aggregate various groups of risk factors along with a consistent order to generate useful risk-based information for decision makers. It is flexible to existent applications of risk assessment. In addition it can be simply applied on the other risk factors not mentioned in this study (such as natural disasters, etc).

4.10. CONCLUSIONS

Offshore terminals and marine ports are vital for the maritime transportation system, thereby facilitating global trade. There are risk factors within these logistics infrastructures, all of which require attention in respect of their identification, assessment, mitigation and cost/benefit analysis with the use of an appropriate RM approach, if they are going to remain responsive to strategic needs and future challenges.

This chapter critically reviewed the identified risk factors revealed through the literature review in Chapter 2. In order to carry out an appropriate check on the proposed risk assessment methodology a variety of test cases were conducted. Test cases were carried out using a generic risk assessment model based on a proposed RM framework in Chapter 3. Moreover FAHP method was used for determining the relative weights of the identified risk factors. Eventually after determining the global weights of the risk factors, they were ranked accordingly as per their priority and the most significant ones were recognised and discussed.

In this chapter a new hierarchical risk-based model was designed and tested while using the procedures explained for the risk assessment methodology. In next the chapter it is appropriate to use the same risk-based model on real cases (i.e. offshore terminals or marine ports) in order to prove the applicability and robustness of the newly developed risk-based model.

CHAPTER 5: DECISION SUPPORT FOR RISK EVALUATION

5.1. INTRODUCTION

In the previous chapter a FAHP method was used for assessment and prioritisation of the identified hazards which were previously revealed through the HAZID process in Chapter 2. The relative weights of all risk factors/hazards for the generic risk-based model and its other subsets were determined. In order to apply the developed generic model to any specific offshore terminal or marine port (e.g. for the purpose of their audit, port-to-port or offshore terminal-to-offshore terminal risk evaluation) there will be a need again to use the experts' judgements and decision makers' preferences for the purpose of that specific offshore terminal or marine port. This new process through expert judgment will help to determine the actual risk levels of the selected port or offshore terminal.

In the past, the risk valuation was all based on the knowledge of managers. However, now managers have understood that it is hard to carry out an evaluation since there are many risk factors that their organisations are involved with and the measurement of some risk factors are vague due to the extremely subjective nature and lack of past experience. Therefore it is necessary to have a decision-aid means to help managers to complete their risk evaluations (Li and Liao, 2007).

As a result in order to evaluate the actual risk factors in real situations by use of the generic models there will be a need to carry out another risk measurement process. This new process will be carried out in order to calculate the levels of the present risks within the selected sea port and/or offshore terminals. The result of these evaluations will be aggregated with the predetermined global weights of the risk factors calculated for the generic model in the previous chapter. This aggregation updates all the related risk factors within the selected site or facility (i.e. combination of the global weights calculated for the generic model in the previous chapter with the evaluated risk levels within the selected sea port and/or offshore terminal in this chapter). For this reason and in order to evaluate the new levels of the risk factors for any specific port or offshore terminal a new methodology will be used hereafter.

5.2. FUZZY SET THEORY (FST)

FST was introduced by Zadeh in 1965. The significance of fuzzy variables is that they facilitate gradual transition between states and consequently, possess a natural capability to express and deal with observation and measurement uncertainties. Traditional variables, which may be referred as crisp variables do not have this capability (Pillay and Wang, 2003). Full explanations for the reason behind using FST and its methodology are explained in Chapter 4. In this chapter FST will be used again due to the nature of data collected.

5.2.1. Risk evaluation using FST

In the previous chapter a hierarchical structure of risk factors in the form of a generic model was constructed (see Figure 4.7); then relative weights for all risk factors were calculated by the use of a FAHP method. The next task is to measure the risk level of each elementary risk factor in respect of the any individually selected port or offshore terminal. For this reason there is a need to define a framework related to the different parameters and ratings of the risk factors in order to determine the risk levels.

As Li and Liao (2007) and ABS (2003) explain there are parameters that may affect each risk level of every elementary risk factor. These parameters include occurrence likelihood (frequency) and consequence severity (impact).

Occurrence likelihood describes the expected number of occurrences of an unwanted incident, while the consequence severity expresses the scale of unwanted event that can harmfully affect subjects of interest i.e. number of people affected (injured or killed), property damaged, amount of a spill, area affected, outage time, mission delay, dollars lost or other measures of negative impact (ABS, 2003).

In this respect ABS (2003) explains that a general risk evaluation and presentation method is just to multiply the occurrence likelihood of each unwanted event by each consequence severity, and after that sum-up these products for all situations considered in the evaluation.

Thus with respect to the above description, risk levels can be obtained by the use of the aforementioned parameters through the following equation:

$$R=L\times S \tag{5.1}$$

where R is the risk associated with each hazardous event, L represents the occurrence likelihood of the hazard; S represents the consequence severity of the hazard and R denotes the multiplication relationship between the occurrence likelihood and consequence severity. This definition has been applied to risk assessment in many applications among other applications explained in the next section. In this chapter, Equation 5.1 will be used to determine the risk levels associated with each risk factor in any specific port or offshore terminal.

This definition indicates that if L and/or S are represented by fuzzy numbers, R will also be a fuzzy number (Anoop *et al*, 2006).

$$\tilde{R}=\tilde{L}\otimes \tilde{S} \tag{5.2}$$

Although in the previous chapter a linguistic approach of the FST was discussed in the next section its usage on other applications will be reviewed.

5.2.2. A brief review of the past research on FST

As Pillay and Wang (2003) explain since FST was proposed almost four decades ago, it has found many useful applications. The linguistic approach based on fuzzy sets has given very good results for modelling qualitative information. It has been widely used in different fields, for example, clinical diagnosis (Degani and Bortolan, 1988), marketing (Yager *et al*, 1994), information retrieval (Bordogna and Pasi, 1993), technology transfer strategy selection (Chang and Chen, 1994), mechanical system design (Wang *et al*, 1995), education (Law, 1996), risk modelling in software development (Lee, 1996a and Lee, 1996b), decision making (Bordogna *et al*, 1997), environmental engineering (Deshpande, 1999), environment modelling (Sadiq *et al*, 2004), process plant (Khan *et al*, 2002; Khan and Haddara, 2003; Krishnasamy *et al*, 2005), water pipe deterioration analysis (Kleiner *et al*, 2006) and hieratical risk assessment of water supply systems (Li, 2007). In the next section it will be described how to use and verify the risk parameters (occurrence likelihood and severity of consequence) under fuzzy environments.

5.2.3. Linguistic variables for risk parameters

Due to the highly subjective nature of data collected, it is usually difficult to measure risk parameters precisely. A practicable and suitable way to explain these parameters is to use qualitative verbal expressions (i.e., linguistic variables) particularly during experts' judgments. To estimate the occurrence likelihood, for example, one may often use such variables as very low, low, medium, high and very high. In addition to estimate the consequence severity one may also often use such variables as slight, minor, moderate, critical and catastrophic.

The subjective linguistic variables can also be defined in terms of membership functions. As Li and Liao (2007) have expressed "a membership function is a curve that defines how each point in the input space is mapped to a membership value between 0 and 1". Among these membership functions, the simplest are the triangular fuzzy number and trapezoidal fuzzy number (see Chapter 4). TFNs are selected for use in this chapter to represent the linguistic variables. They are shown in Table 5.1 and Figure 5.1 based on Yang and Hung (2007). Thus membership degrees of risk parameters can be assigned by experts, with reference to Table 5.1 in a fuzzy environment.

Table 5.1: Transformation for Fuzzy membership functions.

Grade	Occurrence Likelihood($\tilde{L}$)	Consequence Severity ($\tilde{S}$)	Membership function
1	Very Low (VL)	Slight (SL)	(0.00,0.00,0.25)
2	Low (L)	Minor (MI)	(0.00,0.25,0.50)
3	Medium (M)	Moderate (MO)	(0.25,0.50,0.75)
4	High (H)	Critical (CR)	(0.50,0.75,1.00)
5	Very High (VH)	Catastrophic (CA)	(0.75,1.00,1.00)

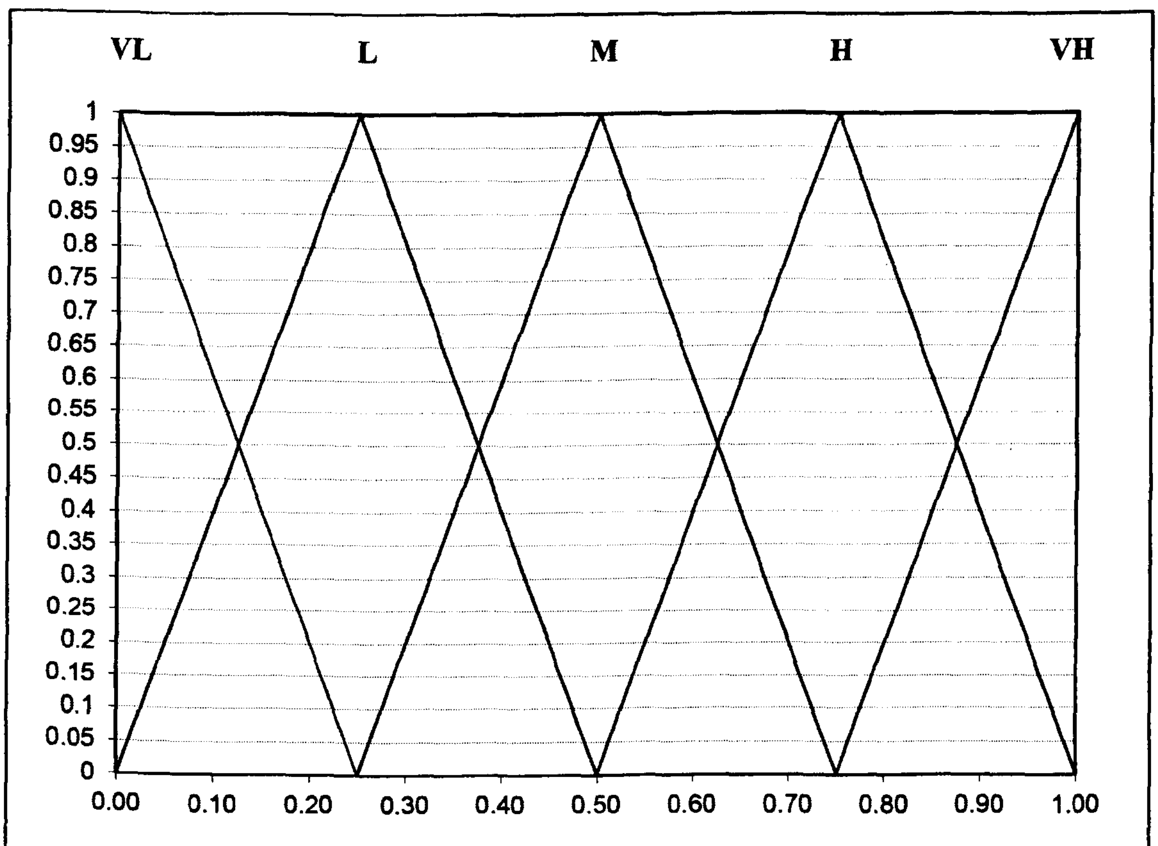


Figure 5.1: Fuzzy triangular membership functions

In addition based on the definition of the risk (i.e. Equation 5.2) and the five grades defined for occurrence likelihood ($\tilde{L}$) and consequence severity ($\tilde{S}$) of the risk level shown in Table 5.1, the linguistic description for risk evaluation can be defined as per Table 5.2. Furthermore the five triangular linguistic terms for risk levels ($\tilde{R}$) can be demonstrated as per Table 5.3.

Table 5.2: Linguistic description for risk levels (R)

Linguistic variables of risk levels (R)	**Description of linguistic values**
Very low (VL)	If likelihood is very low and severity is slight
Low (L)	If likelihood is low and severity is minor
Medium (M)	If the likelihood is medium and severity is moderate
High (H)	If the likelihood is high and severity is critical
Very high (VH)	If the likelihood is very high and severity is catastrophic

Table 5.3: linguistic variables and TFNs for risk levels ($\tilde{R}$)

Risk evaluation variables	**Grade (P)**	**Membership function**
Very low (VL)	1	(0.00,0.00,0.25)
Low (L)	2	(0.00,0.25,0.50)
Medium (M)	3	(0.25,0.50,0.75)
High (H)	4	(0.50,0.75,1.00)
Very high (VH)	5	(0.75,1.00,1.00)

In the next section a new methodology will be utilised to aggregate the above risk evaluation process and enable its application on the real cases, such as risk evaluation on sea ports and offshore terminals. As Li and Liao (2007) explain risk evaluation is regarded as a Multi-Attribute Decision-Making (MADM) problem with uncertainty. Consequently for the purpose of this chapter a new evaluation approach based on the framework of the Evidential Reasoning (ER), under fuzzy environments is proposed to be used hereafter.

5.3. DECISION MAKING UNDER UNCERTAINTY

Several decision problems in engineering and management involve multiple attributes in cooperation with quantitative and qualitative characters. A decision may not be properly taken without fully taking into account all attributes in question (Huang and Yoon, 1981; Saaty, 1988; Stewart, 1992; Chen and Hwang, 1992; Yang and Singh, 1994; Roy and Vanderpooten, 1997; Belton and Stewart, 2002 and Sadiq *el at,* 2008). On the other hand as Fredlob and Schleifer (1999) explain there is a close relationship between complexity and uncertainty and it is said that as the complexity increases, certainty decreases. "Therefore there is a growing need to develop theoretically sound methods and tools for dealing with Multiple Attribute Decision Analysis (MADA) problems under uncertainty in a way that is rational, reliable, repeatable, and transparent" (Yang and Xu, 2002).

5.4. APPLICATION OF THE BELIEF DEGREES IN DETERMINING THE RISK LEVELS

Based on Liu *et al*, (2002) fuzzy logic structures are knowledge-based or rule-based structures built from human understanding in the form of fuzzy IF-THEN rules. For example, a fuzzy IF-THEN rule for safety analysis is:

If FR (i.e. Failure Rate) is frequent AND CS (i.e. Consequence Severity) is catastrophic AND FCP (i.e. Failure Consequence Probability) is likely, THEN safety estimate is Poor.

There is an additional type of uncertainty in representing information when the expert is incapable of forming a strong correlation between premise and conclusion. That is, evidence available is not adequate or experts are not 100% sure to believe in an assumption but only to certain degrees of belief or with credibility. For example, it is possible to have fuzzy rules with belief degrees for all possible consequent terms as follows:

IF FR is frequent AND CS is critical AND FCP is unlikely THEN safety estimate is {(Good, 0), (Average, 0), (Fair, 0.7), (Poor, 0.3)}.

Here {(Good, 0), (Average, 0), (Fair, 0.7), (Poor, 0.3)} is a belief distribution representation of the safety consequent, representing that experts are 70% sure that safety level is Fair, and 30% sure that safety level is Poor.

As Li and Liao (2007) explain, in order to measure the risk level of each risk factor, it is essential to convert the fuzzy ratings of all parameters into belief structures with the same set of evaluation grades. In another instance Yang and Xu (2002) have expressed that an attribute can be evaluated to individual or a subset of the evaluation grades with different degrees of belief. Therefore in order to become familiar with belief degrees the following explanation by Cat (2006) is found to be useful:

"Let X be a classical set of objects denoted by x, called the universe. Let C be a classical subset of X and $m(x)$ be a function from X to the pair of values {0, 1} such that if $x \in C$, $m(x)=1$, and if $x \notin C$, $m(x)=0$. In classical sets, then, either elements of the universe belong to a set or they do not. The set is characterised by a sharp boundary and is identical with its members. By contrast, a fuzzy set $\tilde{F}$, is a subset characterised by the set of pairs " $\tilde{F} = \{(x, \mu\tilde{F}(x)), x \in X\}$", where $\mu\tilde{F}(x)$ represents the degree of membership with possible values ranging over the real interval [0, 1]. A Membership Function (MF) value of one means full representation of the set under consideration. A MF value of zero implies that value does not belong to the set under consideration. A membership somewhere between these two limits indicates the degree of membership. In each context of application of the predicate $\tilde{F}$, the fuzzy set $\tilde{F}$ will be normalised if there exists one x, such that $\mu\tilde{F}(x)=1$. A fuzzy set whose MF only takes on the value of zero or one is called crisp" (Cat, 2006).

Now with the use of aforementioned descriptions the evaluation of risk level of each risk factor for the purpose of this chapter can be explained by the following linguistic variables or evaluation grades:

$$H = [H_1, H_2, H_3, H_4, H_5] = \{\text{Very low, Low, Medium, High, Very high}\} \quad (5.3)$$

In order to transform the fuzzy ratings of all parameters into belief structures with the same set of evaluation grades (i.e. linguistic variables) and be able to calculate the risk levels of each risk factor, risk levels must be calculated by use of Equation 5.2 after the fuzzy ratings of all parameters associated with each risk factor are obtained through the experts' judgements.

As discussed earlier and explained by ABS (2003), the risk is the combination of occurrence likelihood and consequence severity. When the occurrence likelihood and consequence severity are supposed to be independent of each other, their combination is equivalent to the product of the two. Therefore under the same assumption of independence, the risk level of every risk factor under a fuzzy environment can be calculated as the product of the two fuzzy numbers denoted by $\tilde{L} = (a_L, b_L, c_L)$ and $\tilde{S} = (a_S, b_S, c_S)$ as follows (see Chapter 4):

$$FTN_{LS} = FTN_L \otimes FTN_S = (a_L \times a_S, b_L \times b_S, c_L \times c_S) \quad (5.4)$$

As an example and according to Table 5.1, if a risk as per experts' preference has occurrence likelihood ($\tilde{L}$) of (0.00, 0.25, 0.50) (i.e. Low) and consequence severity ($\tilde{S}$) of (0.50, 0.75, 1.00) (i.e. Critical), the FTN_{LS} as per Equation 5.4 will be FTN_{LS} = (0.00, 0.1875, 0.50).

Now for the purpose of Equation 5.4 there are five steps to convert FTN_{LS} into fuzzy risk H i.e. a normalised fuzzy set of 5 linguistic variables or evaluation grades (i.e. belief structure). These steps are based on Miri Lavasani (2010). The proposed steps are illustrated in Figure 5.2 and Table 5.4.

Step 1: Map the new calculated FTN_{LS} over FTN_R (5 grades defined over the universe of discourse of risk i.e. VL, L, M, H, VH triangles shown in Figure 5.1). The new calculated FTN_{LS} is marked as thin circles in Figure 5.2.

Step 2: Determine the points where the newly mapped FTN_{LS} (i.e. the thick circles) intersects each linguistic term of FTN_R shown in Figure 5.2.

Step 3: Use a maximum figure if FTN_{LS} and a linguistic term of FTN_R intersect at more than one point.

Step 4: Establish a set of intersecting points that defines a non-normalised 5 grades in the form of fuzzy set (i.e. thick circles marked in Figure 5.2, H_R [0.57, 0.89, 0.45, 0, 0], which is the intersection of H with FTN_{LS} $(\mu_P, P = 1,2,3,4,5)$ {Very low, Low, Medium, High, Very high} respectively.

Step 5: Normalise the H_R (5 non-normalised grades) to obtain H (5 normalised grades) which is known as a belief structure. In order to find the normalised values (i.e. H grades) all the H_R grades must be added together and in case of Table 5.4 sum of the H_R grades will be 1.91. Then in order to calculate the H grades each H_R grades must be divided by 1.91.

Table 5.4: Converting FTN_{LS} (fuzzy ratings) to H (belief structure) based on Figure 5.2

FTN_{LS}	(0.00, 0.1875, 0.50)				
Grade (*P*)	VL	L	M	H	VH
H_R	0.57	0.89	0.45	0	0
H	[0.30, 0.47, 0.23, 0, 0]				

As mentioned previously in the next section a new methodology based on ER will be utilised in order to aggregate the above risk evaluation process with the relative weights calculated in the previous chapter, enabling its application in offshore terminals and marine ports.

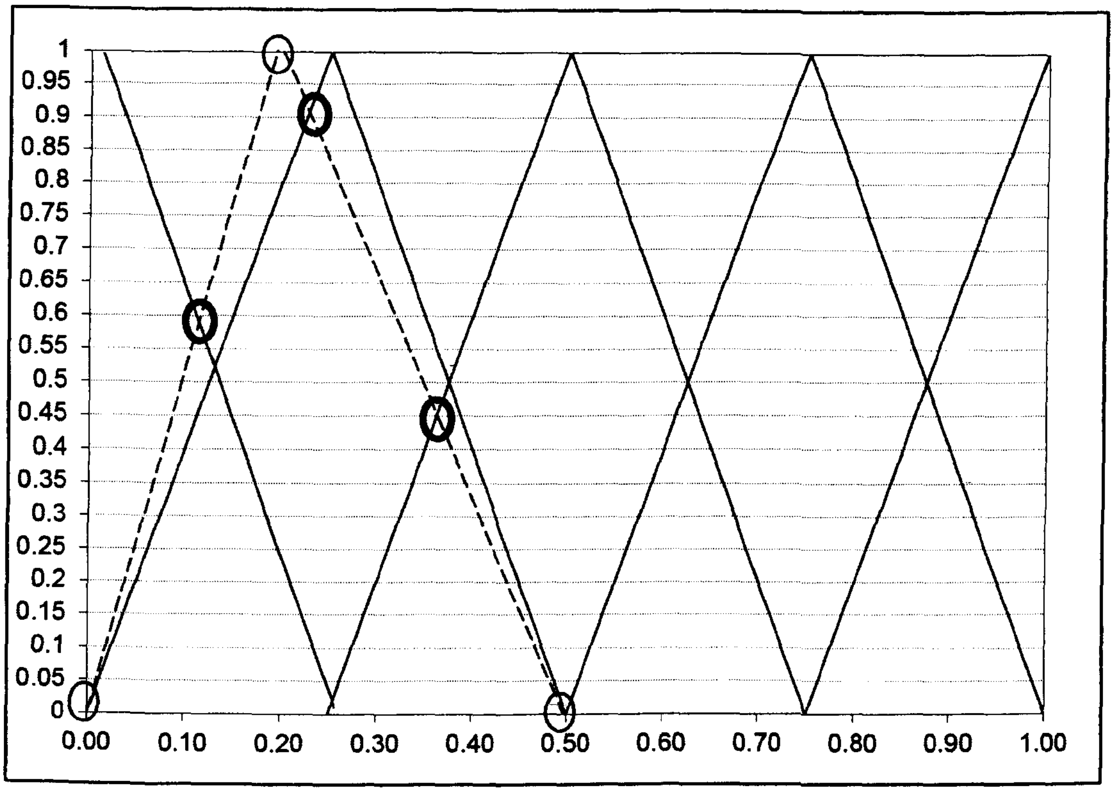


Figure 5.2: Converting FTN_{LS} (fuzzy ratings) to H_R (5 non-normalised grades)

5.5. APPLICATION OF THE ER APPROACH IN OFFSHORE TERMINALS AND MARINE PORTS.

In risk and safety analysis, fundamentally vague data may exist with conditions of "lack of specificity" originating from evidence not adequately strong to completely support a theory but only with degrees of belief or credibility (Binaghi and Madella, 1999). Dempster-Shafer (D-S) theory of evidence (Dempster, 1968; Shafer, 1976) based on the idea of belief function is well suited to modelling subjective credibility induced by partial evidence (Smets, 1988). The D-S theory expands the scope of traditional probability theory, describes and handles uncertainties using the theory of the belief degrees, which can model incompleteness and ignorance clearly.

The theory of evidence was originally created by Dempster (1967) and later developed by Shafer (1976), it is frequently referred to as Dempster-Shafer theory of evidence or D-S theory. The D-S theory was first used for data aggregation in expert systems as an approximate reasoning device (Lopez de Mantaras, 1990). Consequently it has been used to handle multiple criteria decision analysis problems of both a quantitative and qualitative nature with uncertainty (Yang and Singh, 1994; Yang and Sen, 1994; Yang, 2001). The ER rule of combination defines how to combine evidence obtained from two or more sources. It can synthesise all the related risk factors. Furthermore the ER framework is different from most conventional MCDM modelling frameworks in that it employs a belief structure to represent an assessment as a distribution (Li and Liao, 2007). In this chapter ER will be utilised for the aggregation purposes.

5.5.1. A brief review of the past researches on ER

In recent years, the ER approach has been used in decision problems of engineering design, organisational self-assessment, safety and risk assessment and supplier assessment, e.g., motorcycle assessment (Yang and Singh, 1994), safety analysis and synthesis using fuzzy sets and evidential reasoning (Wang *et al*, 1994), general cargo ship design (Sen and Yang, 1994), marine system safety analysis and synthesis (Stewart, 1992; Wang, Yang and Sen, 1995), Multi-person and multi-attribute design evaluations using evidential reasoning based on subjective safety and cost analyses (Wang *et al*, 1996), software safety synthesis (Wang, 1997; Wang and Yang, 2001), a retrofit ferry design (Yang and Sen, 1997), executive car assessment (Yang and Xu, 1998), rule and utility based evidential reasoning approach for MADA under uncertainties (Yang, 2001), addressing the contractor selection problem using an evidential reasoning approach (Sonmez, 2001), organisational self-assessment (Yang and Dale, 2001), on the evidential reasoning algorithm for multiple attribute decision analysis under uncertainty (Yang and Dong, 2002), application of a fuzzy based decision making methodology to construction project risk assessment (Zeng *et al*, 2007), decision support for risk analysis on dynamic alliance (Li and Liao, 2007) and evidential reasoning approach for bridge condition assessment (Wang and Elhag, 2008).

5.5.2. ER based methodology

The core of the ER approach is an evidential reasoning algorithm generated on the basis of a multi-attribute evaluation framework and the evidence combination rule of the D–S theory (Yang and Xu, 2002). It is different from the majority of conventional MADM modelling techniques in the following aspects (Li and Liao, 2007):

- It utilizes a belief structure to represent an evaluation as a distribution instead of as a single numerical score, which can capture variety types of uncertainties such as vague data gathered during subjective judgments.

- When decision makers are not able to grant exact judgments because of shortage of information available, the ER approach allows decision makers to illustrate a degree of belief of less than 1. No other MADM approaches can handle this level of uncertainty.

- It utilizes the evidential combination rule to aggregate the belief degrees rather than scores. In this manner, the ER approach can look after the qualitative aspects of subjective attributes in combination processes.

In order to describe the ER approach, as an example it is preferable to refer to the operational risks model (see Figure III.1 in Appendix III). There is a simple three levels of evaluation hierarchy with a general attribute R, (i.e. Operational Risks) in level 1, six associated sub-attributes (sub-risk factors) (e.g. $R_1, R_2, R_3, \dots, R_6$) in level 2 and moreover subs of sub-attributes (subs of sub-risk factors) (e.g. $R_{11}, R_{12}, R_{13}, \dots, R_{16}$) in level 3. Suppose the weights of the sub-attributes in level 2 are given by W = (W_1, $W_2, W_{3,} \dots, W_L$); $L = 6$, where W_i is the relative weight for a level 2 attribute or risk factor. R_1 is normalized so that:

$0 \le W_i \le 1$ and $\sum_{i=1}^{L} W_i = 1$.

The same condition exists for the level 3 risk factors respectively.

Nevertheless in this respect weights play an important role for the assessment purposes. They may be estimated using existing methods such as expert rating method and AHP (Li and Liao, 2007). The weights used here for operational risk factors have been calculated previously by the Fuzzy AHP method using Chang's (1996) extent analysis. Moreover as Li and Liao (2007) explained attributes may be measured with reference to a set of evaluation grades with various belief degrees. The use of evaluation grades helps data gathering and allows capture of the decision-makers favourite, experience and perception. The general scale of evaluation grades is defined as: $H = \{H_1, H_2, H_3, \dots, H_N\}$. As it was discussed in section 5.4, five evaluation grades for risk factors are defined as follows:

$H = \{H_1, H_2, H_3, H_4, H_5\}$ = {Very low, Low, Medium, High, Very high}

However the assessment of an attribute (a risk factor) R_i, denoted by $S(R_i)$, can be represented using the belief structure as follows (Yang, 2001):

$$S(R_i) = \{(H_1, \beta_{1,i}(R_i)), (H_2, \beta_{2,i}(R_i)), \dots\dots, (H_N, \beta_{N,i}(R_i))\}$$

where $\beta_{n,i}(R_i)$ denotes a degree of belief that the attribute (risk factor) R_i is assessed to the evaluation grade H_n and $\beta_{n,i}(R_i) \geq 0$ with $\sum_{n=1}^{N} \beta_{n,i}(R_i) \leq 1$.

An assessment $S(R_i)$ is complete if $\sum_{n=1}^{N} \beta_{n,i}(R_i) = 1$ and incomplete if $\sum_{n=1}^{N} \beta_{n,i}(R_i) < 1$.

Let $m_{n,i}$ be a basic probability mass representing the degree to which the ith basic attribute (risk factor) R_i supports a hypothesis that the general attribute R is assessed to the nth evaluation grade H_n. Let $m_{H,i}$ be a remaining probability mass unassigned to any individual grade after R_i has been assessed. $m_{n,i}$ and $m_{H,i}$ are calculated as follows (Yang, 2001):

$$m_{n,i} = w_i \beta_{n,i}(R_i), \quad n = 1, 2, \dots, N \quad i = 1, 2, \dots, L,$$

$$m_{H,i} = 1 - \sum_{n=1}^{N} m_{n,i} = 1 - w_i \sum_{n=1}^{N} \beta_{n,i}(R_i), \quad i = 1, 2, \ldots, L.$$

Now in order to assess the sub-attributes (sub-risk factors) of the attribute (risk factor) R_i, the $E_{I(i)}$ can be defined as the subset of the *i*th basic attribute i.e. sub-risk factors of the R_i as follows (this part can be used for the purpose of the level 3 risk factors):

$$E_{I(i)} = \{R_1, R_2, R_3, \ldots, R_i\}.$$

Let $m_{n,I(i)}$ be a probability mass defined as the degree to which all the *i*th attributes in $E_{I(i)}$ support the hypothesis that R_i is assessed to the grade H_n. $m_{H,I(i)}$ is the remaining probability mass unassigned to individual grades after all the basic attributes in $E_{I(i)}$ have been assessed. Obviously, $m_{n,I(1)} = m_{n,1}$ and $m_{H,I(1)} = m_{H,1}\, m_{n,I(L)}$ and $m_{H,I(i)}$ can be generated by aggregating all the all the basic probability assignment, using the ER algorithm (Yang, 2001).

The details about the ER algorithm capable of combining both complete and incomplete assessments can be found in the references e.g. (Yang and Singh, 1994; Yang and Sen, 1994; Yang, 1999 and Yang, 2001).

The aforementioned ER algorithm based on Yang (2001) is integrated into a software package called IDS (Yang and Dong, 2002). In the next section the IDS software will be used for sensitivity analysis following a case study in order to aggregate the input data by using the ER algorithm.

5.6. CASE STUDY

A case study is conducted to evaluate the three Iranian ports of Bushehr, Shahid Rajaie and Chabahar under a fuzzy environment, according to the decision makers or experts' preferences. These ports are marked in Figure 5.3. Furthermore this case study will demonstrate the applicability of the proposed model during the sea ports'/offshore terminals' audits, sea port-to-sea port or offshore terminal-to-offshore terminal risk evaluations or comparisons etc. Operational risk factors (i.e. Figure III.1 in Appendix III) have been chosen to be used as an illustrative example for the evaluation of these sea ports. Figure 5.3 shows the location of the three selected Iranian Ports in the South of Iran.

Figure 5.3: The Ports of Bushehr, Shahid Rajaie and Chabahar.

The first sea port is Bushehr and is located in the Northern coasts of the Persian Gulf. It is a natural harbour. In this port the depth of water is close to 7 metres in the external anchorage leading to internal anchorage by the external channel 9200 meters in length and from the internal anchorage to Bushehr berths. The channel is 140 metres in average width. The port enjoys the existence of favourable hinterlands and the proximity to neighbouring countries such as Kuwait, Iraq, Turkey, Armenia and Azerbaijan. There are 14 of berths which can be used to accommodate vessels for the purpose of the liquid bulks, containers, refer and general cargoes (PMO, 2009).

The second Port of Shahid Rajaie, an artificial harbour having an exceptional geographical location with modern equipment and facilities is one of the most important ports of Iran. It is located at the entrance to the Persian Gulf, at the Strait of Hormoz and North of Qeshem Island, in the Southern part of Iran. It is one of the huge ports situated 20 km west of the Bandar Abbas city. It is well connected with rail and road network to Tehran, the capital and biggest city of Iran, and other cities of Iran as well as neighbouring landlocked countries.

The port of Shahid Rajaie occupies a fifty five percent share of the commercial transaction of Iran through sea. It is considered to be the economical gateway in the field of sea transportation within Middle East and the CIS countries because of ideal geographical location at Persian Gulf and international national rail-road connection with Azerbaijan, Turkmenistan, and Turkey. Maximum draft for this port is 13 metres. This port having 25 berths can accommodate oil, container, general cargo, bulk, multi-purpose vessels (PMO, 2009).

The third port is Chabahar, a natural harbour, located outside of the Persian Gulf in the Oman Sea, South East of Iran. The maximum draft for this port is 11 metres. The port can accommodate general cargo and bulk carriers up to 25000 tonnage. There are only road connections from this port to Pakistan, Afghanistan and Turkmenistan (PMO, 2009).

Three selected experts for the purpose of this case study will use the appropriate linguistic variables shown in Table 5.1 in order to rate these ports for the 22 operational risk factors shown in Figure III.1 in Appendix III. As per Table 5.1, the experts will have to choose an appropriate grade of occurrence likelihood and consequence severity for each risk factor in order to rate the mentioned sea ports.

Appendix III illustrates an evaluation sheet which is used to facilitate the evaluation process of the operational risk factors for the mentioned ports by using the experts' judgments (see Chapter 4 for the procedures of how to collect and analyse data). The nominated experts have long personal experience of serving in these ports especially in managerial positions. Contribution of the experts' and their weights distributions for purpose of the calculations and the defuzzification process of the TFNs have been discussed in detail in Chapter 4. The results of the experts' judgements for operational risks model in respect of the Port of Bushehr, one of the three Iranian ports mentioned in the case study, are depicted in Table 5.5.

Table 5.5: Calculations based on Equation 5.4 for the Port of Bushehr.

Risk	OL	SC	FTN_L	FTN_S	FTN_{LS}	H_R	H
R411	2	3	(0.00,0.25,0.50)	(0.25,0.50,0.75)	(0.00,0.12,0.37)	(0,69,0.735,0.215,0,0)	(0,42,0.45,0.13,0,0)
R412	2	3	(0.00,0.25,0.50)	(0.25,0.50,0.75)	(0.00,0.12,0.37)	(0,69,0.735,0.215,0,0)	(0,42,0.45,0.13,0,0)
R413	4	2	(0.50,0.75,1.00)	(0.00,0.25,0.50)	(0.00,0.19,0.50)	(0.56,0.90,0.45,0,0)	(0.29,0.47,0.24,0,0)
R414	3	4	(0.25,0.50,0.75)	(0.50,0.75,1.00)	(0.12,0.38,0.75)	(0.27,0.76,0.8,0.4.0)	(0.12,0.34,0.36,0.18,0)
R415	2	4	(0.00,0.25,0.50)	(0.50,0.75,1.00)	(0.00,0.19,0.50)	(0,57,0.90,0.45,0,0)	(0.29,0.47,0.24,0,0)
R416	3	4	(0.25,0.50,0.75)	(0.50,0.75,1.00)	(0.12,0.38,0.75)	(0.27,0.76,0,8,0.4.0)	(0.12,0.34,0.36,0.18,0)
R421	2	5	(0.00,0.25,0.50)	(0.75,1.00,1.00)	(0.00,0.25,0.50)	(0.50,0,0.50,0,0)	(0.50,0,0.50,0,0)
R422	3	5	(0.25,0.50,0.75)	(0.75,1.00,1.00)	(0.19,0.50,0.75)	(0.1,0.55,0,0.5,0)	(0.09,0.48,0,0.43,0)
R423	3	3	(0.25,0.50,0.75)	(0.25,0.50,0.75)	(0.06,0.25,0.42)	(0,44,0,0.4,0,0)	(0,52,0,0.48,0,0)
R431	2	4	(0.00,0.25,0.50)	(0.50,0.75,1.00)	(0.00,0.19,0.50)	(0,57,0.90,0.45,0,0)	(0.29,0.47,0.24,0,0)
R432	2	3	(0.00,0.25,0.50)	(0.25,0.50,0.75)	(0.00,0.12,0.37)	(0,69,0.735,0.215,0,0)	(0,42,0.45,0.13,0,0)
R433	2	4	(0.00,0.25,0.50)	(0.50,0.75,1.00)	(0.00,0.19,0.50)	(0,57,0.90,0.45,0,0)	(0.29,0.47,0.24,0,0)
R434	3	4	(0.25,0.50,0.75)	(0.50,0.75,1.00)	(0.12,0.38,0.75)	(0.27,0.76,0,8,0.4.0)	(0.12,0.34,0.36,0.18,0)
R441	3	3	(0.25,0.50,0.75)	(0.25,0.50,0.75)	(0.06,0.25,0.42)	(0,44,0,0.4,0,0)	(0,52,0,0.48,0,0)
R442	2	3	(0.00,0.25,0.50)	(0.25,0.50,0.75)	(0.00,0.12,0.37)	(0,69,0.735,0.215,0,0)	(0,42,0.45,0.13,0,0)
R451	2	3	(0.00,0.25,0.50)	(0.25,0.50,0.75)	(0.00,0.12,0.37)	(0,69,0.735,0.215,0,0)	(0,42,0.45,0.13,0,0)
R452	2	3	(0.00,0.25,0.50)	(0.25,0.50,0.75)	(0.00,0.12,0.37)	(0,69,0.735,0.215,0,0)	(0,42,0.45,0.13,0,0)
R453	2	3	(0.00,0.25,0.50)	(0.25,0.50,0.75)	(0.00,0.12,0.37)	(0,69,0.735,0.215,0,0)	(0,42,0.45,0.13,0,0)
R454	2	3	(0.00,0.25,0.50)	(0.25,0.50,0.75)	(0.00,0.12,0.37)	(0,69,0.735,0.215,0,0)	(0,42,0.45,0.13,0,0)
R461	2	4	(0.00,0.25,0.50)	(0.50,0.75,1.00)	(0.00,0.19,0.50)	(0,57,0.90,0.45,0,0)	(0.29,0.47,0.24,0,0)
R462	3	3	(0.25,0.50,0.75)	(0.25,0.50,0.75)	(0.06,0.25,0.42)	(0,44,0,0.4,0,0)	(0,52,0,0.48,0,0)
R463	4	4	(0.50,0.75,1.00)	(0.50,0.75,1.00)	(0.25,0.56,1.00)	(0,0.45,0.9,0.725,0.36)	(0,0.18,0.37,0.30,0.15)

The results of the experts' judgements for operational risks model in respect of the Port of Shahid Rajaie in the case study are depicted in Table 5.6.

Table 5.6: Calculations based on Equation 5.4 for the Port of Shahid Rajaie.

Risk	OL	SC	FTN_L	FTN_S	FTN_{LS}	H_R	H
R411	2	2	(0.00,0.25,0.50)	(0.00,0.25,0.50)	(0.00,0.06,0.25)	(0,81,0.56,0,0,0)	(0,59,0.41,0,0,0)
R412	3	4	(0.25,0.50,0.75)	(0.50,0.75,1.00)	(0.12,0.38,0.75)	(0.27,0.76,0,8,0.4.0)	(0.12,0.34,0.36,0.18,0)
R413	2	2	(0.00,0.25,0.50)	(0.00,0.25,0.50)	(0.00,0.06,0.25)	(0,81,0.56,0,0,0)	(0,59,0.41,0,0,0)
R414	2	3	(0.00,0.25,0.50)	(0.25,0.50,0.75)	(0.00,0.12,0.37)	(0,69,0.735,0.215,0,0)	(0,42,0.45,0.13,0,0)
R415	4	4	(0.50,0.75,1.00)	(0.50,0.75,1.00)	(0.25,0.56,1.00)	(0,0.45,0.9,0.725,0.36)	(0,0.18,0.37,0.30,0.15)
R416	3	3	(0.25,0.50,0.75)	(0.25,0.50,0.75)	(0.06,0.25,0.42)	(0,44,0,0.4,0,0)	(0,52,0,0.48,0,0)
R421	2	4	(0.00,0.25,0.50)	(0.50,0.75,1.00)	(0.00,0.19,0.50)	(0,57,0.90,0.45,0,0)	(0.29,0.47,0.24,0,0)
R422	2	4	(0.00,0.25,0.50)	(0.50,0.75,1.00)	(0.00,0.19,0.50)	(0,57,0.90,0.45,0,0)	(0.29,0.47,0.24,0,0)
R423	2	4	(0.00,0.25,0.50)	(0.50,0.75,1.00)	(0.00,0.19,0.50)	(0,57,0.90,0.45,0,0)	(0.29,0.47,0.24,0,0)
R431	3	4	(0.25,0.50,0.75)	(0.50,0.75,1.00)	(0.12,0.38,0.75)	(0.27,0.76,0,8,0.4.0)	(0.12,0.34,0.36,0.18,0)
R432	3	4	(0.25,0.50,0.75)	(0.50,0.75,1.00)	(0.12,0.38,0.75)	(0.27,0.76,0,8,0.4.0)	(0.12,0.34,0.36,0.18,0)
R433	3	3	(0.25,0.50,0.75)	(0.25,0.50,0.75)	(0.06,0.25,0.42)	(0,44,0,0.4,0,0)	(0,52,0,0.48,0,0)
R434	2	3	(0.00,0.25,0.50)	(0.25,0.50,0.75)	(0.00,0.12,0.37)	(0,69,0.735,0.215,0,0)	(0.42,0.45,0.13,0,0)
R441	3	4	(0.25,0.50,0.75)	(0.50,0.75,1.00)	(0.12,0.38,0.75)	(0.27,0.76,0,8,0.4.0)	(0.12,0.34,0.36,0.18,0)
R442	2	4	(0.00,0.25,0.50)	(0.50,0.75,1.00)	(0.00,0.19,0.50)	(0,57,0.90,0.45,0,0)	(0.29,0.47,0.24,0,0)
R451	4	4	(0.50,0.75,1.00)	(0.50,0.75,1.00)	(0.25,0.56,1.00)	(0,0.45,0.9,0.725,0.36)	(0,0.18,0.37,0.30,0.15)
R452	4	3	(0.50,0.75,1.00)	(0.25,0.50,0.75)	(0.12,0.38,0.75)	(0.27,0.76,0,8,0.4.0)	(0.12,0.34,0.36,0.18,0)
R453	3	3	(0.25,0.50,0.75)	(0.25,0.50,0.75)	(0.06,0.25,0.42)	(0,44,0,0.4,0,0)	(0,52,0,0.48,0,0)
R454	4	4	(0.50,0.75,1.00)	(0.50,0.75,1.00)	(0.50,0.56,1.00)	(0,0.45,0.9,0.725,0.36)	(0,0.18,0.37,0.30,0.15)
R461	3	3	(0.25,0.50,0.75)	(0.25,0.50,0.75)	(0.06,0.25,0.42)	(0,44,0,0.4,0,0)	(0,52,0,0.48,0,0)
R462	4	4	(0.50,0.75,1.00)	(0.50,0.75,1.00)	(0.25,0.56,1.00)	(0,0.45,0.9,0.725,0.36)	(0,0.18,0.37,0.30,0.15)
R463	3	4	(0.25,0.50,0.75)	(0.50,0.75,1.00)	(0.12,0.38,0.75)	(0.27,0.76,0,8,0.4.0)	(0.12,0.34,0.36,0.18,0)

The results of the experts' judgements for operational risks model in respect of the Port of Chabahar in the case study are shown in Table 5.7.

Table 5.7: Calculations based on Equation 5.4 for the Port of Chabahar.

Risk	OL	SC	FTN_L	FTN_S	FTN_{LS}	H_R	H
R411	1	1	(0.00,0.00,0.25)	(0.00,0.00,0.25)	(0.00,0.00,0.02)	(0,0.03,0,0,0)	(0,1,0,0,0)
R412	1	1	(0.00,0.00,0.25)	(0.00,0.00,0.25)	(0.00,0.00,0.02)	(0,0.03,0,0,0)	(0,1,0,0,0)
R413	3	4	(0.25,0.50,0.75)	(0.50,0.75,1.00)	(0.12,0.38,0.75)	(0.27,0.76,0.8,0.4,0)	(0.12,0.34,0.36,0.18,0)
R414	1	1	(0.00,0.00,0.25)	(0.00,0.00,0.25)	(0.00,0.00,0.02)	(0,0.03,0,0,0)	(0,1,0,0,0)
R415	1	1	(0.00,0.00,0.25)	(0.00,0.00,0.25)	(0.00,0.00,0.02)	(0,0.03,0,0,0)	(0,1,0,0,0)
R416	1	2	(0.00,0.00,0.25)	(0.00,0.25,0.50)	(0.00,0.00,0.12)	(0,0.33,0,0,0)	(0,1,0,0,0)
R421	1	2	(0.00,0.00,0.25)	(0.00,0.25,0.50)	(0.00,0.00,0.12)	(0,0.33,0,0,0)	(0,1,0,0,0)
R422	2	3	(0.00,0.25,0.50)	(0.25,0.50,0.75)	(0.00,0.06,0.25)	(0,81,0.56,0,0,0)	(0,59,0.41,0,0,0)
R423	1	2	(0.00,0.00,0.25)	(0.00,0.25,0.50)	(0.00,0.00,0.12)	(0,0.33,0,0,0)	(0,1,0,0,0)
R431	1	3	(0.00,0.00,0.25)	(0.25,0.50,0.75)	(0.00,0.00,0.19)	(0,0.44,0,0,0)	(0,1,0,0,0)
R432	1	2	(0.00,0.00,0.25)	(0.00,0.25,0.50)	(0.00,0.00,0.12)	(0,0.33,0,0,0)	(0,1,0,0,0)
R433	1	2	(0.00,0.00,0.25)	(0.00,0.25,0.50)	(0.00,0.00,0.12)	(0,0.33,0,0,0)	(0,1,0,0,0)
R434	1	1	(0.00,0.00,0.25)	(0.00,0.00,0.25)	(0.00,0.00,0.02)	(0,0.03,0,0,0)	(0,1,0,0,0)
R441	3	2	(0.25,0.50,0.75)	(0.00,0.25,0.50)	(0.00,0.06,0.25)	(0,81,0.56,0,0,0)	(0,59,0.41,0,0,0)
R442	2	2	(0.00,0.25,0.50)	(0.00,0.25,0.50)	(0.00,0.06,0.25)	(0,81,0.56,0,0,0)	(0,59,0.41,0,0,0)
R451	2	2	(0.00,0.25,0.50)	(0.00,0.25,0.50)	(0.00,0.06,0.25)	(0,81,0.56,0,0,0)	(0,59,0.41,0,0,0)
R452	2	2	(0.00,0.25,0.50)	(0.00,0.25,0.50)	(0.00,0.06,0.25)	(0,81,0.56,0,0,0)	(0,59,0.41,0,0,0)
R453	1	2	(0.00,0.00,0.25)	(0.00,0.25,0.50)	(0.00,0.00,0.12)	(0,0.33,0,0,0)	(0,1,0,0,0)
R454	1	2	(0.00,0.00,0.25)	(0.00,0.25,0.50)	(0.00,0.00,0.12)	(0,0.33,0,0,0)	(0,1,0,0,0)
R461	1	1	(0.00,0.00,0.25)	(0.00,0.00,0.25)	(0.00,0.00,0.02)	(0,0.03,0,0,0)	(0,1,0,0,0)
R462	2	2	(0.00,0.25,0.50)	(0.00,0.25,0.50)	(0.00,0.06,0.25)	(0,81,0.56,0,0,0)	(0,59,0.41,0,0,0)
R463	1	2	(0.00,0.00,0.25)	(0.00,0.25,0.50)	(0.00,0.00,0.12)	(0,0.33,0,0,0)	(0,1,0,0,0)

The following grades are as a result of the final calculations made by using the method explained in Section 5.4 with the use of Equation 5.4. These results along with the relative weights which were determined in Chapter 4, are shown in Table 5.8 and will be fed into the IDS software for further aggregation in order to obtain the final result (i.e. to determine the ranking and overall risk levels of the ports).

Table 5.8: Relative weights and belief degrees for three Iranian ports.

Risk	Weight	*H*(Bushehr)	*H*(Shahid Rajaie)	*H* (*Chabahar*)
R411	(0.0089)	(0,42,0.45,0.13,0,0)	(0,59,0.41,0,0,0)	(0,1,0,0,0)
R412	(0.0632)	(0,42,0.45,0.13,0,0)	(0.12,0.34,0.36,0.18,0)	(0,1,0,0,0)
R413	(0.0184)	(0.29,0.47,0.24,0,0)	(0,59,0.41,0,0,0)	(0.12,0.34,0.36,0.18,0)
R414	(0.0740)	(0.12,0.34,0.36,0.18,0)	(0,42,0.45,0.13,0,0)	(0,1,0,0,0)
R415	(0.0058)	(0.29,0.47,0.24,0,0)	(0,0.18,0.37,0.30,0.15)	(0,1,0,0,0)
R416	(0.0168)	(0.12,0.34,0.36,0.18,0)	(0,52,0,0.48,0,0)	(0,1,0,0,0)
R421	(0.1987)	(0.50,0,0.50,0,0)	(0.29,0.47,0.24,0,0)	(0,1,0,0,0)
R422	(0.0813)	(0.09,0.48,0,0.43,0)	(0.29,0.47,0.24,0,0)	(0,59,0.41,0,0,0)
R423	(0.0166)	(0,52,0,0.48,0,0)	(0.29,0.47,0.24,0,0)	(0,1,0,0,0)
R431	(0.0877)	(0.29,0.47,0.24,0,0)	(0.12,0.34,0.36,0.18,0)	(0,1,0,0,0)
R432	(0.0316)	(0,42,0.45,0.13,0,0)	(0.12,0.34,0.36,0.18,0)	(0,1,0,0,0)
R433	(0.0389)	(0.29,0.47,0.24,0,0)	(0,52,0,0.48,0,0)	(0,1,0,0,0)
R434	(0.0187)	(0.12,0.34,0.36,0.18,0)	(0,42,0.45,0.13,0,0)	(0,1,0,0,0)
R441	(0.0055)	(0,52,0,0.48,0,0)	(0.12,0.34,0.36,0.18,0)	(0,59,0.41,0,0,0)
R442	(0.0024)	(0,42,0.45,0.13,0,0)	(0.29,0.47,0.24,0,0)	(0,59,0.41,0,0,0)
R451	(0.1210)	(0,42,0.45,0.13,0,0)	(0,0.18,0.37,0.30,0.15)	(0,59,0.41,0,0,0)
R452	(0.0390)	(0,42,0.45,0.13,0,0)	(0.12,0.34,0.36,0.18,0)	(0,59,0.41,0,0,0)
R453	(0.0459)	(0,42,0.45,0.13,0,0)	(0,52,0,0.48,0,0)	(0,1,0,0,0)
R454	(0.0369)	(0,42,0.45,0.13,0,0)	(0,0.18,0.37,0.30,0.15)	(0,1,0,0,0)
R461	(0.0069)	(0.29,0.47,0.24,0,0)	(0,52,0,0.48,0,0)	(0,1,0,0,0)
R462	(0.0502)	(0,52,0,0.48,0,0)	(0,0.18,0.37,0.30,0.15)	(0,59,0.41,0,0,0)
R463	(0.0316)	(0,0.18,0.37,0.30,0.15)	(0.12,0.34,0.36,0.18,0)	(0,1,0,0,0)

By using the information gathered and feeding it into the IDS software, results and graphical displays were generated, depicted in Figures 5.4, 5.5 and 5.6.

The average score of the operational risk factors obtained for the Port of Chabahar is 0.7811. Therefore the Port of Chabahar with the highest average score will be the safest port among the three. After the Port of Chabahar, the Port of Bushehr stands second in ranking with an average score of 0.7433 and the Port of Shahid Rajaie stands in the third position with an average score of 0.6562. In terms of riskiness of the ports they can be ranked as follows:

$R_{Shahid\ Rajaie} > R_{Bushehr} > R_{Chabahar}$; $R = \boldsymbol{Riskiness\ of\ the\ ports.}$

In order to prove the aforesaid capability of the IDS software reference can be made to the previous works of Yang and Xu (2002) and Wang and Elhag (2008). Yang and Xu (2002) using the IDS software for comparison of the Kawazaki, BMW, Yamaha and Honda motorcycles have ranked them for their overall performance. For the purpose of comparison they have ranked them as per their average scores derived from the IDS. The one with the highest score stood first. In the same manner Wang and Elhag (2008) have used the IDS for condition assessment of three bridges.

Moreover the following evaluation results are also derived out from the IDS for the Port of Shahid Rajaie. As can be seen in Figure 5.4 the belief degrees of the operational risk factors for the grades of medium, high and very high (i.e. the worse possible cases) have a higher percentage than those shown in Figure 5.5 for the Port of Bushehr and in Figure 5.6 for the Port of Chabahar. In this respect Bushehr is second and Chabahar, as can be seen from Figure 5.6, has got zero percentage for the grade of very high, a minimum percentage in comparison to the other two ports for its worst case. This comparison can provide evidence that the overall level of the operational risks in the Port of Chabahar is lower than the other two ports.

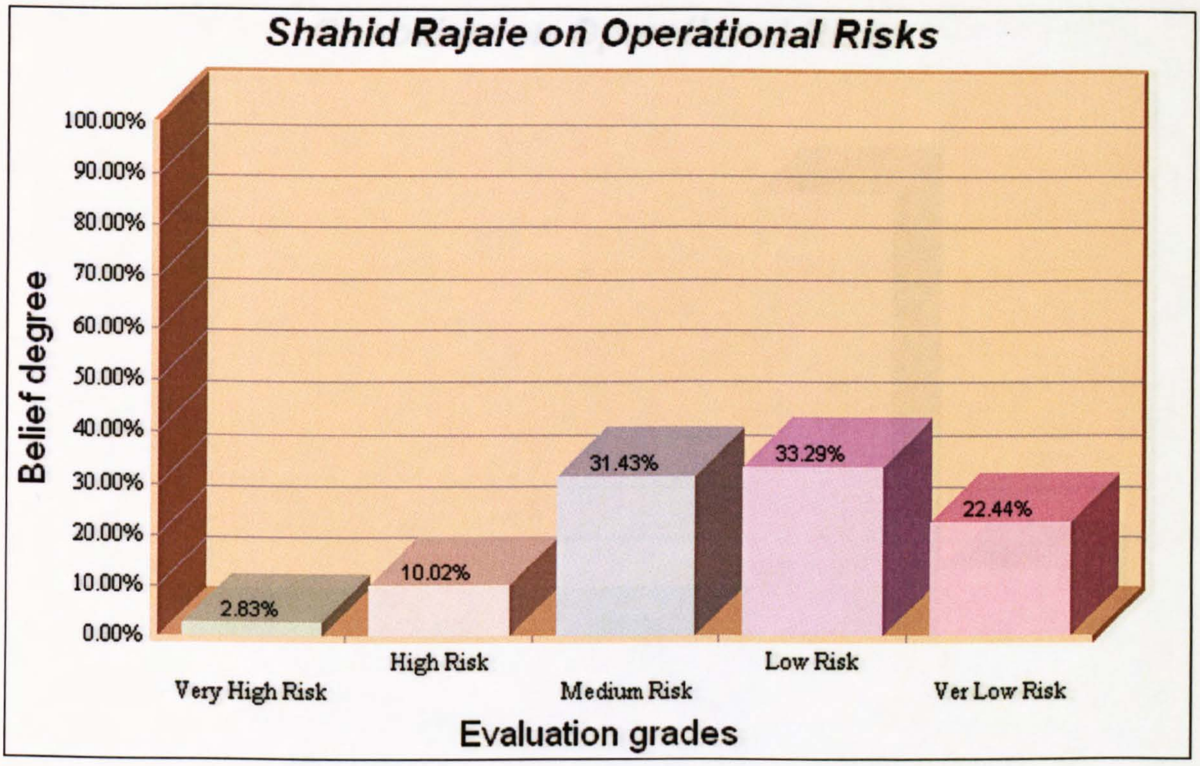


Figure 5.4: Evaluation results for Port of Shahid Rajaie.

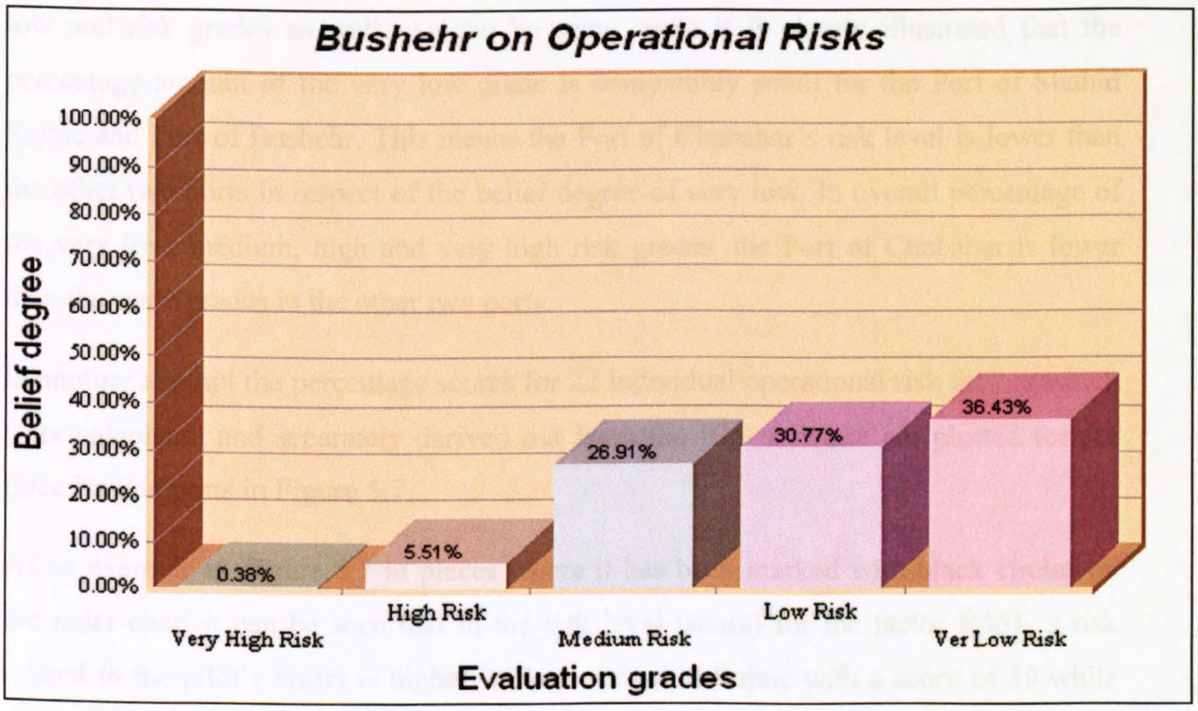


Figure 5.5: Evaluation results for Port of Bushehr.

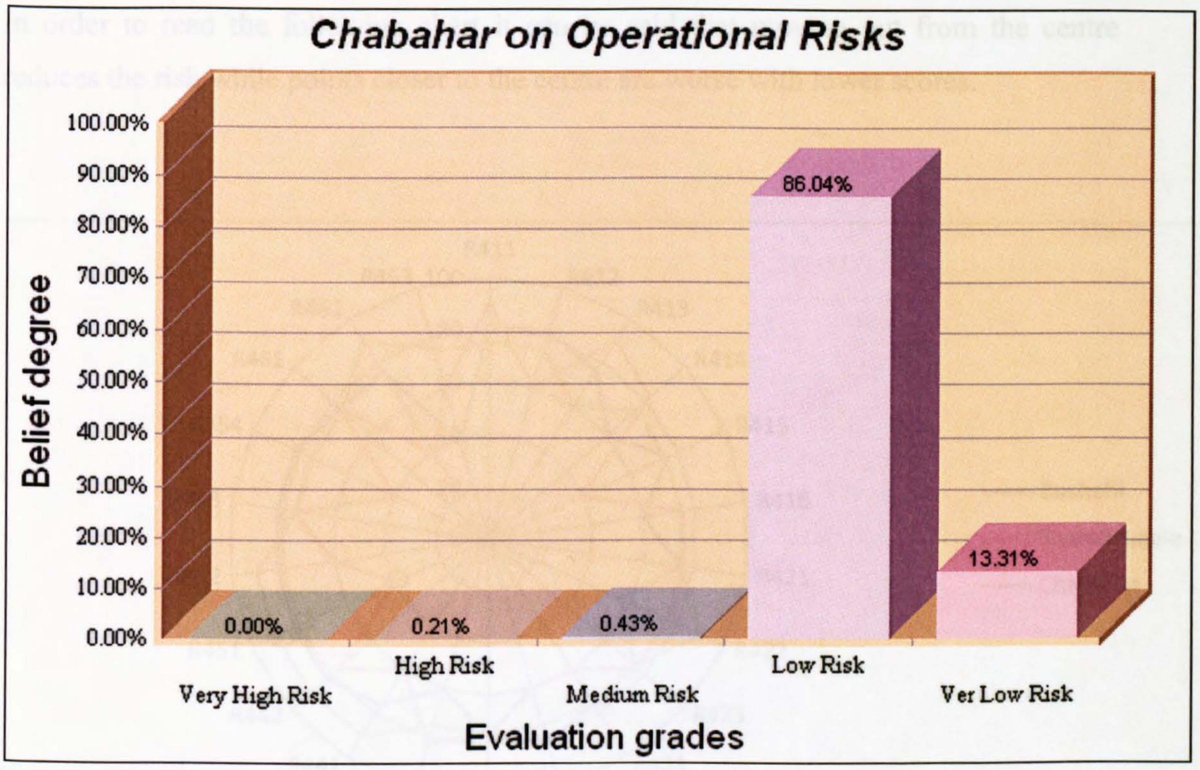


Figure 5.6: Evaluation results for Port of Chabahar.

Comparison of the grades can be explained for these ports in respect of the very low, low and risk grades as well. As can be seen, again it is clearly illustrated that the percentage amount of the very low grade is comparably small for the Port of Shahid Rajaie and Port of Bushehr. This means the Port of Chabahar's risk level is lower than the other two ports in respect of the belief degree of very low. In overall percentage of the very low, medium, high and very high risk grades, the Port of Chabahar is lower than the same grades in the other two ports.

In another attempt the percentage scores for 22 individual operational risk factors which were calculated and separately derived out from the IDS software are plotted for the three Iranian ports in Figure 5.7.

As an example in Figure 5.7 in places where it has been marked with black circles on the radar chart it can be seen that in the risk level (score) for the factor R451, a risk related to the pilot's errors is higher in Port of Shahid Rajaie with a score of 39 while the Port of Bushehr scores 82 and the Port of Chabahar scores of 90. As was explained before a higher score means that the related risk factor is safer.

In order to read the following chart it can be said that moving out from the centre reduces the risk while points closer to the centre are worse with lower scores.

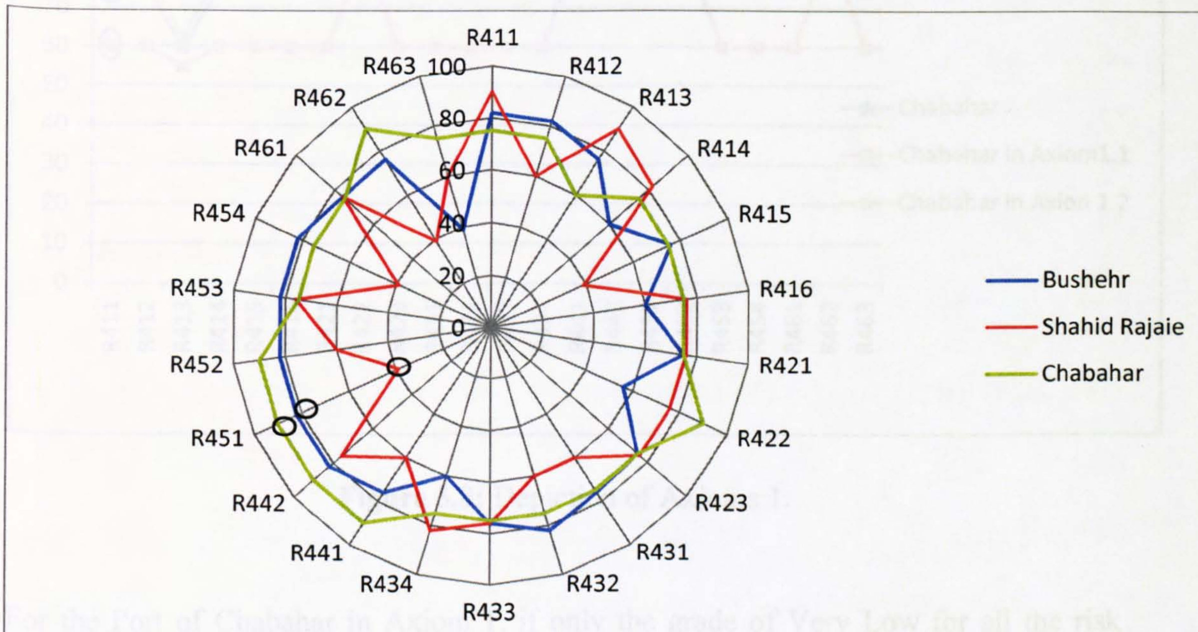


Figure 5.7: Percentage Scores of the operational risk factors for three Iranian Ports.

5.7. SENSITIVITY ANALYSIS

There are several methodologies for validating knowledge-based systems but the most common are informal validation, validation by testing, field tests, subsystem validation and sensitivity analysis. Among these methods sensitivity analysis is a powerful technique in systems relying on uncertainty management (Gonzalez and Dankel, 1993).

Axiom 1: A minor decline or increase of the belief degrees for the risk factors should result in a corresponding change of the output data (i.e. risk levels).

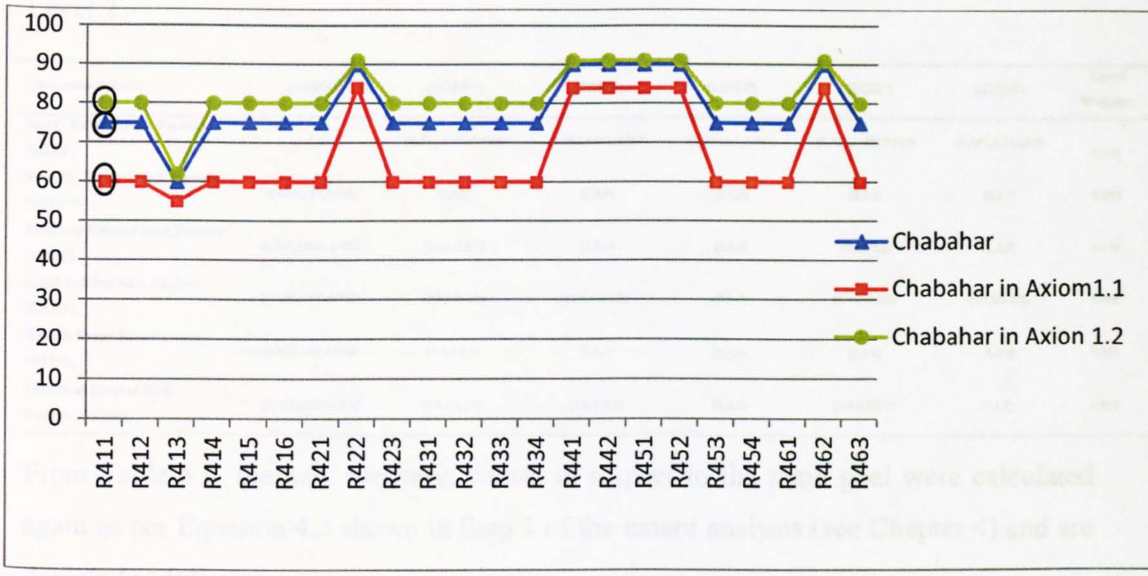


Figure 5.8: Depiction of Axioms 1.

For the Port of Chabahar in Axiom 1, if only the grade of Very Low for all the risk factors shown in Figure 5.8 is decreased by 20% and respectively this 20% is added to the opposite side of the grades (i.e. the grade of Very High) then this will cause a reduction for all of the risk factors as shown in Figure 5.8.

Axiom 2: A minor decline or increase of the relative weights for the risk factors should result in a corresponding change of the output data.

In order to check if the results obtained are in line with Axiom 2 it was decided to decrease only 10% of the FTNs of the experts' judgments just for one of the experts and only for one of the risk factors. As can be seen in Table 5.9 after reducing 10% for one of the experts' FTNs in the safety related risk factor and aggregating the changed FTNs again, the new results for the safety related risk factor will be obtained as shown in Table 5.9.

Table 5.9: Re-calculation of pair-wise comparison matrix of operational risk factors in Level 2

Operational Risks	(SRRF)	(SRRF*)	(PRRF)	(LRRF)	(HERF)	(TRRF)	Local Weights
Safety Related Risk Factors (SRRF)	(1,1,1)	(0.322,0.483,0.967)	(0.967,0.967,0.967)	(1.933,2.9,3.867)	(0.322,0.483,0.967)	(0.967,1.933,2.9)	0.179
Security Related Risk Factors (SRRF*)	(1.034,2.07,3.106)	(1,1,1)	(2,3,4)	(2,3,4)	(1,2,3)	(2,3,4)	0.299
Pollution Related Risk Factors (PRRF)	(1.034,1.034, 1.034)	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)	(1/3,1/2,1)	(1,2,3)	0.179
Legal Related Risk Factors (LRRF)	(0.258,0.345,0.517)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	0.008
Human Error Risk Factors (HERF)	(1.034,2.07,3.106)	(1/3,1/2,1)	(1,2,3)	(1,2,3)	(1,1,1)	(2,3,4)	0.245
Technical Related Risk Factors (TRRF)	(0.345,0.517,1.034)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,2,3)	(1/4,1/3,1/2)	(1,1,1)	0.090

From Table 5.9, the new synthesis values in respect to the main goal were calculated again as per Equation 4.5 shown in Step 1 of the extent analysis (see Chapter 4) and are depicted as follows:

$S1=(5.511, 7.766, 10.668) \otimes (1/66.965, 1/47.967, 1/32.131) = (0.082,0.162,0.332)$,
$S2=(9.034, 14.07, 19.106) \otimes (1/66.965, 1/47.967, 1/32.131)= (0.135,0.293,0.595)$,
$S3=(5.617, 7.867, 10.534) \otimes (1/66.965, 1/47.967, 1/32.131) = (0.084,0.164,0.328)$,
$S4=(2.424, 3.011, 4.517) \otimes (1/66.965, 1/47.967, 1/32.131) = (0.036,0.063,0.141)$,
$S5=(6.367, 10.57, 15.106) \otimes (1/66.965, 1/47.967, 1/32.131) = (0.095,0.220,0.470)$,
$S6=(3.178, 4.683, 7.034) \otimes (1/66.965, 1/47.967, 1/32.131) = (0.047,0.098,0.219)$.

These fuzzy synthesis values are compared with each other using Equation 4.17 (see Chapter 4) and the new values are obtained as follows:

$V(S1 \geq S2)=0.601$, $V(S1 \geq S3)=0.992$, $V(S1 \geq S4)=1$, $V(S1 \geq S5)=0.803$, $V(S1 \geq S6)=1$;
$V(S2 \geq S1)=1$, $V(S2 \geq S3)=1$, $V(S2 \geq S4)=1$, $V(S2 \geq S5)=1$, $V(S2 \geq S6)=1$;
$V(S3 \geq S1)=1$, $V(S3 \geq S2)=0.599$, $V(S3 \geq S4)=1$, $V(S3 \geq S5)=0.806$, $V(S3 \geq S6)=1$;
$V(S4 \geq S1)=0.373$, $V(S4 \geq S2)=0.025$, $V(S4 \geq S3)=0.361$, $V(S4 \geq S5)=0.227$, $V(S4 \geq S6)=0.729$;
$V(S5 \geq S1)=1$, $V(S5 \geq S2)=0.821$, $V(S5 \geq S3)=1$, $V(S5 \geq S4)=1$, $V(S5 \geq S6)=1$;
$V(S6 \geq S1)=0.681$, $V(S6 \geq S2)=0.301$, $V(S6 \geq S3)=0.672$, $V(S6 \geq S4)=1$, $V(S6 \geq S5)=0.504$.

Then the priority weights are calculated using Equation 4.18 shown in Step 3 of the extent analysis (see Chapter 4) as follow:

$d'(C1) = \min(0.601, 1, 0.992, 1, 1) = 0.601$,
$d'(C2) = \min(1, 1, 1, 1, 1) = 1$,
$d'(C3) = \min(1, 0.599, 1, 0.806, 1) = 0.599$,
$d'(C4) = \min(0.373, 0.025, 0.361, 0.227, 0.729) = 0.025$,
$d'(C5)=\min(1, 0.821, 1, 1, 1)=0.821$,
$d'(C6) = \min(0.681, 0.301, 0.672, 1, 0.504) = 0.301$.

$W' = (0.601,1,0.599,0.025,0.821,0.301)$

Collected priority weights are shown in vector W'. Finally after normalisation of these values as per Equation 4.20 shown in Step 4 of the extent analysis (see Chapter 4), the priority weights in respect to the main goal will be calculated as follows for each criterion in Table 5.10:

$W_{New}= (\downarrow 0.179, \uparrow 0.299, \uparrow 0.179, \uparrow 0.008, \uparrow 0.245, \uparrow 0.090)$

$W_{Old} = (0.186,0.297,0.178,0.007,0.243,0.089)$; i.e. Table 4.8

As it is shown here, the new normalised weights (W_{New}) will be obtained as a result of 10% decrease in one of the experts' TFNs in the first risk factor (i.e. safety related risk factor). While this decrease has resulted in a decline in the normalised weight of the first risk factor, it has also caused accordingly an increase of the normalised weights for the rest of the five risk factors in respect of W_{Old}. All the new results are calculated and compared with the old results in Table 5.10.

Table 5.10: Re-calculated global weights for operational risk factors in Level 3

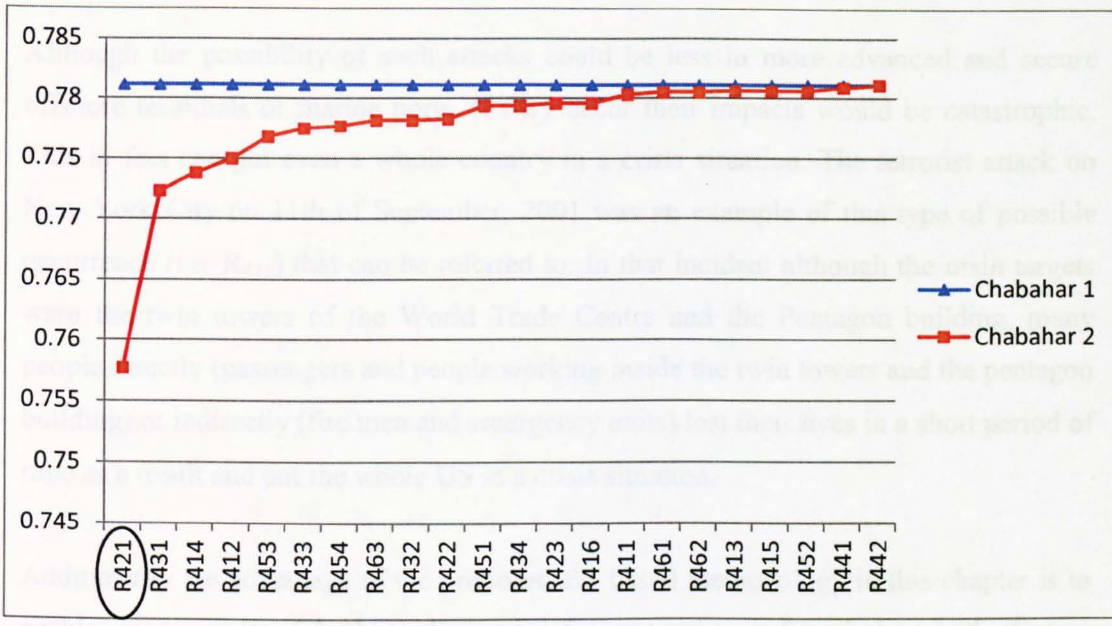
Level 1 Risk	Level 2 Risks	New Local Weights	Level 3 Risks	Local Weights	Old Global Weights	New Global Weights
Operational Risk	Safety Related Risk Factors (SRRF)	↓ (0.179)	Composition of Calling Fleet (CCF)	(0.048)	(0.0089)	↓ (0.0087)
			Traffic Conditions (TC)	(0.340)	(0.0632)	↓ (0.0610)
			Weather Conditions (WC)	(0.099)	(0.0184)	↓ (0.0178)
			Waterway Configuration (WC*)	(0.398)	(0.0740)	↓ (0.0693)
			Potential Consequences of DG Transportation (PCDGT)	(0.027)	(0.0058)	↓ (0.0049)
			Potential Impacts of not having VTM (PIVTM)	(0.088)	(0.0168)	↓ (0.0158)
	Security Related Risk Factors (SRRF*)	↑ (0.299)	People's Safety (PS)	(0.670)	(0.1989)	↑ (0.2004)
			Port Asset (PA)	(0.274)	(0.0813)	↑ (0.0820)
			Port Profit (PP)	(0.056)	(0.0166)	↑ (0.0169)
	Pollution Related Risk Factors (PRRF)	↑ (0.179)	Related Pollutions (SRP)	(0.496)	(0.0877)	↑ (0.0889)
			Cargo Related Pollutions (CRP)	(0.178)	(0.0316)	↑ (0.0320)
			Port Related Pollutions (PRP)	(0.220)	(0.0389)	↑ (0.0395)
			City Related Pollutions (CRP)	(0.106)	(0.0187)	↑ (0.0191)
	Legal Related Risk Factors (LRRF)	↑ (0.008)	Fraud in Contracts (FC)	(0.693)	(0.0055)	↑ (0.0057)
			Regulatory Changes (RC)	(0.307)	(0.0024)	↑ (0.0026)
	Human Error Risk Factors (HERF)	↑ (0.245)	Pilots Related Errors	(0.498)	(0.1210)	↑ (0.1221)
			Ships Personnel Related Errors	(0.161)	(0.0390)	↑ (0.0395)
			Port Personnel Related Errors	(0.189)	(0.0459)	↑ (0.0464)
			Stevedores Related Errors	(0.152)	(0.0369)	↑ (0.0373)
	Technical Related Risk Factors (TRRF)	↑ (0.090)	Lack of Equipment Maintenance (LEM)	(0.078)	(0.0069)	↑ (0.0070)
			Lack of IT Technology (LITT)	(0.566)	(0.0503)	↑ (0.0510)
			Lack of Dredging and Navaids Maintenance (LDNM)	(0.356)	(0.0316)	↑ (0.0321)

In respect of Axiom 2 all new and re-calculated relative weights (new input data) are fed into IDS software in order to see the new results. Following feeding the new relative weights, new average scores (new output data) for three Iranian ports are obtained as follows:

The previous scores were 0.6562, 0.7433 and 0.7811 for the Ports of Shahid Rajaie, Bushehr and Chabahar respectively but the new results after changing the relative weights for the same ports are 0.6552, 0.7440 and 0.7817. To carry out this axiom it was decided to decrease only 10% of the FTNs of the experts' judgments just for one of the experts and only for one of the risk factors. Moreover as it is evident from Table 5.10 the amount of change on the new global weights are very small. Therefore after feeding new global weights into the IDS software and aggregating them with experts' judgement on three nominated ports the amount of changes on the new results are small.

Axiom 3: A minor decline or increment in the input data i.e. belief degrees for any individual risk factor, should result in a decrease or an increase in the overall average scores correspondingly.

The gradual change (red line, line Chabahar 2)in Figure 5.9 on the overall score for the operational risk factors of the Port of Chabahar has been compared against its fixed value score (i.e. 0.7811) derived previously from the IDS software. In this case the belief degrees for each one of the individual risk factors have been changed and after that the new overall scores for operational risk factors have been recorded. These processes have been repeated 22 times in order to complete the shown cycle of the red line. The change of the belief degrees can be of any type but for the case of the Port of Chabahar these changes are based on the same changes which were explained in Axiom 1. As it can be seen from Figure 5.9 the most significant change is for the risk factor R_{421} that is, people's safety in the Port of Chabahar which itself is the subset of the security risk factor in level 3 as shown in Appendix III, Figure III.1.



Figures 5.9: Effect of the changes in the input data on overall scores for the Port of Chabahar in order to fulfil Axiom 3.

5.8. RESULTS AND DISCUSSIONS

After implementing the risk-based model in a real case of port-to-port comparison with the use of IDS software it was possible to check sensitivity of the model by applying minor changes. Apart from overall changes evidenced on the output data as a result of changes from the input side Figure 5.9 also depicts when final analysis was carried out on all risk factors. The amount of change on R_{421} i.e. safety of people in offshore terminals and marine ports was found to be the most significant one.

At any time people working in offshore terminals and marine ports or passengers can become potential targets for terrorists. Terrorism is almost certainly a form of attack that most people fear. Furthermore, terrorists often have much greater destructive ability than other malicious groups do, thus giving them the potential especially to cause a lot of harm to people and endanger their safety. Ports' and offshore terminals' infrastructures (e.g. a passenger quay/terminal, a petrochemical port or an offshore LNG FPSO having alongside an LNG gas carrier) are types of targets for terrorists to attack.

Although the possibility of such attacks could be less in more advanced and secure offshore terminals or marine ports, if they occur their impacts would be catastrophic. This in fact can put even a whole country in a crisis situation. The terrorist attack on New York City on 11th of September, 2001 was an example of this type of possible occurrence (i.e. R_{421}) that can be referred to. In that incident although the main targets were the twin towers of the World Trade Centre and the Pentagon building, many people directly (passengers and people working inside the twin towers and the pentagon building) or indirectly (fire men and emergency units) lost their lives in a short period of time as a result and put the whole US in a crisis situation.

Additionally the advantage of the proposed ER based methodology in this chapter is to enable aggregation of both qualitative and quantitative gathered data with diverse natures into a single structure. That is combining the previously calculated relative weights of the risk factors through the FAHP method with the newly collected belief degrees through expert judgement. The ER can also handle and illustrate data with uncertainties, for which their distributions are vague. Furthermore it has the capability to update estimates based on the recently received information. The ER based methodology is structured in such a way that new data can be managed at any phase and in any shape. It is a simple configurable programme for computer applications therefore it could be used as a risk evaluation technique for the purpose of offshore terminals and marine ports.

5.9. CONCLUSIONS

In this chapter three categories of tasks have been fulfilled in connection to each other in order to complete the risk evaluation process. Obviously this phase is one of the main parts of the RM framework in respect of offshore terminals and marine ports.

In the first part of this chapter after introducing the FST, its application on the different areas specially on engineering and management topics was investigated. It was employed for handling of the risk levels by the use of risk parameters under fuzzy environments.

In the second part in order to aggregate the relative weights calculated via a FAHP method in the previous chapter with the new evaluation results while using FST, an ER approach was found to be the most useful. A brief summary of its application in the other area of the works was investigated. Moreover reasons of using belief degrees and D-S theory were explained to solve the fuzzy rule-based theory. A methodology incorporating the ER algorithm based on Yang (2002) was explained and used for the purpose of this chapter.

Finally, the third part of this chapter proved the applicability and sensitivity of the proposed model. To perform this while using a case study on three Iranian ports, with the use of the FST and ER approach, the IDS software was used to perform the sensitivity analysis. In fact the same approach and methodology can be applied on offshore terminals to investigate the level of their riskiness or to see which one is more reliable and safer when comparing them with each other. Finally operational risk factors were examined in respect of the mentioned three Iranian ports to check the sensitivity of the proposed risk-based model to any change.

In Chapter 4 a generic risk-based model was developed; all the risk factors were prioritised and ranked. Then in Chapter 5 the same risk-based model was used along with the IDS software for port-to-port risk-based evaluation purposes. In the next chapter with the use of the Cause and Consequence Analysis the most significant risk factors (i.e. significant hazards identified from the previous chapter) will be investigated in more detail. The complementary chapter i.e. Chapter 6 will attempt to complete the risk assessment phase of the proposed RM framework for the purpose of offshore terminals and marine ports.

CHAPTER 6: CAUSE AND CONSEQUENCE ANALYSIS

6.1. INTRODUCTION

In the previous chapters all the risk factors identified via a risk-based hierarchy model were assessed, prioritised and ranked. Then the same model was implemented on the real cases for port-to-port evaluation purposes. At the same time the model was tested by the use of sensitivity analysis in order to confirm that the developed model was an appropriate one. The most significant hazards can be investigated more in depth for their causes and effects in this chapter. There has been growing public and private sector concern regarding the threat of the risks associated with the different industry sectors (e.g. offshore terminals and marine ports) to people, assets and the environment. The investigation of almost all the major accidents and various losses in terms of delays and costs shows that those tragedies could have been avoided with effective RM programmes (Wang, 2004). Therefore a high quality RM or at least a high quality risk analysis is necessary for sustainable development.

6.2. RISK ANALYSIS

Risk analysis contains the expansion of an overall assessment of any risk factor by collecting and putting together information about scenarios, probabilities and consequences, and it is a major part of the whole RM process of a particular activity. In the process of risk analysis, both qualitative and quantitative techniques can be used. A simple process of risk analysis is shown in Figure 6.1 (Krishna *et al.*, 2003).

Figure 6.1: The process of risk analysis
Source: Based on Krishna *et al*, (2003)

With the rapid development of industrialisation, the risk of incidents is increasing. Additionally it has become increasingly recognised that there is an extensive tendency for losses due to accidents to rise even more rapidly than gross national product (Lees, 1996).

However no course in RM would be complete without the inclusion of a major component on risk analysis. As Dickson (2003) expresses risk analysis acts as a kind of hub, around which many other practical aspects of RM rotate. Various stages of the risk analysis are shown in Figure 6.2.

Figure 6.2: Various Stages of Risk Analysis
Source: Based on Dickson (2003)

Furthermore Dickson explains that every risk is caused by some factor or factors and results in some effect or effects. It can be viewed rather like a chain. The cause is linked to the nature of the risk and the risk itself is linked to the effect.

A variety of techniques have been used for risk analysis including Physical Inspections, Organisational Charts, Flow Charts, Safety Review, Checklist Analysis, Relative Ranking, "What-if" Analysis, Preliminary Hazard Analysis (PHA), Hazard and Operability Study (HAZOP), Failure Modes and Effects Analysis (FMEA), Fault Tree Analysis (FTA), Event Tree Analysis (ETA), Cause-Consequence Analysis (CCA), Human Reliability Analysis (HRA) (CCPS, 1992; Lees, 1996; Dickson, 2003 and ABS, 2003). These techniques have all been developed in an industrial setting, normally in response to some practical business problems (Dickson, 2003).

Moreover a risk manager is not without practical support when starting the assignment of risk analysis. A risk manager can call on an armoury of methods designed to aid the assignment. It is improbable that one method will resolve all problems or indeed that one method alone is appropriate for all industry types. There is a range of techniques and methods, some of which are quantitative in nature and some qualitative, on which a risk manager can call (Dickson, 2003).

On the base of the Dickson's perception and for the purpose of risk analysis theme in this chapter it has been preferred to launch the Bow-tie method i.e. Cause and Consequence Analysis (CCA) analysis as per subsequent description and literatures.

6.2.1. Bow-tie analysis

Bow-tie is a modern, fast and easy to use device that allows making bow-tie diagrams. Bow-tie applies the modern concepts in RM to the broadly known and proven bow-tie methodology. Moreover the bow-tie illustration provides a dominant graphical representation of the risk assessment process which is easily understood even by the 'non-specialist'. A bow-tie framework has been proposed to integrate broad groups of cause–consequence models (Visser, 1998). The traditional fault tree and event tree models are "bow-tied" and the fault tree's "top event" is connecting with the event tree's "initiating event". The bow-tie will be regarded as a "lens" for focusing on causes of an event and "projecting" that onto the space of the event's consequences. The consequences will eventually be attributed into decision problems for the purpose of RM. The bow-tie's consequence side can make an interface with the decision models, ultimately decisions taken will be reflected back towards the causes (Groeneweg, 1998). Bow-tie framework not only has proven a valuable conception in mishap prediction, but also has demonstrated its importance in analysing the past accidents and signifying improvements to avoid further re-occurrence of undesired events (Bellamy *et al*, 2007). In particular it has proved to provide a suitable level of simplification of the causal factors in order to be able to summarise large quantities of data into a relatively small number of common scenarios, which can cover the majority of the accidents. In an accident scenario, the link between an accident and all its possible causes can be represented in the form of a fault tree (HSE, 2010). In the same time, the relationship between an accident and its possible multiple consequences can be represented by means of an event tree. Fault and event trees can be integrated in the form of a bow-tie diagram where the centre event represents "the release of a hazardous agent" as presented in Figure 5.3. This framework is particularly useful for analysing accidents, as their causes and consequences remain linked together. Moreover, it provides the user with a simplified classification framework where the usually varied information available in incident reports can be consistently stored and summarised according to a fixed common criteria.

A number of research groups have used the bow-tie framework to manage the occupational risks by developing a risk assessment model and software tools (DNV, 2001 and RIVM, 2008). Indeed the bow-tie technique is a tool that has together proactive and reactive components and methodically works through the hazard and its management. It uses a methodology known as the Hazards and Effects Management Process (Edwards, 1999; Zuijderduijn, 1999; Blom, Everdij and Daams 1999). Based on TSO (2006) the bow-tie technique is used to show how efficient a marine facility's safety management system is performing and also to complete gap analyses. The bow-tie framework can be used to demonstrate how the pertinent safety management system element requirements are met with respect to the control and management of hazards and risk factors (Groeneweg, 1998; Cockshott, 2005; ABS, 2007; Bellamy *et al*, 2007; Trbojevic, 2010 and HSE, 2010).

Figure 6.3: A bow-tie diagram
Source: Modified from Storybuilder manual (2008)

DNV (2001) in its offshore technology report and as a part of its marine risk assessment methods has introduced the bow-tie as a semi-quantitative analyse tool. RIVM (2008) national institute for public health and the environment in Netherland for development of a risk assessment model and software has used the bow-tie model for managing the occupational risks. In other efforts ABS (2007) has introduced the bow-tie as a solution for management of risk especially when dealing with the five default hazard categories: Safety, Health, Environment, Business and Security.

In respect of offshore terminals and marine ports and with an approach for developing Integrated Safety Management System (ISMS) for managing navigation and other marine operations DETR (2000) has proposed the same methodology of the bow-tie analysis. The methodology requires that all risk factors are identified and evaluated, that suitable controls and barriers are in place to manage these risk factors, and that the linkage between risk controls, operating procedures, harbour by-laws, and the management activities is explicitly established. This methodology has been applied to a number of marine ports in the UK in compliance with the Port Marine Safety Code (PMSC) requirement (Trbojevic, 2010).

In introducing bow-tie analysis as a transport RM tool Cockshott (2005) explains that the "bow-tie" technique is a productive RM means, providing a graphic illustration of the link between hazards, basic events, controls and effects. It is easily understood by management, engineers, Occupational Health, Safety and Environmental (OHSE) professionals, process operators and maintenance personnel involved in RM. Rapid risk ranking methods are frequently used to evaluate the risk factors of simple cause-consequence pairs and are straightforward in application.

For the purpose of this research risk factors associated in sea ports and offshore terminals were identified in Chapter 2 and their mitigation will be discussed fully in the next chapter. This chapter will only evaluate the most significant risk factors with the use of the bow-tie methodology utilizing both FTA and ETA methods.

6.2.2. FTA

FTA was first introduced in 1961 and has long been adapted for many applications such as in nuclear, rail, oil and gas industries and especially in the process industry (i.e. onshore and offshore sectors). In addition it is used to predict the probability of the hazardous incidents in order to identify the most significant risk contributors. Moreover a fault tree is a logic and graphical representation that explores the interrelationships between a potential critical event in a system and the reasons for this event (Hoyland and Rausand, 1994). A typical fault tree consists of the top event, the basic events, and the logic gates. Figure 6.4 illustrates the key fault tree analysis symbols. There are two important types of events i.e. top event and basic event. The top event represents an undesirable state of the system and the basic event represents the state of the systems component. FTA uses logic gates to describe the relationships between the basic events and the top event. The AND logic gate denotes that the output is in a failure state, if all the inputs are in failure state. The OR logic gate denotes that the output is in failure state, if at least one of the inputs is in failure state. An intermediate event represents an intermediate state of the system that is related directly or indirectly to the top event with a logic gate (Dokas *et al*, 2009).

Figure 6.4: Standard fault tree symbols
Source: Based on Wang (2004)

6.2.2.1. Fuzzy FTA

The conventional FTA has been used broadly, however, it is often very difficult to assess the precise failure rates or failure probabilities of individual components or failure events. This happens particularly in systems like nuclear power plants where available data are insufficient for statistical inferences or the data show a large variation (Jakson *et al*, 1981). To overcome these difficulties the use of FST (as a part of possibility theory) (Liang and Wang, 1993; Singer, 1990) is being considered to overcome the difficulties of probability theory. Possibility theory is a mathematical theory for dealing with certain types of uncertainty and is an alternative to probability theory. Zadeh first introduced possibility theory in 1978 as an extension of his FST (see Chapter 4).

In this respect the failure possibility defined by a triangular fuzzy number on the interval [0,1] is used to characterise the possible deviation of the basic events. Therefore the concept of the failure possibility is applied to replace failure rate or failure probability in fault tree analysis (Liang and Wang, 1993). In this study the same will be used hereafter and the failure possibilities are considered as triangular fuzzy sets to incorporate the uncertainties in the parameters.

In normal cases where there are sufficient data and considering the fact that the probability of the events are only relative frequencies of their occurrences (Andrews and Moss, 2002; Henley and Kumamoto, 1981) for an AND gate event, its probability can be obtained by the Equation 6.1.

$$P_{(AND)} = \prod_{i=1}^{n} P_i \qquad (6.1)$$

where P is the probability of top event; P_i denotes the failure probability of the basic event i and n is the number of basic events associated with the AND gate. For an OR gate event, its probability is determined by Equation 6.2.

$$P_{(OR)} = 1 - \prod_{i=1}^{n} (1 - P_i) \qquad (6.2)$$

Furthermore there is also a gate called NEG gate in which its probability is equivalent to $1\text{-}P_i$ (Cheong and Lan, 2004).

Due to the scarcity of the hazard events and insufficient data as explained before it is realistic to use fuzzy FTA instead of its traditional version. The fuzzy form of "AND" and "OR" operations functions can be obtained in Equation 6.3 and Equation 6.4 as follows (Cheong and Lan, 2004):

$$\tilde{P}_{(AND)} = \prod_{i=1}^{n} \tilde{P}_i \tag{6.3}$$

$$\tilde{P}_{(OR)} = \tilde{1} \ominus \prod_{i=1}^{n} (\tilde{1} \ominus \tilde{P}_i); \qquad \tilde{1} = (1,1,1) \tag{6.4}$$

where $\ominus$ is a symbol of subtraction in this thesis under fuzzy environments where basic operation for subtraction i.e. $\ominus$ can be defined as follows (Yang and Hung, 2007):

$$\tilde{M}_1 \ominus \tilde{M}_2 = (l_1, m_1, u_1) \ominus (l_2, m_2, u_2) = (l_1 - u_2, m_2 - m_1, u_1 - l_2) \tag{6.5}$$

6.2.3. ETA

In risk analysis, the event tree analysis has been used to identify and quantify frequency of outcomes of an initiating event. In addition it is successively used in pre-incident applications, to examine the incident precursors and post-incident application, and to identify the potential outcome events for an accidental event (CMPT, 1999; AIChE, 2000; ABS, 2000; Lees, 2005 and Ferdos, 2009). Qualitative analysis in an event tree identifies the potential outcome events of an initiating event, whereas quantitative analysis estimates the outcome event probability or frequency (likelihood) for the tree. Traditionally, quantitative analysis of an event tree uses crisp probabilities of events to estimate the outcome event probability or frequency. As explained by ABS (2000) and Ferdous (2009) in conventional event tree analysis, the branch probabilities have been treated as exact values. This provides a quick analysis and it uses crisp probabilities in each branch or path of the event tree. Figure 6.5 illustrates a sample of a conventional event tree and the outcome event frequencies, which are crisp numbers.

Figure 6.5: Sample of a conventional event tree
Source: Based on ABS (2000) and Ferdos (2009)

As it is shown P_n denotes the Success/Yes/True probability of the *n*th event whereas the (1- P_n) denotes the Failure/No/False probability of the *n*th event within the same column. S_n is also the calculated outcome event frequency for the *n*th outcome event within the depicted event tree. ABS (2000) explains that this type of analysis can provide (1) qualitative descriptions of potential problems (combinations of events producing various types of problems from initiating events) and (2) quantitative estimates of event frequencies or likelihoods, which assist in demonstrating the relative importance of various failure sequences.

6.2.3.1. Fuzzy ETA

In practice, it is difficult and costly to obtain exact values of event probability because in a most of cases these estimates are the result of an expert's inadequate knowledge, incomplete information, poor quality data or unsatisfactory analysis of a failure mechanism. These unavoidable problems impart uncertainties in the ETA and make the entire risk analysis process less credible for decision making (Ferdous *et al*, 2009). To explain uncertainties in input data (i.e. event frequency) and spread them throughout ETA, as an substitute to objective data, experts' judgments are utilised, particularly when the data gathering is either difficult or very costly (Rosqvist, 2003). On the other hand as the experts' judgments are in the form of qualitative expressions they may suffer from inconsistency if lack of harmony between various experts arises. The traditional probabilistic framework is not very useful in dealing with unclear, incomplete and inconsistent concepts (Druschel *et al*, 2006). Abrahamsson (2002), Thacker and Huyse (2003) and Wilcox and Ayyub (2003) have discussed the techniques to handle uncertainties during experts' judgments and to interpret them for the purpose of conducting risk analysis. In this regard as was explained in the previous chapters FST has proven effective and efficient in handling these types of uncertainties (Cheng, 2000; Sentz and Ferson, 2002; Wilcox and Ayyub, 2003; Bae *et al*, 2004; Agarwal *et al*, 2004; Ayyub and Klir, 2006). Based on the previous explanation the revised event tree with fuzzy parameters is illustrated in Figure 6.6. Therefore under fuzzy environments $\tilde{P}_n$ denotes the Success/True/Yes possibility of the *n*th event whereas$(\tilde{1} \ominus \tilde{P}_n)$ denotes the Failure/False/No possibility of the *n*th event within the same column. Furthermore S_n is also the defuzzified outcome event's occurrence possibility scores (i.e. occurrence likelihood) for the *n*th outcome event within the nominated event tree.

Figure 6.6: Sample of a fuzzy event tree
Source: Based on Huang (2001) and Ferdos *et al*, (2009)

6.3. METHODOLOGY FOR APPLICATION OF THE FTA AND ETA UNDER FUZZY ENVIRONMENTS.

As Andrew and Ridley (2002) have explained a cause and consequence analysis as shown in Figure 6.3 is based on the occurrence of critical event, which for example may be an event, involving the failure of components or subsystems that is likely to produce hazardous effects. Once a critical event has been identified, all relevant and potential causes of it and its potential effects are developed using two conventional reliability analysis methods (i.e. FTA and ETA). FTA is used to describe the causes of an undesired event. ETA shows the consequences that a critical event may lead to if one or more protection systems do not function as designed.

In this chapter with the use of the CCA (i.e. bow-tie method) and FST, failure possibilities for any of top events and also occurrence likelihoods for consequences of the basic events for three most significant operational risk factors found in Chapter 4 will be analysed. These three risk factors will be evaluated and analysed with the use of three independent case studies. This will help to examine the introduced risk analysis tool (i.e. bow-tie method) for the purpose of RM in offshore terminals and marine ports. Figure 6.7 illustrates a generic risk analyse model integrated into a RM framework for the purpose of this thesis.

FST, experts' judgements, converting linguistic terms to fuzzy numbers and defuzzification processes will be used to obtain the possibilities of the basic events as well as failure possibility of the top event hereafter. As in this chapter TFNs will be employed, further explanations relating to TFNs can be found in Chapter 4. Additional information and steps required for the assessment of the risk factors by the use of CCA and FST in the form of FFTA and FETA can be explained as follows:

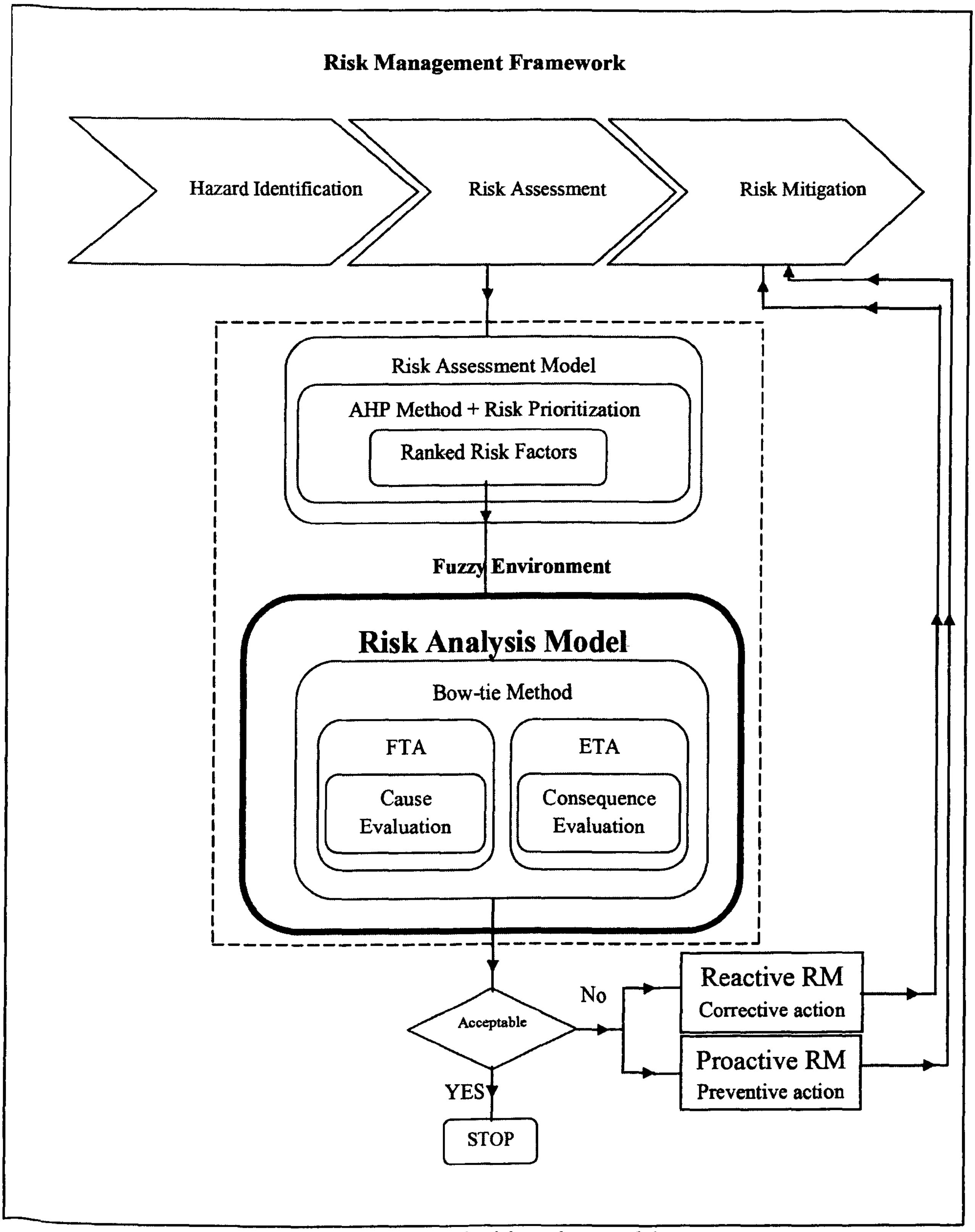


Figure 6.7: A generic risk analyse model

6.3.1. Procedure for carrying out a FFTA

Steps for carrying out a FFTA in this chapter are summarised as follows:

Step 1: Select a top event (i.e. a risk factor) and build a logic fault tree diagram for it.

Step 2: Divide the basic events of any fault tree logic diagram into probability analysis of the known events and possibility analysis (subjective linguistic evaluations) of unknown or vague events.

If all of the events are unknown a subjective linguistic evaluation as explained in Steps 3 and 4 should be carried out in the form of a possibility analysis in order to obtain the failure possibilities for basic events and eventually for top event under fuzzy environments. If all of the events are unknown they will be evaluated by the use of the fuzzy fault tree concept i.e. possibility analysis/approach (see Case Studies 1 and 2). Conversely if all the events are known, they will be evaluated by the use of the conventional or traditional FTA method i.e. probability analysis (see Case Study 3). Nevertheless if some of them are known and the remainder are unknown they will be evaluated by an approach using combining both the possibility and probability concept (see Case Study 4) explained in Steps 5 and 6 respectively.

Step 3: Conduct the linguistic assessments for vague events.

Subjective linguistic variables will be further defined in terms of membership functions. As previously explained a membership function is a curve that defines how each point in the input space is mapped to a membership value between 0 and 1. Furthermore it was explained that of these membership functions, the simplest are the triangular fuzzy number and trapezoidal fuzzy number (Li and Liao, 2007). TFNs in this chapter are preferred to be used to represent the linguistic variables shown in Table 4.3 and Figure 4.9 (Yang and Hung, 2007) respectively (see Chapter 4).

Step 4: Transform linguistic expressions into fuzzy numbers and aggregate the experts' opinions into one fuzzy number.

For this purpose as Clemen and Winkler (1999) explained due to different opinions of possibility of the basic events, it is necessary to combine or aggregate the opinions into a single one. There are many methods to aggregate fuzzy numbers; an appealing approach is the following one (see Chapter 4):

$$M_i = \sum_{i=1}^{m} W_j A_{ij} \qquad j=1, 2, \ldots, n \tag{6.6}$$

where A_{ij} is the linguistic expression of a basic event i given by expert j. m is the number of basic events. n is the number of the experts. W_j is a weighting factor of the expert j and M_i represents combined fuzzy number of the basic event i.

Based on the principle of FST explained in Chapter 4 for addition of the TFNs (Yang and Hung, 2007), M_i is also a triangular fuzzy number. These calculations will be demonstrated in Case Studies 1 and 2.

Step 5: If all the basic events are unknown convert fuzzy numbers into the Fuzzy Possibility Scores (FPSs). If some of the basic events are known and the others are unknown then convert fuzzy numbers of the failure possibilities i.e. FPSs for the vague events into their Fuzzy Failure Probabilities (FFPs) using Equation 6.7 (Onisawa and Nishiwaki, 1988).

$$\text{FFP} = \begin{cases} \frac{1}{10^k}, FPS \neq 0 \\ 0, \ FPS = 0 \end{cases}, \text{K} = \left[\left(\frac{1-FPS}{FPS}\right)\right]^{\frac{1}{3}} \times 2.31 \tag{6.7}$$

When fuzzy ratings are integrated into a FTA problem, the concluded ratings will also become fuzzy numbers. With the purpose of verifying the relationship among them, fuzzy numbers must be converted to crisp scores, named as Fuzzy Possibility Score (FPS) (Yuhua and Dataob, 2005). As fuzzy numbers in this chapter are TFNs, the centre of area defuzzification techniques are selected to be used. As Zhao and Govind (1991) explain defuzzification is the process of producing a quantifiable result in fuzzy logic. For this purpose three fuzzy parameters will be added together; by dividing their total by three their average or centre of gravity will be found (i.e. defuzzification).

Step 6: Convert the available failure probabilities (crisp values) of the real data into Fuzzy Failure Probabilities (FFPs) using Table 6.1 (Lind, 1983; Miller and Swain, 1987).

Table 6.1: Guide line for Lower and Upper Bound of the Estimated Failure Rate.

Source: Based on Lind (1983) and Miller and Swain (1987)

Step 7: If all the basic events are known obtain the failure probability of the top event using Equations 6.1 and/or 6.2. Conversely if all the basic events are unknown obtain the failure possibility of the top event by integrating FPSs of the vague basic events using Equations 6.3 and/or 6.4. However if some of the basic events are known and the others are unknown then obtain the final FFP for the top event by integrating FFPs obtained through Steps 5 and 6 using Equations 6.3 and/or 6.4. In order to defuzzify FFP of the top event three fuzzy parameters will be added together and then will be divided by three to find the centre of their gravity i.e. defuzzification (transforming the fuzzy number to crisp value) (Tuhua and Dataob, 2005; Zhao and Govind, 1991).

Step 8: Analyse and interpret the results.

In fuzzy fault tree applications many researchers have used different data (whether researchers have used entirely unknown data or they have used mixture of the known and unknown data) in order to obtain failure rate of a top event. In this chapter by carrying out 2 illustrated experiments that are shown in Case Studies 1 and 2 the final results will be analysed under fuzzy environments. In the shown experiments by elimination of each basic event their importance and effects on the possibility failure of the top event will be investigated.

6.3.2. Procedure for carrying out a FETA

The following sub-sections describe the steps to analyse an event tree using FST. In the proposed approach, the subjective judgment of event possibility is assumed linguistic and described using TFNs. The fuzzy possibility of an initiating event is then used to estimate the outcome events' possibilities that are also estimated as fuzzy numbers. The fuzzy based approach used for ETA comprises the following five steps:

Step 1: For an initiating event, the set of potential consequence and no consequence states must be defined to construct an event tree logic diagram.

Step 2: Define initiating event's frequency (see Steps 2, 3 and 4 of the FFTA).

Step 3: Determine each of the outcome events' frequency independently (i.e. their probability if data are known or their possibility in the form of TFNs and FPSs if data are entirely or partially unknown) for all the tree paths by using the procedures shown in Figure 6.6 and Step 4 of the FFTA.

Step 4: If frequencies are entirely or partially unknown defuzzify the outcome events' possibilities (i.e. FPSs) to obtain a crisp values for event tree consequences.

Step 5: Analyse and interpret the results.

6.4. PRACTICAL EXAMPLES

Due to the scarcity of data FFTA and FETA in Case Study 1 will be applied on one of the most significant risk factors which were previously identified through the prioritisation process in Chapter 4. The other risk factor in Case Study 2 is an illustrative one and is only used to show the applicability of the proposed combination approach under fuzzy environments.

6.4.1. Case Study 1

This case study relates to the risk factor R_{451} (pilot's related errors) identified through the HAZID process in the literature review (see Chapter 2). The top event is "pilot's related errors", which for example can be initiated by channel, canal, harbour and/or local offshore-based pilots giving 'an inappropriate command'. This may happen when a tanker ship is navigating inside a narrow channel or a canal. In another instance the same situation can happen during tandem operations for a Shuttle Tanker or a LNG Tanker while approaching offshore terminals in oil and gas fields whether the terminals are fixed or floating e.g. FPSO units. As a result consequences of the "pilot's related errors" can be grounding, collision (with other ships, jetties in ports and structures or installations of offshore terminals), fire, explosion, spillage, loss of life, etc (Trbojevic and Carr, 2000 and NE P&I Club, 2008). There are many consequences as a result of the pilot's related errors but the major consequences of pilotage errors are shown in Figure 6.15 (Trbojevic and Carr, 2000).

As Trbojevic and Carr explain during a pilotage if a hazard is released, the accidental event can escalate to one of several possible consequences. Furthermore they explain that in the analysis of marine or engineering operations (Trbojevic *et al,* 1994) the fault and event trees describe not only mechanical failures, but also operators' (human) front line and recovery errors.

As per investigations carried out by Trbojevic and Carr (2000) the major causes of pilotage error in the form of different basic events are shown in Table 6.2.

Table 6.2: Potential basic events which can cause the top event or risk factor of R_{451}.

Source: Based on Trbojevic and Carr (2000)

Figure 6.8 is fault tree diagram of the risk factor R_{451}.

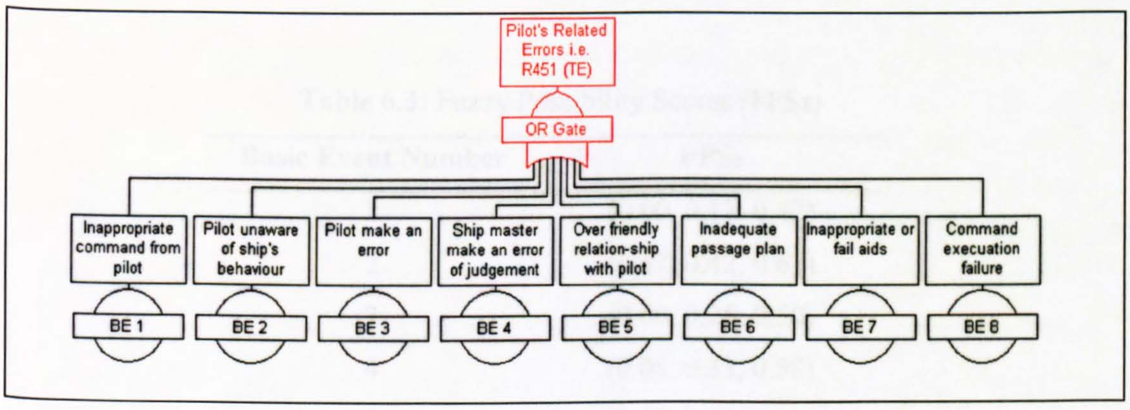


Figure 6.8: Fault tree diagram for top event of "Pilot's Related Errors" along with basic events.

Due to the scarcity of data and the fact that all the basic events are vague and in order to evaluate the risk factor i.e. R_{451} it has been decided to carry out the evaluation using the experts' judgements. To carry out experts' judgements in this chapter, three experts have been selected to carry out the judgement process.

After collecting the experts' opinions through the evaluation sheet shown in Appendix IV by use of Equations 4.2, 4.3 and 6.6 the following calculations are carried out in order to determine the FPSs for the basic events listed in Table 6.2 and shown in Figure 6.8. Table 5.1 and Figure 5.1 are used for carrying out the estimations:

$BE_1 = W_1 \otimes L \oplus W_2 \otimes VL \oplus W_3 \otimes L = (0.00, 0.17, 0.42)$

$BE_2 = W_1 \otimes M \oplus W_2 \otimes L \oplus W_3 \otimes M = (0.17, 0.42, 0.67)$

$BE_3 = W_1 \otimes L \oplus W_2 \otimes L \oplus W_3 \otimes L = (0.00, 0.25, 0.50)$

$BE_4 = W_1 \otimes L \oplus W_2 \otimes L \oplus W_3 \otimes M = (0.08, 0.33, 0.58)$

$BE_5 = W_1 \otimes M \oplus W_2 \otimes L \oplus W_3 \otimes L = (0.08, 0.33, 0.58)$

$BE_6 = W_1 \otimes L \oplus W_2 \otimes L \oplus W_3 \otimes L = (0.00, 0.25, 0.50)$

$BE_7 = W_1 \otimes L \oplus W_2 \otimes L \oplus W_3 \otimes L = (0.00, 0.25, 0.50)$

$BE_8 = W_1 \otimes VL \oplus W_2 \otimes VL \oplus W_3 \otimes VL = (0.00, 0.00, 0.25)$

The calculated Fuzzy Possibility Scores (FPSs) are depicted in Table 6.3.

Table 6.3: Fuzzy Possibility Scores (FPSs)

Basic Event Number	FPSs
1	(0.00, 0.17, 0.42)
2	(0.17, 0.42, 0.67)
3	(0.00, 0.25, 0.50)
4	(0.08, 0.33, 0.58)
5	(0.08, 0.33, 0.58)
6	(0.00, 0.25, 0.50)
7	(0.00, 0.25, 0.50)
8	(0.00, 0.00, 0.25)

Now the occurrence possibility of the top event (i.e. pilot's related errors) will be calculated by the use of the fuzzy fault three analysis using Equation 6.4 as follows:

$$\tilde{P}_{(OR)} = \tilde{1} \ominus \prod_{i=1}^{n} (\tilde{1} \ominus \tilde{P}_i); \qquad \tilde{1} = (1,1,1)$$

$$\tilde{P}_{TE(R451)} = \tilde{1} \ominus [(\tilde{1} \ominus \tilde{P}_{BE1}) \otimes (\tilde{1} \ominus \tilde{P}_{BE2}) \otimes (\tilde{1} \ominus \tilde{P}_{BE3}) \otimes (\tilde{1} \ominus \tilde{P}_{BE4}) \otimes (\tilde{1} \ominus \tilde{P}_{BE5}) \otimes (\tilde{1} \ominus \tilde{P}_{BE6}) \otimes (\tilde{1} \ominus \tilde{P}_{BE7}) \otimes (\tilde{1} \ominus \tilde{P}_{BE8})] = (0.297, 0.955, 0.997)$$

In the previous step the defuzzified occurrence possibility of the top event was 0.750.

Now by elimination of each basic event the new defuzzified failure possibility numbers will be obtained respectively as shown in Table 6.4. Subsequently the amount of each deviation i.e. ($\tilde{P}_{TE(R451)} \ominus \tilde{P}_{TEi}$) has been recorded in the deviation index column in Table 6.4. A basic event with a higher deviation index will reduce the failure possibility of the top event (R_{451}) more. As it is shown in Table 6.4 basic event number 2 (i.e. BE_2) has the highest deviation index value.

Table 6.4: Importance of elimination of each basic event in occurrence possibility of the top event.

Elimination of Basic Events	Possibility Approach					
	Fuzzy number			Failure possibility	Deviation index	Ranking
	l	*m*	*u*			
BE_1	0.297	0.946	0.995	0.746	0.004	4
BE_2	0.154	0.922	0.991	0.689	0.061	1
BE_3	0.297	0.940	0.994	0.744	0.006	3
BE_4	0.236	0.933	0.993	0.721	0.029	2
BE_5	0.236	0.933	0.993	0.721	0.029	2
BE_6	0.297	0.940	0.994	0.747	0.003	5
BE_7	0.297	0.940	0.994	0.747	0.003	5
BE_8	0.297	0.955	0.996	0.749	0.001	6

Figure 6.9 illustrates the sensitivity analysis carried out for the top event or risk factor R_{451}, based on the results shown in Table 6.4. It shows how the occurrence possibility for the top event is reduced by elimination of each basic event.

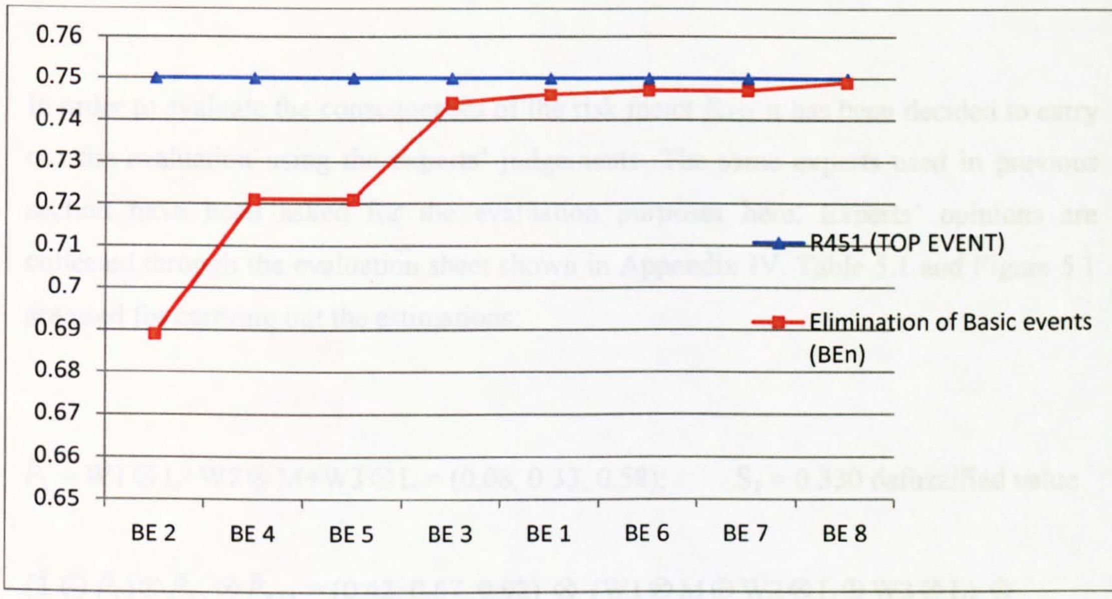


Figure 6.9: Sensitivity analysis of the top event or risk factor of R_{451}

Figure 6.10 illustrates the event tree analysis of the R_{451} (Pilot's related errors) along with linguistic fuzzy variables after aggregation of the experts' judgements as described before.

Figure 6.10: Event tree analysis for risk factor R_{451}
Source: Consequences are based on Trbojevic and Carr (2000)

In order to evaluate the consequences of the risk factor R_{451} it has been decided to carry out the evaluation using the experts' judgements. The same experts used in previous section have been asked for the evaluation purposes here. Experts' opinions are collected through the evaluation sheet shown in Appendix IV. Table 5.1 and Figure 5.1 are used for carrying out the estimations:

$\tilde{P}_1 = W1 \otimes L + W2 \otimes M + W3 \otimes L = (0.08, 0.33, 0.58)$; $S_1 = 0.330$ defuzzified value

$(\tilde{1} \ominus \tilde{P}_1) \otimes \tilde{P}_{21} \otimes \tilde{P}_{321} = (0.42, 0.67, 0.92) \otimes (W1 \otimes M \oplus W2 \otimes L \oplus W3 \otimes L) \otimes$
$(W1 \otimes VL \oplus W2 \otimes H \oplus W3 \otimes H) = (0.42, 0.67, 0.92) \otimes (0.08, 0.33, 0.58) \otimes$
$(0.58, 0.83, 1.00) = (0.006, 0.061, 0.534)$; $S_2 = 0.200$ defuzzified value

$(\tilde{1} \ominus \tilde{P}_1) \otimes \tilde{P}_{21} \otimes (\tilde{1} \ominus \tilde{P}_{321}) = (0.42, 0.67, 0.92) \otimes (0.08, 0.33, 0.58) \otimes$
$(0.00, 0.17, 0.42) = (0.00, 0.037, 0.224)$; $S_3 = 0.087$ defuzzified value

$(\tilde{1} \ominus \tilde{P}_1) \otimes \tilde{P}_{22} \otimes \tilde{P}_{322} = (0.42, 0.67, 0.92) \otimes (W1 \otimes L \oplus W2 \otimes L \oplus W3 \otimes L) \otimes$
$(W1 \otimes VH \oplus W2 \otimes H \oplus W3 \otimes VH) = (0.42, 0.67, 0.92) \otimes (0.00, 0.25, 0.50) \otimes$
$(0.67, 0.92, 1.00) = (0.00, 0.154, 0.46)$; $S_4 = 0.205$ defuzzified value

$(\tilde{1} \ominus \tilde{P}_1) \otimes \tilde{P}_{22} \otimes (\tilde{1} \ominus \tilde{P}_{322}) = (0.42, 0.67, 0.92) \otimes (0.00, 0.25, 0.50) \otimes$
$(0.00, 0.08, 0.33) = (0.00, 0.013, 0.152)$; $S_5 = 0.055$ defuzzified value

$(\tilde{1} \ominus \tilde{P}_1) \otimes \tilde{P}_{23} = (0.42, 0.67, 0.92) \otimes (W1 \otimes VL \oplus W2 \otimes VL \oplus W3 \otimes VL) =$
$(0.42, 0.67, 0.92) \otimes (0.00, 0.00, 0.25) = (0.00, 0.00, 0.23)$;
$S_6 = 0.077$ defuzzified value

The final results for different consequences are listed in Table 6.5.

Table 6.5: Occurrence likelihoods for different consequences

Consequences	likelihoods
No consequences	0.330
Grounding	0.200
Pollution as a result of grounding	0.087
Collision	0.205
Pollution as a result of collision	0.055
Loss of life	0.077

6.4.2. Case Study 2

This case study relates to the hazards associated with the potential incidents and accidents in offshore terminals (i.e. installations/rigs) which are in the form of offshore fixed units engaged in the oil and gas explorations and exploitations located within the Caspian Sea.

There are many hazards with different natures and categories but in this study only the ones which can directly affect an offshore terminal and cause physical damage or in extreme cases would lead to total destruction of the offshore terminals as shown in Table 6.6 will be examined. That means "damage to offshore terminals" will be regarded as an illustrative risk factor (i.e. Top Event) for the purpose of this case study. As was mentioned before there are many other types of hazards which can affect the offshore sites indirectly and they cannot be regarded as direct causes of a damage or destruction. Some of these are blowouts, cranes, falling objects, leakages, spills/releases, well problems etc which it has been decided not to incorporate in this study. Apart from the basic events (hazards) such as BE_1 to BE_4 which can be classified under operational risks, others e.g. BE_5 to BE_9 can only be initiated via external sources of uncertainties such as natural disasters, act of war, terrorism, etc.

Table 6.6: Potential Basic Events which can cause the Top Event of "damage to offshore terminals".

Source: Based on (UKHSE, 2010; Mather, 2009 and Sharp, 2009)

Figure 6.11: Map of Caspian Sea
Source: Based on World Atlas (2011)

As shown in Figure 6.11 the Caspian Sea is the largest lake on the planet. The sea is bordered by the countries of Azerbaijan, Russia, Kazakhstan, Turkmenistan and Iran..

There are many oil and natural gas production platforms along the edges of the sea especially within the coasts of Azerbaijan and Turkmenistan. In addition, large quantities of sturgeon live in its waters, and the caviar produced from their eggs is a valuable commodity. Fresh water flows into the sea via the Volga River and Ural River in the North, however, the sea remains somewhat salty only in the centre and South of the Caspian Sea. The highest depth of water is 1025 m in the South.

To date the Caspian Sea has not been struck by any heavy storms, earthquakes/tsunamis or severe ice. However occasional passing fronts in autumns and winters with North Atlantic origin disturb the sea in timely bases but cannot be accounted as severe types to damage the offshore terminals. As they pass in West-East direction, the area they affect is small in comparison to other seas e.g. North Sea, Mediterranean Sea. Additionally in the North of the Caspian Sea during winters formation of ice is always evident. Ice formation had not taken place in central parts and Southern parts of the sea (Barannik *et al*, 2004).

Presently there is no available data or report on terrorism activities in the region. The nearest of such activities can be traced in Republic of Chechnya (Groznyy) in Russia which is near to Northwest of Caspian Sea (CNN, 2011). There is no report on any war or potential political perils except the international disputes which have been going on for nearly a decade among the states bordering the Caspian Sea for settling the dispute about the legal status of the sea (Haghayeghi, 2003).

All five littoral states of Iran, Azerbaijan, Russia, Kazakhstan and Turkmenistan have plans to further exploit the sea's estimated oil reserves. Presently major oil companies e.g. TOTAL, BP, EXXONMOBILE, CHEVRON etc with a good reputation are active in the Caspian Sea near coasts of Azerbaijan especially in conjunction with the major pipeline project of BAKU-JIHAN. Such activities mean drilling new wells, highlighting risks for an incident that could cause catastrophic effects such as damage to offshore terminals within the landlocked Caspian Sea i.e. the largest inland body of water on earth (OWJE, 2011).

"The accident in the Gulf of Mexico shows that such a disaster could happen anywhere. The United States, with its super-modern technologies, is barely capable of stopping this disaster," Gulaliyev says. "You can imagine the scale of the damages to the environment from such incidents in countries like Azerbaijan" (RFERL, 2011).

As a result major consequences for the risk factor i.e. "damage to offshore terminals" can be loss of life, property, reputation and damage to the environment (ABS, 2000). Figure 6.12 is the fault tree diagram for the Top Event i.e. "damage to offshore terminals".

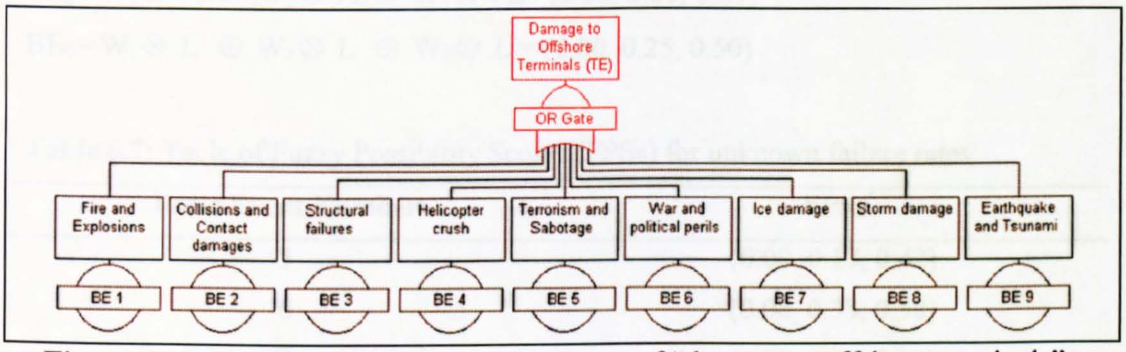


Figure 6.12: Fault tree diagram for Top Event of "damage to offshore terminals".

Occurrence probabilities (crisp values) for hazards BE_1, BE_2, BE_3 and BE_4 in the form of frequencies (per year) are (0.2140), (0.0385), (0.0034) and (0.0016) respectively. The origin of data is based on the accident statistics for the offshore fixed units from 1990 to 2007. These data are based on the combination of original data gathered from different databases as mentioned in (Oil and Gas UK, 2012). The available probabilities will be transformed into FFPs using Table 6.1 in order to combine these failure probabilities with the failure possibilities calculated in the following section. The calculated FFPs of the known probabilities are shown in Table 6.8.

On the other hand as there is no data for hazards of BE_5, BE_6, BE_7, BE_8 and BE_9, via using possibility approach the FPSs obtained through the experts' judgements will be transformed into FFPs using Equation 6.7.

After collecting the experts' opinions through the evaluation sheet shown in Appendix IV using of Equations 4.2, 4.3 and 6.6 the following calculations are carried out in order to determine the FPSs for the mentioned basic events listed in Table 6.7. Furthermore

Table 5.1 and Figure 5.1 are used for carrying out the estimations. Further explanations for collecting data, calculating the results, experts' judgements etc for the purpose of carrying out the estimations are the same as those described in Case Study 1. The calculated Fuzzy Possibility Scores (FPSs) are depicted in Table 6.7.

$BE_5 = W_1 \otimes L \oplus W_2 \otimes VL \oplus W_3 \otimes L = (0.00, 0.17, 0.42)$

$BE_6 = W_1 \otimes L \oplus W_2 \otimes L \oplus W_3 \otimes M = (0.08, 0.33, 0.58)$

$BE_7 = W_1 \otimes VL \oplus W_2 \otimes L \oplus W_3 \otimes VL = (0.00, 0.08, 0.33)$

$BE_8 = W_1 \otimes VL \oplus W_2 \otimes VL \oplus W_3 \otimes VL = (0.00, 0.00, 0.25)$

$BE_9 = W_1 \otimes L \oplus W_2 \otimes L \oplus W_3 \otimes L = (0.00, 0.25, 0.50)$

Table 6.7: Table of Fuzzy Possibility Scores (FPSs) for unknown failure rates.

Basic Event Number	FPSs
5	(0.00, 0.17, 0.42)
6	(0.08, 0.33, 0.58)
7	(0.00, 0.08, 0.33)
8	(0.00, 0.00, 0.25)
9	(0.00, 0.25, 0.50)

In this regard the calculated FFPs of the unknown failure rates are shown in Table 6.8.

Table 6.8: Table of Fuzzy Failure Probabilities (FFPs) for the known and unknown failure rates.

Basic Events (Hazards) Number	FFP
BE_1	(0.0428, 0.2140, 0.4280)
BE_2	(0.0077, 0.0385, 0.0770)
BE_3	(0.0011, 0.0034, 0.0102)
BE_4	(0.0005, 0.0016, 0.0048)
BE_5	(0.0000, 0.0001, 0.0027)
BE_6	(0.000006, 0.0012, 0.0048)
BE_7	(0.0000, 0.000006, 0.0012)
BE_8	(0.0000, 0.0000, 0.0005)
BE_9	(0.0000, 0.0005, 0.0049)

After collecting the experts' opinions and integrating them by means of Equations 4.2 and 4.3, with the use of Equation 6.6 the required calculations will be carried out in order to find out the final FFP of the nominated top event. The calculated FFP of the top event was found to be 0.265. Then by eliminating each basic event the new FFPs for the top event will be obtained respectively as shown in Table 6.9. Subsequently each deviation i.e. $[\tilde{P}_{TE} \ominus \tilde{P}_{TEi}]$ has been recorded under the deviation index column in Table 6.9.

Table 6.9: Importance of elimination of each basic event in occurrence probability of the top event.

Elimination of Basic Events	FFPs for new Top Events after elimination of the related Basic Events (Hazards)			Defuzzified FFPs for new Top Events	Deviation index	Ranking
	l	*m*	*u*			
BE 1	0.010	0.045	0.114	0.0563	0.2087	1
BE 2	0.045	0.219	0.451	0.2383	0.0267	2
BE 3	0.051	0.246	0.488	0.2616	0.0034	3
BE 4	0.052	0.248	0.491	0.2637	0.0013	6
BE 5	0.052	0.250	0.492	0.2647	0.0003	9
BE 6	0.052	0.248	0.489	0.2630	0.0020	4
BE 7	0.052	0.249	0.489	0.2633	0.0017	5
BE 8	0.052	0.249	0.492	0.2643	0.0007	8
BE 9	0.052	0.249	0.491	0.2640	0.0010	7

FFP for the top event is calculated by the use of the fuzzy fault three analysis using Equation 6.4 as follows:

$$\tilde{P}_{(OR)} = \tilde{1} \ominus \prod_{i=1}^{n} (\tilde{1} \ominus \tilde{P}_i); \qquad \tilde{1} = (1,1,1)$$

$$\tilde{P}_{TE} = \tilde{1} \ominus [(\tilde{1} \ominus \tilde{P}_{BE1}) \otimes (\tilde{1} \ominus \tilde{P}_{BE2}) \otimes (\tilde{1} \ominus \tilde{P}_{BE3}) \otimes (\tilde{1} \ominus \tilde{P}_{BE4}) \otimes (\tilde{1} \ominus \tilde{P}_{BE5}) \otimes (\tilde{1} \ominus \tilde{P}_{BE6}) \otimes (\tilde{1} \ominus \tilde{P}_{BE7}) \otimes (\tilde{1} \ominus \tilde{P}_{BE8}) \otimes (\tilde{1} \ominus \tilde{P}_{BE9})] = (0.052, 0.249, 0.493)$$

In the previous step the defuzzified occurrence possibility of the top event was 0.265.

Figure 6.13 illustrates the sensitivity analysis carried out for the top event based on the results shown in Table 6.9. It shows how the failure possibility for the top event is reduced by elimination of each basic event.

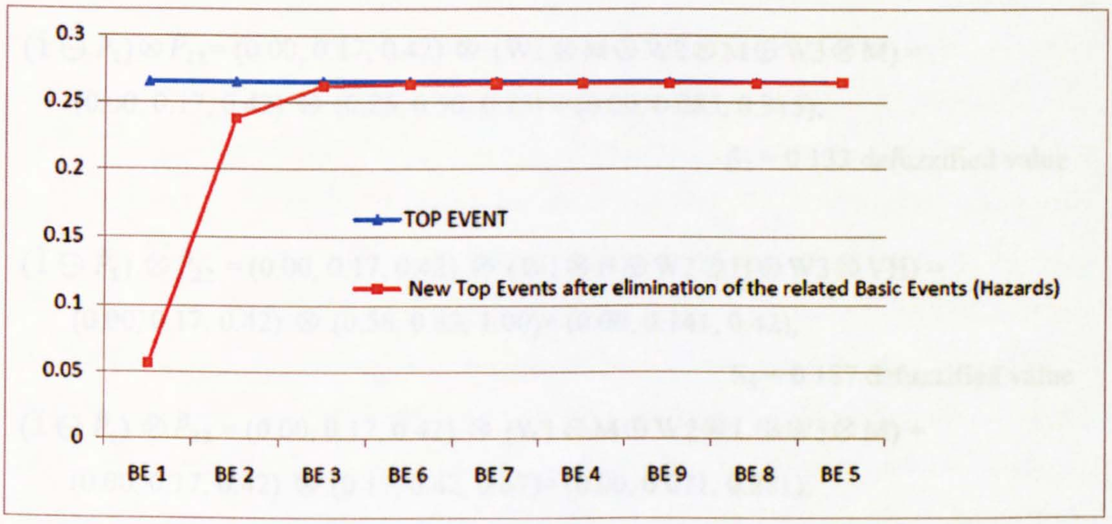


Figure 6.13: Sensitivity analysis for top event of i.e. "damage to offshore terminals"

Figure 6.14 illustrates the event tree analysis for the risk factor of "damage to offshore terminals" along with linguistic fuzzy variables after aggregation of the experts' judgements as described before.

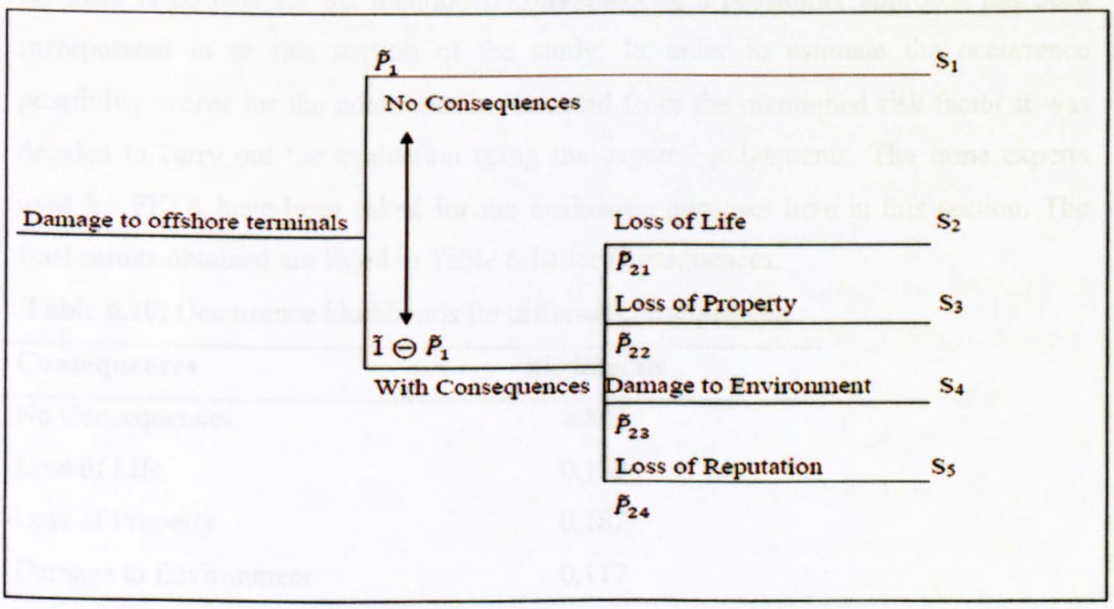


Figure 6.14: Event tree analysis for risk factor "damage to offshore terminals"
Source: Consequences are based on ABS (2000)

Estimations for the event tree shown in Figure 6.14 are as follows:

$\tilde{P}_1 = W_1 \otimes H + W_2 \otimes H + W_3 \otimes VH = (0.58, 0.83, 1.00)$; $S_1 = 0.803$ defuzzified value

$(\tilde{1} \ominus \tilde{P}_1) \otimes \tilde{P}_{21} = (0.00, 0.17, 0.42) \otimes (W1 \otimes M \oplus W2 \otimes M \oplus W3 \otimes M) =$
$(0.00, 0.17, 0.42) \otimes (0.25, 0.50, 0.75) = (0.00, 0.085, 0.315)$;

$S_2 = 0.133$ defuzzified value

$(\tilde{1} \ominus \tilde{P}_1) \otimes \tilde{P}_{22} = (0.00, 0.17, 0.42) \otimes (W1 \otimes H \oplus W2 \otimes H \oplus W3 \otimes VH) =$
$(0.00, 0.17, 0.42) \otimes (0.58, 0.83, 1.00) = (0.00, 0.141, 0.42)$;

$S_3 = 0.187$ defuzzified value

$(\tilde{1} \ominus \tilde{P}_1) \otimes \tilde{P}_{23} = (0.00, 0.17, 0.42) \otimes (W1 \otimes M \oplus W2 \otimes L \oplus W3 \otimes M) =$
$(0.00, 0.17, 0.42) \otimes (0.17, 0.42, 0.67) = (0.00, 0.071, 0.281)$;

$S_4 = 0.117$ defuzzified value

$(\tilde{1} \ominus \tilde{P}_1) \otimes \tilde{P}_{24} = (0.00, 0.17, 0.42) \otimes (W1 \otimes L \oplus W2 \otimes L \oplus W3 \otimes L) =$
$(0.00, 0.17, 0.42) \otimes (0.00, 0.25, 0.50) = (0.00, 0.042, 0.21)$;

$S_5 = 0.084$ defuzzified value

As there is no data for the mentioned consequences, a possibility approach has been incorporated in to this section of the study. In order to estimate the occurrence possibility scores for the consequences initiated from the mentioned risk factor it was decided to carry out the evaluation using the experts' judgements. The same experts used for FFTA have been asked for the evaluation purposes here in this section. The final results obtained are listed in Table 6.10 for consequences.

Table 6.10: Occurrence likelihoods for different consequences.

Consequences	likelihoods
No Consequences	0.803
Loss of Life	0.133
Loss of Property	0.187
Damage to Environment	0.117
Loss of Reputation	0.084

6.5. RESULTS AND DISCUSSIONS

In Case Study 1 as is shown in Table 6.2 basic event number two (i.e. Pilot unaware of ship's behaviour) had the highest importance on the failure possibility of the top event. Most of the times when pilots board vessels during ships' arrivals and departures from or to offshore terminals and marine ports when they arrive to the conning positions they do sign in but they do not read the Pilot Cards (i.e. an internationally recognised check list form explains ship's details and particulars needed for navigating pilots and normally are designed by flag state administrators or by their recognised third-parties e.g. approved classification societies. Moreover Pilot Cards are designed using procedures and guide lines mentioned in quality management systems or ISO Standards) properly. If pilots read the ships' details properly and ask for any clarification from the ships' masters or officers in charge about the ships' characteristics or manoeuvrability if they are in doubt, they would avoid the mentioned error. Moreover as can be seen consequence number one (i.e. Pilot error with no consequences) has the highest occurrence likelihood. As pilot error with no consequence can be regarded as a near miss situation therefore it is evident that the occurrence likelihood of near miss situations as a result of pilot error is high. As on board ships there are always secondary standby devices ready to be used during emergencies, or pilots boarding ships sometimes have additional back-ups (e.g. tugboats or additional pilot), normally most pilot errors can be avoided in due time. Results obtained for consequences in this case study can be used as a bench mark and only for comparison purposes in offshore terminals and marine ports by harbour masters and port/terminal risk managers.

In Case Study 2 basic event number one (i.e. Fire and explosion) had the highest importance. Offshore terminals are structures involved with processing, drilling, producing, loading of cargoes having oil and gas properties. As a result any incident can very quickly turn into an accident such as fire and eventually, or instantly, an explosion. It can be seen that consequence number one which is damage to offshore terminals with no consequences (i.e. near miss situations) had the highest occurrence likelihood. Offshore terminals maintain a high level of safety precautions and additionally there are available alert systems which can be activated during emergency situations and in early stages. Therefore most likely incidents on offshore platforms before turning to accidents can be mitigated in appropriate time. Results obtained for consequences in this case study can be used as a bench mark and only for comparison purposes in offshore terminals by HSE or risk managers.

In addition the methodology for application of the FTA and ETA under fuzzy environments can be regarded as another solution to prevail over the limitation of the traditional approach. Traditional approaches lack adequate data concerning the relative frequencies for causes and effects of hazardous events (i.e. top events or initiating events). Via using TFNs, it is possible to manage the fuzziness involved in the phrase of the occurrence of a basic event or a consequence. Moreover, the state of each basic event or consequence can be explained in a more simple way, by using the FST. Tables showing the importance of elimination of each basic event in occurrence possibility of the top event (i.e. Tables 6.4 and 6.9) can provide useful information for improving the Quality, Health, Safety, Environment and Security (QHSES) performance in offshore terminals and marine ports.

6.6. CONCLUSIONS

In this chapter four significant risk factors (hazards), three of which were identified and prioritised in Chapter 4, have been analysed by the use of the CCA in order to complete the risk assessment phase of the RM framework proposed for the purpose of this research.

In the first part of this chapter after introducing the CCA or bow-tie method, reasons for its usage were described and its application in marine industry was investigated. Subsequently it was used for analysing the nominated risk factors, their causes and consequences.

In the second part in order to evaluate the main causes of these risk factors while using the FFTA/traditional FTA and experts' judjements, the occurrence possibility/probability for the top events was calculated and by eliminating each basic event the occurrence likelihood for the top event was obtained to see the number of changes. Consequently the significant basic events influencing the nominated risk factors were identified via this procedure.

In the third part in order to analyse the consequences of these risk factors using the FETA/traditional ETA and experts' judgements, the possibility/probability of each consequence was calculated. Consequently the most significant consequence was revealed.

In the next chapter in order to independently manage any of the identified hazards associated with offshore terminals and marine ports an individual RM approach will be utilised. To fullfill this the most significant risk factor is selected to be dealt with.

CHAPTER 7: SECURITY RISK MANAGEMENT AND CASE STUDIES

7.1. INTRODUCTION

Through the previous chapters risk factors associated with offshore terminals and marine ports were identified, assessed, prioritised and ranked accordingly. The most significant risk factors were analysed separately by CCA. Among them the most significant one revealed was security related risk factor. As a result due to importance of the mentioned risk factor this chapter will define a separate strategy for RM of the same risk factor. The following sections will investigate the case in depth in order to design an appropriate additional framework to handle the security related risk factor.

As a typical example in offshore terminals and marine ports Petrochemical Sea Ports and Offshore Terminals (PSPOTs) are essential elements for the operation of every country's economy that can affect their cost structures, industrial competitiveness and existing standards. In fact these logistics infrastructures can provide fundamental support to energy, transportation, agriculture and manufacturing sectors in any nation. However these crucial components of the global transportation historically have not been yet subjected to comprehensive governmental regulation and security oversight. In this regard the terrorist attacks on September 11, 2001 was the first paradigm-shifting event for transportation systems' security in general. For the maritime industry, that event has prompted remarkable shifts in the focused perspectives on security now required by anyone even remotely associated with the management of port and offshore terminal security, as well as the ships, adjacent plants or facilities involved.

Many of the sea ports are situated near chemical plants such as oil refineries, fertilizer plants and different petrochemical production units. Otherwise many are in a form of complexes especially for importing or/and exporting of crude oil, Liquefied Natural Gas

(LNG), Liquefied Petroleum Gas (LPG) as well as the various hazardous petrochemical products such as naphtha, ammonia, chlorine, urea, sulphur, coal etc. Some of these terminals are in a form of a fixed or floating offshore terminal situated in middle of sea used for the same purposes such as Floating, Production, Storage and Offloading (FPSO) units all of which have fixed process facilities on board. Their processing facilities are used to separate natural gas, crude oil, water and mud prior to loading of tandem tankers in middle of sea.

Any accidental or intentional release or undesirable event relating to the mentioned hazardous materials can adversely affect the health and safety of employees and the public in great extent whilst harming the environment. Accidental releases can result from possible accidents within the facilities or natural disasters. Accidents take place when employees make mistakes or are due to equipment malfunctions. Natural disasters are phenomena such as earthquake, flooding, tsunami, lighting strikes, tropical revolving storms etc, all of which can have destructive effects on the petrochemical seaports and terminals. On the other hand intentional releases can be as a result of planned and malicious acts. However all of the mentioned events whether they are as a result of intentional or accidental acts can cause toxic releases, fires, explosions and eventually can lead to massive fatalities, property damages, economic losses and environmental harms (Ishikawa and Tsujimoto, 2009).

As PSPOTs handle hazardous products and cargoes on a regular basis, they can easily become potential targets for malicious attacks (Sutton, 2010) under the three main categories i.e. those by members of the public, sabotage and terrorism. Public members' security breaches are acts such as vandalism, theft and activists. While they may wish to cause damage, they do not usually want to create a catastrophe. In case of a sabotage attacker who can create a very threatening situation the acts are not intended for a worst case. Terrorism is probably the form of attack that people fear the most, not least because terrorists internationally want to create fear. Moreover, terrorists often have much greater destructive capability than that of other malicious people, thus giving them the potential to cause a lot of damage and to operate at a long range (Sutton, 2010).

Accidental events are outside the scope of this chapter and they will not be discussed any further here. They can be investigated under process safety or process risk and reliability management but not under the heading of Security Risk Management (SRM). The intentional events as mentioned i.e. only the three categories of malicious anti-security or deliberate acts will be covered in this chapter for the purpose of the PSPOTs. In this regard a SRM framework will be introduced in the next section to overcome the security challenges within the PSPOTs.

7.2. SECURITY RISK MANAGEMENT

Based on the existing literature from Borodzicz (2004) the ancient philosophers of China, Greece and Egypt were certainly not the only members of early civilizations to have been worried regarding security. In fact some form of security must have been the basis for these early civilizations to exist. Moreover "the relationship between risk and security is perhaps more than simply a linguistic term. Indeed, security can be seen as an element of risk management in a holistic sense" (Borodzicz, 1996).

From PSPOT's risk perspective, security can be viewed reasonably as just another hazardous exposure. Although SRM may be viewed as a cost against the operation, it also represents a significant threat if not treated seriously. In fact treating PSPOTs' security risk factors as a loss prevention activity can help a broader assessment of PSPOTs exposure. As explained earlier this could acknowledge terrorists' threats, but also allow for a wider security agenda. Such losses could be the result of either internal or external terrorists' crime, but they could also start from an accident or natural disaster with no relationship to criminal behaviour. Terrorist attacks such as in the New York (11th of September, 2001), Madrid (11th of March, 2004), London (7th of July, 2005), Bali (1st of October 2005) and Mumbai (26th of November, 2008) are examples that can happen again in any place at any time even in PSPOTs.

A terrorist attack on a port, especially if several of such attacks occur simultaneously, can also disrupt nations' economies. Ports have a tendency to be large and extensive, therefore it is unlikely that any attack would destroy a port's infrastructure. On the other hand a terrorist attack on an offshore terminal can easily destroy or sink the facility. For example an attack on a petrochemical port could disrupt this distribution node for a considerable time and would probably lead to a delay at all ports within the vicinity until security measures are reviewed and upgraded. In the case of petrochemical and process facilities if they are situated nearby or within the ports' or onshore terminals' borders the overall view like the one explained above will be changed. In fact these kinds of sea ports and terminals will be considered as process facilities rather than being described like a normal transportation centre. In this case almost the same security threats, vulnerabilities and risk factors applicable to process industries with a little modification will be applied to these critical logistics centres.

Additionally there is a significant security risk due to the hazardous nature and quantity of chemicals and cargoes being handled by ships, ports and offshore terminals, extreme processing conditions of temperature and pressure, and value of the products to the nation. Terrorists having adequate information may use them to cause toxic releases, fires and explosions. Some of this information are such as the location of hazardous chemicals, position of FPSOs, storage tanks and contains onshore, pipelines, bypass valves, crucial safety and warning systems, emergency shutdown/stop buttons or devices, locations and time schedules for entering and leaving ships. Different types of ships will be also in interest of terrorists (e.g. tandem tankers, crude oil tankers, LNG, LPG, chemical tankers, bulk carriers carrying hazardous cargoes). Additional type of information are that such as location of the shore based terminals in which the loadings and discharging take place, the amount, duration and type of cargo, their inventory, type of the chemical operations and other sensitive information. This can result in severe impact on economy, health, safety of people and public, environmental pollution and damage as well as casualties (CSC, 2010) both in "on-site and off-site" locations.

However a theoretical approach toward a generic SRM for the purpose of PSPOTs in this chapter aims to identify the threats resulting from terrorism. The proposed framework also establishes appropriate security procedures for assets characterisation, assessing the security risk factors (threats), security threat/vulnerability analysis and moreover takes appropriate measures against the identified/assessed threats. For this reason a generic SRM framework for PSPOTs can be demonstrated in Figure 7.1.

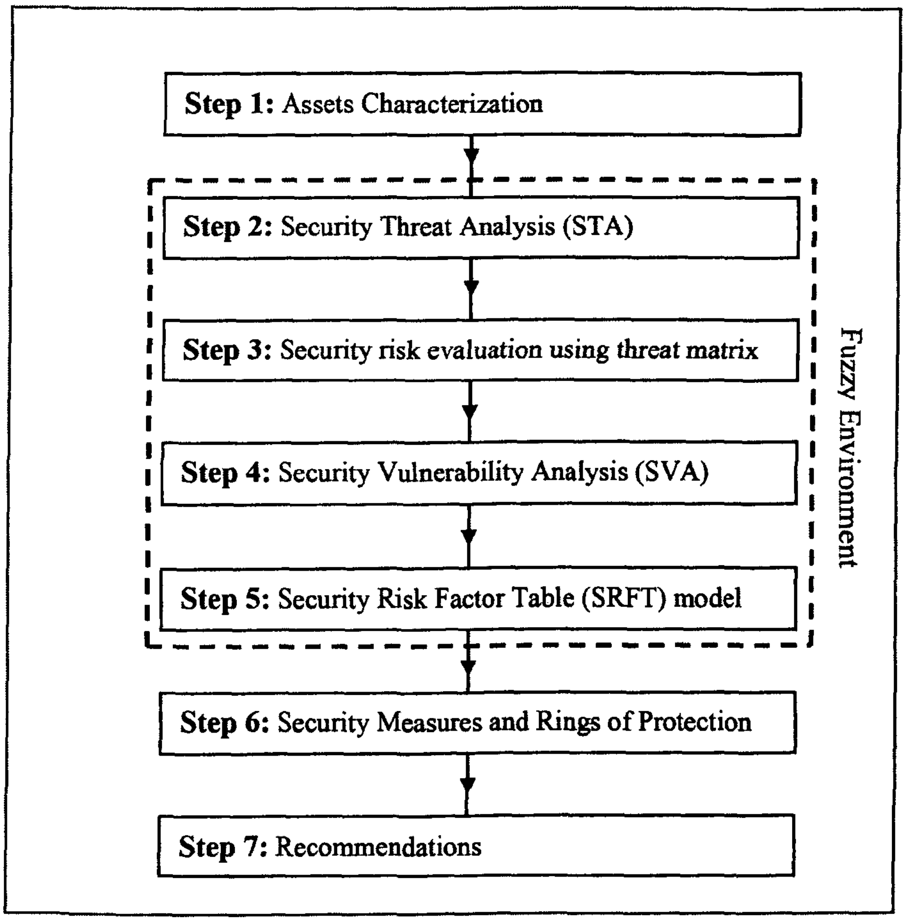


Figure 7.1: A generic SRM framework for the purpose of PSPOTs

Security threats like acts of terrorism on a facility such as a PSPOT can be avoided if the security chain reaction shown in Figure 7.2 within a facility can be broken. This can be achieved by an intentional and planned programme (e.g. SRM) as a security sequence which develops to halt or reduce the progress of a security incident (e.g. a terrorist attack). An appropriate security triangle for this is shown in Figure 7.2. This diagram indicates that if any of the illustrated elements is sufficiently halted or controlled the risk of a security attack by terrorists can be prevented. This can be satisfied by exactly knowing which assets in a PSPOT are critical or by undertaking an appropriate STA and/or SVA to halt and reduce the level of the security threats or vulnerabilities. For the purpose of the aforementioned statements as shown in Figure 7.1 i.e. Steps 1, 2 and 4 which are used for assets characterisation, STA and SVA, will be dealt with separately in Section 7.4.

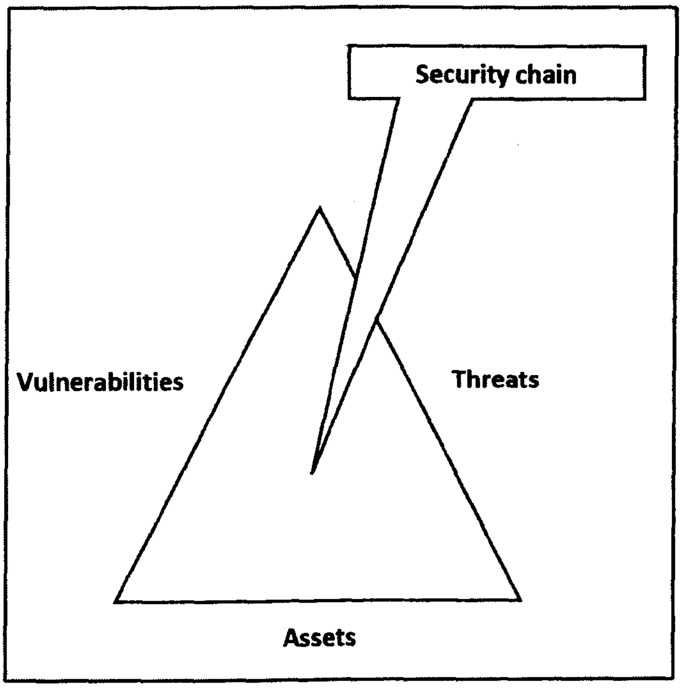


Figure 7.2: Security triangle

7.3. FUZZY SET THEORY

FST is fully discussed in Chapter 4. The subjective linguistic variables (see Section 7.4, Step 3 and Step 5) used in this chapter for evaluation of the security risk factors (threats) can be defined in terms of membership functions. A membership function is a curve that defines how each object or point (i.e. security risk factor) e.g. low and high in the input space is mapped to a membership value. For example triangular numbers are used to define fuzzy linguistic scales (five points) of very low, low, medium, high and very high shown in Figure 7.3. Additionally another example (i.e. trapezoidal numbers) for defining the fuzzy linguistic scales (three points) of low, medium and high is illustrated in Figure 7.4. Figure 7.4 was previously used in the work of the Baipai *et al* (2010); further explanations can be found in their work.

Figure 7.3: Example of fuzzy triangular membership functions

Source: Modified from Yang and Hung (2007)

Figure 7.4: Fuzzy trapezoidal membership functions

Source: Bajpai *et al,* (2010)

Consequently as the results of the calculations carried out for the purpose of this chapter in the form of fuzzy numbers, an additional defuzzification process is utilised in order to convert them into crisp numbers. The centre of area defuzzification technique is selected to be used for this purpose hereafter. This technique was developed in 1985 (Sugeno, 1999). It is the most commonly used technique and is accurate. This method can be expressed for triangular and trapezoidal fuzzy numbers as per following formulas:

Triangular fuzzy number $\widetilde{M}=(l,\ m,\ u)$ can be defuzzified to a crisp number of M by:

$$M=\frac{(l+m+u)}{3} \tag{7.1}$$

For a trapezoidal fuzzy number of $\widetilde{M}=(l,\ m,\ n,\ u)$:

$$M=\frac{1}{3}\times\frac{(u+n)^2-(u\times n)-(l+m)^2+(l\times m)}{(u+n-m-l)} \tag{7.2}$$

7.4. METHODOLOGY TO CARRY OUT THE PROPOSED SRM IN PSPOTS

An appropriate methodology comprising seven steps was shown in Figure 7.1. The illustrated steps can be easily applied to different petrochemical ports' or offshore terminals' facilities and operations at varying degrees of detail as necessary.

Step 1: Assets characterisation: To divide the PSPOTs into areas or zones and to characterize them in order to know critical assets, their importance and their interdependencies and the supporting infrastructure (API, 2003 and Nolan, 2008).

In case of the PSPOTs apart from visiting ships, critical assets are mainly export and import terminals where ships will be made fast alongside the specialised jetties or moored to Catenary Anchor Leg Mooring (CALM) buoys, port control tower or vessel traffic service/management, lights, sound or fog signals, warehouses, maintained depth of water, breakwaters, fire fighting, policing, security, emergency, health and patrol units, office buildings, support vessels, accommodation barges, tugs, pilot boats, dredgers, loading/discharging arms and platforms, power generators, area lightings, CCTVs, fences, gates, emergency shutdown valves, cargo transfer equipment, safety and security equipment, alarms, gas detection systems and any other equipment and devices related or connected to the adjacent processing units or plants etc (OCIMF, 2004 and Mather, 2009).

Step 2: Security Threat Analysis (STA): To undertake a STA by identifying sources, types and determining likelihood of threats. Then each probable threat within the process area is evaluated (Nolan, 2008).

As Kamien (2006) explains a threat analysis can be based on types or sources of threats. In this regard the United States' Office of Domestic Preparedness (ODP) focuses on the category of weapon that terrorists may use – chemical, biological, radiological, nuclear, and explosive. Another option is to focus on the sources of threat – on any organisation with the motivation, capability, and opportunity to launch a successful attack on their systems. Therefore it is important to develop a range of scenarios that can correspond to potential types of attacks. Moreover each scenario should contain assets, weapons, and mode of delivery. In case of PSPOTs and based on the sources of threats whether they are based from internal or external sources is illustrated in Table 7.1.

Table 7.1: Examples of sources of threats in PSPOTs

Source: Adapted from Sutton (2010)

The following lists are potential types of threats in PSPOTs as a result of terrorists' deliberate acts (ISPS Code, 2003 and Sutton, 2010):

- Release of hazardous cargo from ship or shore-based storage tanks, causing toxic gas dispersion, fire and explosion.
- Theft of confidential information from PSPOTs facilities.
- Major damage to port and offshore terminal infrastructure e.g. FPSO, storage tanks, entrance channel.
- Cargo loading or discharging tampering by changing control settings.
- Creation of hazardous situations through tampering with valves, or adding contaminants, and so on.
- Devastating port and offshore terminal operators, security guards, and so on.
- Theft of hazardous products for utilizing elsewhere.
- Vandalism of onshore or offshore based cargo control rooms and equipment.
- Immobilizing safety and security units and systems.
- Immobilizing port/terminal control and vessel traffic services/management centres.
- Immobilizing ships.
- Bomb threats by third party, port/terminal employees or an entered ship.
- Cyber threats (threats to critical equipment that are attached to computers having Internet).
- Terrorists' attack from ship to a port or an offshore terminal by the use of ship's cargo i.e. use of a ship as a mode of delivery.
- Terrorists' long reach attack using military-style weapons like an attack from air to port e.g. passenger planes or long-range missiles, attack from sea to a port or an offshore terminal e.g. pirates or speed boats.
- A terrorist attack upon a ship in a port area or while afloat or alongside of an offshore terminal.

Other factors such as types and volume of cargoes handled or presented in PSPOTs, meteorological conditions, different type of access to the port/terminal facility, operating hours etc are among the factors which can affect the threats' likelihood. The likelihoods of the probable threats can be estimated by experts using the defined five points of the triangular fuzzy numbers. By use of a threat matrix explained in the next section the estimated likelihoods will be used for evaluating and prioritising of the security risk factors (threats) of a PSPOT. Furthermore in a PSPOT the various mentioned terrorist acts can be organised in such a way to be carried out even by international or domestic pirates (e.g. Somalia pirates), stowaways and illegal entrants.

Step 3: Security risk evaluation using threat matrix: There are different security risk evaluation methods and tools to help security experts to estimate the different security risks' levels within the selected facilities. In this regard both qualitative and quantitative approaches are found useful. In qualitative methods the parameters used as decision basis are subjective and estimated by experts' judgements. Quantitative methods describe the risk by calculations, and a numerical target value is compared with the result. Which methods to apply rely primarily on whether the necessary risk reduction is specified in a numerical manner or qualitative manner. The scope and extent of the analysis would also be an influencing factor (Marszal and Scharpf, 2002). Risk matrix, or as often referred to, hazard matrix which is called threat matrix in this chapter, is one of the most accepted risk determination methods due to its ease. The threat matrix takes likelihood (frequency) and severity (consequence or impact) of the threats into account qualitatively, based on a classification of the threat parameters. Figure 7.5 shows a typical threat matrix diagram which is adapted for security risks evaluation purposes. The severity and likelihood of threats make one axis each, enabling the user to plot the situation under consideration in the diagram. If each box in the diagram has an attached classified security risk level e.g. very high risk, the determination process is simple. The severity categories may be expressed in terms of human (people's security), economic (assets or profit losses) or environmental loss. The categories also divide the threat severities into minor, slight, moderate, critical and catastrophic categories according to the level of threat's severity. The likelihood categories are also divided into very low, low, medium, high and very high ones. The categories can be selected qualitatively, using experts' judgments as explained above and shown in Figure 7.5, but quantitative tools (e.g. fuzzy set numbers explained in Section 7.3) can also be utilized by experts to make it easier for the threat levels to be estimated. In Figure 7.5, different threat levels are illustrated. For example, minor severity/low likelihood leads to very low security risk (threat) requisite. This means that the security risk is considered tolerable. Minor severity/medium likelihood leads to a low security risk, while critical severity/high likelihood will leads to a high security risk requisite.

As ABS (2003) discusses a common risk evaluation and presentation method is simply to multiply the likelihood (L) of each undesirable event by each severity (S), and then sum these products for all situations is considered in the evaluation.

Thus with respect to the above descriptions, security risk levels can be obtained by use of the mentioned parameters through Equations (5.1) and (5.2). These equations are fully discussed in Chapter 5. In this chapter they specifically will be used for calculating the security threats.

Figure 7.5: Typical threat matrix designed for security risk evaluations in PSPOTs
Source: Adapted from ABS (2000)

As Buybott (2007) explains a threat matrix can be used to measure each of the individual security risk factors (threats) associated within a facility without having a clear background of the various prevention measures that may be part of a specific threat scenario. In this case the evaluated threat levels can be used as a preliminary stage to make a decision on the extent of a SVA that should be performed, as well as the levels of security measures and safeguards that should be maintained or to be implemented at an initial stage. As a result of combining of both the qualitative and quantitative approaches to security risk factors (threats) can be ranked for further use and purposes. As per Figure 7.3 appropriate fuzzy linguistic scales along with their membership functions have been illustrated for the occurrence likelihoods. The same fuzzy scales and numbers are applicable for the corresponding occurrence severities. That means that a fuzzy triangular number of (0.50, 0.75, 1.00) as shown in Figure 7.3

can be used for both of the occurrence likelihood of very high and occurrence severity of catastrophic.

As an example and according to Figure 7.3, if a security risk factor (threat) as per expert's preference has occurrence likelihood ($\tilde{L}$) of (0.00, 0.25, 0.50) i.e. low, and consequence severity ($\tilde{S}$) of (0.50, 0.75, 1.00) i.e. critical, the ($\tilde{R}$) as per Equation 4.3 will be (0.00, 0.1875, 0.50). However as the result is a triangular number it can be defuzzified to obtain a crisp number as per Equation 7.1 which is equal to 0.23. In fact the same operation in this step must be carried out for all of the security risk factors one by one in order to obtain a crisp number for each. Then they can be prioritised and ranked according to their significance. Then as per their priorities a detailed SVA can be planned and carried out in order to continue the proposed SRM framework.

Step 4: Security Vulnerability Analysis (SVA): To identify vulnerabilities against each threat by the use of brainstorming and checklist approach (Nolan, 2008 and Sutton, 2010).

As Kamien (2006) discusses SVA is used to evaluate vulnerability of the critical assets in the scenarios i.e. for a given weapon and a given target, the probability that an attack will be successful depends on our ability to detect it, the warning time, the system's response, and the ability of the attacker to overcome the response. In assessing these factors, it is important to consider, for each target, any current countermeasures, relevant physical layouts, geographical configurations, etc, that might prevent access to the target, ability to detect an attack in progress, or assistance in defeating a detected attack. In this regard based on Sutton (2010) many companies and organisations carry out a SVA in order to identify areas where they may be the most vulnerable, and to make a decision on how to improve security. The team that conducts and supports a SVA must be intimately familiar with the industrial or commercial processes under examination. For example, an oil or gas refinery operator should not be chosen to support a review of a fertilizer plant. The typical review team should also have a balanced number of individuals from different organisations such as company employees, consultants, equipment fabricators, intelligence agencies and law enforcement officials.

Based on Nolan (2008) three types of individuals are needed to support a SVA: (1) a team leader, (2) a recorder/scribe, and (3) the experts. The experts are commonly (1) the project manager or engineer who has designed the facility, (2) a person familiar with how the facility will be operated e.g. a process or a safety engineer, and (3) a person familiar with loss or security risk aspects related to the facility under examination. SVAs will normally be applicable to all facilities; however, there will be more concern to apply its review to highly visible, valuable and important facilities or operations.

As a SVA is a qualitative form of an assessment the following steps must be carried out by SVA team members in order to achieve a successful analysis (ISPS Code, 2003; Gupta, 2005 and Nolan, 2008):

- Split the PSPOT facility into zones of different security levels e.g. critical-risk, high-risk, moderate-risk and low-risk areas. The main plan is to classify the critical locations in the onshore or offshore terminals, refineries and plants that can be potential targets e.g. FPSOs, storage tanks and ships.
- Identify the threats from potential terrorists in each zone.
- Identify the vulnerabilities within each zone. Develop various scenarios in which the realistic threats identified through STA could be understood.
- State worst possible impacts in-site/off-site in case of a successful terrorist attack to determine severity (S).
- Examine efficiency of the existing security measures for any specific threat.
- Recommend additional security measures to reduce likelihood (L) or severity (S) of a possible attack.

Step 5: SRFT model: The security condition for facilities like PSPOTs can be demonstrated practically by making a SRFT (ACS, 2002; Bajpai and Gupta, 2005 and CSC, 2010). In SRFT several security risk factors that can influence the entire security of PSPOTs are illustrated. After scoring the security risk factors listed in SRFT by experts or security auditors, using the three points trapezoidal fuzzy numbers shown in Figure 7.4. The total score obtained from SRFT will lead to make out and estimate the existing security risk level of a PSPOT.

Based on CSC (2010) SRFT can be used as a security risk assessment tool and as per Bajpai and Gupta (2005) in a form of a pre-screening tool to determine whether another detailed threat and vulnerability analysis is required. The person or team developing a SRFT should be also reasonably familiar with the facility in question. Moreover the following explanations are found valuable about the security risk factors being used in a SRFT model.

Usually terrorist groups and organisations focus on targets that can impact upon large populations. Thus, a facility situated in a rural location is much less attractive than a target like a petrochemical port located just near a city. As a result, being close to centres of high population areas increases the attractiveness of a facility as a target. A facility like a port neighbouring a major petrochemical tank farm is inherently at higher risk than many others. As large tanker ships from different destinations arrive at these ports, terrorists can plan in advance different ways to use these floating explosives as a delivery device just to destroy the terminals, refinery and plants in order to affect the nearby populations. To a lesser extent crude oil or LNG tanker ships can be used as a delivery device to destroy a FPSO which will cause huge physical, economic, environmental etc losses to a nation. Furthermore terrorists mostly try to generate panic by targeting large, recognized organisations, such as major corporations. A small and medium sized enterprise or private firm in a country is less likely to be targeted than a facility identified under ownership of a wealthy government.

The presence of existing security controls in PSPOTs lowers their attractiveness as a target. For example a port facility on its shore side which has very tight perimeter control with all access points secured, having extra monitors (e.g. sensors, patrols and/or video surveillance i.e. CCTVs) is a more difficult target than PSPOTs without this equipment. On the coastal side, if a petrochemical port is not controlled and watched by its coastguard patrols it is more prone to a terrorist attack than a PSPOT having 24 hours security watch. Additionally following 9/11, as the ISPS Code has been established, it has been embodied in Chapter Eleven of the Safety of Life at Sea Convention (SOLAS) 1974 of the International Maritime Organization (IMO). Due to the fact the Code has been enforced internationally by the IMO since July 2006 all the signatory states have to comply with the Code. The implementation of the Code since July 2006 helps ports to monitor their security levels. As a result in fact after 9/11 the vulnerability of an attack on nations' states through ships and ports has been more realised. In this respect as per ISPS Code there are three major areas of concern (ISPS Code, 2003 and ICS, 2007):

- The use of ship as a delivery system for a terrorist attack within a port.
- A terrorist attack upon a ship.
- The use of cargo used as a delivery system for targets away from the port.

In this regard as per regulations mentioned in the ISPS Code, pre-arrival security formalities and checks on tanker ships as well as ships' physical security inspections by port security officers or coastguard agencies prior to cargo operations will reduce the probability of a potential attack to ship or port facility by terrorist groups.

The presence of interested targets i.e. weapons that terrorists may use – chemical, biological, radiological, nuclear, and explosive – to carry out terrorist attacks in any PSPOT facility will raise the security risk of the port. As the amount of a specific target increases, the security risk will increase correspondingly. In other words in a PSPOT if the ability of target identification by terrorists increases the security risks will increase as well. Therefore the presence of the mentioned weapons as targets in a PSPOT will increase the security risk. There are a variety of chemicals of fear, including Chemical Weapon (CW) agents such as mustard gas, chlorine, ammonia and hydrogen cyanide. The most hazardous biological agents include anthrax and smallpox. Other organisms are also of worry, including viruses like yellow fever or bacteria - like anthrax. There are radiological agents with advanced precise action and longer half-life and the chemical form all contribute to the increased target potential of radiological materials. Even uranium composites may be attractive for use in a "dirty bomb". While the risk of significant radiological injury from a dirty bomb is much less than the risk of injury from the explosion, the psychological impact of such an occurrence on the affected population will be considerable. In this regard safety specialists in PSPOTs should train their employees regarding the real importance of a potential terrorist attack with the mentioned natures (CSC, 2010). In this regard training of port employees must be a part of the port's security risk management programme. In fact more practical trainings will reduce the potentials for a port facility to become a target. Additionally long term employees are much less likely to take part in a planned terrorist activity than new employees. Thus, new employees require much higher concern than long term employees to achieve the same level of security.

There are also worst case outcomes impacting on a port facility and its surrounding area as a result of any terrorist attacks. They can be evaluated based on the development of scenarios of the consequences of a terrorist incident at a port facility. To evaluate the worst case scenario and to estimate the severity of the outcome on a port facility and on its surrounding locations professional experts are required to score these factors carefully in order to obtain a sensible result (JISC, 2010).

There are other factors in PSPOTs that must be taken into account during building a SRFT such as visibility status of the FPSOs, ships or tank farms used for storage of the imported crude oil or natural gas or storage of the processed highly dangerous substances for export and internal use within the host country. If they are highly visible from the nearby areas this will increase the potential of an attack. Apart from visibility the number, capacity, volume and size of the storage tanks, FPSOs and ships also will play an important role for an attack to take place. Presence of terrorist groups in the region or vicinity of facilities, security background or history of the facilities in respect of the number of security incidents happened, etc plays important roles in examining a security level of the facility. At the end reliability and status of readiness of the emergency units in respect of health, safety, environment, security of PSPOTs will play an important role prior, during and after a successful terrorist attack (ISPS Code, 2003 and Sutton, 2010).

Step 6: Security measures and rings of protection: To list security safeguards against threat scenarios and to evaluate them to see if the protective measures are adequate.

Rings of protection are needed to be used as a risk mitigation method and they can be used for different applications. For the purpose of SRM in PSPOTs the same is applicable. In this regard the American Chemistry Council (ACC, 2001) states that security tends to emphasize "rings of protection," meaning that, if possible, the most important or most valuable assets should be placed in the centre of concentric levels of increasingly stringent security measures.

For example, where practicable, in a petrochemical port electronic control rooms of the refinery units should not be placed right next to the building's reception area; rather, it should be located deeper within the building so that, to reach the control room, terrorist would have to go through and pass numerous rings of protection, such as a fence at the facility boundaries, a locked exterior door, an alert receptionist, an elevator with key controlled floor buttons, and a locked door to the control room. To determine if the rings of protection are efficient, security programmes must usually be evaluated through the use of penetration tests and security drills in which the port/terminal facility has to have individuals who can play the role of attacker to see if the barriers work as expected. The same are applicable on ships interfacing with offshore terminals, FPSOs ports or different units situated within port facilities e.g. ports controls, export/import terminals, etc (ISPS Code, 2003).

Based on IMO (2003) and under the ISPS Code, security measures as rings of protection for ships and port facilities are defined by Security Level 1 (i.e. the level for which minimum appropriate protective security measures shall be maintained at all times), Security Level 2 (i.e. the level for which appropriate additional protective security measures shall be maintained for a period of time as a result of heightened risk of a security incident) and Security Level 3 (i.e. the level for which further specific protective security measures shall be maintained for a limited period of time when a security incident is probable or imminent, although it may not be possible to identify the specific target). However in very unsafe situations when the predicted security risk status is extreme, an additional ISPS security measure (i.e. Level 3 + State of high alert) will used as an extra ring of protection in petrochemical sea ports and offshore terminals. In this step the mentioned security levels are integrated in Table 7.2 which originally was based on CSC (2010) and used to be a part of their risk assessment tool.

In Table 7.2 crisp numbers of 24, 48 and 72 (shown under column of actual points obtained) are used to measure the security risk status in a sea port or an offshore terminal after scoring of the security risk factors using a SRFT. In Table 7.2 formation of the crisp numbers is based on the total number of security risk factors made-up in SRFTs (i.e. Tables 7.4 and 7.5) and the numbers used in Figure 7.4 for defining of the linguistic scales used in the SRFTs.

Table 7.2: Security measures and recommendations based on a score obtained from SRFT

Source: Adapted from CSC (2010)

Step 7: Recommendations: To determine if the recommendations are appropriate (ranking of security risk factors after using a threat matrix or a SRFT can be used to determine necessity).

Table 7.2 illustrates further guidelines to be adhered to in different security conditions, depending on the level of security a port or an offshore terminal facility maintains. Apart from taking into consideration the issues such as health, safety, environmental factors, the incorporated guidelines must be consistent with the elements for enhancing the security of PSPOTs. For example, initiatives such as port/terminal facility security plan, emergency response and emergency preparedness plans are used as mitigation methods. Also in this regard there are further recommendations along with the essential countermeasures which can be used for the purpose of key concepts such as how to detect, delay and respond to a terrorist attack. These plans are developed to ensure the application of measures designed to protect the PSPOT facility and ships, persons, cargo, cargo transport units and ship's stores within the PSPOT facility from risks of a security incident. Consequently after ranking the security risk factors by use of the SRFT, the required guidelines can be modified and applied on PSPOTs.

All steps explained here will be applied and are linked to case studies 1 and 2 as demonstrated and are discussed in the following sections.

7.5. CASE STUDY 1: PETROCHEMICAL SEA PORT OF (α)

Sea Port (α) shown in Figure 7.6 is a petrochemical complex including Zones A, B and C which are described thoroughly in Table 7.3.

Figure 7.6: Sketch for Petrochemical Sea Port of (α)
Source: Modified from Bajpai and Gupta (2005)

- Zone A: a refinery with different petrochemical units for refining the imported crude oil and natural gas with the ability to produce naphtha, ammonia and other types of petrochemical products (Bajpai and Gupta, 2005);

- Zone B: including import terminals for receiving and storage of crude oil and LNG cargo by Crude Oil Carriers and LNG tanker ships as well as export terminals for exporting naphtha by product carriers, ammonia by LPG tankers and bagged fertilizer cargo i.e. urea by dry bulk cargo ships;

- Zone C: a fertilizer plant with capability to produce urea (Bajpai and Gupta, 2005).

Table 7.3: Area description for Petrochemical Sea Port of (α)

Zone A (Refinery)	Zone B (Harbour and Terminals)	Zone C (Fertilizer Plant)	
1 Atmospheric distillation unit	16 Canteen	27 Power Plant	
2 Vacuum distillation unit	17 Seaman Club	28 Coal storage	
3 Catalytic reforming unit	18 Administrative Building for Oil Refinery	29 Urea Plant	
4 Calcinations unit	19 Administrative Building for Fertilizer Plant	30 Urea storage and Bagging plant	
5 Coker unit	20 Car and port's machinery parking	31 Ash Pond	
6 DSC Control room	21 Port Control		
7 Ammonia Plant	22 Crude Oil Import Terminal		
8 LPG bottling	23 LNG Import Terminal	**Symbols and limits**	
9 Naphtha Tank Farm	24 Naphtha Export Terminal		
10 Power Plant	25 Ammonia Export Terminal	Coast Lines	••••••••••
11 Control room	26 Fertilizer Export Terminal	Rail way	▬ ▪ ▬ ▪
12 Effluent treatment plant	32 Gate	Export Pipelines	▬▬▬
13 Crude Oil Tank Farm	33 Guard room	Fences	———
14 Natural Gas Tank Farm	34 Administrative Block	Zone Margins	— — — -
15 Ammonia Tank Farm	35 Fire Brigades	Guard Towers	■

Table 7.4: Security Risk Factor Table (SRFT) for Petrochemical Sea Port of (α)

Source: Modified from CSC (2010)

In construing and complying with the proposed SRM methodology in this chapter the Port (α) has been divided into three different zones as depicted in Figure 7.6 and the sections are listed in Table 7.3. In order to calculate the total security score of the petrochemical port (α) there is a need to modify the SRFT which was designed originally by CSC (2010). The newly designed SRFT and the identified security risk factors are based on the following descriptions.

Petrochemical port (α) is situated within 1 km distance from a very small city. The direction of the city from the port is shown in Figure 7.6. As it is shown there is a permanent wind gusting only during daytime from sunrise to sunset in the form of land breeze from sea toward shore in the shown direction. Except for some of the tall buildings in the petrochemical complex, port storage tanks, ships and other units situated within the harbour, the refinery and fertilizer plant are not visible from outside the port. Vertical tall walls and existing break waters around the port make all of them obscured and invisible. The port is under ownership of the government. Up to this time there have not been any reports terrorist activities except some criminal actions that have happened outside the port area. There has not been any type of accident reported. Traffic conditions, types and volume of hazardous cargoes are traceable through port authorities by the involved bodies or persons.

The port authority has been implementing the ISPS Code since July 2006. Ship to port security interface ISPS procedures and formalities are always maintained in very high intensity. Existing security measure types along with the other security risk factors which are considered as the most important contributing factors affecting the port are all listed in the newly designed SRFT i.e. Table 7.4.

A port security auditor as an expert has been asked to perform this task in order to rate the port (α) for the security risk factors listed in Table 7.4. Appendix V illustrates the SRFT and additional information which are used to facilitate the scoring process. The security auditor has used the fuzzy linguistic scales of trapezoidal numbers shown in Figure 4 to rate the risk factors. The fuzzy trapezoidal numbers used for corresponding linguistic scales shown in Figure 7.4 are: low (0,0,1,2), medium (1,2,3,4) and high (3,4,5,5). After rating all security risk factors using the mentioned linguistic scales, defuzzification is conducted in order to obtain the corresponding crisp numbers in the form of scores before adding them all together to obtain the total score. The total score is the security score of the port (α) which is used to determining further examination in association with Table 7.2. The total score obtained for the port (α) is found to be 40.14.

7.6. CASE STUDY 2: ILLUSTRATIVE EXAMPLE OF AN OFFSHORE TERMINAL

Halcrow Group Limited is owned by the Halcrow Trust and employee shareholders (a UK based company). It was appointed by Venice Port Authority to carry out a feasibility study in November, 2010 for a new £1.1 billion offshore deep water terminal outside Venice Lagoon. As part of the encouraged plan, a new platform will be positioned about 14km from the mainland where the depth of water is 20m.

Figure 7.7: Offshore Terminal of Venice under study
Source: Based on Halcrow (2010)

The Port of Venice is part of the new Northern Adriatic multiport system, created to play a greater role in handling extra Europe-Asia and Europe-Mediterranean cargo flows over the next ten years. The offshore terminal will provide a consolidated port base in the Mediterranean and absorb incoming vessels from the Suez Canal.

The location of the Port of Venice (and that of other North Adriatic ports) is exceptionally suitable for goods imported or exported both from markets in the Far East and those in the Southern Mediterranean. The port will also act as a "refuge berth" when the MOSE barriers (Venices' anti-flood system) are closed (Halcrow, 2010).

The port will be equipped to receive oil tankers, container ships, feeder container ships as well as to provide space for future expansion into other categories of goods, such as solid bulk cargo coming in on Capesize vessels (Halcrow, 2010).

Nevertheless for the purpose of this chapter and ignoring the above mentioned facts the map shown in Figure 7.7 will be used only as an illustrative example to carry out this case study. The map is divided into three separate zones of A, B and C shown in Figure 7.8 and is explained as follows.

The offshore terminal shown in Figure 7.8 is equipped to receive crude oil tankers via T-jetties of Alpha and Bravo, (see Zone A). The two berth oil terminal site is designed to receive ships of over 150,000 tonnes, unloading directly into an underwater pipeline linked to the onshore refineries.

Additionally the mentioned offshore terminal has three container terminals namely Terminal 1, 2 and 3 (see Zone B). They enable containers to be transferred to or from inland terminals where they can be processed and distributed by rail and road links to the main local inland routes, as well as to and from markets in central and Eastern Europe. The facility is able to handle three ships of capacity between 6,000 and 14,000 TEU at the same time. Each container terminal has five gantry cranes and ten small semi locked jetties enabling smaller container feeder ships operating between onshore and offshore terminals to load and discharge containers constantly.

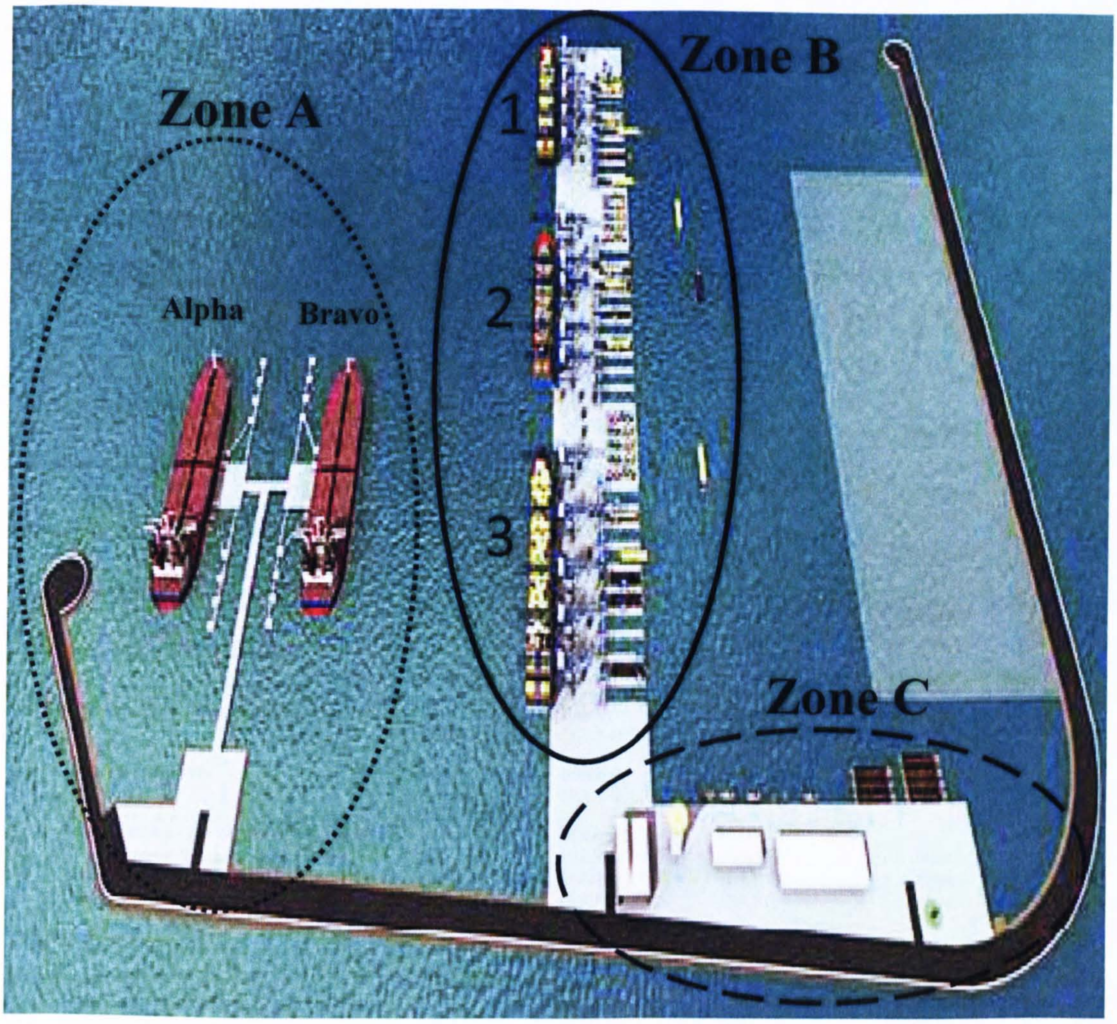


Figure 7.8: Venice Offshore Terminal

Support services (see Zone C) including terminal's port control, master tug boats, pilot vessels, coast guard, HSE and security section, emergency heliport, medical centre, buildings for staff, canteens and offices all of which are supplied by undersea electrical cables supplemented with electricity derived from renewable sources. The outer breakwater will protect the terminal in all weather.

In order to examine the proposed SRM methodology in this chapter the offshore terminal depicted in Figure 7.8 will be used to calculate the total security score designed in the SRFT. The identified security risk factors and the total security score gained are based on the following descriptions.

Table 7.5: Security Risk Factor Table (SRFT) for Offshore Terminal

Source: Modified from CSC (2010)

Venice offshore terminal is near eight nautical miles from the Port of Venice situated in Northeast of Italy in Adriatic Sea. This offshore terminal apart from visiting ships and other official visitors coming from the mainland is designed to accommodate 105 staff working in the site involved with different operations. The facility is owned and handled by a private Italian company looking after a medium range of shipping traffic within the facility. Occasionally there are swells and wind gusts coming from open sea, the direction from which is shown in Figure 7.7. In this context for safety reasons the breakwater of the facility is designed in such a way to minimise the effect of winds and swells to provide a good shelter for visiting ships. The breakwater also helps to reduce the visibility of the berthed ships and the whole operations within the facility for the purpose of security. Although there are no storage tanks for the processed gases and chemicals within the site the terminal always handles lots of containers in the form of Dangerous Good (DG) Containers. These specially designed containers in fact carry different types of IMO classed DGs such as different hazardous processed gases and chemicals. As soon as the mentioned DG containers arrive to site, very quickly they will be transferred and loaded into the outgoing container or feeder ships but will only remain on the jetties in terminals 1, 2 and 3 for a very short period of time. The imported crude oil will be pumped out from the berthed crude oil tankers via pipelines to shore based refineries or other destinations. There is no history on security incidents or any sign for the presence of terrorist groups or similar activities in the regions.

The Venice Port Authority and in fact this offshore facility have been implementing the ISPS Code since July 2006. Ship to port security interface ISPS procedures and formalities are always maintained in very high level and intensity. Existing security measure types along with the other security risk factors which are considered as the most important contributing factors affecting this offshore terminal are all listed in the modified SRFT i.e. Table 7.5.

A port security auditor as an expert has been asked to perform this task in order to rate the port (α) for the security risk factors listed in Table 7.5. Appendix V illustrates the SRFT and additional information which are used to facilitate the scoring process. The security auditor has used the fuzzy linguistic scales of trapezoidal numbers shown in Figure 7.4 to rate the risk factors. The fuzzy trapezoidal numbers used for corresponding linguistic scales shown in Figure 7.4 are: low (0,0,1,2), medium (1,2,3,4) and high (3,4,5,5). After rating all security risk factors using the mentioned linguistic scales, defuzzification is conducted in order to obtain the corresponding crisp numbers in the form of scores before adding them all together to obtain the overall score. Total security score obtained for the mentioned offshore terminal is 23.88.

7.7. RESULTS AND DISCUSSIONS

In Case Study 1 the obtained total score for the port (α) was 40.14. By matching the obtained total score with the actual security points available in Table 7.2 it is understood that this number lies within the range from 24 to 48 (i.e. where the security risk status is moderate). This means that the port (α) must maintain and take measures as per ISPS Code security level 2. The related recommendations are explained in Table 7.2. Moreover as it can be seen from Table 7.4 security risk factors (i.e. port's ownership, worst impact on-site/port facility and meteorological conditions) with the maximum score of 4.22 for each can be regarded as the most significant risk factors for the petrochemical port of (α).

In Case Study 2 the obtained total score for the mentioned offshore terminal was 23.88. By matching the obtained total score with the actual security points available in Table 7.2 it is understood that as this number lies within the range from 0 to 24; therefore the security risk status is low. This means the Venice offshore terminal must maintain and take measures as per ISPS Code security level 1. The related recommendations are explained in Table 7.2. Moreover as it can be seen from Table 7.5 security risk factors i.e. visibility status of ships and infrastructures, range of shipping traffic and worst impact on-site/port facility each with a maximum score of 2.5 can be regarded as the most significant security risk factors of the Venice offshore terminal.

In both case studies all of the mentioned security risk factors in SRFTs are inherent. They are unavoidable in terms of their likelihood, they cannot be reduced and/or mitigated permanently. Therefore the maximum efforts to reduce the level of such threats are only to reduce their severities. In this case an appropriate emergency preparedness plan or proper instructions must be developed by specialists and experts such as SVA team members to reduce the impact of such probable threats.

7.8. CONCLUSIONS

Security of PSPOTs is binding for all nations and antiterrorism is a critical accomplishment. The security threats cannot be eliminated altogether, but they must be reduced. An appropriate SRM requires changes in organisational culture that take time and expertise if they are to succeed. The key is to follow a systematic approach to identify critical assets, assess security risk factors, and make smart decisions for managing the potential security risk factors. Therefore it is important to tailor the SRM programmes to potential consequences by the resources involved at the moment. Major consequences of terrorism allow for carrying out a more detailed SRM. Through a resource allocation process based on available details and through STA and/or VSA, effective and efficient management of the potential security risk factors is possible.

Ultimately in this chapter a generic SRM methodology tailored and modified for the purpose of PSPOTs is introduced to overcome the security threats as a result of the potential terrorists' attacks. For future work, security and risk management professionals or experts in offshore terminals and marine ports, especially those operating under a petrochemical environment can integrate the study carried out in this chapter with crisis, business continuity management and resilience related studies. This will help the offshore and port industries to survive if they are under permanent danger of the potential security threats.

In the next chapter in order to mitigate the identified hazards associated with offshore terminals and marine ports a Fuzzy TOPSIS technique will be used. This will help to select the previously introduced risk mitigation strategies for managing the related identified risk factors. Through the next chapter a RM framework for offshore terminals and marine ports will be concluded.

CHAPTER 8: SELECTING THE BEST MITIGATION STRATEGIES

8.1. INTRODUCTION

In the previous chapters potential risk factors affecting the offshore terminals and marine ports were identified and assessed. Then as a risk-based model was developed it was implemented on real cases for port-to-port risk-based comparisons. In a later stage the most significant risk factors were analysed individually using CCA. In order to complete the predefined addressed RM framework it is required to mitigate the identified risk factors and complete the RM framework. This chapter intends to introduce a number of risk mitigation strategies and inspect their priorities over the previously identified risk factors using an appropriate MCDM tool.

8.2. MCDM METHODS

MCDM problems are discussed previously in Chapter 4. Nevertheless several methods exist for MCDM (Vincke, 1992 and Zeleny, 1982). There are no better or worse techniques, but some techniques are better suited to particular decision problems than others (Mergias *et al*, 2007). Among these methods, the most popular ones lately used by researchers are the Analytic Hierarchy Process (AHP) (Golec and Taskin, 2007), Analytic Network Process (ANP) (Yuksel and Dagdeviren, 2007), Axiomatic Design (AD) (Kulak and Kahraman, 2005), TOPSIS (Kahraman *et al*, 2007), ELECTRE (Wang and Triantaphyllou, 2005) and PROMETHEE (Dagdeviren, 2008). It is necessary to develop all fundamentals linked to the condition in detail before selecting a suitable MCDM method to solve the problem (Bufardi *et al*, 2004; Mergias *et al*, 2007). "The MCDM method choice decision should wait until the analyst and the decision- makers understand the problem, the feasible alternatives, different outcomes, conflicts between the criteria and level of the data uncertainty" (Mergias *et al*, 2007). There are other additional methods such as scoring models (Nelson, 1986) and utility models (Munoz and Sheng, 1995) which are used occasionally in this respect.

For the purpose of offshore terminals and marine ports as the importance weights of the criteria (risk factors) were calculated by the AHP method under a fuzzy environment (see Chapter 4), in order to obtain feasible alternatives (mitigation/control options) by further extension of the FAHP method, a TOPSIS method is preferred to be employed under the same fuzzy environments. FTOPSIS will be used hereafter for 4 reasons: (a) TOPSIS technique is reasonable and clear; (b) the calculation procedures are simple; (c) the idea allows the chase of best alternatives for each criterion illustrated in a straightforward mathematical outline, (d) the most significance weights are included in the comparison procedures (Wang and Chang, 2007).

As Yoon and Hwang (1985) explain TOPSIS is one of the useful MADM techniques to manage real-world problems. TOPSIS technique was initially proposed by Hwang and Yoon (1981). According to this method, the paramount alternative would be the one that is closest to the positive ideal solution and farthest away from the negative ideal solution (Benitez, Martin, and Roman, 2007). The positive ideal solution is a resolution that increases the benefit criteria and reduces the cost criteria, whereas the negative ideal solution increases the cost criteria and reduces the benefit criteria (Wang and Elhag, 2006). Overall, the positive ideal solution consists of all best values attainable for the criteria, while the negative ideal solution consists for the all worst values attainable of criteria (Wang, 2007).

8.3. A BRIEF REVIEW OF PAST RESEARCHES ON FTOPSIS

In Chapters 4 and 5 respectively FAHP and ER were implemented. Apart from the fact that both techniques were decision making tools specifically FAHP was used for calculating the weights of the risk factors while ER also was used when experts are not one hundred percent sure to believe in an assumption but only to certain degrees of belief. In this chapter it is intended to use another decision making technique (i.e. FTOPSIS) which has not been used before in the thesis. More features of FTOPSIS are detailed in the following sections. There are many fuzzy TOPSIS methods proposed by various researchers. The latest contributions are described as follows.

Chen (2000) has used the extensions of the TOPSIS for group decision-making under a fuzzy environment. As per the theory of the TOPSIS, he has defined a closeness coefficient to conclude the ranking order of all alternatives by calculating the distances to both the fuzzy positive-ideal solution and fuzzy negative-ideal solution at the same time. Yurdakul and Ic (2005) by using the FAHP and FTOPSIS methods have developed a performance measurement model that could be used to get an overall performance score by measuring the success of a manufacturing company in its operational activities. In another instance Zarghaami *et al,* (2007) have used the TOPSIS technique as a fuzzy multiple attribute decision making on their water resources projects case study for ranking water transfers to Zayanderud basin in Iran. Buyukozkan *et al,* (2008) for selection of the strategic alliance partner in logistics value chain after creating the evaluation criteria hierarchy and computation of the criteria weights by applying the AHP method, have used the FTOPSIS to get the final partner ranking results.

Ebrahimnejad *et al,* (2009) have used the TOPSIS in a fuzzy decision-making model for risk ranking with an application to an onshore gas refinery. Furthermore they have proposed that the selection of a proper MCDM model for risk ranking depends on the project's nature, the precision of data gathered on risk and knowledge. Dagdeviren *et al,* (2009) in their work have developed an evaluation model based on the AHP and the TOPSIS, to help the users in defence industries for the selection of optimal weapon under fuzzy environments where the vagueness and subjectivity are handled with linguistic values parameterised by TFNs. Another example is Celik *et al,* (2009)'s work i.e. application of axiomatic design and TOPSIS methodologies under fuzzy environments for proposing competitive strategies on Turkish container ports in maritime transportation network. Ertugrul and Karakasoglu (2009) in their work have used FAHP method for determining the weights of the criteria by decision makers and then rankings of the Turkish cement firms were calculated by a FTOPSIS method. The proposed method was used for evaluating the performance of the 15 Turkish cement firms in the Istanbul Stock Exchange by using their financial tables. Then the rankings of the firms were determined according to their results. As mentioned by Kandakoglu *et al*, (2009) they have used both FAHP and FTOPSIS to support the critical decision process on shipping registry selection under multiple criteria. In the latest work Torfi *et al*, (2010) have used a FAHP to compute the relative weights of their evaluation criteria and FTOPSIS to rank their alternatives.

In this thesis a FAHP method has been used for calculating the relative weights of the risk factors (i.e. criteria) and here in this part by extending the FAHP, FTOPSIS can be utilised for selecting the most suitable alternatives i.e. mitigation factors. As in Chapter 4 while using FAHP, relative weights of the risk factors in offshore terminals and marine ports were calculated. Therefore in this chapter FTOPSIS is based on the existing literatures will be utilised hereafter.

8.4. THE FTOPSIS METHODOLOGY

The principles of a TOPSIS technique is based on selecting the best alternative, which has the shortest distance from the positive-ideal solution and the longest distance from the negative-ideal solution (Hwang and Yoon, 1981). It is often difficult for a decision maker to allocate an accurate performance rating to an alternative for the criteria under investigation. The good point of using a fuzzy approach is to allocate the relative importance of the criteria using fuzzy numbers instead of precise numbers. This research expands the TOPSIS to the fuzzy environment. The Fuzzy MCDM can be briefly illustrated in a matrix format as shown in Equation 8.1 and Equation 8.2.

$$\begin{array}{c c} & \begin{array}{cccccc} C_1 & C_2 & \cdots & C_j & \cdots C_n & \end{array} \\ \begin{array}{c} A_1 \\ A_2 \\ \vdots \\ A_i \\ \vdots \\ A_m \end{array} & \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \cdots & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \cdots & \cdots & \tilde{x}_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \tilde{x}_{ij} & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \cdots & \cdots & \tilde{x}_{mn} \end{bmatrix} \end{array} = \tilde{D} \qquad (8.1)$$

$$\widetilde{W} = [\widetilde{w}_1, \widetilde{w}_2, ..., \widetilde{w}_j, ..., \widetilde{w}_n] \quad (8.2)$$

where $\tilde{x}_{ij}, i = 1; 2; \ldots, m; j = 1, 2, \ldots, n$ and $\widetilde{w}_j, j = 1, 2, \ldots, n$ are linguistic TFNs, $\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij})$ and $\widetilde{w}_j = (a_{j1}, b_{j2}, c_{j3})$. Note that $\tilde{x}_{ij}$ is the performance rating of the ith alternative, A_i, with respect to the jth criterion, $\widetilde{w}_j$ represents the weight of the jth criterion, C_j. The normalised fuzzy decision matrix denoted by $\tilde{R}$ is shown in Equation 8.3:

$$\tilde{R} = [\tilde{r}_{ij}]_{m \times n} \quad (8.3)$$

The weighted fuzzy normalised decision matrix is depicted in Equation 8.4:

$$\tilde{V} = \begin{bmatrix} \widetilde{v}_{11} & \widetilde{v}_{12} & \cdots & \widetilde{v}_{1n} \\ \widetilde{v}_{21} & \widetilde{v}_{22} & \cdots & \widetilde{v}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \widetilde{v}_{m1} & \widetilde{v}_{n2} & \cdots & \widetilde{v}_{mn} \end{bmatrix} = \begin{bmatrix} \widetilde{w_1}\widetilde{r}_{11} & \widetilde{w_2}\widetilde{r}_{12} & \cdots & \widetilde{w_n}\widetilde{r}_{1n} \\ \widetilde{w_1}\widetilde{r}_{21} & \widetilde{w_2}\widetilde{r}_{22} & \cdots & \widetilde{w_n}\widetilde{r}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \widetilde{w_1}\widetilde{r}_{m1} & \widetilde{w_2}\widetilde{r}_{m2} & \cdots & \widetilde{w_n}\widetilde{r}_{mn} \end{bmatrix} \quad (8.4)$$

The advantage of using a fuzzy approach is to allocate the relative importance of the risk factors using fuzzy numbers rather than exact numbers. This study utilises the TOPSIS under fuzzy environments. This technique is particularly appropriate for solving the group decision making problems under fuzzy environments. Using the mentioned fuzzy approach, the designed fuzzy TOPSIS process is then defined as follows (Torfi, 2010):

Step 1: Select the linguistic variable $(\tilde{x}_{ij})$ $i = 1, 2, \ldots, m; j = 1, 2, \ldots, n$ for mitigation options with respect to risk factors and the appropriate linguistic variables ($\widetilde{w}_j$; $j = 1, 2, \ldots, n$) for the weights of the risk factors. The fuzzy linguistic variable $(\tilde{x}_{ij})$ preserves the property that the ranges of normalised TFNs belong to [0, 1]; thus, there is no need for a normalisation procedure. For example, the $\widetilde{D}$ defined by Equation 8.1 is equivalent to the $\tilde{R}$ defined by Equation 8.3.

Step 2: Create the weighted normalised fuzzy decision matrix. The weighted normalised value $\tilde{V}$ is determined by Equation 8.4.

Step 3: Select the positive ideal (A^*) and negative ideal (A^-) solutions. The fuzzy positive ideal solution (FPIS, A^*) and the fuzzy negative ideal solution (FNIS, A^-) are shown in Equation 8.5 and Equation 8.6:

$$A^* = \{\tilde{V}_1^*, \tilde{V}_2^*, \dots, \tilde{V}_n^*\} = \{(\max_i \tilde{v}_{ij} | \, i = 1, \dots, m), j=1, 2, \dots, n\} \quad (8.5)$$

$$A^- = \{\tilde{V}_1^-, \tilde{V}_2^-, \dots, \tilde{V}_n^-\} = \{(\min_i \tilde{v}_{ij} | \, i = 1, \dots, m), j=1, 2, \dots, n\} \quad (8.6)$$

Maximum and minimum operations do not give TFN but it is likely to state the approximated values of minimum and maximum as TFNs (Kwang, 2005). It is known that the elements $\tilde{v}_{ij}$ $\forall i,j$ are normalised positive TFNs and their ranges belong to the closed interval [0,1]. Thus, it can define the fuzzy positive ideal solution and the negative ideal solution as $\tilde{V}_i^* = (1, 1, 1)$ and $\tilde{V}_i^- = (0, 0, 0)$, j=1, 2, …, n (Isiklar and Buyukozkan, 2006).

Step 4: Determine the separation measures. The distance of any mitigation option from A^* and A^- can be estimated using Equation 8.7 and Equation 8.8.

$$d_i^* = \sum_{j=1}^{n} d\,(\tilde{v}_{ij}, \tilde{v}_j^*), \quad i = 1, 2, \dots, m \quad (8.7)$$

$$d_i^- = \sum_{j=1}^{n} d\,(\tilde{v}_{ij}, \tilde{v}_j^-), \quad i = 1, 2, \dots, m \quad (8.8)$$

Step 5: Determine the similarities to ideal solution. This step resolves the similarities to an ideal solution by Equation 8.9:

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-} \quad (8.9)$$

Step 6: Ranking the mitigation options. Select a mitigation option with maximum CC_i^* or rank mitigation options according to CC_i^* in downward order (Yang and Hung, 2007).

8.5. RISK MITIGATION

Risk mitigation is a decision making process whereby actions are taken in view of the outcomes of risk assessment. Standard risk prevention strategies aim either at reducing the probability of an incident (pre-accident intervention) or at minimising the degree of fatalities if the accident occurs (post-accident intervention). This process is generally combined with Cost-Benefit Analysis (CBA) for optimal decision-making (UNCTAD, 2006).

CBA is one of the best standard methods for identifying the best benefit-to-cost ratio, typically by contrasting loss earnings, or the cost of failure, in opposition to the benefits of fulfilment. CBA was first introduced by the Formal Safety Assessment (FSA) guidelines as approved by IMO in 2001 and later on adopted in agendas such as regulatory assessment of maritime security (UNCTAD, 2006).

In another instance IRM (2002) expresses risk treatment as a process of selecting and implementing measures to modify the risk. Risk treatment includes as its major element, risk control/mitigation, but extends further, for example, risk avoidance, risk transfer, risk financing etc.

In this respect Ward (2005) explains that a proactive RM is an *ex ante* approach to handling uncertainty. The focus is usually the identification of potential threats and planning for and influencing future events. Where uncertainty presents potential future threats, a proactive RM seeks to modify the future incidence and quality of threats and their possible impact on performance goals.

Nevertheless, Ward (2005) argues that on the other hand a reactive RM is an after-the-end approach, usually concerned with mitigating the effects of threats that have occurred, when in managing crisis situations. An effective reactive RM requires the capability to rapidly identify and respond to a wide range of possible events in order for problems to be remedied.

Figure 8.1: Proactive and reactive management of uncertainty.
Source: Based on Ward (2005)

Ultimately as Irukwu (1991) explains once hazards have been identified and the associated risks assessed, all techniques to manage risks fall into one or more of these four major categories:

- Avoidance (eliminate, withdraw or not become involved).
- Reduction (optimise - mitigate).
- Sharing (transfer - outsource or insure).
- Retention (accept and budget).

In Chapters 4, 5, 6 and 7 all of the discussed risk factors identified through the literature review (see Chapter 2) were assessed, evaluated and analysed. In this chapter in order to complete the RM framework it is necessary to complete this cycle via a mitigation phase. In this respect for mitigating the risk factors first it is essential to identify the different mitigation strategies or sources and then by utilising an appropriate methodical means to prioritise them for their application purposes.

As it was shown before in Figure 4.3 different sources of risks and uncertainties in offshore terminals and marine ports were divided into two main categories of the external (country and business risk factors) and internal (organisational and operational risk factors) risk factors. Nevertheless in order to manage the mentioned risk factors it is necessary to identify the most ideal strategies for their mitigation. Figure 8.2 illustrates a decision hierarchy structured for selection of the best strategies to mitigate the hazards or risk factors in offshore terminals and marine ports.

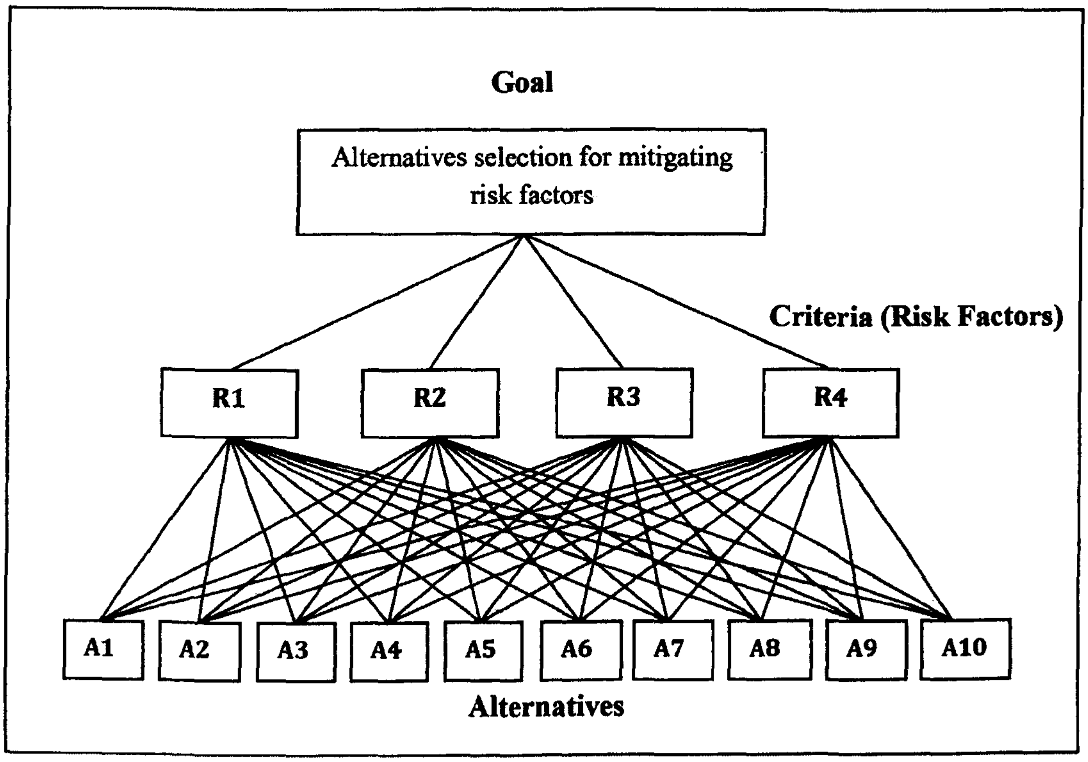


Figure 8.2: Decision making using 10 alternatives for mitigating risk factors in offshore terminals and marine ports (see Table 8.1).

8.6. IDEAL ALTERNATIVES FOR RISK MITIGATION

8.6.1. Deregulation and privatisation

To meet challenges of globalisation, ports have to increase both capacity and efficiency while reducing costs. Traditionally, ports were not only publicly owned but also politically controlled and regulated. This replaces the possibility of market failure (because the port is a monopoly and not subject to competitive disciplines) with state failure: inefficient ports, choking trade and development. To overcome these sorts of problems there are two possible remedies, deregulation or privatisation (UNCTAD, 1995; ICS, 2007 and World Bank, 2007).

Deregulation is the reduction of the role of the government in an enterprise, with market forces replacing government regulation as the regulator of acceptable industry performance (ICS, 2007).

When valuable competition can be maintained in the related markets and activities, privatisation has been demonstrated to have huge prospects for reducing costs and getting better service quality. Without competition, privatisation can still bring some improvements, but the gains are quite restricted (World Bank, 2007).

A review of the top 100 container ports in the world carried out in 1997 showed that 88 of these ports have been privatised to some degree (Juhel, 2001). The extensive carrying out of port privatisation policies in Asia, North America, Europe and Latin America is explained, respectively in Cullinane and Song (2001), Ircha (2001), Notteboom and Winkelmans (2001), Hofmann (2001) and Stache *et al*, (2002). Juhel (2001) expands on a new global perspective on port privatisation.

8.6.2. Quality standards: IMS (ISO: 9000, 14000, 18000) and ISO 20000

Economic uncertainty has forced companies to find ways to become more efficient in order to maintain their profitability and integrity. Formal performance improvement programmes such as ISO series of 9000, 14000, 18000 which as a whole are called Integrated Management Systems (IMS), and also ISO 20000 helps companies to improve their quality and operational efficiency, granting companies a competitive edge (ICS, 2007; UNCTAD, 1995; ISO, 2002; Oakland, 2002; BPM, 2010 and DNV, 2010).

One of the earlier examples of Quality Management Systems is the case of the Port of Nantes in France which is available in UNCTAD (1998) monographs on port management. In the monograph the following features of the Quality Management Systems used within the mentioned port are detailed:

- The development of quality schemes:
    - Beginning of the projects.
    - Design of the schemes.
    - Choice of activities.
    - The question of certification.
- Quality management at the agri-food terminal:
    - Treatment of incoming vessels – quality charter.
    - The quality of the agri-food terminal technical facilities.
    - Cargo handling.
- Another aspect of quality – safety at the oil terminal:
    - Use of industrial hazard analysis.
    - Production of safety recommendations.
    - Recommendations for vessels calling at the oil terminal.
    - Evaluating the benefits.

Additionally one of the latest examples for IMS implementation is the case of the Port of Felixstowe in February 2011 (Port of Felixstowe, 2011).

Based on BPM (2010) and others the following are brief descriptions for ISO series that can be used as risk mitigation options (alternatives) during ports and offshore terminals operations and managements.

8.6.2.1. ISO 9000

Quality Management ISO 9000 is rapidly becoming the most essential international standard since it ensures quality, saves money and helps ports and offshore terminals to convince customer expectations. ISO 9000 provides a quality management system for recovering and controlling the quality of services and products. It also decreases the costs linked with lesser quality management processes, making ports and terminals more competitive (BPM, 2010 and ISO, 2000).

In addition organisations such as ports and terminals for achieving world-class performance can use the framework shown in Figure 8.3 as defined by Oakland (2002). As it can be seen in his framework ISO 9000 is a key factor for analysing the processes.

Figure 8.3: The framework for total organisational excellence
Source: Based on Oakland (2002)

OCIMF (2004) explains that marine terminals should have a management system in place which is able to demonstrate and document proof of compliance with regulatory requirements and company policy and procedures. Terminal management should designate a person to be responsible for ensuring compliance with the regulations and company policy and procedures. Furthermore terminals should seek assurance that vessels visiting their berths comply with applicable international, national and local marine regulations.

8.6.2.2. ISO 14000

Environmental Management ISO 14000 ensures that offshore terminals and marine ports reduce the consequence of their activities on the environment by executing specific controls at the process stage. ISO 14000 enables ports and terminals to decrease the penalties and fines imposed when environmental laws are violated. Furthermore, the acceptance of ISO 14000 reduces waste, cutting down overhead, and ensuring the efficient use of materials (BPM, 2010).

In this respect as OCIMF (2004) explains, marine terminals should have procedures in place for the handling or control of waste and harmful emissions generated as a result of its operations. For this purpose terminals should have terminal oil/chemical spill response or contingency plans and should at regular intervals carry out oil spill response drills. For this purpose by implementing ISO 14000, it will help to meet all the required criteria.

8.6.2.3. ISO 18000

Occupational Health and Safety Management System (OHSMS) ISO 18000 can be applied by sea ports and offshore terminals as a part of their RM scheme to address changing legislation and look after their labour force. An OHSMS promotes a safe and healthy working environment by providing a framework that permits ports and terminals to constantly discover and manage their health and safety risks, reduce the probability of accidents, help legislative fulfilment and improve overall performance (BPM, 2010).

As per OCIMF (2004) marine terminals should have dynamic and broad safety programmes intended to deliver a high level of safety performance in respect of fire protection, access to the terminal, notices (warning/safety/pollution/security), life saving , first aid, occupational health and hazardous substances. In this respect ISO 18000 can meet all these challenges.

8.6.2.4. ISO 20000

Technology Management ISO 20000 is an IT governance scheme planned to regulate IT policy by adopting standard best practice procedures in IT service. ISO 20000 is rapidly becoming essential to modern business, while IT and business become more dependent on each other. By attaining fulfilment under ISO 20000, offshore terminals and marine ports can boost the efficiency for delivery of IT services by providing an expertise framework (BPM, 2010 and ISO, 20000, 2010).

8.6.3. Safety cases and safety reports

Based on Wilson *et al,* (1995) "the purpose of a safety case is to present a clear, comprehensive and defensible argument supported by calculation and procedure that a system or installation will be acceptably safe throughout its life (and decommissioning)".

In seaports, especially petrochemical ones and in offshore terminals whether in the form of floating structures such as LNG FPSOs etc or in the form of fixed structures e.g. fixed offshore terminals for loading and unloading of LNG tanker ships, the safety case and safety reports play an important role in meeting standards, certifications, for insurance purposes etc. Without conducting an appropriate safety case and safety report, if an offshore terminal continues to operate, it will be difficult for the operators to defend any claim raised against them after a potential accident or incident occurs.

8.6.4. Health, Safety and Environment Management Systems (HSE-MS)

Based on WG and BP (2011) in most countries an inclusive legal structure exists that necessitates companies to handle their own HSE matters in such a way to anticipate, avoid and restrict occupational injuries, ill health and harm to the environment. Availability of an appropriate HSE Management System (HSE-MS) with the intention of fulfilment with these requirements is necessary. It is based on the widely recognised management systems discussed earlier i.e. IMS.

HSEMS can be integrated with the management of other aspects of the business e.g. in offshore terminals and marine ports in order to:

- Minimise risk to individuals and the environment.
- Improve business performance.
- Assist ports and offshore terminals to establish a responsible image within the market place and on behalf of stakeholders.

8.6.5. Internal audits and inspections

As per APB (1995) and OCIMF (2004) the internal control system includes the control environment and control procedures. It contains all the policies and procedures (internal controls) adopted by the directors and management of an entity to help in attaining their objective of ensuring, so far as possible, the tidy and competent manner of its business, including obedience to internal policies, the protection of assets, the avoidance and identification of fraud and error, the precision and unity of the accounting records and appropriate preparation of consistent financial information.

For instance inspections of the foreign entering vessels by Port State Control (PSC) under IMO and ILO regulations are examples of internal audits/controls/inspections in sea ports and offshore terminals. This process internationally is known as ships' vetting.

8.6.6 Vessel Traffic Management Systems (VTMS)

Successful VTM is essential to the safety of sea ports, offshore terminals and waterways. The United States and other maritime countries have had complexity in establishing reasonable criteria for selecting ports requiring vessel traffic systems and for knowing the level of complexity of the VTMS required. The importance of the VTM becomes such that the US congress directed the USCG to reconsider the Vessel Traffic Service (VTS) acquirement with focus on meeting user requirements (Harrald and Merrick, 2000).

8.6.7. ISPS Code

In recent times offshore terminals and marine ports have turned into parts of critical infrastructure within the trading system. Some places categorize them as "hub Ports" that due to their size and capacity have become vital to the global supply chain (Bateman, 2003 and APEC, 2003). Current post September 11, 2001 concerns about maritime commerce relate to the impact of a terrorist incident in such a location and the disorderly result on seaborne trade. However an efficient ISPS Code regime during maritime trade will require more than just the carrying out of these systems but the recognition and response to organisational complexity at two levels: (1) at sea ports and port-related infrastructures e.g. offshore terminals or petrochemical ports and (2) within the interrelated "system of systems" that is the world maritime trading network (Barnes, 2004).

8.6.8. Port Risk Manager (PRM)

The role of the PRM is like the discussions about the role of port planners in port strategic planning. However both of these tasks should be kept firmly within management. Instead, risk managers can contribute to RM development by acting as "finders of strategies", as "analysts", and as "catalysts", in much the same way as Mintzberg (1994) planners can contribute to strategy development.

The AIRMIC propose that the corporate risk manager (the same is applicable for port risk manager) should take action as a coordinator and advisor with responsibilities such as to (Butterworth, Reddaway and Benson, 1996):

- Design an integrated RM strategy, philosophy, and policy statement for communication all through the organisation.
- Launch and preserve a detailed RM methodology suitable to the company's requirements; to contain formalised hazard identification techniques, quantitative and qualitative risk assessment and cost effective methods for risk reduction and transfer.
- Monitor the application and efficiency of RM.

8.7. APPLICATION OF THE FTOPSIS ON OFFSHORE TERMINALS AND MARINE PORTS

In Chapter 4 all of the relative weights for risk factors (i.e. criteria) in offshore terminals and marine ports by use of the FAHP method were calculated. In this Chapter ten mitigation options (i.e. alternatives) which were identified previously in Section 8.2 will be applied on offshore terminals and marine ports using the FTOPSIS method. This process is carried out to rank the alternatives as per their priorities for risk mitigation purposes as per the following steps:

Step 1: At this stage of the decision procedure, the established decision matrices are based on the evaluation sheet shown in Appendix VI. It is used for comparing ten alternatives (mitigation options) for each of the criterion (risk factor) separately. Furthermore for the fuzzy evaluation of the established matrices in order to evaluate the alternatives, linguistic variables were used. TFNs in this chapter were preferred to represent the linguistic variables as shown in Table 5.1 and Figure 5.1 (Yang and Hung, 2007) respectively.

The same experts introduced in Chapter 4 have contributed to the evaluation purposes here in this chapter. After collecting the experts' opinions through the evaluation sheet constructed, explained and depicted in Appendix VI by using Equation 6.5 the results of the evaluations while using Equation 8.1 and Equation 8.2 are calculated and illustrated in Tables 8.1, 8.2, 8.3 and 8.4. Furthermore criteria or attributes used in these tables are the Level 2 risk factors which were developed in the form of a risk-based model in Chapter 4. Moreover the relative weights calculated in Chapter 4 for the Level 2 risk factors are used in these tables to develop the fuzzy weighted decision tables in the next step.

Table 8.1: Evaluation matrix for alternatives to mitigate the country risk factors.

Alternatives	C1 (R11)	C2 (R12)	C3 (R13)	C4 (R14)	C5 (R15)
A1	(0.75, 1.00, 1.00)	(0.42, 0.67, 0.92)	(0.67, 0.92, 1.00)	(0.50, 0.75, 1.00)	(0.00, 0.08, 0.33)
A2	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)
A3	(0.00, 0.00, 0.25)	(0.00, 0.00, 0.25)	(0.17, 0.42, 0.67)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)
A4	(0.00, 0.00, 0.25)	(0.00, 0.00, 0.25)	(0.00, 0.00, 0.25)	(0.75, 1.00, 1.00)	(0.08, 0.33, 0.58)
A5	(0.00, 0.00, 0.25)	(0.00, 0.00, 0.25)	(0.00, 0.00, 0.25)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)
A6	(0.00, 0.00, 0.25)	(0.00, 0.00, 0.25)	(0.00, 0.00, 0.25)	(0.58, 0.83, 1.00)	(0.75, 1.00, 1.00)
A7	(0.00, 0.08, 0.33)	(0.00, 0.00, 0.25)	(0.00, 0.00, 0.25)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)
A8	(0.00, 0.00, 0.25)	(0.00, 0.00, 0.25)	(0.00, 0.00, 0.25)	(0.58, 0.83, 1.00)	(0.75, 1.00, 1.00)
A9	(0.00, 0.00, 0.25)	(0.08, 0.33, 0.58)	(0.00, 0.00, 0.25)	(0.25, 0.50, 0.75)	(0.75, 1.00, 1.00)
A10	(0.00, 0.00, 0.25)	(0.00, 0.00, 0.25)	(0.00, 0.00, 0.25)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)
Weight	0.312	0.061	0.052	0.204	0.371

Table 8.2: Evaluation matrix for alternatives to mitigate the business risk factors.

Alternatives	C1 (R21)	C2 (R22)	C3 (R23)
A1	(0.75, 1.00, 1.00)	(0.08, 0.33, 0.58)	(0.58, 0.83, 1.00)
A2	(0.75, 1.00, 1.00)	(0.58, 0.83, 1.00)	(0.75, 1.00, 1.00)
A3	(0.75, 1.00, 1.00)	(0.00, 0.00, 0.25)	(0.75, 1.00, 1.00)
A4	(0.00, 0.00, 0.25)	(0.00, 0.00, 0.25)	(0.00, 0.00, 0.25)
A5	(0.00, 0.00, 0.25)	(0.00, 0.00, 0.25)	(0.00, 0.00, 0.25)
A6	(0.75, 1.00, 1.00)	(0.00, 0.08, 0.33)	(0.00, 0.17, 0.42)
A7	(0.75, 1.00, 1.00)	(0.00, 0.00, 0.25)	(0.00, 0.00, 0.25)
A8	(0.75, 1.00, 1.00)	(0.00, 0.00, 0.25)	(0.67, 0.92, 1.00)
A9	(0.00, 0.00, 0.25)	(0.00, 0.00, 0.25)	(0.00, 0.00, 0.25)
A10	(0.75, 1.00, 1.00)	(0.00, 0.00, 0.25)	(0.00, 0.08, 0.33)
Weight	0.566	0.357	0.080

Table 8.3: Evaluation matrix for alternatives to mitigate the organisational risk factors.

Alternatives	C1 (R31)	C2 (R32)	C3 (R33)	C4 (R34)	C5 (R35)
A1	(0.08, 0.33, 0.58)	(0.33, 0.42, 0.67)	(0.25, 0.50, 0.75)	(0.33, 0.58, 0.83)	(0.58, 0.83, 1.00)
A2	(0.58, 0.83, 1.00)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)
A3	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)
A4	(0.00, 0.00, 0.25)	(0.00, 0.00, 0.25)	(0.00, 0.00, 0.25)	(0.00, 0.00, 0.25)	(0.00, 0.00, 0.25)
A5	(0.00, 0.00, 0.25)	(0.58, 0.83, 0.75)	(0.00, 0.25, 1.00)	(0.75, 1.00, 1.00)	(0.00, 0.00, 0.25)
A6	(0.58, 0.83, 1.00)	(0.67, 0.92, 1.00)	(0.67, 0.92, 1.00)	(0.58, 0.83, 1.00)	(0.75, 1.00, 1.00)
A7	(0.25, 0.50, 0.75)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)	(0.67, 0.92, 1.00)	(0.67, 0.92, 1.00)
A8	(0.00, 0.00, 0.25)	(0.00, 0.00, 0.25)	(0.00, 0.00, 0.25)	(0.00, 0.00, 0.25)	(0.00, 0.00, 0.25)
A9	(0.00, 0.00, 0.25)	(0.58, 0.83, 1.00)	(0.50, 0.75, 1.00)	(0.00, 0.17, 0.42)	(0.00, 0.00, 0.25)
A10	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)
Weight	**0.161**	**0.122**	**0.353**	**0.118**	**0.246**

Table 8.4: Evaluation matrix for alternatives to mitigate the operational risk factors.

Alternatives	C1 (R41)	C2 (R42)	C3 (R43)	C4 (R44)	C5 (R45)	C6 (R46)
A1	(0.00, 0.00, 0.25)	(0.00, 0.00, 0.25)	(0.00, 0.00, 0.25)	(0.00, 0.00, 0.25)	(0.00, 0.00, 0.25)	(0.00, 0.00, 0.25)
A2	(0.00, 0.00, 0.25)	(0.00, 0.00, 0.25)	(0.00, 0.00, 0.25)	(0.75, 1.00, 1.00)	(0.00, 0.00, 0.25)	(0.75, 1.00, 1.00)
A3	(0.00, 0.25, 0.50)	(0.00, 0.17, 0.42)	(0.42, 0.67, 0.92)	(0.67, 0.92, 1.00)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)
A4	(0.08, 0.33, 0.58)	(0.00, 0.25, 0.50)	(0.75, 1.00, 1.00)	(0.08, 0.33, 0.58)	(0.00, 0.17, 0.42)	(0.17, 0.42, 0.67)
A5	(0.75, 1.00, 1.00)	(0.67, 0.92, 1.00)	(0.00, 0.17, 0.42)	(0.00, 0.17, 0.42)	(0.08, 0.33, 0.58)	(0.17, 0.42, 0.67)
A6	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)	(0.08, 0.33, 0.58)	(0.00, 0.17, 0.42)	(0.75, 1.00, 1.00)	(0.67, 0.92, 1.00)
A7	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)	(0.58, 0.92, 1.00)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)
A8	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)	(0.00, 0.00, 0.25)	(0.75, 1.00, 1.00)	(0.67, 0.92, 1.00)
A9	(0.50, 0.75, 1.00)	(0.75, 1.00, 1.00)	(0.00, 0.17, 0.42)	(0.00, 0.00, 0.25)	(0.00, 0.08, 0.33)	(0.00, 0.08, 0.33)
A10	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)
Weight	**0.186**	**0.297**	**0.178**	**0.007**	**0.243**	**0.089**

Step 2: After the fuzzy evaluation matrix was determined, the next step is to obtain a fuzzy weighted decision table. Using the criteria weights calculated by FAHP in Chapter 4 through this step, the weighted evaluation matrices are established using Equation 8.3 and Equation 8.4.

Step 3: The resulting fuzzy weighted decision matrices are shown in Tables 8.5, 8.6, 8.7 and 8.8.

Table 8.5: Weighted evaluation for the alternatives to mitigate the country risk factors.

Alternatives	C1 (R11)	C2 (R12)	C3 (R13)	C4 (R14)	C5 (R15)
A1	(0.234, 0.312, 0.312)	(0.026, 0.041, 0.056)	(0.035, 0.048, 0.052)	(0.102, 0.153, 0.204)	(0.000, 0.030, 0.122)
A2	(0.234, 0.312, 0.312)	(0.046, 0.061, 0.061)	(0.039, 0.052, 0.052)	(0.153, 0.204, 0.204)	(0.278, 0.371, 0.371)
A3	(0.000, 0.000, 0.078)	(0.000, 0.000, 0.015)	(0.009, 0.022, 0.035)	(0.153, 0.204, 0.204)	(0.278, 0.371, 0.371)
A4	(0.000, 0.000, 0.078)	(0.000, 0.000, 0.015)	(0.000, 0.000, 0.013)	(0.153, 0.204, 0.204)	(0.030, 0.122, 0.215)
A5	(0.000, 0.000, 0.078)	(0.000, 0.000, 0.015)	(0.000, 0.000, 0.013)	(0.153, 0.204, 0.204)	(0.278, 0.371, 0.371)
A6	(0.000, 0.000, 0.078)	(0.000, 0.000, 0.015)	(0.000, 0.000, 0.013)	(0.118, 0.169, 0.204)	(0.278, 0.371, 0.371)
A7	(0.000, 0.025, 0.103)	(0.000, 0.000, 0.015)	(0.000, 0.000, 0.013)	(0.153, 0.204, 0.204)	(0.278, 0.371, 0.371)
A8	(0.000, 0.000, 0.078)	(0.000, 0.000, 0.015)	(0.000, 0.000, 0.013)	(0.118, 0.169, 0.204)	(0.278, 0.371, 0.371)
A9	(0.000, 0.000, 0.078)	(0.005, 0.020, 0.035)	(0.000, 0.000, 0.013)	(0.051, 0.102, 0.153)	(0.278, 0.371, 0.371)
A10	(0.000, 0.000, 0.078)	(0.000, 0.000, 0.015)	(0.000, 0.000, 0.013)	(0.153, 0.204, 0.204)	(0.278, 0.371, 0.371)
A^*	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)
A^-	(0.000, 0.000, 0.000)	(0.000, 0.000, 0.000)	(0.000, 0.000, 0.000)	(0.000, 0.000, 0.000)	(0.000, 0.000, 0.000)

Table 8.6: Weighted evaluation for the alternatives to mitigate the business risk factors.

Alternatives	C1 (R21)	C2 (R22)	C3 (R23)
A1	(0.424, 0.566, 0.566)	(0.029, 0.118, 0.207)	(0.046, 0.066, 0.080)
A2	(0.424, 0.566, 0.566)	(0.207, 0.296, 0.257)	(0.060, 0.080, 0.080)
A3	(0.424, 0.566, 0.566)	(0.000, 0.000, 0.089)	(0.060, 0.080, 0.080)
A4	(0.000, 0.000, 0.141)	(0.000, 0.000, 0.089)	(0.000, 0.000, 0.020)
A5	(0.000, 0.000, 0.141)	(0.000, 0.000, 0.089)	(0.000, 0.000, 0.020)
A6	(0.424, 0.566, 0.566)	(0.000, 0.029, 0.118)	(0.000, 0.014, 0.034)
A7	(0.424, 0.566, 0.566)	(0.000, 0.000, 0.089)	(0.000, 0.000, 0.020)
A8	(0.424, 0.566, 0.566)	(0.000, 0.000, 0.089)	(0.054, 0.074, 0.080)
A9	(0.000, 0.000, 0.141)	(0.000, 0.000, 0.089)	(0.000, 0.000, 0.020)
A10	(0.424, 0.566, 0.566)	(0.000, 0.000, 0.089)	(0.000, 0.006, 0.026)
A^*	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)
A^-	(0.000, 0.000, 0.000)	(0.000, 0.000, 0.000)	(0.000, 0.000, 0.000)

Table 8.7: Weighted evaluation for the alternatives to mitigate the organisational risk factors.

Alternatives	C1 (R31)	C2 (R32)	C3 (R33)	C4 (R34)	C5 (R35)
A1	(0.001, 0.053, 0.093)	(0.040, 0.051, 0.082)	(0.088, 0.176, 0.265)	(0.039, 0.068, 0.098)	(0.143, 0.204, 0.246)
A2	(0.093, 0.134, 0.161)	(0.091, 0.122, 0.122)	(0.265, 0.353, 0.353)	(0.088, 0.118, 0.118)	(0.184, 0.246, 0.246)
A3	(0.121, 0.161, 0.161)	(0.091, 0.122, 0.122)	(0.265, 0.353, 0.353)	(0.088, 0.118, 0.118)	(0.184, 0.246, 0.246)
A4	(0.000, 0.000, 0.040)	(0.000, 0.000, 0.030)	(0.000, 0.000, 0.088)	(0.000, 0.000, 0.029)	(0.000, 0.000, 0.061)
A5	(0.000, 0.000, 0.040)	(0.071, 0.101, 0.122)	(0.000, 0.088, 0.353)	(0.088, 0.118, 0.118)	(0.000, 0.000, 0.061)
A6	(0.093, 0.134, 0.161)	(0.082, 0.112, 0.122)	(0.236, 0.325, 0.353)	(0.068, 0.098, 0.118)	(0.184, 0.246, 0.246)
A7	(0.040, 0.080, 0.121)	(0.091, 0.122, 0.122)	(0.265, 0.353, 0.353)	(0.079, 0.109, 0.118)	(0.165, 0.226, 0.246)
A8	(0.000, 0.000, 0.040)	(0.000, 0.000, 0.030)	(0.000, 0.000, 0.088)	(0.000, 0.000, 0.029)	(0.000, 0.000, 0.061)
A9	(0.000, 0.000, 0.040)	(0.071, 0.101, 0.122)	(0.176, 0.265, 0.353)	(0.000, 0.020, 0.050)	(0.000, 0.000, 0.061)
A10	(0.121, 0.161, 0.161)	(0.091, 0.122, 0.122)	(0.265, 0.353, 0.353)	(0.088, 0.118, 0.118)	(0.184, 0.246, 0.246)
A^*	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)
A^-	(0.000, 0.000, 0.000)	(0.000, 0.000, 0.000)	(0.000, 0.000, 0.000)	(0.000, 0.000, 0.000)	(0.000, 0.000, 0.000)

Table 8.8: Weighted evaluation for the alternatives to mitigate the operational risk factors.

Alternatives	C1 (R41)	C2 (R42)	C3 (R43)	C4 (R44)	C5 (R45)	C6 (R46)
A1	(0.000, 0.000, 0.009)	(0.000, 0.000, 0.074)	(0.000, 0.000, 0.044)	(0.000, 0.000, 0.002)	(0.000, 0.000, 0.061)	(0.000, 0.000, 0.006)
A2	(0.000, 0.000, 0.009)	(0.000, 0.000, 0.074)	(0.000, 0.000, 0.044)	(0.005, 0.007, 0.007)	(0.000, 0.000, 0.061)	(0.067, 0.089, 0.089)
A3	(0.000, 0.009, 0.017)	(0.000, 0.050, 0.125)	(0.075, 0.119, 0.164)	(0.005, 0.006, 0.007)	(0.182, 0.243, 0.243)	(0.067, 0.089, 0.089)
A4	(0.001, 0.061, 0.108)	(0.000, 0.074, 0.148)	(0.133, 0.178, 0.178)	(0.001, 0.002, 0.004)	(0.000, 0.041, 0.102)	(0.015, 0.037, 0.060)
A5	(0.139, 0.186, 0.186)	(0.199, 0.273, 0.297)	(0.000, 0.030, 0.075)	(0.000, 0.001, 0.003)	(0.019, 0.080, 0.141)	(0.015, 0.037, 0.060)
A6	(0.139, 0.186, 0.186)	(0.223, 0.297, 0.297)	(0.014, 0.059, 0.103)	(0.000, 0.001, 0.003)	(0.182, 0.243, 0.243)	(0.060, 0.082, 0.089)
A7	(0.139, 0.186, 0.186)	(0.223, 0.297, 0.297)	(0.133, 0.178, 0.178)	(0.004, 0.006, 0.007)	(0.182, 0.243, 0.243)	(0.067, 0.089, 0.089)
A8	(0.139, 0.186, 0.186)	(0.223, 0.297, 0.297)	(0.133, 0.178, 0.178)	(0.000, 0.000, 0.002)	(0.182, 0.243, 0.243)	(0.060, 0.082, 0.089)
A9	(0.093, 0.139, 0.186)	(0.223, 0.297, 0.297)	(0.000, 0.030, 0.075)	(0.000, 0.000, 0.002)	(0.000, 0.019, 0.080)	(0.000, 0.007, 0.029)
A10	(0.139, 0.186, 0.186)	(0.223, 0.297, 0.297)	(0.133, 0.178, 0.178)	(0.005, 0.007, 0.007)	(0.182, 0.243, 0.243)	(0.067, 0.089, 0.089)
A^*	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)
A^-	(0.000, 0.000, 0.000)	(0.000, 0.000, 0.000)	(0.000, 0.000, 0.000)	(0.000, 0.000, 0.000)	(0.000, 0.000, 0.000)	(0.000, 0.000, 0.000)

As it was explained before the fuzzy positive ideal solution and the negative ideal solution for the ten alternatives (mitigation options) were considered as $\tilde{V}_1^*$= (1, 1, 1) and $\tilde{V}_1^-$= (0, 0, 0) respectively.

Step 4: For the fourth step, the distance of each alternative from d_i^* and d_i^- can be calculated using Equation 8.7 and Equation 8.8. In order to illustrate the calculations used in Step 3 by using the definition 4.2 and the Equation 8.10 the following example derived from Table 8.5 for the alternative A1 is used.

As previously was shown in Figure 4.9 let $\widetilde{M}_1 = (l_1, m_1, u_1)$ and $\widetilde{M}_2 = (l_2, m_2, u_2)$ be two TFNs, then the vertex method can be defined to calculate the distance between them, as follows (Yang and Hung, 2007):

$$d(\widetilde{M}_1, \widetilde{M}_2) = \sqrt{\frac{1}{3}\left[(l_1 - l_2)^2 + (m_1 - m_2)^2 + (u_1 - u_2)^2\right]} \qquad (8.10)$$

$$\begin{aligned} d_i^* = &\sqrt{\frac{1}{3}\left[(1-0.234)^2 + (1-0.312)^2 + (1-0.312)^2\right]} \\ &+\sqrt{\frac{1}{3}\left[(1-0.026)^2 + (1-0.041)^2 + (1-0.056)^2\right]} \\ &+\sqrt{\frac{1}{3}\left[(1-0.035)^2 + (1-0.048)^2 + (1-0.052)^2\right]} \\ &+\sqrt{\frac{1}{3}\left[(1-0.102)^2 + (1-0.153)^2 + (1-0.204)^2\right]} \\ &+\sqrt{\frac{1}{3}\left[(1-0.000)^2 + (1-0.030)^2 + (1-0.122)^2\right]} = 4.428 \end{aligned}$$

$$\begin{aligned} d_i^- = &\sqrt{\frac{1}{3}\left[(0-0.234)^2 + (0-0.312)^2 + (0-0.312)^2\right]} \\ &+\sqrt{\frac{1}{3}\left[(0-0.026)^2 + (0-0.041)^2 + (0-0.056)^2\right]} \\ &+\sqrt{\frac{1}{3}\left[(0-0.035)^2 + (0-0.048)^2 + (0-0.052)^2\right]} \\ &+\sqrt{\frac{1}{3}\left[(0-0.102)^2 + (0-0.153)^2 + (0-0.204)^2\right]} \\ &+\sqrt{\frac{1}{3}\left[(0-0.000)^2 + (0-0.030)^2 + (0-0.122)^2\right]} = 0.608 \end{aligned}$$

Step 5: This step solves the similarities to an ideal solution by the use of Equation 8.9 as follows:

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-} = \frac{0.608}{4.428+0.608} = 0.1207$$

Similar calculations are done for the other alternatives and the results of fuzzy TOPSIS analysis for country, business, organisational and operational risk factors are summarised in Tables 8.9, 8.10, 8.11 and 8.12.

Step 6: Based on the CC_i values, rankings for mitigation alternatives for different criteria i.e. R1, R2, R3 and R4 can be depicted separately in Tables 8.9, 8.10, 8.11 and 8.12.

Table 8.9: Fuzzy TOPSIS results for mitigating country risk factors.

Alternatives	D_i^*	D_i^-	CC_i	Rankings
A1	4.428	0.608	0.1207	3
A2	4.085	0.923	0.1843	1
A3	4.422	0.609	0.1210	2
A4	4.660	0.393	0.0778	8
A5	4.440	0.592	0.1176	5
A6	4.464	0.571	0.1134	6
A7	4.477	0.608	0.1196	4
A8	4.464	0.571	0.1134	6
A9	4.511	0.528	0.1048	7
A10	4.440	0.592	0.1176	5

Table 8.10: Fuzzy TOPSIS results for mitigating business risk factors.

Alternatives	D_i^*	D_i^-	CC_i	Rankings
A1	2.307	0.726	0.2394	2
A2	2.160	0.853	0.2831	1
A3	2.384	0.648	0.2137	3
A4	2.919	0.143	0.0467	8
A5	2.919	0.143	0.0467	8
A6	2.422	0.614	0.2022	5
A7	2.450	0.585	0.1927	7
A8	2.388	0.644	0.2124	4
A9	2.919	0.143	0.0467	8
A10	2.446	0.589	0.1941	6

Table 8.11: Fuzzy TOPSIS results for mitigating organisational risk factors.

Alternatives	D_i^*	D_i^-	CC_i	Rankings
A1	4.459	0.587	0.1163	6
A2	4.104	0.907	0.1810	3
A3	4.128	0.924	0.1829	2
A4	4.919	0.143	0.0282	9
A5	4.627	0.477	0.0934	7
A6	4.146	0.868	0.1731	4
A7	4.181	0.844	0.1680	5
A8	4.919	0.143	0.0282	9
A9	4.585	0.463	0.0917	8
A10	4.085	0.924	0.1845	1

Table 8.12: Fuzzy TOPSIS results for mitigating operational risk factors.

Alternatives	D_i^*	D_i^-	CC_i	Rankings
A1	5.936	0.112	0.0185	9
A2	5.851	0.196	0.0324	8
A3	5.505	0.527	0.0874	6
A4	5.623	0.439	0.0724	7
A5	5.423	0.617	0.1021	4
A6	5.200	0.820	0.1362	3
A7	5.085	0.923	0.1536	1
A8	5.095	0.914	0.1521	2
A9	5.510	0.513	0.0879	5
A10	5.085	0.923	0.1536	1

8.8. FINAL RESULTS

Based on the CC_i values shown in Tables 8.9, 8.10, 8.11 and 8.12 separately and as it was mentioned in Chapter 4 that the risk factors R1, R2, R3 and R4 had equal weights in respect of each other, in order to calculate the final CC_i values it is necessary to sum up the $CC_i s$ and then divide them by four to get the final CC_i values as shown in Table 8.13 which also illustrates the final rankings of the alternatives.

Table 8.13: Overall Fuzzy TOPSIS results for mitigating risk factors.

Alternatives	Names	CC_i	Rankings
A1	Internal Audits and Inspections	0.1237	7
A2	Privatisation	0.1702	1
A3	ISPS Code	0.1512	5
A4	ISO 20000	0.0563	10
A5	Port Risk Manager	0.0899	8
A6	Safety Cases and Safety Reports	0.1562	4
A7	IMS (ISO: 9000,14000,18000)	0.1585	3
A8	VTMS	0.1265	6
A9	Deregulation	0.0828	9
A10	HSE-MS	0.1624	2

Additionally Figure 8.4 depicts the results for different criteria i.e. R1 (Country risk factors), R2 (Business risk factors), R3 (Organisational risk factors) and R4 (Operational risk factors) and the sensitivity of the results on different mitigation alternatives for the purpose of managing the mentioned risk factors in offshore terminals and marine ports.

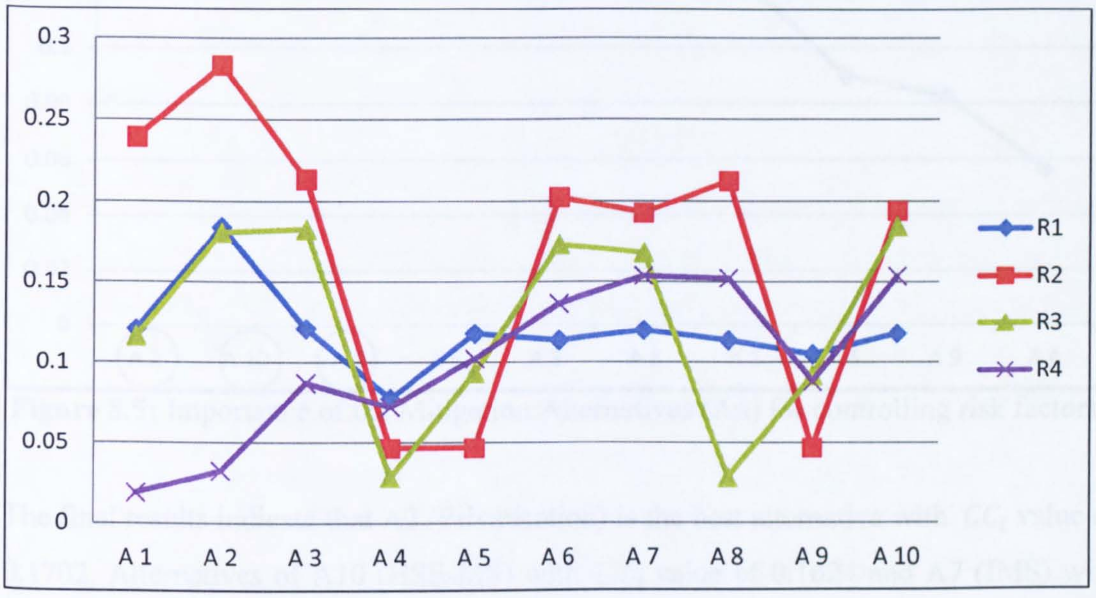


Figure 8.4: Sensitivity of the results on different mitigation alternatives.

8.9. RESULTS AND DISCUSSIONS

In this chapter the FTOPSIS technique was used. It is an appropriate tool to help MADM under a fuzzy environment where the available data is subjective and vague. The FTOPSIS allows decision makers to include and aggregate subjective judgments. The basic principle of the TOPSIS technique is that the selected mitigation factor should have the farthest distance from the negative ideal solution and shortest distance from the positive ideal solution. The proposed FTOPSIS technique can be used as an optional technique for cost/benefit estimations in conditions where together qualitative and quantitative information must be combined. By using the method proposed and presented in this chapter, offshore terminal and port managers can select the ideal solutions or alternatives (i.e. mitigation factors) based on their requirements while considering the factors such as benefits and costs.

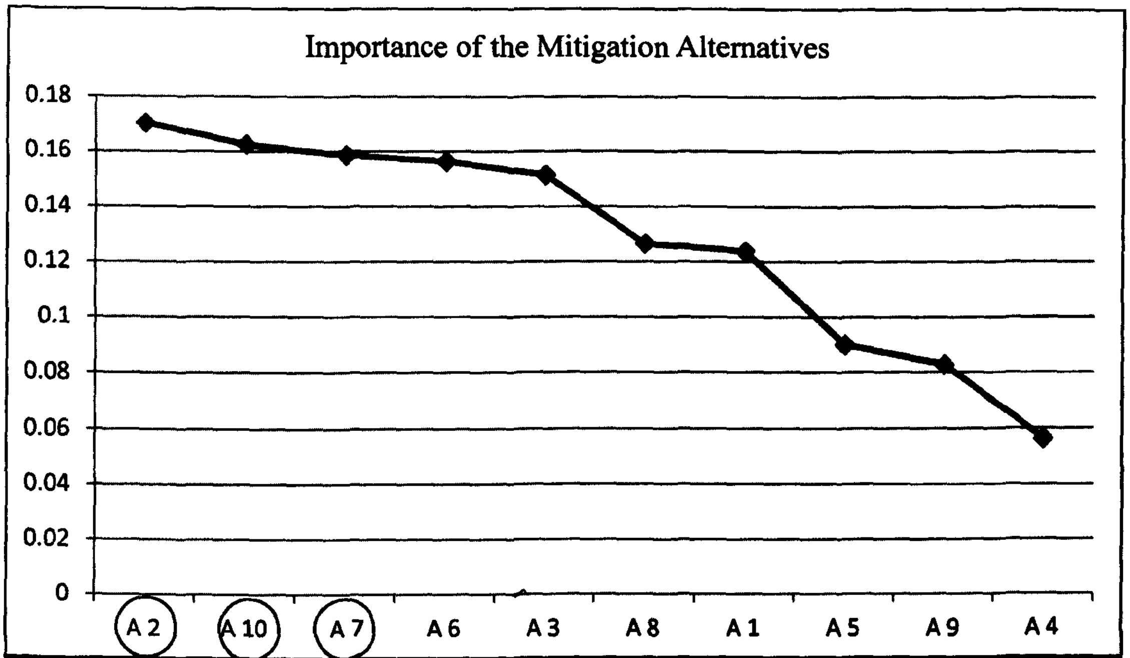


Figure 8.5: Importance of the Mitigation Alternatives (An) for controlling risk factors.

The final results indicate that A2 (Privatisation) is the best alternative with CC_i value of 0.1702. Alternatives of A10 (HSE-MS) with □C_i value of 0.1624 and A7 (IMS) with CC_i value of 0.1585 are ranked in second and third positions respectively. Furthermore in order to justify and analyse the above mentioned results the following comments from different sources should be taken into account. Figure 8.5 depicts the most significance mitigation alternatives for the purpose of offshore terminals and marine ports in an illustrative manner.

Regarding A2 i.e. privatisation and in order to provide evidence for its importance World Bank (2007) explains motives that force without delay governments or port/offshore authorities to enter in the privatization course of action. The Port of Cartagena in Colombia and Port of Buenos Aires in Argentina are some of the examples mentioned by the World Bank (2007) that privatization led ports to improve their performance, become more competitive and better managed. This in fact can reduce business, operational and organizational risk factors. Other examples for privatisation are the cases of ports in United Kingdom, Ports in New Zealand and Ports in Morocco which are explained in detail by UNCTAD (1995) as to how these ports are reformed and improved as a result of privatisation.

In another effort ICS (2007) expresses that in a private port everything is owned and operated by the private sector, apart from regulatory and statutory functions which are performed by the public authority. In private ports managements are less influenced by political decisions and there will be higher efficiency in asset and human resources management.

In respect of the HSE-MS (i.e. A10) as it was explained in Chapter 4 e.g. for the case of the explosion of an offshore terminal (i.e. Platform of ONGC at Bombay High which happened in July 2005), the root cause of the suffered loss was due to the danger from ineffective HSE controls and management systems and what barriers were missing can be listed as follows (OLI, 2011):

- Design: Unprotected marine risers close to boat landing.
- Operational: Failure to assess risk of routine activities in abnormal conditions.
- Cultural: Investigation "poked glaring holes at the 'safety culture' within ONGC, and criticised India's most valuable company on every safety aspect."

Therefore in offshore terminals and marine ports, industrial users should:

- Rebuild an appropriate HSE-MS based on a variety of the identified risk factors.
- Create a policy/process/procedure/work instruction for managing the related risk factors.
- Plan techniques to ease the execution of a detailed HSE-MS.

Based on Oil and Gas UK (2011) several projects were undertaken by DNV on behalf of the UK HSE with the purpose of obtaining accident statistics for offshore fixed and floating units on the UK Continental Shelf (UKCS). In this respect, four databases holding information about incidents having occurred on offshore units on the UKCS were interrogated. Additionally the main objective of the project was to obtain complete statistics for accidents and incidents having occurred on offshore fixed and floating units engaged in the oil and gas exploration and exploitation on the UKCS in the period 1990-2007. Data for each accident type (explosion, fire, blowout, helicopter, list, spill etc) were illustrated and compared for durations 1990-1999 and 2000-2007. Many of the accidents, with some exceptions, were reduced as a result of effective HSE controls and management systems which were put in place.

Regarding application of the IMS (i.e. A7) in offshore terminals and marine ports, it will provide port and terminal operators, contractors and authorities an extensive stance and understanding of port operations essential to operate economically, eliminating the number of overlapping processes across their operations. Based on BPM (2010) the programmes i.e. IMS will facilitate to cut costs, maximize potentials, and clear the way for ports'/terminals' developments. Examples of this e.g. the Port of Felixstowe in UK and the Port of Nantes in France are explained and referenced in Section 8.3.2.

The latest proposed form of RM related ISO which at the end of the year 2009 was introduced, is ISO 31000. It is anticipated to be a family of standards relating to RM classified by the ISO. The purpose of ISO 31000 is to provide principles and generic guidelines on RM. It seeks to provide a universally known model for specialists and companies employing RM processes to change many of the existing standards, methodologies and paradigms that differed between industries. However still it is not tested in offshore terminals and marine ports (ISO 31000, 2011).

8.10. CONCLUSIONS

In this chapter in order to mitigate the identified hazards (risk factors) through the HAZID process, the FTOPSIS method was utilised in order to complete the RM framework for the purpose of offshore terminals and marine ports.

In the first part of this chapter different mitigation strategies or control options were identified through the existing literature.

In the second part in order to apply the recognised risk mitigation options the FTOPSIS technique was introduced to complete the last phase of the RM framework.

In the third part the alternatives (i.e. mitigation strategies) were ranked as per their priorities for mitigation or controlling the risk factors in offshore terminals and marine ports.

The contributions made on this thesis and the areas of future work for the purpose of appropriate RM in offshore terminals and marine ports will be discussed in the next chapter.

CHAPTER 9: CONCLUSIONS AND SUGGESTIONS

9.1. INTRODUCTION

RM framework and risk-based model for managing hazards and risk factors in the offshore and marine industries have been developed in this research and the validity of the proposed risk-based model in the field carried out. It is now appropriate to reflect the outcome of the study detailed in previous chapters in the form of following sections.

9.2. CONCLUSIONS

Offshore terminals and marine ports are essential elements for the operation of every country's economy that can affect their cost structures, industrial competitiveness and living standards. Moreover as discussed earlier hazards or risk factors exist in these logistics infrastructures, all of which require attention in respect of their identification, assessment and mitigation with the use of an appropriate RM approach, if offshore terminals and marine ports are going to remain responsive to the strategic needs and future challenges.

As a result in this research by using the HAZID process with an appropriate literature review, it was possible to identify major externally and internally driven risk factors (i.e. Country, business, organisational and operational risk factors) associated with offshore terminals and marine ports. Hazard identification was carried out using the documents and references from the different offshore, marine and logistics related sources (see Chapter 2).

In order to cope with the identified risk factors a generic RM framework was developed and an appropriate research methodology was defined. The proposed research methodology was used to analyse and handle each phase of the defined RM framework (see Chapter 3).

In the next phase of research a FAHP method based on Chang's extent analysis along with experts' judgments was used to assess a developed risk-based hierarchy model to determine the relative weights of the identified risk factors presented in different levels of the risk-based model. Eventually after determining the global weights of the risk factors they were ranked according to their priority. For this reason FAHP as a decision making tool was found to be a useful method for assessing the complex multi criteria alternatives involving subjective and uncertain judgments. Additionally during risk-based modelling, the FAHP method was found to be a useful analytical tool for finding the relative weights of the risk factors. In this regard the illustrated calculations for this method have shown the flexibility and effectiveness of the proposed risk assessment methodology to directly tap the subjectivity and preferences of the decision makers (see Chapter 4).

The proposed generic risk-based model illustrating the identified risk factors and their global weights could be applied to any specific offshore terminal or marine port during the course of their audits, port-to-port or terminal-to-terminal risk evaluation periods. As a result this can help the ports' and terminals' managers and professionals, to take corrective and preventive actions at early stages to overcome various problems, the problems which are always sources of delays and costs to the parties involved. For this reason in the subsequent phase, in order to evaluate the actual risk factors in any port for real situations by use of the developed generic risk-based model, another risk measurement process was carried out. This new risk-based measurement was carried out in order to calculate the levels of the present risk factors within the selected or any specific port/offshore terminals. The results of these evaluations were aggregated with the predetermined global weights of risk factors calculated for the generic risk-based model. The purpose of this aggregation was to update all the related risk factors within the selected sites, e.g. offshore terminals or marine ports (i.e. combination of the global weights calculated for the developed generic risk-based model with the newly evaluated risk levels for the nominated port). As a result in order to evaluate the new levels of the risk factors for the selected ports, FST and experts' judgements along with the ER approach were utilised. The ER in this research was found to be a useful decision support tool that could deal with fuzziness in data for aggregation and updating the gathered data. The ER based aggregation in this research was carried out using the IDS software in order to update data (see Chapter 5).

As every risk factor is caused by some basic event or events and results in some effect or effects, it can be viewed rather like a chain. The cause is linked to the nature of the risk factor and the risk factor itself is linked to the effect. With the use of this view in the next phase of the research in order to analyse the most significant risk factors or hazards identified, CCA under fuzzy environments was used. There are many other risk analysis methods such as What-if analysis, Preliminary Hazard Analysis (PHA), Hazard and Operability Study (HAZOP) and Failure Modes and Effects Analysis (FMEA). In this research CCA was found to be a useful one. For example in this regard, the PHA method is mostly used for offshore terminals and marine ports (specifically during their design stages). However this research was only investigating the hazards during their operations and management which is unrelated to the design agenda. Furthermore What-if analysis, PHA, HAZOP and FMEA are only qualitative methods and not the quantitative tools. This research has used both quantitative and qualitative analysis within offshore terminals and marine ports. The bow-tie model using the fault tree and event tree analysis was found to be a suitable tool for managing both quantitative and qualitative data and also integrating broad classes of cause–consequence analysis. In other words the familiar fault tree and event tree models were 'bow-tied' in this way and indeed attaching the fault tree's "top event" with the event tree's "initiating event". As FTA and ETA were both quantitative and qualitative methods, by using the experts' judgements these methods were incorporated to complete the CCA phase of the research. In this way the most significant hazards and risk factors evidenced in the offshore terminals and marine ports were interpreted more specifically while using the FTA and ETA under fuzzy environments (see Chapter 6).

In the next phase of the thesis a separate and individual RM strategy was tailored and implemented on the furthermost significant risk factor to show the capability of the RM that can take into custody any of the identified risk factors separately. For this purpose by using STA, SVA, threat matrix, SRFT etc techniques, the most significant risk factor identified in this research was individually handled (see Chapter 7).

In the last phase of the research and in order to mitigate the identified hazards or risk factors by using an appropriate MCDM tool and to complete the RM framework it was decided to use a TOPSIS method under fuzzy environments. After a set of alternatives was compared against a set of criteria the best alternatives (i.e. identified mitigation strategies) were ranked in ascending orders. The most suitable mitigation strategies were selected. The mitigation factors can be used in a form of a single package (e.g. Integrated Management System) in order to become more effective. Some of these mitigating factors have been used previously by DNV, Lloyds Register and different insurance companies as a part of their IMS packages for mitigating the identified risk factors in different industries such as offshore and port sectors (see Chapter 8).

9.3. CONTRIBUTION TO KNOWLEDGE

The main contribution of the research was the creation of a generic RM framework and a generic risk-based model, to guide the industrial RM professionals such as port/terminal risk managers, auditors etc through a series of well-defined structured phases and steps necessary to make knowledgeable, reliable and efficient changes to their business processes in offshore and marine industry. It is a holistic framework with relevant tools and techniques, enabling the offshore and port industrial RM professionals to facilitate the process-based change effectively at any point. The implemented framework provides a logical and organised procedure. It has been shown that the benefits can be gained from using the defined RM framework. Moreover management research is the systematic and objective process of gathering, recording and analysing data for improving managerial decision-making. The discussion of the results in the light of the theory and practice has enabled determination of the implications of the research to the body of knowledge.

The research has thus established important findings and suggestions on RM that will be valuable to the decision-making process in the offshore and marine industry. The most important contribution was to establish the framework comprising the process, techniques and tools for structuring, assessing, analysing and managing risk factors that affect offshore terminals and marine ports. The proposed RM framework provides a platform to facilitate a generic risk-based model. The proposed risk assessment methodology is in fact an objective way to handle subjective information in establishing a risk analysis to guide the development of risk control measures. This can help the offshore terminal and marine port managers and professionals, e.g. HSE or risk managers, to take corrective and preventive actions at early stages to overcome various problems which are always sources of problems to the parties involved.

The main managerial implication of the research is to help HSE and risk managers in offshore and marine industry to design and establish an integrated RM strategy, philosophy and policy statement for communication throughout their sites and facilities. The proposed RM framework and risk-based model will facilitate HSE and risk managers to establish and maintain a detailed RM methodology. It includes formalised hazard identification techniques, quantitative and qualitative risk assessment and cost effective methods with the aim of elimination, reduction and controlling of the prospective risk factors and hazards in offshore and marine industry.

9.4. SUGGESTIONS FOR FURTHER RESEARCH

The research has achieved its aim of developing a RM framework for managing risk factors affecting offshore terminals and marine ports. Although it is not claimed to be a definitive framework it can play a valuable role as a methodology for addressing risk factors. Several important issues were raised both at the beginning and throughout the research process. Some of these have been analysed, described, and incorporated into the study. Others, however, could not be incorporated due to scope, time constraints and because the research has prominently been exploratory and experimental. The aspects that were not covered in detail are part of suggestions for further work that should be pursued. In this respect additional research seems therefore to be needed on the following aspects:

The proposed risk-based model could be extended to incorporate other categories of risk factors such as natural disasters, etc that were not included in the present study. Furthermore, in extending the RM framework it would be desirable to consider the main phases of RM in offshore terminals and marine ports namely hazard identification, risk assessment, risk mitigation and risk review. Such a structure would be useful to main players in offshore and marine industry including managers, clients, operators, contractors, insurers and regulators. Furthermore, it would be important to investigate RM practices from their perspective.

In offshore and marine industry in conditions where the nature of data is vague and subjective, many of judgements and estimations require to be involved subjectively during data analysis. Other than the ER approach used in this research, it would also be useful to develop new approaches such as a Bayesian Network capable of dealing with uncertainty and combining expert judgement with empirical or historical data to evaluate hazards and risk factors.

The difficulty associated with generating membership functions has been considered a major drawback in developing fuzzy based methodologies. The development and experiments of membership functions using different methods such as Artificial Neural Networks and Genetic Algorithms should be encouraged. These optimisation technologies seem to be effective in generating much more reliable membership functions with optimal value than casual methods and would help in firming up a family of these functions.

The offshore and marine industry, by taking into account a strategic management approach, is advancing toward a risk-based regulatory scheme. This gives risk and QHSES managers more flexibility to use innovative and the most recent risk-based models, RM frameworks and MCDM tools. The FAHP, ER, SVA, CCA and FTOPSIS methods used in this research may be some of these useful approaches. It may be helpful if these tools utilised in this study could be additionally implemented to facilitate other risk-based modelling and MADM occasions. Therefore, the practical application of the mentioned tools to offshore and marine industry can be highlighted. Furthermore, since the proposed RM framework and risk-based model in this research are generic, such a framework and model can be further incorporated for the risk-based topics outside the offshore and marine industry. In fact this can support and contribute towards the advertising of their applications in other industry related sectors.

The RM framework developed in this PhD can be integrated (or embedded) into all of the functions and processes within the different industry users while taking strategic management approaches to RM development, thus improving risk-based decision making.

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APPENDIX I

Questionnaire used in Survey 1 for the purpose of Chapter 4

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Dear Sir,

Offshore terminals and marine ports play an important role in world trade, international logistics and global supply chain management. Their operations are associated with a high level of uncertainty because they operate in a dynamic environment in which hazards may cause possible accidents.

A research project at Liverpool John Moores University is currently being carried out with regard to a generic risk assessment model which is based on a risk management framework to identify the critical hazards that can lead to catastrophic damages to offshore terminals and marine ports. Therefore the proposed model will be used to determine the relative weights of the risk factors identified during the offshore terminals' and marine ports' operations and management. Now the requirement for this investigation is to use experts' judgements who are working in the related fields to compare the provided risk factors in order to enable researcher to prioritise the risk factors and to detect the most significance ones. Eventually this can help port professionals and port risk managers to develop appropriate strategies and take preventive/corrective actions for mitigating risks toward a successful offshore terminals' and marine ports' operations and management.

Thus this survey sets out to provide an organized method for collecting views and information pertaining to the implementation of an appropriate risk management framework in offshore terminals and marine ports. I should be most grateful if I could ask you to spare some of your very valuable time to complete the accompanying questionnaire and to email or post it to myself at the address as shown above. Your vital feedback will greatly benefit and contribute in the formulation of an industry wide opinion. I can assure you that the confidentiality of your response will be honoured and respected.

Best Regards
Captain Kambiz Mokhtari
PhD Student
MSc, BSc, Master Mariner, MICS

SECTION 1: PERSONAL DETAILS

- Please mark the appropriate answer for each question:

1. Please mark your age range:

   A. Less than 30 years old

   B. Between 30 and 40 years old

   C. 40 years old or more

2. Please mark your appropriate qualification:

   A. Postgraduate

   B. Undergraduate

   C. High School Diploma

3. Please mark your work experiences:

   A. Work experience < 10

   B. 10 ≤ Work experience ≤ 20

   C. 20 < Work experience

SECTION 2: MEASUREMENT SCALES

Please select one of the linguistic values including intermediate values and equal value from the following table that in your opinion is the most appropriate one and use it during pair-wise comparisons in the next section for marking the provided matrix.

Table I.1: Linguistic Values and TFNs.

Linguistic Values	TFNs
Weak Strong	N_1= (1, 1, 2)
Fairly Strong	N_3= (2, 3, 4)
Highly Strong	N_5= (4, 5, 6)
Very Highly Strong	N_7= (6, 7, 8)
Absolute	N_9= (8, 9, 9)
Intermediate values N_2= (1, 2, 3) N_4= (3, 4, 5) N_6= (5, 6, 7) N_8= (7, 8, 9)	
Equal value = (1,1,1)	

SECTION 3: EXPLANATIONS AND EXAMPLES

Read the followings and put check marks on the below shown pair-wise comparison matrix. If a risk factor on the left is more important than the matching risk factor on the right, put your check mark to the left of the importance ''Equal'' under the importance level you prefer. If any one of risk factors on the left is less important than its' matching risk factors on the right, put your check mark to the right of the importance 'Equal' under the importance level you prefer. Now with respect to the risk factors associated with offshore terminals' and marine ports' operations and management which are depicted in following matrix first read the below examples and then start marking the following matrix:

Question 1: How important is "Country Risks" when it is compared with "Business Risks" during of the offshore terminals' and sea ports' operations and management?

Question 2: How important is "Operational Risks" when it is compared with "Organisational Risks" during of the offshore terminals' and sea ports' operations and management?

SECTION 4: RISK MATRIX SAMPLE

Table I.2: Risk matrix

Risk Factors			Importance of one risk factor over another																	
Main risk factors in offshore terminals and marine ports	Absolute (8, 9, 9)	Intermediate (7, 8, 9)	Very Highly Strong (6, 7, 8)	Intermediate (5, 6, 7)	Very Strong (4, 5, 6)	Intermediate (3, 4, 5)	Fairly Strong (2, 3, 4)	Intermediate (1, 2, 3)	Weak Strong I (1, 1, 2)	Equal I (1, 1, 1)	Weak Strong I (1, 1, 2)	Intermediate (1, 2, 3)	Fairly Strong (2, 3, 4)	Intermediate (3, 4, 5)	Very Strong (4, 5, 6)	Intermediate (5, 6, 7)	Very Highly Strong (6, 7, 8)	Intermediate (7, 8, 9)	Absolute (8, 9, 9)	
Country Risks																				Business Risks
Country Risks																				Organisational Risks
Country Risks																				Operational Risks
Business Risks																				Organisational Risks
Business Risks																				Operational Risks
Operational Risks																				Organisational Risks

APPENDIX II: Calculations for Level 3 risk factors not shown in Chapter 4.

Tables II.1, II.2, II.3, II.4 and II.5 are used to show the pair-wise comparision and local weights' calculations for risk factors associated with Level 3 country risks in offshore terminals and marine ports.

Table II.1: Local weights and pair-wise comparison matrix for Macro-economic Practices

Macro-economic Practices	(EI)	(AIRFER)	(GDPG)	(BNSD)	Local Weights
Economic Invigoration (EI)	(1,1,1)	(8,9,9)	(1/7,1/6,1/5)	(1,2,3)	**0.519**
Stability in Interest Rates and Foreign Exchange Rates (AIRFER)	(1/9,1/9,1/8)	(1,1,1)	(1,2,3)	(3,4,5)	**0.181**
GDP growth (GDPG)	(5,6,7)	(1/3,1/2,1)	(1,1,1)	(1/6,1/5,1/4)	**0.202**
Balancing of national saving and dept (BNSD)	(1/3,1/2,1)·	(1/5,1/4,1/3)	(4,5,6)	(1,1,1)	**0.097**

$\lambda_{max}=4.231$ CI = 0.077 RI=0.90 CR=0.086< 0.1

From Table II.1, synthesis values in respect to main goal are calculated as per Equation 4.11 shown in Section 1 of the extent analysis and are depicted as follows:

S1 = (10.143, 12.167, 13.2) ⊗(1/39.908, 1/33.728, 1/27.287) = (0.254,0.361,0.484),

S2 = (5.111, 7.111, 9.125) ⊗(1/39.908, 1/33.728, 1/27.287) = (0.128,0.211,0.334),

S3 = (6.5, 7.7, 9.25) ⊗(1/39.908, 1/33.728, 1/27.287) = (0.163,0.228,0.339),

S4 = (5.533, 6.75, 8.333) ⊗(1/39.908, 1/33.728, 1/27.287) = (0.139,0.200,0.305).

These fuzzy synthesis values are compared with each other by using Equation 4.17 shown in Section 2 of the extent analysis and new values are obtained as follows:

V(S1≥S2)=1, V(S1≥S3)=1, V(S1≥S4)=1;
V(S2≥S1)=0.348, V(S2≥S3)=0.91, V(S2≥S4)=1;
V(S3≥S1)=0.390, V(S3≥S2)=1, V(S3≥S4)=1;
V(S4≥S1)=0.187, V(S4≥S2)=0.711, V(S4≥S3)=0.835.

Then priority weights are calculated by using Equation 4.18 shown in Section 3 of the extent analysis as follow:

$d'(C1) = \min(1, 1, 1) = 1$,

$d'(C2) = \min(0.348, 0.910, 1) = 0.348$,

$d'(C3) = \min(0.390, 1, 1) = 0.390$,

$d'(C4) = \min(0.187, 0.711, 0.835) = 0.187$.

$W' = (1,0.348,0.390,0.187)$

Collected priority weights are shown in vector W'. Finally after normalisation of these values as per Equation 4.20 shown in Section 4 of the extent analysis, priority weights in respect to the main goal will be calculated as follows for each criterion in Table II.1:

$W = (0.519,0.181,0.202,0.097)$

Table II.2: Local weights and pair-wise comparison matrix for Political and Social Systems

Political and Social Systems	(PS)	(GEI)	(I)	(SS)	Local Weights
Political Stability (PS)	(1,1,1)	(7,8,9)	(1/5,1/4,1/3)	(1,2,3)	0.477
Stability in Interest Rates and Foreign Exchange Rates (AIRFER)	(1/9,1/8,1/7)	(1,1,1)	(3,4,5)	(3,4,5)	0.357
Government inefficiency and corruption (GEI)	(3,4,5)	(1/5,1/4,1/3)	(1,1,1)	(1/5,1/4,1/3)	0.108
Social Stability (SS)	(1/3,1/2,1)	(1/5,1/4,1/3)	(3,4,5)	(1,1,1)	0.108

$\lambda_{max} = 4.19$ CI = 0.063 RI=0.90 CR=0.071 < 0.1

From Table II.2, synthesis values in respect to main goal are calculated as per Equation 4.11 shown in Section 1 of the extent analysis and are depicted as follows:

$S1 = (9.2, 11.25, 13.333) \otimes (1/38.499, 1/31.625, 1/25.244) = (0.239,0.356,0.528)$,

$S2 = (7.111, 9.125, 11.167) \otimes (1/38.499, 1/31.625, 1/25.244) = (0.185,0.288,0.442)$,

$S3 = (4.4, 5.5, 6.666) \otimes (1/38.499, 1/31.625, 1/25.244) = (0.114,0.174,0.264)$,

$S4 = (4.533, 5.75, 7.333) \otimes (1/38.499, 1/31.625, 1/25.244) = (0.118,0.182,0.290)$.

These fuzzy synthesis values are compared with each other by using Equation 4.17 shown in Section 2 of the extent analysis and new values are obtained as follows:

V(S1≥S2)=1, V(S1≥S3)=1, V(S1≥S4)=1;

V(S2≥S1)=0.749, V(S2≥S3)=1, V(S2≥S4)=1;

V(S3≥S1)=0.121, V(S3≥S2)=0.409, V(S3≥S4)=0.948;

V(S4≥S1)=0.227, V(S4≥S2)=0.498, V(S4≥S3)=1.

Then priority weights are calculated by using Equation 4.18 shown in Section 3 of the extent analysis as follow:

$d'(C1) = \min(1, 1, 1) = 1$,

$d'(C2) = \min(0.749, 1, 1) = 0.749$,

$d'(C3) = \min(0.121, 0.409, 0.948) = 0.121$,

$d'(C4) = \min(0.277, 0.498, 1) = 0.277$.

$W' = (1, 0.749, 0.121, 0.227)$

Collected priority weights are shown in vector W'. Finally after normalisation of these values as per Equation 4.20 shown in Section 4 of the extent analysis, priority weights in respect to the main goal will be calculated as follows for each criterion in Table II.2:

$W = (0.477, 0.357, 0.058, 0.108)$

Table II.3: Local weights and pair-wise comparisons for Foreign Enterprise Policy

Foreign Enterprise Policy	(CRC)	(TI)	(TR)	Local Weights
Capital and remittance control (CRC)	(1,1,1)	(1/3,1/2,1)	(4,5,6)	0.556
Tax incentives (TI)	(1,2,3)	(1,1,1)	(1/3,1/2,1)	0.260
Trade restriction (TR)	(1/6,1/5,1/4)	(1,2,3)	(1,1,1)	0.184

$\lambda_{max} = 3.102$ CI = 0.051 RI=0.58 CR=0.088 < 0.1

From Table II.3, synthesis values in respect to main goal are calculated as per Equation 4.11 shown in Section 1 of the extent analysis and are depicted as follows:

$S1 = (5.333, 6.5, 8) \otimes (1/17.25, 1/13.2, 1/9.833) = (0.309, 0.492, 0.813)$,

$S2 = (2.333, 3.5, 5) \otimes (1/17.25, 1/13.2, 1/9.833) = (0.135, 0.265, 0.508)$,

$S3 = (2.167, 3.2, 4.25) \otimes (1/17.25, 1/13.2, 1/9.833) = (0.126, 0.242, 0.432)$.

These fuzzy synthesis values are compared with each other by using Equation 4.17 shown in Section 2 of the extent analysis and new values are obtained as follows:

$V(S1 \geq S2)=1$, $V(S1 \geq S3)=1$;
$V(S2 \geq S1)=0.467$, $V(S2 \geq S3)=1$;
$V(S3 \geq S1)=0.330$, $V(S3 \geq S2)=0.928$.

Then priority weights are calculated by using Equation 4.18 shown in Section 3 of the extent analysis as follow:

$d'(C1) = \min(1, 1) = 1$,
$d'(C2) = \min(0.467, 1) = 0.467$,
$d'(C3) = \min(0.330, 0.928) = 0.330$.

$W' = (1,0.467,0.330)$

Collected priority weights are shown in vector W'. Finally after normalisation of these values as per Equation 4.20 shown in Section 4 of the extent analysis, priority weights in respect to the main goal will be calculated as follows for each criterion in Table II.3:

$W = (0.556,0.260,0.184)$

Table II.4: Local weights and pair-wise comparison matrix for Port Development Policy

Port Development Policy	(POP)	(LID)	(IPNA)	(PRN)	Local Weights
Port Organisational Pattern (POP)	(1,1,1)	(2,3,4)	(1/7,1/6,1/5)	(1/3,1/2,1)	0.156
Liberalisation and Internationalisation Degree (LID)	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)	(2,3,4)	0.325
Industrial Potential in Neighbouring Areas (IPNA)	(5,6,7)	(1/4,1/3,1/2)	(1,1,1)	(1,2,3)	0.414
Positioning Relative to other ports within Nation (PRN)	(1,2,3)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,1,1)	0.105

$\lambda_{max} = 4.205$ CI = 0.068 RI=0.90 CR=0.076 < 0.1

From Table II.4, synthesis values in respect to main goal are calculated as per Equation 4.11 shown in Section 1 of the extent analysis and are depicted as follows:

$S1 = (3.476, 4.667, 6.2) \otimes (1/32.7, 1/25.166, 1/18.559) = (0.106,0.185,0.334)$,

$S2 = (5.25, 7.333, 9.5) \otimes (1/32.7, 1/25.166, 1/18.559) = (0.160,0.291,0.512)$,

$S3 = (7.25, 9.333, 11.5) \otimes (1/32.7, 1/25.166, 1/18.559) = (0.222,0.371,0.620)$,

$S4 = (2.583, 3.833, 5.5) \otimes (1/32.7, 1/25.166, 1/18.559) = (0.079,0.152,0.296)$.

These fuzzy synthesis values are compared with each other by using Equation 4.17 shown in Section 2 of the extent analysis and new values are obtained as follows:

$V(S1 \geq S2)=0.621$, $V(S1 \geq S3)=0.376$, $V(S1 \geq S4)=1$;
$V(S2 \geq S1)=1$, $V(S2 \geq S3)=0.784$, $V(S2 \geq S4)=1$;
$V(S3 \geq S1)=0.121$, $V(S3 \geq S2)=1$, $V(S3 \geq S4)=1$;
$V(S4 \geq S1)=0.852$, $V(S4 \geq S2)=0.494$, $V(S4 \geq S3)=0.253$.

Then priority weights are calculated by using Equation 4.18 shown in Section 3 of the extent analysis as follow:

$d'(C1) = \min(0.621, 0.376, 1) = 0.376$,
$d'(C2) = \min(1, 0.784, 1) = 0.784$,
$d'(C3) = \min(1, 1, 1) = 1$,
$d'(C4) = \min(0.852, 0.494, 0.253) = 0.253$.

$W' = (0.376,0.784,1,0.253)$

Collected priority weights are shown in vector W'. Finally after normalisation of these values as per Equation 4.20 shown in Section 4 of the extent analysis, priority weights in respect to the main goal will be calculated as follows for each criterion in Table II.4:

$W = (0.156,0.325,0.414,0.105)$

Table II.5: Local weights and pair-wise comparison matrix for Port Management Policy

Port Management Policy	**(PF)**	**(PDC)**	**(EPOP)**	**(CP)**	**Local Weights**
Private Financing of port infrastructure and equipment (PF)	(1,1,1)	(3,4,5)	(1/3,1/2,1)	(1/6,1/5,1/4)	**0.073**
Port Dues and Charges (PDC)	(1/5,1/4,1/3)	(1,1,1)	(6,7,8)	(3,4,5)	**0.632**
Efficient Port Operation Policy (EPOP)	(1,2,3)	(1/8,1/7,1/6)	(1,1,1)	(2,3,4)	**0.155**
Custom Practices (CP)	(4,5,6)	(1/5,1/4,1/3)	(1/4,1/3,1/2)	(1,1,1)	**0.140**

$\lambda_{max} = 4.16$ CI = 0.053 RI=0.90 CR=0.059 < 0.1

From Table II.5, synthesis values in respect to main goal are calculated as per Equation 4.11 shown in Section 1 of the extent analysis and are depicted as follows:

S1 = (4.5, 5.7, 7.25) ⊗ (1/37.583, 1/30.676, 1/24.275) = (0.120,0.186,0.299),

S2 = (10.2, 12.25, 14.333) ⊗ (1/37.583, 1/30.676, 1/24.275) = (0.271,0.399,0.590),

S3 = (4.125, 6.143, 8.167) ⊗ (1/37.583, 1/30.676, 1/24.275) = (0.110,0.200,0.336),

S4 = (5.45, 6.583, 7.833) ⊗ (1/37.583, 1/30.676, 1/24.275) = (0.145,0.215,0.323).

These fuzzy synthesis values are compared with each other by using Equation 4.17 shown in Section 2 of the extent analysis and new values are obtained as follows:

V(S1≥S2)=0.116, V(S1≥S3)=0.931, V(S1≥S4)=0.841;

V(S2≥S1)=1, V(S2≥S3)=1, V(S2≥S4)=1;

V(S3≥S1)=1, V(S3≥S2)=0.246, V(S3≥S4)=0.927;

V(S4≥S1)=1, V(S4≥S2)=0.220, V(S4≥S3)=1.

Then priority weights are calculated by using Equation 4.18 shown in Section 3 of the extent analysis as follow:

$d'(C1)$ = min (0.116, 0.931, 0.841) = 0.116,

$d'(C2)$ = min (1, 1, 1) = 1,

$d'(C3)$ = min (1, 0.246, 0.927) = 0.246,

$d'(C4)$ = min (1, 0.220, 1) = 0.220.

$W' = (0.116, 1, 0.246, 0.220)$

Collected priority weights are shown in vector W'. Finally after normalisation of these values as per Equation 4.20 shown in Section 4 of the extent analysis, priority weights in respect to the main goal will be calculated as follows for each criterion in Table II.5:

$W = (0.073, 0.632, 0.155, 0.140)$

Tables II.6 and II.7 are used to show the pair-wise comparision and local weights' calculations for risk factors associated with business risks within sea ports and offshore terminals.

Table II.6: Local weights and pair-wise comparison matrix for Competition Factors

Competition Factors	(PTE)	(LA)	(CBC)	(LVAS)	(R)	(DW)	(PL)	(SF)	(AS)	(PRUN)	(ACME)	Local weights
Port (Terminal) Efficiency (PTE)	(1,1,1)	(1/4,1/3,1/2)	(1/8,1/7,1/6)	(4,5,6)	(1/4,1/3,1/2)	(6,7,8)	(4,5,6)	(1/8,1/7,1/6)	(4,5,6)	(6,7,8)	(6,7,8)	0.106
Landside Accessibility (LA)	(2,3,4)	(1,1,1)	(1/8,1/7,1/6)	(6,7,8)	(1/6,1/5,1/4)	(1/9,1/8,1/7)	(4,5,6)	(1/8,1/7,1/6)	(6,7,8)	(1/8,1/7,1/6)	(1/9,1/9,1/8)	0.061
Cargo Handling Charges (CBC)	(6,7,8)	(6,7,8)	(1,1,1)	(1,1,1)	(3,4,5)	(1/5,1/4,1/3)	(6,7,8)	(1,1,1)	(1/8,1/7,1/6)	(8,9,9)	(1/7,1/6,1/5)	0.184
Logistics and Value Added Services (LVAS)	(1/6,1/5,1/4)	(1/8,1/7,1/6)	(1,1,1)	(1,1,1)	(1,2,3)	(4,5,6)	(6,7,8)	(1/7,1/6,1/5)	(2,3,4)	(1/4,1/3,1/2)	(6,7,8)	0.095
Port Reliability (R)	(2,3,4)	(4,5,6)	(1/5,1/4,1/3)	(1/3,1/2,1)	(1,1,1)	(2,3,4)	(1/6,1/5,1/4)	(1/8,1/7,1/6)	(2,3,4)	(2,3,4)	(1/9,1/9,1/8)	0.022
Depth of Water (DW)	(1/8,1/7,1/6)	(7,8,9)	(3,4,5)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1,1,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(2,3,4)	(4,5,6)	0.047
Port Location (PL)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1/8,1/7,1/6)	(1/8,1/7,1/6)	(4,5,6)	(2,3,4)	(1,1,1)	(6,7,8)	(2,3,4)	(1/6,1/5,1/4)	(1,1,1)	0.026
Shipping Frequency (SF)	(6,7,8)	(6,7,8)	(1,1,1)	(5,6,7)	(6,7,8)	(2,3,4)	(1/8,1/7,1/6)	(1,1,1)	(1,1,1)	(1,2,3)	(1,1,1)	0.173
Adequate Service (AS)	(1/6,1/5,1/4)	(1/8,1/7,1/6)	(6,7,8)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(4,5,6)	(1/4,1/3,1/2)	(1,1,1)	(1,1,1)	(5,6,7)	(4,5,6)	0.085
Port's Response to User's Need (PRUN)	(1/8,1/7,1/6)	(6,7,8)	(1/9,1/9,1/8)	(2,3,4)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(4,5,6)	(1/3,1/2,1)	(1/7,1/6,1/5)	(1,1,1)	(4,5,6)	0.049
Ability to Changing Market Environment (ACME)	(1/8,1/7,1/6)	(8,9,9)	(5,6,7)	(1/8,1/7,1/6)	(1/6,1/5,1/4)	(8,9,9)	(1/6,1/5,1/4)	(1,1,1)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1,1,1)	0.072

$\lambda_{max} = 12.19$ CI = 0.119 RI=1.53 CR=0.078 < 0.1

From Table II.6, synthesis values in respect to main goal are calculated as per Equation 4.11 shown in Section 1 of the extent analysis and are depicted as follows:

S1=(31.750, 37.952, 44.334) ⊗ (1/352.248, 1/301.01, 1/248.86) = (0.090, 0.126, 0.178),

S2=(19.764, 23.865, 28.061) ⊗ (1/352.248, 1/301.01, 1/248.86) = (0.056,0.079,0.113),

S3=(32.468, 37.560, 41.700) ⊗ (1/352.248, 1/301.01, 1/248.86) = (0.092,0.152,0.167),

S4=(21.685, 26.843, 32.117) ⊗ (1/352.248, 1/301.01, 1/248.86) = (0.062,0.089,0.129),

S5=(13.936, 19.204, 24.875) ⊗ (1/352.248, 1/301.01, 1/248.86) = (0.039,0.064,0.100),

S6=(18.209, 22.542, 27.167) ⊗ (1/352.248, 1/301.01, 1/248.86) = (0.052,0.075,0.109),

S7=(16.751, 20.886, 25.084) ⊗ (1/352.248, 1/301.01, 1/248.86) = (0.047,0.069,0.101),

S8=(30,125, 36.143, 42.167) ⊗ (1/352.248, 1/301.01, 1/248.86) = (0.085,0.120,0.169),

S9=(22.042, 26.342, 30.917) ⊗ (1/352.248, 1/301.01, 1/248.86) = (0.062,0.087,0.124),
S10=(18.212, 22.587, 27.492)⊗ (1/352.248, 1/301.01, 1/248.86) = (0.052,0.075,0.110),
S11=(23.918, 27.086, 28.334)⊗ (1/352.248, 1/301.01, 1/248.86) = (0.068,0.090,0.114).

These fuzzy synthesis values are compared with each other by using Equation 4.17 shown in Section 2 of the extent analysis and new values are obtained as follows:

V(S1≥S2)=1, V(S1≥S3)=1, V(S1≥S4)=1, V(S1≥S5)=1, V(S1≥S6)=1, V(S1≥S7)=1, V(S1≥S8)=1, V(S1≥S9)=1, V(S1≥S10)=1, V(S1≥S11)=1;

V(S2≥S1)=0.328, V(S2≥S3)=0.313, V(S21≥S4)=0.836, V(S2≥S5)=1, V(S2≥S6)=1, V(S2≥S7)=1, V(S2≥S8)=0.406, V(S2≥S9)=0.864, V(S2≥S10)=1, V(S2≥S11)=0.804;

V(S3≥S1)=0.987, V(S3≥S2)=1, V(S3≥S4)=1, V(S3≥S5)=1, V(S3≥S6)=1, V(S3≥S7)=1, V(S3≥S8)=1, V(S3≥S9)=1, V(S3≥S10)=1, V(S3≥S11)=1;

V(S4≥S1)=0.513, V(S4≥S2)=1, V(S4≥S3)=0.507, V(S4≥S5)=1, V(S4≥S6)=1, V(S4≥S7)=1, V(S4≥S8)=0.587, V(S4≥S9)=1, V(S4≥S10)=1, V(S4≥S11)=1;

V(S5≥S1)=0.139, V(S5≥S2)=0.746, V(S5≥S3)=0.116, V(S5≥S4)=0.603, V(S5≥S6)=0.814, V(S5≥S7)=0.914, V(S5≥S8)=0.211, V(S5≥S9)=0.623, V(S5≥S10)=0.813, V(S5≥S11)=0.552;

V(S6≥S1)=0.271, V(S6≥S2)=0.930, V(S6≥S3)=0.254, V(S6≥S4)=0.770, V(S6≥S5)=1, V(S6≥S7)=1, V(S6≥S8)=0.348, V(S6≥S9)=0.797, V(S6≥S10)=1, V(S6≥S11)=0.732;

V(S7≥S1)=0.162, V(S7≥S2)=0.818, V(S7≥S3)=0.138, V(S7≥S4)=0.661, V(S7≥S5)=1, V(S7≥S6)=0.891, V(S7≥S8)=0.239, V(S7≥S9)=0.684, V(S7≥S10)=0.891, V(S7≥S11)=0.611;

V(S8≥S1)=0.929, V(S8≥S2)=1, V(S8≥S3)=0.939, V(S8≥S4)=1, V(S8≥S5)=1, V(S8≥S6)=1, V(S8≥S7)=1, V(S8≥S9)=1, V(S8≥S10)=1, V(S8≥S11)=1;

V(S9≥S1)=0.466, V(S9≥S2)=1, V(S9≥S3)=0.457, V(S9≥S4)=0.969, V(S9≥S5)=1, V(S9≥S6)=1, V(S9≥S7)=1, V(S9≥S8)=1, V(S9≥S10)=1, V(S9≥S11)=1;

V(S10≥S1)=0.282, V(S10≥S2)=0.931, V(S10≥S3)=0.265, V(S10≥S4)=0.774, V(S10≥S5)=1, V(S10≥S6)=1, V(S10≥S7)=1, V(S10≥S8)=0.357, V(S10≥S9)=0.800, V(S10≥S11)=0.737;

V(S11≥S1)=0.4, V(S11≥S2)=1, V(S11≥S3)=0.386, V(S11≥S4)=1, V(S11≥S5)=1, V(S11≥S6)=1, V(S11≥S7)=1, V(S11≥S8)=0.491, V(S11≥S9)=1, V(S11≥S10)=1.

Then priority weights are calculated by using Equation 4.18 shown in Section 3 of the extent analysis as follow:

$d'(C1)= \min(1,1,1,1,1,1,1,1,1,1) = 1$,
$d'(C2)= \min(0.328, 0.313, 0.836, 1, 1, 1, 0.406, 0.864, 1, 0.804) = 0.313$,
$d'(C3)= \min(0.987, 1, 1, 1, 1, 1, 1, 1, 1, 1) = 0.987$,
$d'(C4)= \min(0.513, 1, 0.507, 1, 1, 1, 0.587, 1, 1, 1) = 0.507$,
$d'(C5)=\min(0.139, 0.746, 0.116, 0.603, 0.814, 0.914, 0.211, 0.623, 0.813, 0.552)=0.116$,
$d'(C6)= \min(0.271, 0.930, 0.254, 0.770, 1, 1, 0.348, 0.797, 1, 0.732) = 0.254$,
$d'(C7)= \min(0.162, 0.818, 0.138, 0.661, 1, 0.891, 0.239, 0.684, 0.891, 0.611) = 0.138$,
$d'(C8)= \min(0.929, 1, 0.939, 1, 1, 1, 1, 1, 1, 1) = 0.929$,
$d'(C9)= \min(0.466, 1, 0.457, 0.969, 1,1,1,0.542,1,1) = 0.457$,
$d'(C10)= \min(0.282, 0.931, 0.265, 0.774, 1, 1, 1, 0.357, 0.8, 0.737) = 0.265$,
$d'(C11)= \min(0.4, 1, 0.386, 1, 1, 1, 1, 0.491, 1) = 0.386$.

$W' = (1,0.313,0.987,0.507,0.116,0.254,0.138,0.929,0.457,0.265,0.386)$

Collected priority weights are shown in vector W'. Finally after normalisation of these values as per Equation 4.20 shown in Section 4 of the extent analysis, priority weights in respect to the main goal will be calculated as follows for each criterion in Table II.6:

$W= (0.186,0.061,0.184,0.095,0.022,0.047,0.026,0.173,0.085,0.049,0.072)$

Table II.7: Local weights and pair-wise comparison matrix of Competition Factors

Industry Change	(FSI)	(CAOC)	(PGSPU)	Local Weights
Fluctuation in Shipping Industry (FSI)	(1,1,1)	(1,2,3)	(1/4,1/3,1/2)	**0.312**
Consolidation Among Ocean Carriers (CAOC)	(1/3,1/2,1)	(1,1,1)	(1/3,1/2,1)	**0.140**
Potential for Global Substitutes for Port Users (PGSPU)	(2,3,4)	(1,2,3)	(1,1,1)	**0.548**

$\lambda_{max} = 2.038$ CI = 0.019 RI=0.58 CR=0.033 < 0.1

From Table II.7, synthesis values in respect to main goal are calculated as per Equation 4.11 shown in Section 1 of the extent analysis and are depicted as follows:

S1= =(2.25, 3.333, 4.5) $\otimes$ (1/15.5, 1/11.333, 1/7.916) = (0.145,0.294,0.568),

S2= =(1.666, 2, 3) $\otimes$ (1/15.5, 1/11.333, 1/7.916) = (0.107,0.176,0.379),

S3= =(4, 6, 8) $\otimes$ (1/15.5, 1/11.333, 1/7.916) = (0.258,0.529,1.010).

These fuzzy synthesis values are compared with each other by using Equation 4.17 shown in Section 2 of the extent analysis and new values are obtained as follows:

V(S1≥S2)=1, V(S1≥S3)=0.569;

V(S2≥S1)=0.665, V(S2≥S3)=0.255;

V(S3≥S1)=1, V(S3≥S2)=1.

Then priority weights are calculated by using Equation 4.18 shown in Section 3 of the extent analysis as follow:

$d'(C1) = \min(1, 0.569) = 0.569$,

$d'(C2) = \min(0.665, 0.255) = 0.255$,

$d'(C3) = \min(1, 1) = 1$.

$W' = (0.569, 0.255, 1)$

Collected priority weights are shown in vector W'. Finally after normalisation of these values as per Equation 4.20 shown in Section 4 of the extent analysis, priority weights in respect to the main goal will be calculated as follows for each criterion in Table II.7:

$W = (0.312, 0.140, 0.548)$.

Tables II.8, II.9, II.10, II.11 and II.12 are used to show the pair-wise comparision and local weight's calculations for risk factors associated with organisational risks within sea ports and offshore terminals.

Table II.8: Local weights and pair-wise comparison matrix for Organisational Structure

Organisational Structure	(LSTRD)	(LACD)	Local Weights
Lack of Subdividing Tasks & Responsibilities among Departments (LSTRD)	(1,1,1)	(1/3,1/2,1)	**0.307**
Lack of Achieving Co-ordination between Departments (LACD)	(1,2,3)	(1,1,1)	**0.693**

As RI for matrix 2x2 is equal to zero then CR= 0 < 0.1

From Table II.8, synthesis values in respect to main goal are calculated as per Equation 4.11 shown in Section 1 of the extent analysis and are depicted as follows:

$S1=(1.333, 1.5, 2) \otimes (1/6, 1/4.5, 1/3.333) = (0.222,0.333,0.600)$,

$S2=(2, 3, 4) \otimes (1/6, 1/4.5, 1/3.333) = (0.333,0.667,1.200)$.

These fuzzy synthesis values are compared with each other by using Equation 4.17 shown in Section 2 of the extent analysis and new values are obtained as follows:
$V(S1 \geq S2)=0.444$; $V(S2 \geq S1)=1$.

Then priority weights are calculated by using Equation 4.18 shown in Section 3 of the extent analysis as follow:

$d'(C1) = \min(0.444) = 0.444$,
$d'(C2) = \min(1) = 1$.
$W' = (0.444,1)$

Collected priority weights are shown in vector W'. Finally after normalisation of these values as per Equation 4.20 shown in Section 4 of the extent analysis, priority weights in respect to the main goal will be calculated as follows for each criterion in Table II.8:

$W = (0.307,0.693)$

Table II.9: Local weights and pair-wise comparison matrix for Management

Management	(LDAERA)	(QRJSM)	(LAUK)	(LCSMP)	Local Weights
Lack of Direct Authority to Effect Remedial Action (LDAERA)	(1,1,1)	(1/4,1/3,1/2)	(1,2,3)	(1,2,3)	0.286
Quality Required by the Job for Senior Managers (QRJSM)	(2,3,4)	(1,1,1)	(2,3,4)	(1,2,3)	0.437
Lack of Adequacy in Upgrading Knowledge (LAUK)	(1/3,1/2,1)	(1/4,1/3,1/2)	(1,1,1)	(1,2,3)	0.189
Lack of Continuity in Senior Managers Position's (LCSMP)	(1/3,1/2,1)	(1/3,1/2,1)	(1/3,1/2,1)	(1,1,1)	0.088

$\lambda_{max} = 4.105$ CI = 0.035 RI=0.90 CR=0.039 < 0.1

From Table II.9, synthesis values in respect to main goal are calculated as per Equation 4.11 shown in Section 1 of the extent analysis and are depicted as follows:

S1=(3.25, 5.333,7.5) $\otimes$(1/29, 1/20.666, 1/13.832) = (0.112,0.258,0.542),

S2=(6, 9, 12) $\otimes$(1/29, 1/20.666, 1/13.832) = (0.207,0.435,0.867),

S3=(2.583, 3.833, 5.5) $\otimes$(1/29, 1/20.666, 1/13.832) = (0.089,0.185,0.398),

S4=(1.999, 2.5, 4) $\otimes$(1/29, 1/20.666, 1/13.832) = (0.069,0.110,0.289).

These fuzzy synthesis values are compared with each other by using Equation 4.17 shown in Section 2 of the extent analysis and new values are obtained as follows:

V(S1≥S2)=0.654, V(S1≥S3)=1, V(S1≥S4)=1;

V(S2≥S1)=1, V(S2≥S3)=1, V(S2≥S4)=1;

V(S3≥S1)=0.797, V(S3≥S2)=0.433, V(S3≥S4)=1;

V(S4≥S1)=0.545, V(S4≥S2)=0.201, V(S4≥S3)=0.727.

Then priority weights are calculated by using Equation 4.18 shown in Section 3 of the extent analysis as follow:

d'(C1) = min (0.654, 1, 1) = 0.654,

d'(C2) = min (1, 1, 1, 1) = 1,

d'(C3) = min (0.797, 0.433, 1) = 0.433,

d'(C4) = min (0.545, 0.201, 0.727) = 0.201.

W'= (0.654, 1, 0.433, 0.201)

Collected priority weights are shown in vector W'. Finally after normalisation of these values as per Equation 4.20 shown in Section 4 of the extent analysis, priority weights in respect to the main goal will be calculated as follows for each criterion in Table II.9:
W = (0.286,0.437,0.189,0.088)

Table II.10: Local weights and pair-wise comparison matrix for Quality Process

Quality Process	(LPMDR)	(LPSI)	(LPIIC)	(LCRPC)	Local Weights
Lack of Procedures, Manuals, Documents and Records (LPMDR)	(1,1,1)	(1,2,3)	(2,3,4)	(2,3,4)	0.445
Lack of Processes e.g. Ship inspection, etc (LPSI)	(1/3,1/2,1)	(1,1,1)	(1,2,3)	(1,2,3)	0.306
Lack of Process e.g. Internal Inspection and Control (LPIIC)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,1,1)	(1,2,3)	0.193
Lack of Customer Related Processes (Complaints) (LCRPC)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1/3,1/2,1)	(1,1,1)	0.056

$\lambda_{max} = 4.175$ $CI = 0.058$ RI=0.90 CR=0.065 < 0.1

From Table II.10, synthesis values in respect to main goal are calculated as per Equation 4.11 shown in section 1 of the extent analysis and are depicted as follows:
S1=(6, 9, 12) $\otimes$(1/29, 1/3.833, 1/5.5) = (0.207,0.435,0.867),
S2=(3.333, 5.5, 8) $\otimes$(1/29, 1/3.833, 1/5.5) = (0.115,0.266,0.578),
S3=(2.583, 3.833, 5.5) $\otimes$(1/29, 1/3.833, 1/5.5) = (0.089,0.185,0.397),
S4=(1.916, 2.333, 3.5) $\otimes$(1/29, 1/3.833, 1/5.5) = (0.066,0.113,0.253).

These fuzzy synthesis values are compared with each other by using Equation 4.17 shown in section 2 of the extent analysis and new values are obtained as follows:
V(S1≥S2)=1, V(S1≥S3)=1, V(S1≥S4)=1;
V(S2≥S1)=0.687, V(S2≥S3)=1, V(S2≥S4)=1;
V(S3≥S1)=0.432, V(S3≥S2)=0.777, V(S3≥S4)=1;
V(S4≥S1)=0.125, V(S4≥S2)=0.474, V(S4≥S3)=0.695.

Then priority weights are calculated by using Equation 4.18 shown in section 3 of the extent analysis as follow:
d'(C1) = min (1, 1, 1) = 1,
d'(C2) = min (0.687, 1, 1) = 0.687,
d'(C3) = min (0.432, 0.777, 1) = 0.432,

$d'(C4) = \min(0.125, 0.474, 0.695) = 0.125.$

$W' = (1, 0.687, 0.432, 0.125)$

Collected priority weights are shown in vector W'. Finally after normalisation of these values as per Equation 4.20 shown in section 4 of the extent analysis, priority weights in respect to the main goal will be calculated as follows for each criterion in Table II.10:

$W = (0.445, 0.306, 0.193, 0.056)$

Table II.11: Local weights and pair-wise comparison matrix for Human Resources

Human Resources	(LDM)	(LQ)	(LE)	(LT)	(LJ)	(LSCHA)	(PC)	(LS)	Local Weights
Lack of Decision Making (LDM)	(1,1,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,2,3)	(1/3,1/2,1)	(1/3,1/2,1)	(1/3,1/2,1)	0.039
Lack of Qualification (LQ)	(2,3,4)	(1,1,1)	(1,2,3)	(2,3,4)	(2,3,4)	(2,3,4)	(2,3,4)	(2,3,4)	0.238
Lack of Experience (LE)	(2,3,4)	(1/3,1/2,1)	(1,1,1)	(1,2,3)	(2,3,4)	(2,3,4)	(2,3,4)	(2,3,4)	0.219
Lack of Training (LT)	(2,3,4)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,1,1)	(2,3,4)	(2,3,4)	(2,3,4)	(1,2,3)	0.195
Lack of Judgment (LJ)	(1/3,1/2,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)	(1/3,1/2,1)	(1/3,1/2,1)	(1/3,1/2,1)	0.002
Lack of Safety Culture and... (LSCHA)	(1,2,3)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,2,3)	(1,1,1)	(1,2,3)	(1,2,3)	0.126
Poor Communication (PC)	(1,2,3)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,2,3)	(1/3,1/2,1)	(1,1,1)	(1,2,3)	0.101
Lack of Skills (LS)	(1,2,3)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,2,3)	(1/3,1/2,1)	(1/3,1/2,1)	(1,1,1)	0.080

$\lambda_{max} = 8.779$ CI = 0.111 RI=1.41 CR=0.079 < 0.1

From Table II.11, synthesis values in respect to main goal are calculated as per Equation 4.11 shown in Section 1 of the extent analysis and are depicted as follows:

S1=(3.749, 5.499, 8.5) $\otimes$(1/127.5, 1/90.495, 1/59.079) = (0.029,0.061,0.144),

S2=(14, 21, 28) $\otimes$(1/127.5, 1/90.495, 1/59.079) = (0.109,0.232,0.474),

S3=(12.333, 18.5, 25) $\otimes$(1/127.5, 1/90.495, 1/59.079) = (0.097,0.204,0.423),

S4=(10.583, 15.833, 21.5) $\otimes$(1/127.5, 1/90.495, 1/59.079) = (0.083,0.175,0.363),

S5=(3.082, 3.999, 6.5) $\otimes$(1/127.5, 1/90.495, 1/59.079) = (0.024,0.044,0.110),

S6=(5.75, 9.999, 14.5) $\otimes$(1/127.5, 1/90.495, 1/59.079) = (0.045,0.110,0.245),

S7=(5.083, 8.499, 12.5) $\otimes$(1/127.5, 1/90.495, 1/59.079) = (0.040,0.094,0.211),

S8=(4.499, 7.166, 11) $\otimes$(1/127.5, 1/90.495, 1/59.079) = (0.035,0.079,0.186).

These fuzzy synthesis values are compared with each other by using Equation 4.17 shown in Section 2 of the extent analysis and new values are obtained as follows:

V(S1≥S2)=0.166, V(S1≥S3)=0.247, V(S1≥S4)=0.348, V(S1≥S5)=1, V(S1≥S6)=0.669, V(S1≥S7)=0.759, V(S1≥S8)=0.858;

V(S2≥S1)=1, V(S2≥S3)=1, V(S21≥S4)=1, V(S2≥S5)=1, V(S2≥S6)=1, V(S2≥S7)=1, V(S2≥S8)=1;

V(S3≥S1)=1, V(S3≥S2)=0.918, V(S3≥S4)=1, V(S3≥S5)=1, V(S3≥S6)=1, V(S3≥S7)=1, V(S3≥S8)=1;

V(S4≥S1)=1, V(S4≥S2)=0.816, V(S4≥S3)=0.902, V(S4≥S5)=1, V(S4≥S6)=1, V(S4≥S7)=1, V(S4≥S8)=1;

V(S5≥S1)=0.826, V(S5≥S2)=0.005, V(S5≥S3)=0.075, V(S5≥S4)=0.170, V(S5≥S6)=0.496, V(S5≥S7)=0.583, V(S5≥S8)=0.682;

V(S6≥S1)=1, V(S6≥S2)=0.527, V(S6≥S3)=0.611, V(S6≥S4)=0.714, V(S6≥S5)=1, V(S6≥S7)=1, V(S6≥S8)=1;

V(S7≥S1)=1, V(S7≥S2)=0.425, V(S7≥S3)=0.509, V(S7≥S4)=0.612, V(S7≥S5)=1, V(S7≥S6)=0.912, V(S7≥S8)=1;

V(S8≥S1)=1, V(S8≥S2)=0.335, V(S8≥S3)=0.416, V(S8≥S4)=0.517, V(S8≥S5)=1, V(S8≥S6)=0.819, V(S8≥S7)=0.907.

Then priority weights are calculated by using Equation 4.18 shown in Section 3 of the extent analysis as follow:

d'(C1) = min (0.166, 0.247, 0.348, 1, 0.669, 0.759, 0.858) = 0.166,
d'(C2) = min (1, 1, 1, 1, 1, 1, 1) = 1,
d'(C3) = min (1, 0.918, 1, 1, 1, 1, 1) = 0.918,
d'(C4) = min (1, 0.816, 0.902, 1, 1, 1, 1) = 0.816,
d'(C5)=min(0.826, 0.005, 0.075, 0.170, 0.496, 0.583, 0.682)=0.005,

$d'(C6) = \min(1, 0.527, 0.611, 0.714, 1, 1, 1) = 0.527,$

$d'(C7) = \min(1, 0.425, 0.509, 0.612, 1, 0.912, 1) = 0.425,$

$d'(C8) = \min(1, 0.335, 0.416, 0.517, 1, 0.819, 0.907) = 0.335.$

$W' = (0.166,1,0.918,0.816,0.005,0.527,0.425,0.335)$

Collected priority weights are shown in vector W'. Finally after normalisation of these values as per Equation 4.20 shown in Section 4 of the extent analysis, priority weights in respect to the main goal will be calculated as follows for each criterion in Table II.11:

$W = (0.039,0.238,0.219,0.195,0.002,0.126,0.101,0.080)$

Table II.12: Local weights and pair-wise comparison matrix for Port Performance Indicators.

P.P.I	(POPI)	(PFPI)	(PQPI)	Local Weights
Port Operational Performance indicators (POPI)	(1,1,1)	(2,3,4)	(1,2,3)	0.548
Port Financial Performance indicators (PFPI)	(1/4,1/3,1/2)	(1,1,1)	(1,2,3)	0.312
Port Quality Performance indicators (PQPI)	(1/3,1/2,1)	(1/3,1/2,1)	(1,1,1)	0.140

$\lambda_{max} = 3.053$ CI = 0.026 RI=0.58 CR=0.046 < 0.1

From Table II.12, synthesis values in respect to main goal are calculated as per Equation 4.11 shown in Section 1 of the extent analysis and are depicted as follows:

$S1=(4, 6, 8) \otimes (1/15.5, 1/11.333, 1/7.916) = (0.258,0.529,1.011),$

$S2=(2.25, 3.333, 4.5) \otimes (1/15.5, 1/11.333, 1/7.916) = (0.145,0.294,0.568),$

$S3=(1.666, 2, 3) \otimes (1/15.5, 1/11.333, 1/7.916) = (0.107,0.176,0.379).$

These fuzzy synthesis values are compared with each other by using Equation 4.17 shown in section 2 of the extent analysis and new values are obtained as follows:

$V(S1 \geq S2)=1, V(S1 \geq S3)=1;$

$V(S2 \geq S1)=0.569, V(S2 \geq S3)=1;$

$V(S3 \geq S1)=0.255, V(S3 \geq S2)=0.665.$

Then priority weights are calculated by using Equation 4.18 shown in section 3 of the extent analysis as follow:

$d'(C1) = \min(1, 1) = 1$,

$d'(C2) = \min(0.569, 1) = 0.569$,

$d'(C3) = \min(0.255, 0.665, 1) = 0.255$.

$W' = (1, 0.569, 0.255)$

Collected priority weights are shown in vector W'. Finally after normalisation of these values as per Equation 4.20 shown in Section 4 of the extent analysis, priority weights in respect to the main goal will be calculated as follows for each criterion in Table II.12:

$W = (0.548, 0.312, 0.140)$

Tables II.13, II.14, II.15, II.16, II.17 and II.18 are used to show the pair-wise comparision and local weight's calculations for risk factors associated with operational risks within sea ports and offshore terminals.

Table II.13: Safety Related Risk Factors (R41) based on Harrald and Merrick (2000)

Level 3 Operational Risks	(CCF)	(TC)	(WC)	(WWC)	(PCDGT)	(PIVTM)	Local Weights
Composition of Calling Fleet (CCF)	(1,1,1)	(1,2,3)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,2,3)	(1,2,3)	0.048
Traffic Conditions (TC)	(1/3,1/2,1)	(1,1,1)	(1/6,1/5,1/4)	(1/3,1/2,1)	(1,2,3)	(1,2,3)	0.340
Weather Conditions (WC)	(2,3,4)	(4,5,6)	(1,1,1)	(1/4,1/3,1/2)	(1,2,3)	(1,2,3)	0.099
Waterway Configuration (WWC)	(2,3,4)	(1,2,3)	(4,5,6)	(1,1,1)	(1,2,3)	(1,2,3)	0.398
Potential Consequences of DG Transportation (PCDGT)	(1,1,1)	(1/8,1/7,1/6)	(1/3,1/2,1)	(1/4,1/3,1/2)	(1,1,1)	(1,2,3)	0.027
Potential Impacts of not having VTM (PIVTM)	(1,2,3)	(1,1,1)	(1/3,1/2,1)	(1/3,1/2,1)	(1/3,1/2,1)	(1,1,1)	0.088

$\lambda_{max} = 6.328$ CI = 0.065 RI=1.24 CR=0.053 < 0.1

From Table II.13, synthesis values in respect to main goal are calculated as per Equation 4.11 shown in Section 1 of the extent analysis and are depicted as follows:

$S1=(3.833, 5.166, 7) \otimes (1/68.083, 1/51.009, 1/36.523) = (0.056, 0.101, 0.192)$,

$S2=(4.833, 6.2, 8.25) \otimes (1/68.083, 1/51.009, 1/36.523) = (0.071, 0.121, 0.226)$,

$S3=(9.2, 13.25, 17.333) \otimes (1/68.083, 1/51.009, 1/36.523) = (0.135, 0.260, 0.475)$,

$S4=(11, 16, 21) \otimes (1/68.083, 1/51.009, 1/36.523) = (0.162, 0.314, 0.575)$, S5=(3.658, 4.893, 6.5) ⊗(1/68.083, 1/51.009, 1/36.523) = (0.054,0.096,0.178),

S6=(3.999, 5.5, 8) ⊗(1/68.083, 1/51.009, 1/36.523)= (0.059,0.108,0.220).

These fuzzy synthesis values are compared with each other by using Equation 4.17 shown in Section 2 of the extent analysis and new values are obtained as follows:

V(S1≥S2)=0.857, V(S1≥S3)=0.260, V(S1≥S4)=0.120, V(S1≥S5)=1, V(S1≥S6)=0.949;

V(S2≥S1)=1, V(S2≥S3)=0.396, V(S21≥S4)=0.250, V(S2≥S5)=1, V(S2≥S6)=1;

V(S3≥S1)=1, V(S3≥S2)=1, V(S3≥S4)=0.853, V(S3≥S5)=1, V(S3≥S6)=1;

V(S4≥S1)=1, V(S4≥S2)=1, V(S4≥S3)=1, V(S4≥S5)=1, V(S4≥S6)=1;

V(S5≥S1)=0.960,V(S5≥S2)=0.811,V(S5≥S3)=0.208,V(S5≥S4)=0.068,V(S5≥S6)=0.908;

V(S6≥S1)=1, V(S6≥S2)=0.920, V(S6≥S3)=0.358, V(S6≥S4)=0.220, V(S6≥S5)=1.

Then priority weights are calculated by using Equation 4.18 shown in Section 3 of the extent analysis as follow:

d'(C1) = min (0.857, 0.260, 0.120, 1, 0.949) = 0.120,

d'(C2) = min (1, 1, 0.853, 1, 1) = 0.853,

d'(C3) = min (1, 0.396, 0.250, 1, 1) = 0.250,

d'(C4) = min (1, 1, 1, 1, 1) = 1,

d'(C5)=min(0.960, 0.811, 0.208, 0.068, 0.908)=0.068,

d'(C6) = min (1, 0.920, 0.358, 0.220, 1) = 0.220.

W' = (0.120,1,0.853,0.250,1,0.068,0.220)

Collected priority weights are shown in vector W'. Finally after normalisation of these values as per Equation 4.20 shown in Section 4 of the extent analysis, priority weights in respect to the main goal will be calculated as follows for each criterion in Table II.13:

W = (0.048,0.340,0.099,0.394,0.027,0.088)

Table II.14: Local weights and pair-wise comparison matrix for Security Related Risk Factors

Pollution Related Risk Factors	(PS)	(PA)	(PP)	Local Weights
People's Safety (PS)	(1,1,1)	(1,3,4)	(2,3,4)	0.670
Port Asset (PA)	(1/4,1/3,1/2)	(1,1,1)	(1,2,3)	0.274
Port Profit (PP)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,1,1)	0.056

$\lambda_{max} = 3.054$ CI = 0.027 RI=0.58 CR=0.047 < 0.1

From Table II.14, synthesis values in respect to main goal are calculated as per Equation 4.11 shown in Section 1 of the extent analysis and are depicted as follows:

S1=(5, 7, 9) $\otimes$(1/16.5, 1/12.33, 1/8.833) = (0.303,0.568,1.019),

S2=(2.25, 3.33, 4.5) $\otimes$(1/16.5, 1/12.33, 1/8.833) = (0.136,0.270,0.509),

S3=(1.583, 2, 3) $\otimes$(1/16.5, 1/12.33, 1/8.833) = (0.096,0.162,0.340).

These fuzzy synthesis values are compared with each other by using Equation 4.17 shown in Section 2 of the extent analysis and new values are obtained as follows:

V(S1≥S2)=1, V(S1≥S3)=1;

V(S2≥S1)=0.408, V(S2≥S3)=1;

V(S3≥S1)=0.083, V(S3≥S2)=0.654.

Then priority weights are calculated by using Equation 4.18 shown in Section 3 of the extent analysis as follow:

d'(C1) = min (1, 1) = 1,

d'(C2) = min (0.408, 1) = 0.408,

d'(C3) = min (0.083, 0.654) = 0.083.

W' = (1,0.408,0.083)

Collected priority weights are shown in vector W'. Finally after normalisation of these values as per Equation 4.20 shown in Section 4 of the extent analysis, priority weights in respect to the main goal will be calculated as follows for each criterion in Table II.14:

W = (0.670,0.374,0.056)

Table II.15: Local weights and pair-wise comparison matrix for Pollution Related Risk Factors

Pollution Related Risk Factors	(SRP)	(CRP)	(PRP)	(CRP)	Local Weights
Ship Related Pollutions (SRP)	(1,1,1)	(1,2,3)	(2,3,4)	(3,4,5)	0.496
Cargo Related Pollutions (CRP)	(1/3,1/2,1)	(1,1,1)	(1,2,3)	(1/3,1/2,1)	0.178
Port Related Pollutions (PRP)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,1,1)	(2,3,4)	0.220
City Related Pollutions (CRP)	(1/5,1/4,1/3)	(1,2,3)	(1/4,1/3,1/2)	(1,1,1)	0.106

$\lambda_{max} = 4.186$ CI = 0.062 RI=0.90 CR=0.069 < 0.1

From Table II.15, synthesis values in respect to main goal are calculated as per Equation 4.11 shown in Section 1 of the extent analysis and are depicted as follows:

S1=(7, 10, 13) $\otimes$(1/30.333, 1/22.416, 1/15.699) = (0.231,0.446,0.828),

S2=(2.666, 4, 6) $\otimes$(1/30.333, 1/22.416, 1/15.699)= (0.088,0.178,0.382),

S3=(3.583, 4.833, 6.5) $\otimes$(1/30.333, 1/22.416, 1/15.699) = (0.118,0.216,0.414),

S4=(2.45, 3.583, 4.833) $\otimes$(1/30.333, 1/22.416, 1/15.699) = (0.081,0.160,0.308).

These fuzzy synthesis values are compared with each other by using Equation 4.17 shown in Section 2 of the extent analysis and new values are obtained as follows:

V(S1≥S2)=1, V(S1≥S3)=1, V(S1≥S4)=1;

V(S2≥S1)=0.360, V(S2≥S3)=0.874, V(S2≥S4)=1;

V(S3≥S1)=0.443, V(S3≥S2)=1, V(S3≥S4)=1;

V(S4≥S1)=0.212, V(S4≥S2)=1, V(S4≥S3)=0.772.

Then priority weights are calculated by using Equation 4.18 shown in Section 3 of the extent analysis as follow:

d'(C1) = min (1, 1, 1) = 1,

d'(C2) = min (0.360, 0.874, 1) = 0.360,

d'(C3) = min (0.443, 1, 1) = 0.443,

d'(C4) = min (0.212, 1, 0.772) = 0.212.

W' = (1,0.360,0.443,0.212)

Collected priority weights are shown in vector W'. Finally after normalisation of these values as per Equation 4.20 shown in Section 4 of the extent analysis, priority weights in respect to the main goal will be calculated as follows for each criterion in Table II.15:

$W = (0.496, 0.178, 0.220, 0.106)$

Table II.16: Local weights and pair-wise comparison matrix for Legal Related Risk Factors

Legal Related Risk Factors	(RC)	(FC)	Local Weights
Regulatory Changes (RC)	(1,1,1)	(1,2,3)	0.693
Fraud in Contracts (FC)	(1/3,1/2,1)	(1,1,1)	0.307

As RI for matrix 2x2 is equal to zero then CR= $0 < 0.1$

From Table II.16, synthesis values in respect to main goal are calculated as per Equation 4.11 shown in Section 1 of the extent analysis and are depicted as follows:

S1=(2, 3, 4) $\otimes$(1/6, 1/4.5, 1/3.333) = (0.333,0.667,1.200),
S2=(1.333, 1.5, 2) $\otimes$(1/6, 1/4.5, 1/3.333) = (0.222,0.333,0.600).

These fuzzy synthesis values are compared with each other by using Equation 4.17 shown in Section 2 of the extent analysis and new values are obtained as follows:

V(S1≥S2)=1; V(S2≥S1)=0.444.

Then priority weights are calculated by using Equation 4.18 shown in Section 3 of the extent analysis as follow:

$d'(C1) = \min(1) = 1$,
$d'(C2) = \min(0.444) = 0.360$.
$W' = (1, 0.444)$

Collected priority weights are shown in vector W'. Finally after normalisation of these values as per Equation 4.20 shown in Section 4 of the extent analysis, priority weights in respect to the main goal will be calculated as follows for each criterion in Table II.16:

$W = (0.693, 0.307)$

Table II.17: Local weights and pair-wise comparison matrix for Human Error Risk Factors

Human Error Risk Factors	(PRE)	(PPRE)	(SPRE)	(SRP)	Local Weights
Pilot Related Errors (PRE)	(1,1,1)	(2,3,4)	(1,2,3)	(3,4,5)	0.498
Port Personnel Related Errors (PPRE)	(1/4,1/3,1/2)	(1,1,1)	(1,2,3)	(1/3,1/2,1)	0.161
Ship's Personnel Related Errors (SPRE)	(1/3,1/2,1)	(1/3,1/2,1)	(1,1,1)	(1,2,3)	0.189
Stevedore's Related Errors (SRP)	(1/5,1/4,1/3)	(1,2,3)	(1/3,1/2,1)	(1,1,1)	0.152

$\lambda_{max} = 4.18$ CI = 0.06 RI=0.90 CR=0.067 < 0.1

From Table II.17, synthesis values in respect to main goal are calculated as per Equation 4.11 shown in Section 1 of the extent analysis and are depicted as follows:

S1=(7, 10, 13) $\otimes$(1/29.833, 1/21.583, 1/14.782)= (0.235,0.463,0.879),

S2=(2.583, 3.833, 5.5) $\otimes$(1/29.833, 1/21.583, 1/14.782)= (0.086,0.177,0.372),

S3=(2.666, 4, 6) $\otimes$(1/29.833, 1/21.583, 1/14.782) = (0.089,0.185,0.406),

S4=(2.533, 3.75, 5.333) $\otimes$(1/29.833, 1/21.583, 1/14.782) = (0.085,0.174,0.361).

These fuzzy synthesis values are compared with each other by using Equation 4.17 shown in Section 2 of the extent analysis and new values are obtained as follows:

V(S1≥S2)=1, VS1≥S3)=1, V(S1≥S4)=1;

V(S2≥S1)=0.324, V(S2≥S3)=0.972, V(S2≥S4)=1;

V(S3≥S1)=0.381, V(S3≥S2)=1, V(S3≥S4)=1;

V(S4≥S1)=0.304, V(S4≥S2)=0.989, V(S4≥S3)=0.961.

Then priority weights are calculated by using Equation 4.18 shown in Section 3 of the extent analysis as follow:

$d'(C1) = \min(1, 1, 1) = 1$,

$d'(C2) = \min(0.324, 0.972, 1) = 0.324$,

$d'(C3) = \min(0.381, 1, 1) = 0.381$,

$d'(C4) = \min(0.304, 0.989, 0.961) = 0.304$.

$W' = (1, 0.324, 0.381, 0.304)$

Collected priority weights are shown in vector W'. Finally after normalisation of these values as per Equation 4.20 shown in Section 4 of the extent analysis, priority weights in respect to the main goal will be calculated as follows for each criterion in Table II.17:

$W = (0.498, 0.161, 0.189, 0.152)$

Table II.18: Local weights and pair-wise comparison matrix for Technical Related Risk Factors

Technical Related Risk Factors	(LEM)	(LITT)	(CRP)	Local Weights
Lack of Equipment Maintenance (LEM)	(1,1,1)	(1/4,1/3,1/2)	(1/3,1/2,1)	0.078
Lack of IT Technology (LITT)	(2,3,4)	(1,1,1)	(1,2,3)	0.566
Lack of Dredging and Navaids Maintenance (LDNM)	(1,2,3)	(1/3,1/2,1)	(1,1,1)	0.356

$\lambda_{max} = 4.15$ CI = 0.051 RI=0.58 CR=0.089 < 0.1

From Table II.18, synthesis values in respect to main goal are calculated as per Equation 4.11 shown in Section 1 of the extent analysis and are depicted as follows:

S1=(1.583, 1.833, 2.5) $\otimes$(1/15.5, 1/11.333, 1/7.916)= (0.102,0.162,0.316),

S2=(4, 6, 8) $\otimes$(1/15.5, 1/11.333, 1/7.916)= (0.258,0.529,1.011),

S3=(2.333, 3.5, 5) $\otimes$(1/15.5, 1/11.333, 1/7.916)= (0.150,0.309,0.632).

These fuzzy synthesis values are compared with each other by using Equation 4.17 shown in Section 2 of the extent analysis and new values are obtained as follows:

$V(S1 \geq S2)=0.136$, $V(S1 \geq S3)=0.530$;

$V(S2 \geq S1)=1$, $V(S2 \geq S3)=1$;

$V(S3 \geq S1)=1$, $V(S3 \geq S2)=0.629$.

Then priority weights are calculated by using Equation 4.18 shown in Section 3 of the extent analysis as follow:

$d'(C1) = \min(0.136, 0.530) = 0.136,$

$d'(C2) = \min(1, 1) = 1,$

$d'(C3) = \min(1, 0.629) = 0.629.$

$W' = (0.136, 1, 0.629)$

Collected priority weights are shown in vector W'. Finally after normalisation of these values as per Equation 4.20 shown in Section 4 of the extent analysis, priority weights in respect to the main goal will be calculated as follows for each criterion in Table II.18:

$W = (0.078, 0.566, 0.356)$

After pair-wise comparisions and global weights' calculations using Level 2 and Level 3 risk factors the final results for the country, business and organisational risk factors are illustrated in Tables II.19, II.20 and II.21 respectively (results for operational risk factors were already illustrated in Chapter 4). In the following tables the final ranking of the risk factors are shown just after the global weights. Final ranking of the risk factors are based on their weight magnitute.

Table II.19: Level 3 Country Risks – Global weights and rankings

Level 1 Risk	Level 2 Risks	Local Weights	Level 3 Risks	Local Weights	Global Weights	Rankings
Country Risks	Macro-economic Practices	0.312	Economic invigoration	0.519	0.162	2
			Stability in interest and foreign exchange rates	0.181	0.056	7
			GDP growth	0.202	0.063	5
			Balancing of national saving and dept	0.097	0.030	10
	Political and Social Systems	0.061	Political stability	0.477	0.029	11
			Government efficiency and incorrupt ion	0.357	0.022	14
			Internationalisation	0.058	0.003	19
			Social stability	0.108	0.007	18
	Foreign Enterprise Policy	0.052	Capital and remittance control	0.556	0.029	12
			Tax incentives	0.260	0.014	16
			Trade restriction	0.184	0.010	17
	Port Development Policy	0.204	Port organisation pattern	0.156	0.032	9
			Liberalisation and internationalisation degree	0.325	0.066	4
			Industrial potential in neighbouring areas	0.414	0.085	3
			Positioning relative to ports within a nation	0.105	0.021	15
	Port Management Policy	0.371	Private financing of port infrastructure and equipments	0.073	0.027	13
			Port/terminal dues and charges	0.632	0.235	1
			Efficient port operation policy	0.155	0.057	6
			Custom practice	0.140	0.052	8

Table II.20: Level 3 Business Risks – Global weights and rankings

Level 1 Risk	Level 2 Risks	Local Weights	Level 3 Risks	Local Weights	Global Weights	Rankings
Business Risk	Competition Factors (CF)	(0.566)	Port (Terminal) Efficiency (PTE)	(0.186)	(0.1052)	**3**
			Landside Accessibility (LA)	(0.061)	(0.0345)	11
			Cargo Handling Charges (CHC)	(0.184)	(0.1040)	4
			Logistics and Value Added Services (LVAS)	(0.095)	(0.0532)	7
			Port/offshore terminal Reliability (PR)	(0.022)	(0.0124)	15
			Depth of Water (DW)	(0.047)	(0.0266)	13
			Port/offshore terminal Location (PL)	(0.026)	(0.0147)	14
			Shipping Frequency (SF)	(0.173)	(0.0970)	5
			Adequate Service (AS)	(0.085)	(0.0480)	9
			Port's Response to User's Need (PRUN)	(0.049)	(0.0273)	12
			Ability to Changing Market Environment (ACME)	(0.072)	(0.0403)	10
	Industry Change (IC)	(0.357)	Fluctuation in Shipping Industry (FSI)	(0.312)	(0.1113)	**2**
			Consolidation among Ocean Carriers (CAOC)	(0.140)	(0.0499)	8
			Potential for Global Substitutes for Port/offshore terminal Users (PGSPU)	(0.548)	(0.1956)	**1**
	Customer Change (CC)	(0.080)	Increase in Ship Size (ISS)	(0.080)	(0.0800)	6

Table II.21: Level 3 Organisational Risks – Global weights and rankings

Level 1 Risk	Level 2 Risks	Local Weights	Level 3 Risks	Local Weights	Global Weights	Rankings
Organisational Risk	Organisational Structure (OS)	(0.161)	Lack of Subdividing Tasks & Responsibility among departments (LSTRD)	(0.307)	(0.0494)	8
			Lack of Achieving Co-ordination between Departments (LACD)	(0.693)	(0.1115)	3
	Management (M)	(0.122)	Lack of Direct Authority to Effect Remedial Action (LDAERA)	(0.286)	(0.0349)	9
			Quality Required by the Job for Senior Managers (QRJSM)	(0.437)	(0.0539)	7
			Lack of Adequacy in Upgrading Knowledge (LAUK)	(0.189)	(0.0230)	13
			Lack of Continuity in Senior Managers Position's (LCSMP)	(0.088)	(0.0107)	18
	Quality Process (QP)	(0.353)	Lack of Procedures, Manuals, Documents and Records (LPMDR)	(0.445)	(0.1570)	1
			Lack of Processes e.g. Ship inspection, etc (LPSI)	(0.306)	(0.1080)	4
			Lack of Process e.g. Internal Inspection and Control (LPIIC)	(0.193)	(0.0681)	6
			Lack of Customer Related Processes (Complaints) (LCRPC)	(0.056)	(0.0197)	15
	Human Resource (HR)	(0.118)	Lack of Decision Making (LDM)	(0.039)	(0.0047)	20
			Lack of Qualification (LQ)	(0.238)	(0.0280)	11
			Lack of Experience (LE)	(0.219)	(0.0258)	12
			Lack of Training (LT)	(0.195)	(0.0230)	14
			Lack of Judgment (LJ)	(0.002)	(0.0003)	21
			Lack of Safety Culture and… (LSCHA)	(0.126)	(0.0148)	16
			Poor Communication (PC)	(0.101)	(0.0119)	17
			Lack of Skills (LS)	(0.080)	(0.0094)	19
	Key Performance Indicators (KPI)	(0.246)	Port/terminal Operational Performance indicators (POPI)	(0.548)	(0.1348)	2
			Port/terminal Financial Performance indicators (PFPI)	(0.312)	(0.0767)	5
			Port/terminal Quality Performance indicators (PQPI)	(0.140)	(0.0344)	10

APPENDIX III

Questionnaire used in Survey 2 for the purpose of Chapter 5

Liverpool John Moores University
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Email : k.mokhtari@2007.ljmu.ac.uk
Date : 21.09.2010

Dear Sir,

As offshore terminals and marine ports are valuable assets, in today's uncertain and complex environment further refinements are needed to assess risk factors and prioritise protective measures for these critical logistics infrastructures. From other hand the problem facing port professionals, such as port risk managers and port auditors is lack of an appropriate methodology upon which to base their evaluation techniques to support the ports risk management strategies.

A research project at Liverpool John Moores University is currently being carried out with regard to a generic risk assessment model which is based on a risk management framework of offshore terminals and marine ports. The proposed model is intended to be applied on real offshore terminal and marine port cases. Now the requirement for this investigation is to use experts' judgements who are working in the related fields and to rate the motioned risk factors on the nominated ports. Eventually outcome of this survey can help port professionals and port risk managers to audit and compare their ports. In latter stages this will lead to develop appropriate strategies to take preventive/corrective actions for mitigating risk factors toward a successful port and terminal operations and management.

Thus this survey sets out to provide an organized method for collecting views and information pertaining to the implementation of an appropriate risk management framework in offshore terminals and marine ports. I should be most grateful if I could ask you to spare some of your very valuable time to complete the accompanying questionnaire and to email or post it to myself at the address as shown above. Your vital feedback will greatly benefit and contribute in the formulation of an industry wide opinion. I can assure you that the confidentiality of your response will be honoured and respected.

Best Regards
Captain Kambiz Mokhtari
PhD Student
MSc, BSc, Master Mariner, MICS

SECTION 1: PERSONAL DETAILS

- Please mark the appropriate answer for each question:

1. Please mark your age range:

   A. Less than 30 years old

   B. Between 30 and 40 years old

   C. 40 years old or more

2. Please mark your appropriate qualification:

   A. Postgraduate

   B. Undergraduate

   C. High School Diploma

3. Please mark your work experiences:

   A. Work experience < 10

   B. $10 \leq$ Work experience ≤ 20

   C. $20 <$ Work experience

SECTION 2: MEASUREMENT SCALES

Table III.1: Different Grades for rating of the Operational Risk Factors

Occurrence Likelihood (OL)	Grade	Consequence Severity (CS)
Very Low	1	Slight
Low	2	Minor
Medium	3	Moderate
High	4	Critical
Very High	5	Catastrophic

SECTION 3: EXPLANATIONS AND EXAMPLES

Please study the operational risks model in Figure III.1. Subsequently fill the empty spaces of the evaluation sheet shown in Table III.2 by selecting the appropriate grades from Table III.1 for the Ports of Bushehr, Shahid Rajaie and Chabahar. Empty spaces must be filled with respect to the 22 operational risk factors shown in Level 3 of the operational risks model in Figure III.1. As it is shown in Table III.1 "Occurrence Likelihood" describes the frequency happening of the risk factors depicted in the model which may occur within the mentioned ports, whereas the "Consequence Severity" describes the magnitude of the possible losses if these risk factors happen in the selected ports.

With respect to the mentioned operational risk factors during ports' and terminals' operations and management in Ports of Bushehr, Shahid Rajaie and Chabahar following question is an example which will help in filling the evaluation sheet shown in Table III.2.

Question: What is the Occurrence Likelihood (OL) of the risk factor of "Pilots' related errors i.e. R_{52}" in Port of Shahid Rajaie? How severe can be the Consequence Severity (CS) of any "Pilots' related errors" affect and cause loss or damage to the Port of Shahid Rajaie?

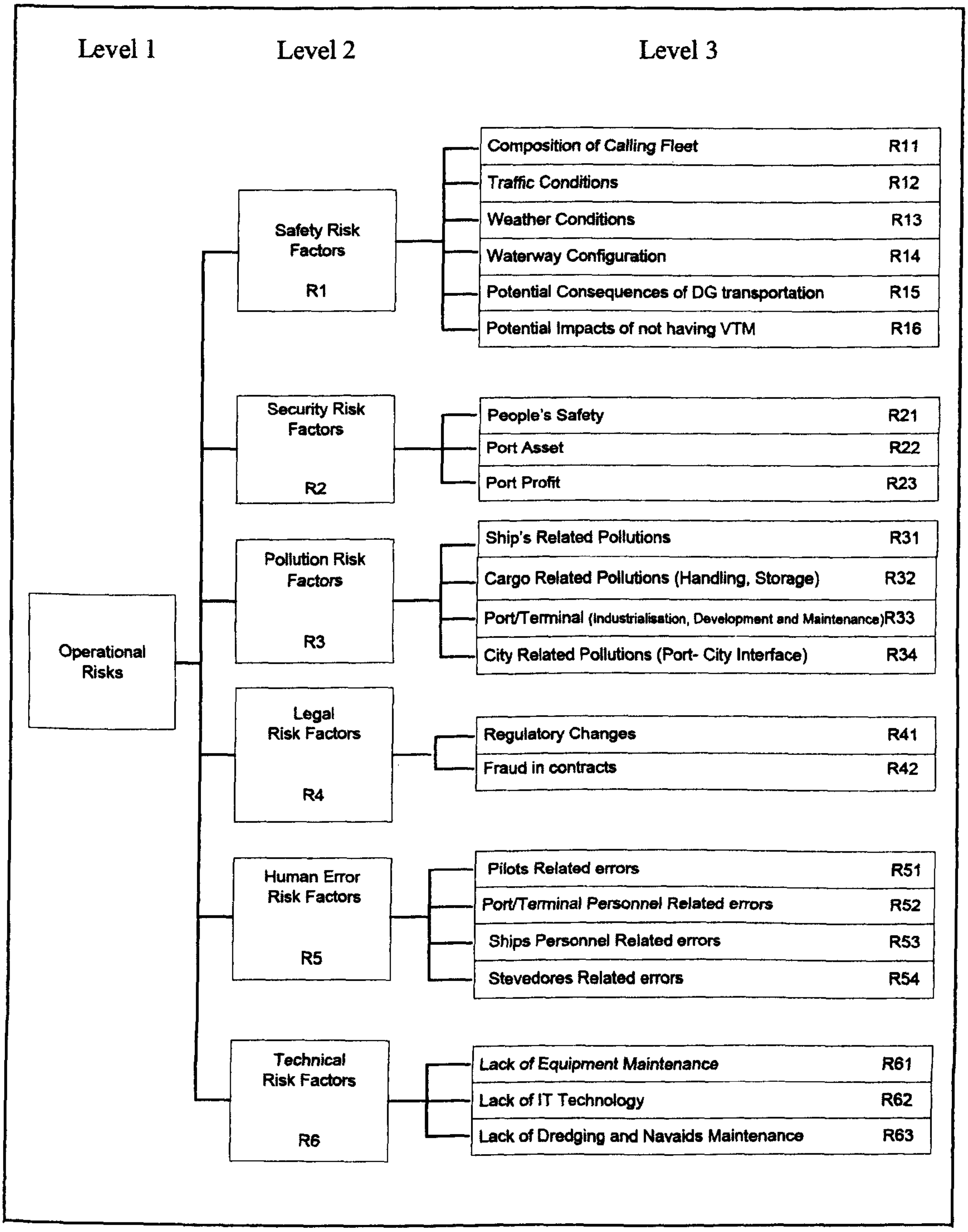

Figure III.1: Operational risk model to be used during offshore terminals' and marine ports' operations and management

SECTION 4: RISK SCORING SHEET

Table III.2: Evaluation sheet.

Risk	Name of Risks	Bushehr		Shahid Rajaie		Chahbahar	
		OL	CS	OL	CS	OL	CS
R411	Composition of Calling Fleet						
R412	Traffic Conditions						
R413	Weather Conditions						
R414	Waterway Configuration						
R415	Potential Consequences of DG Transportation						
R416	Potential Impacts of not having V.T.M						
R421	Security of peoples in port						
R422	Security of port's Assets						
R423	Security of Port's Profit						
R431	Ship's Related Pollutions						
R432	Cargo Related Pollutions						
R433	Port Related Pollutions e.g. Port Development						
R434	City Related Pollutions (Port and City interface)						
R441	Regulatory Changes						
R442	Fraud in contracts						
R451	Pilot's Related Errors						
R452	Port's Personnel Related Errors						
R453	Ship's Personnel Related Errors						
R454	Stevedore's Related Errors						
R461	Lack of Equipment Maintenance						
R462	Lack of IT Technology						
R463	Lack of Dredging and Navaids Maintenance						

APPENDIX IV

Questionnaire used in Survey 3 for the purpose of Chapter 6

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Date : 14.11.2010

JMU

Dear Sir,

Ports and offshore terminals are critical infrastructure resources and play key roles in the transportation of goods and people. With more than eighty percent of international trade by volume being carried out by sea, ports and offshore terminals are vital for seaborne trade and international commerce. Furthermore in today's uncertain and complex environment there is a need to analyse the participated risk factors in order to prioritise protective measures in these critically logistics infrastructures.

A research project at Liverpool John Moores University is currently being carried out with regard to a generic risk assessment model which is based on a risk management framework to identify the critical hazards that can lead to catastrophic damages to offshore terminals and marine ports. After identifying the most significant hazards it has been decided to investigate each hazard individually to check occurrence likelihood of the nominated causes and consequences of each hazard. Now the requirement for this investigation is to use experts' judgements who are working in the related fields to rate the causes and consequences of each hazards in order to detect the most significance ones. Eventually this can help port professionals and port risk managers to develop appropriate strategies and take preventive/corrective actions for mitigating risks toward a successful offshore terminals' and marine ports' operations and management.

Thus this survey sets out to provide an organized method for collecting views and information pertaining to the implementation of an appropriate risk management framework in offshore terminals and marine ports. I should be most grateful if I could ask you to spare some of your very valuable time to complete the accompanying questionnaire and to email or post it to myself at the address as shown above. Your vital feedback will greatly benefit and contribute in the formulation of an industry wide opinion. I can assure you that the confidentiality of your response will be honoured and respected.

Best Regards
Captain Kambiz Mokhtari
PhD Student
MSc, BSc, Master Mariner, MICS

SECTION 1: PERSONAL DETAILS

- Please mark the appropriate answer for each question:

1. Please mark your age range:

   A. Less than 30 years old

   B. Between 30 and 40 years old

   C. 40 years old or more

2. Please mark your appropriate qualification:

   A. Postgraduate

   B. Undergraduate

   C. High School Diploma

3. Please mark your work experiences:

   A. Work experience < 10

   B. 10 ≤ Work experience ≤ 20

   C. 20 < Work experience

SECTION 2: MEASUREMENT SCALES

Table IV.1: Different occurrence likelihood grades to be used for rating the causes and consequences of the risk factors

Occurrence Likelihood (OL)	Grade
Very Low	1
Low	2
Medium	3
High	4
Very High	5

SECTION 3: CASE STUDIES

CASE STUDY 1

Please read Table IV.2.1 which has listed the main causes for initiating a pilot's related errors which probably can lead to the accidents shown in Figure IV.1.

Table IV.2.1: Main causes of the pilot's related errors.

Main causes of pilot's related errors	Event No
Inappropriate command from pilot	Event 1
Pilot unaware of ship's behaviour	Event 2
Pilot make an error	Event 3
Ship master make an error of judgement	Event 4
Over friendly relation-ship with pilot	Event 5
Inadequate passage plan	Event 6
Inappropriate or fail aids	Event 7
Command execution failure	Event 8

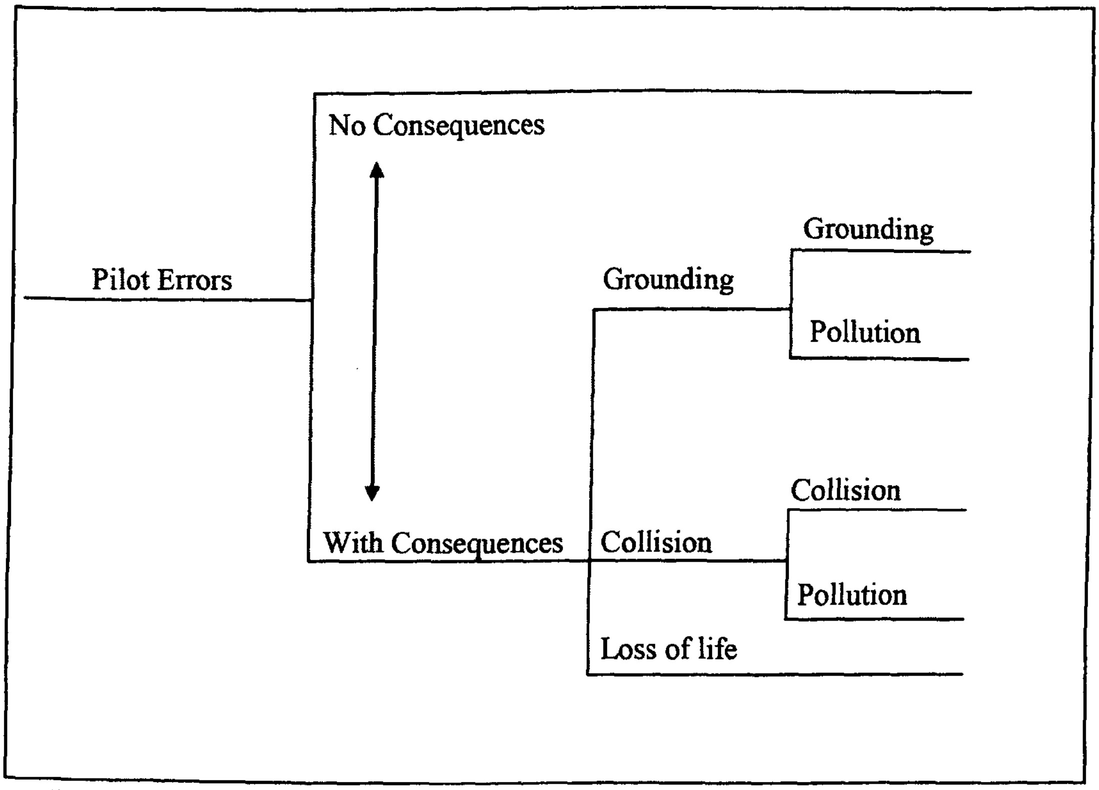

Figure IV.1: Event tree of consequences as a result of when a pilot makes an error

Now with using the occurrence likelihood grades illustrated in Table IV.1 mark the evaluation sheets in Tables IV.2.2 and IV.2.3.

Table IV.2.2: Evaluation Sheet.

Main causes of pilot error	**Event No**	**Occurrence Likelihood**
Inappropriate command from pilot	Event 1	
Pilot unaware of ship's behaviour	Event 2	
Pilot make an error	Event 3	
Ship master make an error of judgement	Event 4	
Over friendly relation-ship with pilot	Event 5	
Inadequate passage plan	Event 6	
Inappropriate or fail aids	Event 7	
Command execution failure	Event 8	

Table IV.2.3: Evaluation sheet.

Possibility of consequences after initiation of the security risk factors	**Occurrence likelihood**
Possibility of pilot's error without consequence	
Possibility of pilot's error with consequence of grounding	
Possibility of pilot's error with consequence of collision	
Possibility of pilot's error with consequence of loss of life	
Possibility of pilot's error with consequence of grounding but without further consequence of pollution	
Possibility of pilot's error with consequence of collision but without further consequence of pollution	

CASE STUDY 2

Please read Table IV.3.1 which has listed the main causes for damage to offshore terminals that eventually can lead into the consequences shown in Figure IV.2.

Table IV.3.1: Main causes of the damages to offshore terminals in Caspian Sea.

Basic Events (Hazards)
Terrorism and Sabotage
War and political perils
Ice damage
Storm damage
Earthquake and Tsunami

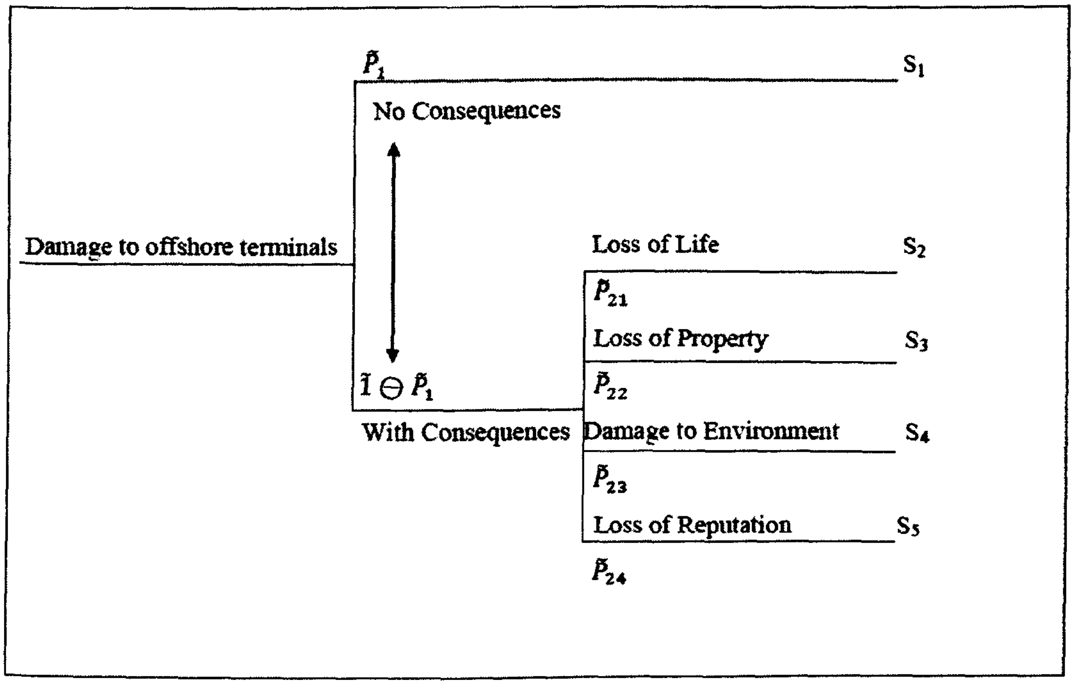

Figure IV.2: Event tree of consequences as a result of damages to offshore terminals

Now in respect of the Caspian Sea while using the occurrence likelihood grades illustrated in Table IV.1 mark the evaluation sheets shown in Tables IV.3.2 and IV.3.3.

Table IV.3.2: Evaluation Sheet.

Main causes for damage to offshore terminals	**Possibility**
Terrorism and Sabotage	
War and political perils	
Ice damage	
Storm damage	
Earthquake and Tsunami	

Table IV.3.3: Evaluation sheet.

Consequences as a result of damages to offshore terminals	**Occurrence likelihood**
Possibility of damage to offshore terminal without consequence	
Loss of life	
Loss of property	
Damage to environment	
Loss of reputation	

APPENDIX V

Questionnaire used in Survey 4 for the purpose of Chapter 7

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Email : k.mokhtari@2007.ljmu.ac.uk
Date : 16.02.2011

Dear Sir,

Security assurance across maritime trading systems is a critical factor for international transport and logistics and in the evolution of international trade generally. A security attack on a petrochemical port or an offshore terminal, especially if several of such attach occur simultaneously, can disrupt nations' economies. This in fact can result in severe impact on economy, health, safety of people and public, environmental pollution and damage as well as casualties.

A research project at Liverpool John Moores University is currently being carried out with regard to a risk management framework to identify, assess and manage the critical hazards that can lead to catastrophic damages to offshore terminals and marine ports. After identifying and assessing the most significant hazards among them the foremost significant one revealed was security related risk factor. As a result due to importance of the mentioned risk factor it was decided to define a separate strategy for managing of the security risk factor. Now the requirement for this investigation is to use an expert's judgement who is working in the related fields to score the security risk factors shown in the provided security risk factor table. After rating of all security risk factors the total score in later stage will be determined to present the security risk status for the selected site. Eventually this can help port professionals and port risk managers to develop appropriate strategies and take preventive/corrective actions for mitigating security threats toward a successful offshore terminals' and marine ports' operations and management.

Thus this survey sets out to provide an organized method for collecting views and information pertaining to the implementation of an appropriate risk management framework in offshore terminals and marine ports. I should be most grateful if I could ask you to spare some of your very valuable time to complete the accompanying questionnaire and to email or post it to myself at the address as shown above. Your vital feedback will greatly benefit and contribute in the formulation of an industry wide opinion. I can assure you that the confidentiality of your response will be honoured and respected.

Best Regards
Captain Kambiz Mokhtari
PhD Student
MSc, BSc, Master Mariner, MICS

SECTION 1: PERSONAL DETAILS

- Please mark the appropriate answer for each question:

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   A. Less than 30 years old

   B. Between 30 and 40 years old

   C. 40 years old or more

2. Please mark your appropriate qualification:

   A. Postgraduate

   B. Undergraduate

   C. High School Diploma

3. Please mark your work experiences:

   A. Work experience < 10

   B. $10 \leq$ Work experience ≤ 20

   C. 20 < Work experience

SECTION 2: MEASUREMENT SCALES

Table V.1: Linguistic scales used for rating of the security risk factors in Table V.2.

Linguistic scales
Low
Medium
High

SECTION 3: EXPLANATIONS AND EXAMPLES

Please read the following case studies carefully to determine security risk status within the described petrochemical sea port and offshore terminal. To perform this task security risk factors for both sites will be rated by using Table V.3. After rating the all security risk factors using the mentioned linguistic scales in Table V.3 in later stage total score will be obtained to determine security risk status for each site. Finally this will result to take appropriate security measures and to select the suitable advised recommendations based on a total score obtained from table for each site. Now with respect to the security risk factors associated with petrochemical sea port and offshore terminal which are depicted in the following case studies first read the below examples and then start rating the security risk factors shown in Table V.3.

Example 1: In your opinion in Case Study 1 the illustrated petrochemical sea port of (α) has located near to which areas? Answer: urban

Example 2: In Case Study 2 what is your opinion regarding the existing security measures taken by the illustrated offshore terminal in respect of the access control from sea? Answer: High level

CASE STUDY 1: PETROCHEMICAL SEA PORT OF (α)

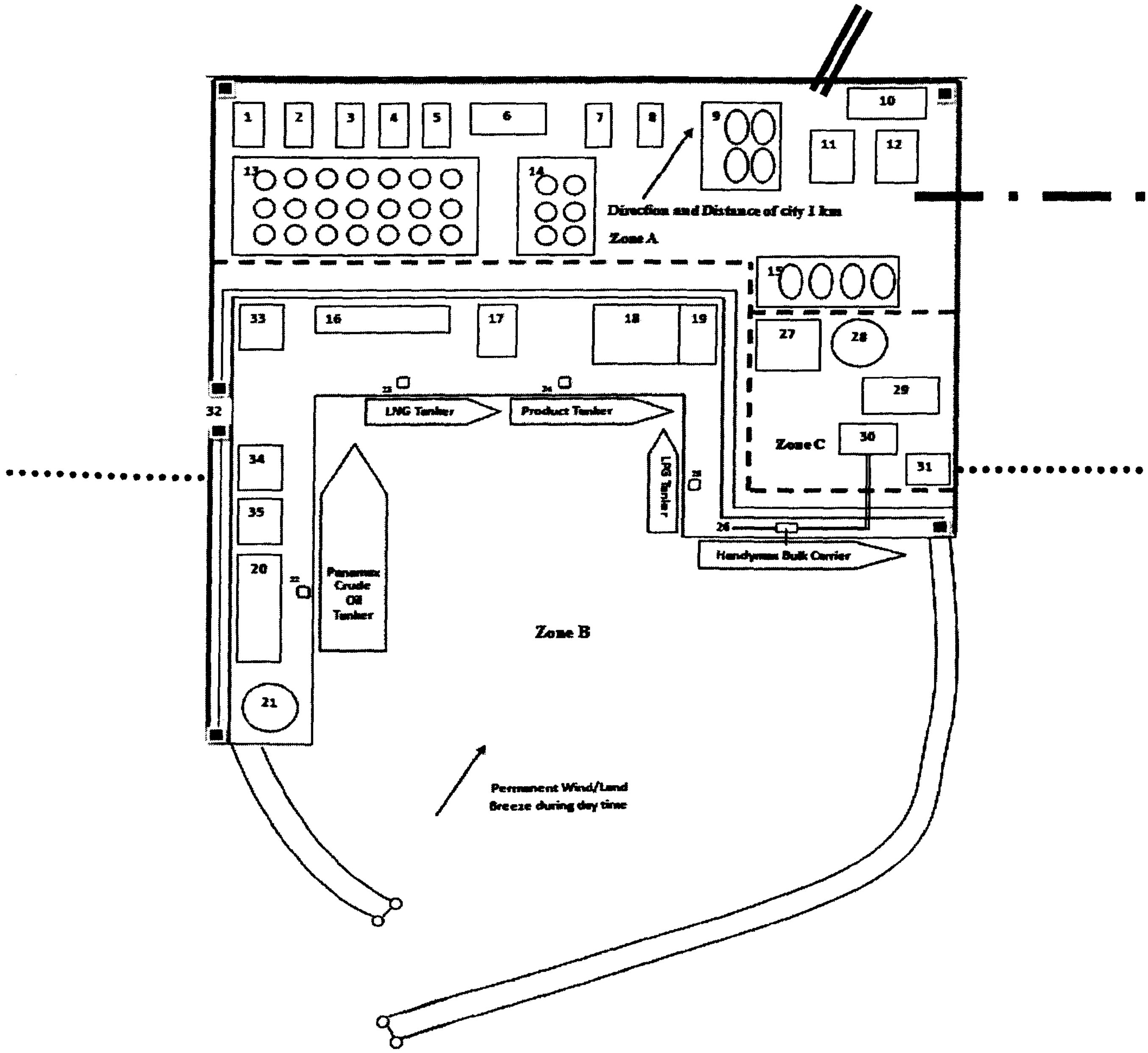

Figure V.1: Sketch for Petrochemical Sea Port of (α)

Table V.2: Area description for Petrochemical Sea Port of (α)

Zone A (Refinery)	Zone B (Harbour and Terminals)	Zone C (Fertilizer Plant)
1 Atmospheric distillation unit	16 Canteen	27 Power Plant
2 Vacuum distillation unit	17 Seaman Club	28 Coal storage
3 Catalytic reforming unit	18 Administrative Building for Oil Refinery	29 Urea Plant
4 Calcinations unit	19 Administrative Building for Fertilizer Plant	30 Urea storage and Bagging plant
5 Coker unit	20 Car and port's machinery parking	31 Ash Pond
6 DSC Control room	21 Port Control	
7 Ammonia Plant	22 Crude Oil Import Terminal	
8 LPG bottling	23 LNG Import Terminal	**Symbols and limits**
9 Naphtha Tank Farm	24 Naphtha Export Terminal	
10 Power Plant	25 Ammonia Export Terminal	Coast Lines
11 Control room	26 Fertilizer Export Terminal	Rail way
12 Effluent treatment plant	32 Gate	Export Pipelines
13 Crude Oil Tank Farm	33 Guard room	Fences
14 Natural Gas Tank Farm	34 Administrative Block	Zone Margins
15 Ammonia Tank Farm	35 Fire Brigades	Guard Towers

Sea Port (α) shown in Figure V.1 is a petrochemical complex including different parts as explained in Table V.2 and as follows:

- Zone A: a refinery with different petrochemical units for refining the imported crude oil and natural gas with the ability to produce naphtha, ammonia and other types of petrochemical products;

- Zone B: including import terminals for receiving and storage of crude oil and LNG cargo by Crude Oil Carriers and LNG tanker ships as well as export terminals for exporting naphtha by product carriers, ammonia by LPG tankers and bagged fertilizer cargo i.e. urea by dry bulk cargo ships;

- Zone C: a fertilizer plant with capability to produce urea.

Petrochemical port (α) is situated within 1 km distance from a very small city. The direction of the city from the port is shown in Figure V.1. As it is shown there is always a permanent wind gusting only during daytime from sunrise to sunset in the form of land breeze from sea toward shore in the shown direction. Except some of the tall buildings in the petrochemical complex, port storage tanks, ships and other units situated within the harbour, refinery and fertilizer plant are not visible from outside the port. Vertical tall walls and existing break water around the port make all of them obscured and invisible. The port is under ownership of the government. Up to the time there have not been any reports for terrorist activities except some criminal actions that have happened outside the port area. There has not been any type of accident reported. Traffic conditions, types and volume of hazardous cargoes are traceable through port authorities by the involved bodies or persons.

The port authority has been implementing the ISPS Code since July 2006. Ship to port security interface ISPS procedures and formalities are always maintained in very high intensity. Existing security measure types along with the other security risk factors which are considered as the most important contributing factors affecting the port are all listed in the Table V.3.

CASE STUDY 2: ILLUSTRATIVE EXAMPLE OF AN OFFSHORE TERMINAL

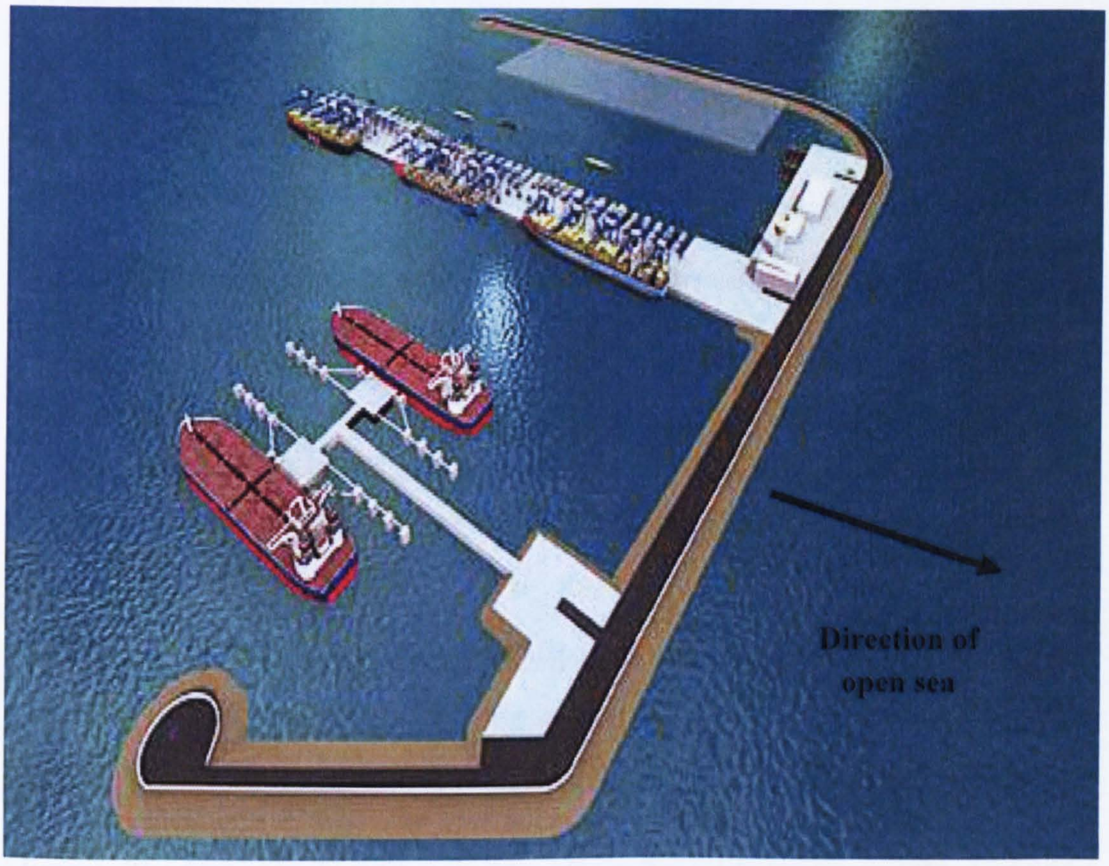

Figure V.2: Offshore Terminal of Venice under study

Halcrow Group Limited is owned by the Halcrow Trust and employee shareholders (a UK based company). It was appointed by Venice Port Authority to carry out a feasibility study in November, 2010 for a new £1.1 billion offshore deep water terminal outside Venice Lagoon. As part of the encouraged plan, a new platform will be positioned about 14km, from the mainland where the depth of water is 20m. The Port of Venice is part of the new Northern Adriatic multiport system, created to play a greater role in handling extra Europe-Asia and Europe-Mediterranean cargo flows over the next ten years. The offshore terminal will provide a consolidated port base in the Mediterranean and absorb incoming vessels from the Suez Canal. The location of the Port of Venice (and that of other North Adriatic ports) is exceptionally suitable for goods imported or exported both from markets in the Far East and those in the Southern Mediterranean. The port will also act as a "refuge berth" when the MOSE barriers (Venices' anti-flood system) are closed.

The port will be equipped to receive oil tankers, container ships, feeder container ships as well as to provide space for future expansion into other categories of goods, such as solid bulk cargo coming in on Capesize vessels.

The shown offshore terminal is divided into three separate zones of A, B and C shown in Figure V.3 and is explained as follows.

The offshore terminal shown in Figure V.3 is equipped to receive crude oil tankers via T-jetties of Alpha and Bravo, (see Zone A). The two berth oil terminal site is designed to receive ships of over 150,000 tonnes, unloading directly into an underwater pipeline linked to the onshore refineries.

Additionally the mentioned offshore terminal has three container terminals namely Terminal 1, 2 and 3 (see Zone B). They enable containers to be transferred to or from inland terminals where they can be processed and distributed by rail and road links to the main local inland routes, as well as to and from markets in central and Eastern Europe. The facility is able to handle three ships of capacity between 6,000 and 14,000 TEU at the same time. Each container terminal has five gantry cranes and ten small semi locked jetties enabling smaller container feeder ships operating between onshore and offshore terminals to load and discharge containers constantly.

Support services (see Zone C) including terminal's port control, master tug boats, pilot vessels, coast guard, HSE and security section, emergency heliport, medical centre, buildings for staff, canteens and offices all of which are supplied by undersea electrical cables supplemented with electricity derived from renewable sources. The outer breakwater will protect the terminal in all weather.

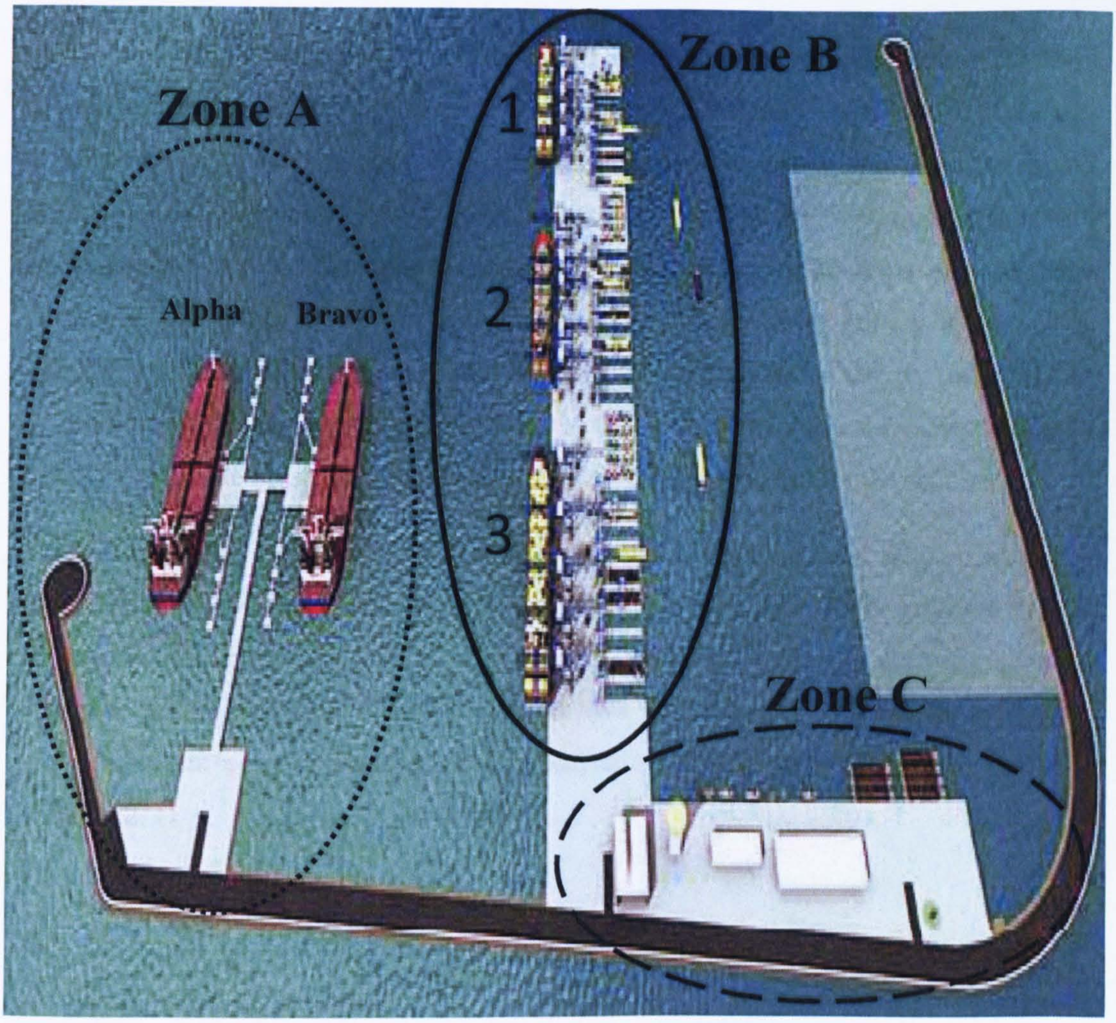

Figure V.3: Venice Offshore Terminal

Venice offshore terminal is near eight nautical miles from the Port of Venice situated in Northeast of Italy in Adriatic Sea. This offshore terminal apart from visiting ships and other official visitors coming from the mainland is designed to accommodate 105 staff working in the site involved with different operations. The facility is owned and handled by a private Italian company looking after a medium range of shipping traffic within the facility. Occasionally there are swells and wind gusts coming from open sea, the direction from which is shown in Figure V.2. In this context for the safety reasons the breakwater of the facility is designed in such a way to minimise the effect of winds and swells to provide a good shelter for visiting ships. The breakwater also helps to reduce the visibility of the berthed ships and the whole operations within the facility for the purpose of security. Although there are no storage tanks for the processed gases and chemicals within the site but the terminal always handles lots of containers in the form of Dangerous Good (DG) Containers. These specially designed containers in fact carry different types of IMO classed DGs such as different hazardous processed gases and chemicals. As soon as the mentioned DG containers arrive to site, very quickly they will be transferred and loaded into the outgoing container or feeder ships but only will remain on the jetties in terminals 1, 2 and 3 for a very short period of time. The imported crude oil will be pumped out from the berthed crude oil tankers via pipelines to shore based refineries or other destinations. There is no history on security incidents or any sign for the presence of terrorist groups or similar activities in the regions.

The Venice Port Authority and in fact this offshore facility have been implementing the ISPS Code since July 2006. Ship to port security interface ISPS procedures and formalities are always maintained in very high level and intensity. Existing security measure types along with the other security risk factors which are considered as the most important contributing factors affecting this offshore terminal are all listed in Table V.2.

Table V.3: Security Risk Factor Table (SRFT) for petrochemical sea ports and offshore terminals

Security risk factors	Linguistic Scales for rating security risk factors			Security Auditor's ratings	
Site's location	Rural	Urban	High Density		
Visibility status of ships and storage tanks	Not Visible	Less Visible	Highly Visible		
Processed gas and liquid chemicals storage	Medium	Large	Very Large		
Imported crude oil and natural gas storage	Medium	Large	Very Large		
Tanker ships traffic	Low	Medium	High		
Site's ownership	Private	Public/Private	Government		
Presence of terrorist groups in region	Low quantity	Medium quantity	Large quantity		
Worst impact on-site	Low	Moderate	Severe		
Worst impact off-site	Low	Moderate	Severe		
History of security incidents in site	Nil	Few	Frequent		
Meteorological conditions	Good	Moderate	Bad		
Target identification – chemical – by terrorists:					
• **CW (Chemical Weapon) agents**	None	Minimum	Present		
• **Listed chemicals of concern**	None	Minimum	Present		
• **Chemicals of extreme toxicity**	None	Minimum	Present		
Existing security measures:					
• **Access control from land**	High level	Ordinary	Poor/Ordinary		Poor/none
• **Access control from sea**	High level	Ordinary	Poor/Ordinary		Poor/none
• **Perimeter protection**	High level	Ordinary	Poor/Ordinary		Poor/none
• **Mitigation potential**	High level	Ordinary	Poor/Ordinary		Poor/none
• **Proper lighting (All over the port)**	High level	Ordinary	Poor/Ordinary		Poor/none
• **Use of metal detector/X-ray/ CCTV (at entrance and at all critical locations)**	High level	Ordinary	Poor/Ordinary		Poor/none
• **Pre-arrival security control of ships**	High level	Ordinary	Poor/Ordinary		Poor/none
• **Security inspection of ships in terminals before cargo operations begin**	High level	Ordinary	Poor/Ordinary		Poor/none
Employees preparedness, awareness and trainings	Well prepared	Average	Poor		
Reliability and status of readiness of emergency units e.g. health, safety, environment, security	Well prepared	Average	Poor		

APPENDIX VI

Questionnaire used in Survey 5 for the purpose of Chapter 8

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Date : 11.05.2011

JMU

Dear Sir,

Ports and offshore terminals are critical infrastructure resources and play key roles in the transportation of goods and people. With more than eighty percent of international trade by volume being carried out by sea, ports and offshore terminals are vital for seaborne trade and international commerce. Furthermore in today's uncertain and complex environment there is a need to analyse the participated risk factors in order to prioritise protective measures in these critically logistics infrastructures. Protective measures must be identified and selected using appropriate tools and techniques.

A research project at Liverpool John Moores University is currently being carried out with regard to a risk management framework to identify, assess and manage the critical hazards that can lead to catastrophic damages to offshore terminals and marine ports. After identifying and assessing the most significant hazards it has been decided to introduce and select the best strategies in order to mitigate the risk factors. Now the requirement for this investigation is to use experts' judgements who are working in the related fields to rate and select the best strategies for mitigating the identified risk factors. Eventually this can help port professionals and port risk managers to develop appropriate strategies and take preventive/corrective actions for mitigating risks toward a successful offshore terminals' and marine ports' operations and management.

Thus this survey sets out to provide an organized method for collecting views and information pertaining to the implementation of an appropriate risk management framework in offshore terminals and marine ports. I should be most grateful if I could ask you to spare some of your very valuable time to complete the accompanying questionnaire and to email or post it to myself at the address as shown above. Your vital feedback will greatly benefit and contribute in the formulation of an industry wide opinion. I can assure you that the confidentiality of your response will be honoured and respected.

Best Regards
Captain Kambiz Mokhtari
PhD Student
MSc, BSc, Master Mariner, MICS

SECTION 1: PERSONAL DETAILS

- Please mark the appropriate answer for each question:

1. Please mark your age range:

   A. Less than 30 years old

   B. Between 30 and 40 years old

   C. 40 years old or more

2. Please mark your appropriate qualification:

   A. Postgraduate

   B. Undergraduate

   C. High School Diploma

3. Please mark your work experiences:

   A. Work experience < 10

   B. $10 \leq$ Work experience ≤ 20

   C. $20 <$ Work experience

SECTION 2: MEASUREMENT SCALES

Table VI.1: Grades used for showing importance of the best strategy for mitigating the Level 2 risk factors shown in Figure VI.1

Effect of the mitigation or control options over the level 2 risk factors	Grade
Very Low	1
Low	2
Medium	3
High	4
Very High	5

SECTION 3: EXPLANATIONS AND EXAMPLES

First look at the general risk-based model used for the purpose of the offshore terminals' and marine ports' operations and management as shown in Figure VI.1. Subsequently fill the empty spaces of the evaluation sheet shown in Table VI.3 by selecting the appropriate grades from Table VI.1 for the purpose of mitigation or controlling the Level 2 risk factors listed in the said evaluation sheet. The grades in Table VI.1 show the effect or importance value of the ten mitigation or control options illustrated in Table VI.2 over the nineteen risk factors in Level 2. As a result empty spaces must be filled by selecting an appropriate importance value for each of the mitigation options against nineteen depicted Level 2 risk factors shown in Figure VI.1 and listed in Table VI.3. Now read the following examples and then by using the appropriate tables fill the evaluation sheet in Table VI.3.

Example 1: What is the importance of a VTMS (Vessel Traffic Management System) A8 (shown in Table VI.2) in order to mitigate the safety risk factor R11 (shown in Figure VI.1) during of offshore terminals' and marine ports' operations and management? Answer: Very High – Grade (5)

Example 2: What is the importance of (Privatisation) A2 (shown in Table VI.2) of a sea port or an offshore terminal in order to mitigate the competition risk factor R21 (shown in Figure VI.1) during the offshore terminals and marine ports?

Answer: Very High – Grade (5)

Example 3: What is the importance of (ISPS Code) A9 (shown in Table VI.2) in order to mitigate the quality process risk factor R33 (shown in Figure VI.1) during the offshore terminals and marine ports operations and management?

Answer: Very Low – Grade (1)

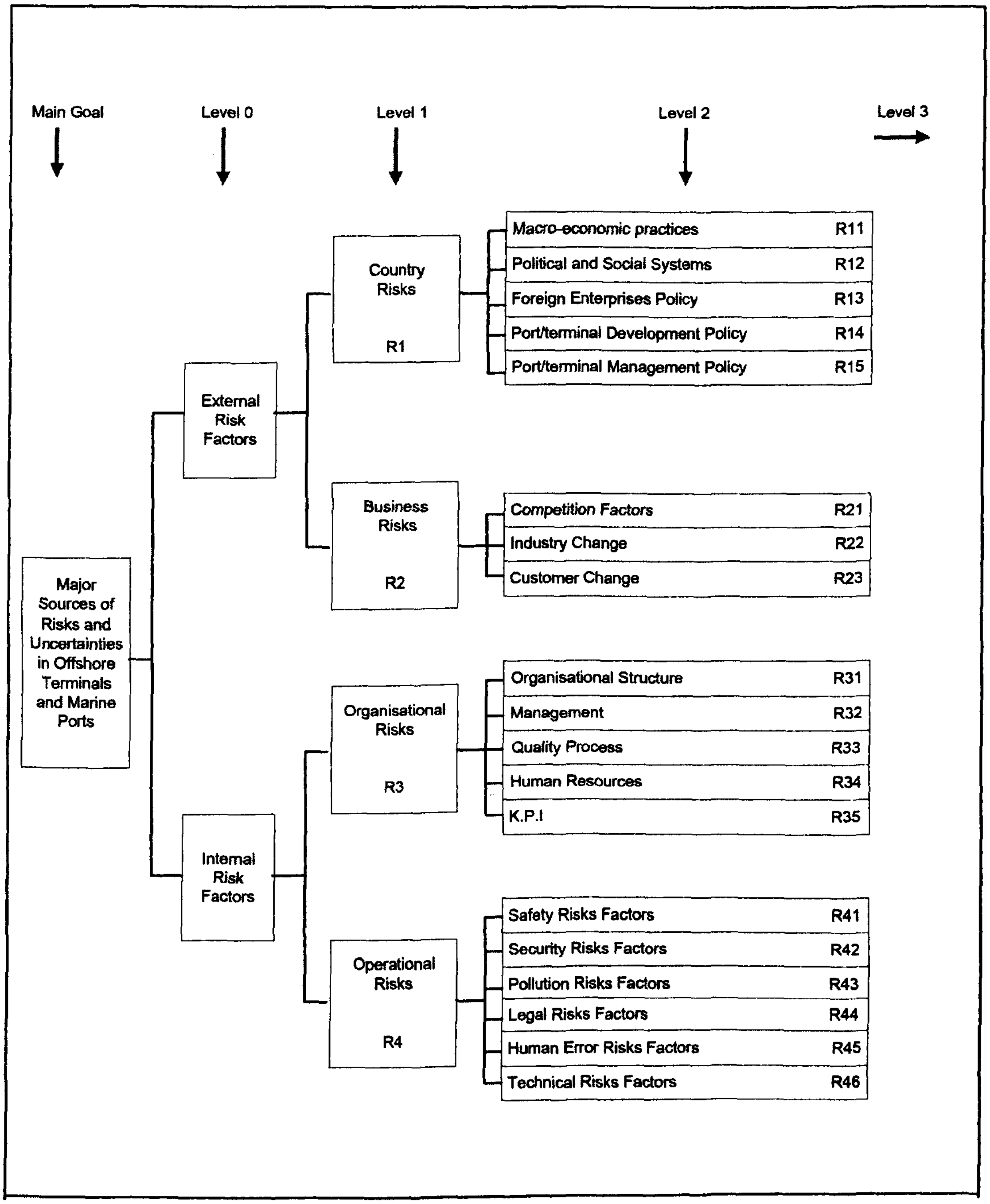

Figure VI.1: A generic risk-based model in offshore terminals and marine ports

Table VI.2: Best alternatives for mitigating Level 2 risk factors shown in Figure VI.1.

Alternatives	Names
A1	Internal Audits and Inspections
A2	Privatisation
A3	ISPS Code
A4	ISO 20000
A5	Port Risk Manager
A6	Safety Cases and Safety Reports
A7	IMS (ISO: 9000, 14000, 18000)
A8	VTMS
A9	Deregulation
A10	HSE-MS

Table VI.3: Evaluation sheet.

Level 2 Risk Factors	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
R11										
R12										
R13										
R14										
R15										
R21										
R22										
R23										
R31										
R32										
R33										
R34										
R35										
R41										
R42										
R43										
R44										
R45										
R46										

APPENDIX VII

First journal paper published as part of the thesis

APPENDIX
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