Risks Related to the Maritime Transportation of Oil and Gas (mainly Crude oil, LPG, and LNG)

-A Conceptual Study and Empirical Outlook on the Baltic Sea and UK Territorial Waters to Mitigate Risks

Yarmohammad Razmjooeee
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Master thesis

Subject Category: Technology

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Date: 07/05/2012

Keywords: Maritime transportation, Safety, Tanker, Crude oil, LPG, LNG, Risk, Accidents, Causes of accidents, Risk analysis
Acknowledgments

This master’s thesis represents the main part of my achievements within studying master program in the field of Industrial Engineering-logistics at university of Borås. Contribution and communication with professors, lecturers, and guest lecturers during this period of study inspired me in this field of study and also gave me the opportunity to update and enhance my knowledge in this field.

Hereby, I would like to express my deepest gratitude to all people and organizations for their help in enriching the quality of this thesis work.

I would like to acknowledge my supervisor Daniel Ekwall who really inspired me regarding this thesis work. His guidance and advises are appreciated.

I would like to thank Helsinki Commission (HELCOM) and Marine Accident Investigation Branch (MAIB) for their contribution by giving useful and related data.

I would like to thank my parents for their endless support throughout my life. Finally, thank to all my friends.
Abstract
Transportation of oil and gas by the Sea characterizes challenges from a safety viewpoint. In this type of transportation, different sizes of special tankers carrying oil and gas. The marine transportation of these scarce natural riches is involved with risks and hazards, which may lead to many losses; for instance, wasting oil and gas, injuries of people, damaging ships and properties, and damaging environment. The main purpose of this thesis is to evaluate the risks, hazards, and accidents during transportation of oil and gas (mainly Crude Oil, liquefied petroleum gas, and Liquefied natural gas) by the Sea with concentrating on transport safety. Hence, a better understanding of these risks and hazards can contribute to decrease of addressed losses.

This study is carried out on risks associated with maritime transportation of oil and gas starting with describing the general casual chain (dealing with causes, incidents, accidents and consequences/causalities), continuing with describing risk analysis techniques (including event tree analysis and fault tree analysis) and risk control measures/options, and finally implementing aforesaid investigations on real data from two areas; namely UK territorial waters and the Baltic Sea.

In this study, the results of analyzing data from 1991 to 2010 in UK territorial waters revealed that collision and grounding were two most common accidents in terms of crude oil tankers, LPG and LNG carriers in which 44% of all accidents were equally divided between collision and grounding. In this case, investigation on data from 2004 to 2010 in the Baltic Sea regarding tankers with cargo types of crude oil, oil, oil product and gases also repeated the same findings in that collision and grounding shared the biggest proportion of accidents with 50% and 34% respectively. Analysis of data in UK territorial waters provided that human factor was the main reason behind accidents with 46% followed by technical factor with 39%. Human factor and technical factor recognized also as the main causes of accidents in the Baltic Sea with 33% and 25% respectively. Regarding this subject, human error recognized as the chief culprit and failures in part of design & construction was the second main initial causes of accidents in terms of both human and technical factors. The results of analyzing records from the Baltic Sea also provided that whilst human factor shared the biggest proportion of causes behind accidents, technical factor was the only cause of accidents contributing to all types of accidents. Findings are useful from safety outlook as if specifying accidents and causes of accidents during the Sea transportation of oil and gas.

Key words: Maritime transportation, Safety, Tanker, Crude oil, LPG, LNG, Risk, Accidents, Causes of accidents, Risk analysis
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<tbody>
<tr>
<td>LPG</td>
<td>Liquefied Petroleum Gas</td>
</tr>
<tr>
<td>LNG</td>
<td>Liquefied Petroleum Gas</td>
</tr>
<tr>
<td>MAIB</td>
<td>Marine Accident Investigation Branch</td>
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<td>HELCOM</td>
<td>Helsinki Commission</td>
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<td>IMO</td>
<td>International Maritime Organization</td>
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<tr>
<td>ISM Code</td>
<td>International Safety Management Code</td>
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<tr>
<td>SMS</td>
<td>Safety Management System</td>
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<td>FSA</td>
<td>Formal Safety Management</td>
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<td>ETA</td>
<td>Event Tree Analysis</td>
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<tr>
<td>FTA</td>
<td>Fault Tree Analysis</td>
</tr>
<tr>
<td>DWT (dwt)</td>
<td>Deadweight tonnage</td>
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<tr>
<td>SA</td>
<td>Situation Awareness</td>
</tr>
<tr>
<td>ULCCs</td>
<td>Ultra-Large Crude Carriers</td>
</tr>
<tr>
<td>VLCCs</td>
<td>Very Large Crude Carriers</td>
</tr>
<tr>
<td>EC</td>
<td>European Commission</td>
</tr>
<tr>
<td>IEO</td>
<td>International Energy Outlook</td>
</tr>
<tr>
<td>MARIN</td>
<td>Maritime Research Institute Netherlands</td>
</tr>
<tr>
<td>UNEP</td>
<td>United Nations Environment Programme</td>
</tr>
<tr>
<td>ICS</td>
<td>International Chamber of Shipping</td>
</tr>
<tr>
<td>OCIMF</td>
<td>Oil Companies International Marine Forum</td>
</tr>
<tr>
<td>IAPH</td>
<td>International Association of Ports and Harbors</td>
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1 Introduction

1.1 Background
The issue of maritime transportation of dangerous goods with the risks they pose has gained more attention in comparison with recent past and it has become one of the most important hot subjects in today's environmental and transportation literature, which requires close scrutiny with great emphasis on sound and proactive risk management, mostly due to increasing global demand for crude oil and petroleum products as well as a consequent worldwide increase of tanker traffic (Iakovou 2001). In the case of accident, marine transport of dangerous goods has shared large proportion of accidents with fatalities compare to other modes of transport, especially when the dangerous goods come to the subject of oil and gas (Romer, Haastrius et al. 1995). Statistics is an evidence for maritime transportation of oil and gas by tanker to be as risky as transport it via underwater pipeline (Lesikhina, Rudaya et al. 2007). In spite of increasing and rapid proliferation of transportation of oil and gas by water in bulk, the risks and hazards still exist due to paucity of pondering over this subject. Reviewing of many accidents case histories depicts that ships carrying oil and gas were involved in very serious marine accidents in that many ships have been completely disappeared with cargoes on board in coastal and sensitive regions, large amount of these scarce and valuable natural riches are vanished over board, miles of beaches have been sealed for many days, and many people have been subjected to costly recovery or cleaning up operations. Marine transportation of oil and gas is keeping up to avoid accidents toward person, property and damage to the environment as far as possible. For this respect, strategic planning at different levels are intended wishing to improve the safety, health and protecting the marine environment. This thesis deals with recognizing and mitigating risks relating to the marine transportation of oil and gas, mainly in the cases of crude oil, liquefied petroleum gas (LPG), and liquefied natural gas (LNG) wishing to achieve the most efficiency.

1.2 Research questions
- What can go wrong? (identification of hazards and accidents scenarios, together with potential causes and outcomes)
- How bad and how likely? (risk assessment-use of risk analysis techniques)
- Can matter be improved? (assessing risk control options/measures to mitigate the identified risks)

1.3 Limitations
The theoretical part of this study looks into the purpose on the base of different sources and reports with related subjects. The empirical part of this study is limited to data from UK territorial waters and the Baltic Sea. Investigation of data from UK territorial waters is carried out concerning crude oil, liquefied petroleum gas (LPG), and liquefied natural gas (LNG). Analysis of data from the Baltic Sea is done regarding tankers with crude oil, oil, oil product, and gas cargos. The results can be useful for further investigations and decrease the risks and hazards during the Sea transportation of oil and gas in the future.
2 Methodology
This thesis is based on understanding and getting comprehensive information from library studies, reviewing several articles, reports, case studies, books, home pages, and empirical work on real records with relevant subjects to the purpose from four reliable methods. First, “Samsök”, which is a search engine from the University of Borås comprising many reliable databases such as Academic Search Premier, Business Source premier, DOAJ, Emerald Journals, IEEE Xplore, ScienceDirect, SpringerLink and Wiley InterScience, is used to find reliable articles and case studies with relevant subjects to the purpose of this thesis work. Second, three books are used; namely International Safety Guide for Oil Tankers and Terminals (ISGOTT), Assessing Safety Risks for the Sea Transport Link of a Multimodal Dangerous Goods Transport Chain, and Supply Chain Risk. Third, three homepages with their published reports; namely International maritime organization\(^1\) (IMO), Marine accident investigation branch\(^2\) (MAIB), and Helsinki commission\(^3\) (HELCOM) are used. Fourth, relevant numerical data related to the purpose is collected by MAIB and HELCOM.

2.1 Data collection & analysis
Collecting data from both MAIB and HELCOM were directly by contacting their organizations. Investigation on data from MAIB is carried out from 1991 to 2010 centralizing on Crude oil tankers, LPG and LNG carriers. Data collected from HELCOM covered related information to all types of ships from 1989 to 2010 but as during 1989 until 2003 types of ships were not specified, made it impossible to distinguish the oil tankers from other types of ships; therefore, analysis is focused on data from 2004 to 2010 concerning tankers with the cargo types of crude oil, oil, oil products, and gas. In the first step, analysis is carried out on data to finding the general causes of accidents, types of accidents and consequences in both UK territorial waters and Baltic Sea. Lack of information in terms of detailed causes of accidents from the Baltic Sea did not support the second step of analysis (risk analysis techniques); consequently, this part of analysis is done on the base of information regarding detailed causes of accidents in UK territorial waters. The third part of analysis (risk control options/measures) is carried out on the base of findings from the second part. It should be noted that although the second part of analysis is done on the base of availability of information in UK territorial waters, but findings in the presented part may works and be useful for the Baltic Sea as both areas provided almost the same results in the first step.

2.2 Research approach
In this research three methods used; namely qualitative, quantitative, and positivistic. Qualitative method is used in this study because the theoretical framework is constructed on the base of observation of previous studies, articles, reports and case studies related to the subject of this work. Quantitative approach is also used in this research as the numeric

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1 IMO is the United Nations specialized agency with responsibility for the safety and security of shipping and the prevention of marine pollution by ships.

2 Marine Accident Investigation Branch (MAIB) is responsible to investigate all types of marine accidents to or on board UK vessels worldwide, and other vessels in UK territorial waters.

3 Helsinki Commission (HELCOM) is liable of protecting the maritime environment of the Baltic Sea between the European community, Denmark, Estonia, Finland, Sweden, Germany, Poland, Latvia, Russia, and Lithuania.
records from MAIB and HELCOM are used for investigation and analysis in the empirical part. This thesis also follows positivistic paradigm as both theoretical and empirical sides are created with description and explanation and also the analysis are based on real data and information, which are tangible and objective in the environment. Hence, the analysis is based on the fact and valid information, which occurred in the nature.

2.3 Validity and Reliability

This study has the validity as investigation is implemented on valid data in the real world condition. I can say that this research is reliable provided that the same results as well as conclusions of any investigation with the same topic will repeat in the future.

All investigations and analysis in the empirical part of this research are done with relevant records from MAIB and HELCOM in the Excel sheet. The designation of Excel sheet containing records of vessel’s accidents was organized with a good quality format, which increased the accuracy of author to distinguish and separate the necessary and related information for reliable analysis and investigation.
3 Theoretical frame of references

In this part theories relating to the research issues, which are relevant to this thesis work, are described. The main purpose of this part is creating a theoretical framework and acquiring theoretical results from research questions.

3.1 Importance of maritime transportation system (maritime logistics)

Maritime transportation system or waterborne, by which the world has dramatically revolutionized, plays a vital role in international trade and world economic growth. It has also enhanced the growing of population, fast industrialization, eliminating and removing the obstacles of trading, road congestion, and etc (Christiansen, Fagerholt et al. 2007). So, it can be said that society is also affected by maritime transportation in four major features; namely economical, political, environmental, and social (Mullai 2006). Maritime transport is necessary to the appropriate operation of the economy of any nation and also it is imperative part of transport infrastructure of a country (Esq 2001). Another importance of maritime transportation is its connection to the whole transport chain and maritime industries cluster (EC 1996). Increasing of marine accidents (e.g. oil spill) and also tanker traffics derive from boosting global supply and demand of oil, gas, and petroleum products (Iakovou 2001). It goes without saying that maritime transportation has shared the biggest proportion of fulfilling of this worldwide demand/supply of crude oil and petroleum products. Minimizing the costs for both expected risk and transportation are the main purpose of the maritime transportation system for crude oil and petroleum products. Logistics researchers, governments, and agencies of governments are three major parties concerning the risks in transportation of oil and petroleum products. The presented parties implement legislation and guideline as well as instruction wishing to cope with the risks and also decrease the level of the risks (Iakovou, Douligeris et al. 1999). Cost is the main factor, which makes a sharp contrast between maritime transport and other types of transportation such as land and air transport. This merit also may raise a paradox, bearing in mind that fairly low cost of this type of transportation give rise to low standard of safety (Kristiansen 2004); however, the notion based on which many argue that the safety of standard in maritime transportation is low, can be refuted due to the fact that a large amount of bulky and dangerous goods such as crude oil, gas, and petroleum products are carried in today’s maritime transportation. On-the-other-hand, a lot of passengers is transported by the ships and they enjoy this voyage trip. In spites of all addressed advantages, it has some disadvantages given time and schedule in which it needs a longer time and also its schedule strongly depends on the weather condition. Three major parts of the operation of maritime transport industry are liner, tramp, and industrial shipping. In this case, the trump shipping refers to transportation of bulky products mainly crude oil. In this type of shipping, the schedule and routes of transport are unstable and also the price of transport is not regular and in the steady way. When the operation comes to the liner shipping, some factors such as price, routes, and ships as well as regular voyages are the same. Besides, sometimes it requires particular containers for natural gas (Tseng, Yue et al. 2005). It should be noted that in maritime transportation system, traffic patterns and its risks are in the conditional variables; for example, ice and wind modifies over time. So, system simulation is implemented by exporters to follow four main purposes; namely facilitating the design of port, evaluating the service levels of maritime transportation system,
carrying out the logistical analysis, and evaluating the change of risk in the maritime transportation system (van Dorp and Merrick 2011).

3.2 Crude oil, liquefied gases, and petroleum products

As can be seen in Figure 3.2-1 Crude oil, liquefied petroleum gas (LPG), and liquefied natural gas (LNG) are subsets of bulk dangerous goods.

Figure 3.2-1 Bulk dangerous goods sourced by Mullai (2006)

Crude oil, Liquefied petroleum gas (LPG), and Liquefied natural gas (LNG) are defined and explained in the same way in Investopedia4 and other sources. Crude oil or petroleum, also known as black gold is a simple natural or unrefined oil. The compounds of making crude oil are usually hydrocarbon. Diesel, gasoline, and other petrochemical products are produced after refining crude oil. The presented products are used for the power of different types of transportation such as aircraft, vessels, trains as well as motor vehicles in the world. Other types of oil products given motor gasoline, jet fuel, diesel fuel, and heating oil, supply the energy consumed by households, businesses, and manufacturers worldwide (Kenneth Grant 2006). Therefore, the demand for petroleum products, especially in the part of transportation clearly signifies the value of oil. The significance of consumption of crude petroleum is abundantly clear in the UK as a supply of many fuels; for example, oil gas, petrol fuel oil, and aviation fuel (Mackay and Probert 1996). Liquefied petroleum gas (LPG) is referred to a group of hydrocarbon-based gases, which are originated from crude oil and natural gas with the proportion of 45% and 55% respectively (Energy 2003). Liquefied natural gas or LNG, which consists of mainly methane and ethane, is cooled to -256 degrees Fahrenheit, which makes it easy to transport. The volume of natural gas as liquid is 1/600th of its volume as gas, which facilitate its transporting and storing, especially when the pipeline transportation is not

4 Investopedia is one of the Internet’s largest sites devoted entirely for investing education and is home to 13,000 dictionary entries, over 6,300 articles, and 750 pages of tutorials covering all aspects of finance and investing. http://www.investopedia.com/dictionary.
possible (Foss 2007). Exploration, liquefaction, shipping, and storage are the major stages of the LNG value chain. In addition, oil products and natural gas share the proportion of around 40 and 25 percent of the world energy consumption respectively, which is estimated from 2002 to 2025 (IEO 2005). The process of coming crude oil from the Alaska, South America, and Middle East to the port and transferring to the smaller tankers in the global waters is called lightering (Douligeris, Iakovou et al. 1997).

3.3 Tankers and containers
In this part, a brief description regarding oil and liquefied gas tankers, mainly crude oil and LPG tankers are represented.

3.3.1 Crude oil and oil tankers
Oil tankers, in the other words; petroleum tankers are designed for the bulk transport of oil. Basically, there are two sorts of oil tankers; namely crude tanker and product tanker. Product tankers are usually smaller compare to crude tankers. Crude tankers transport large amounts of crude oil from the point of extraction to the point of refineries; on the other hand, transporting petrochemicals from the point of refineries to the point of near consuming market is a task upon product market (Keever 2003).

Crude oil, liquefied gases (LNG, LPG), and petroleum products (such as gasoline, jet fuel, and others) are subsets of bulk liquid and for the type of cargo, they are placed in the bulk cargo. Transferring huge amount of presented bulk liquid cargoes are carried out by special designed tankers with bulk cargoes. Tankers and carriers have developed in size. Table 3.3.1-1 shows crude oil tankers with their sizes (Mullai 2006).

<table>
<thead>
<tr>
<th>Crude oil Tanker</th>
<th>Size</th>
</tr>
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<tbody>
<tr>
<td>ULCC - Ultra Large Crude Carrier</td>
<td>300,000 deadweight tonnage(^3) (dwt) plus</td>
</tr>
<tr>
<td>VLCC - Very Large Crude Carrier</td>
<td>200,000-300,000 deadweight tonnage (dwt)</td>
</tr>
<tr>
<td>Suezmax</td>
<td>100,000-149,999 deadweight tonnage (dwt)</td>
</tr>
<tr>
<td>Aframax</td>
<td>50,000-99,999 deadweight tonnage (dwt)</td>
</tr>
</tbody>
</table>

3.3.2 LNG and LPG tankers
Both LPG and LNG tankers are designed with high speed and this is the main characteristic of these tankers. LPG and LNG tankers have different sizes. The capacity of LPG tankers is up to 110,000m\(^3\); meanwhile, the capacity for LNG tankers is up to 140,000m\(^3\) and even the large vessels with the capacity of more than 200,000m\(^3\) are under development (Marin.nl). More detailed information about LPG, LNG, and Oil tankers are available through the homepage of Maritime Research Institute Netherlands\(^6\).

\(^5\) Deadweight tonnage (also known as deadweight, abbreviated to DWT, D.W.T., d.w.t., or dwt) is referred to a commonly used measure of a vessel’s carrying capacity in tons or how much weight they can carry safely.

\(^6\) Maritime Research Institute Netherlands is one of the leading organizations in the world for hydrodynamic research and maritime technology. It offers service to the shipbuilding, offshore industry, and governments.
3.4 General casual chain in maritime transportation

Figure 3.4-2, which is known as casual chain, demonstrates that how risks may happen in maritime transportation and sometimes give rise to destructive consequences such as loss of goods, loss of life, injuries and environmental damaging such as spillage of oil and gas and also pollution.

![Fig 3.4-2 General casual chain in maritime transportation](image)

Incident is referred to an unintended event, which may result to the accident; for instance, foggy weather or leakage of oil and gas tanker. Accident is referred to an unintended event (for example explosion or grounding) with a potential to damage the environment, loosing or damaging ship and property, injury, and fatality (Ellis, Forsman et al. 2008). Marine causality is defined as any event relating to the maritime system, which contributes to undesirable effects on the environment, property, community, commerce, ship, and members (Lee 2009).

Most typical causes resulting in marine casualties are derived from human factors, equipment failures, and external events. Human factor, which is the main reason behind the marine accidents, has connection with all parts of the life of the ship, which are operation, designation, and construction. Around 20% of the casualties of ships stem from faulty or bad design of the ship (Kobyliński 2008). The operation part of the ship depends of three factors; namely direct human errors, organization and system (Kobyliński 2008). In this respect, three main factors contribute to the human errors are: 1) physical predispositions and health 2) individual character of the operator, morale, and integrity 3) knowledge, experience, and training degree. These factors comprise negligence, unawareness, jealousy, carelessness, boredom, alcohol, drugs, and lack of education, fatigue, arrogance, sluggishness, wrong assessment, and wrong intention. In the part of organization, bad management or bad organization resulted in many accidents. In the operation part, bad organization follows from some reasons such as lack of instructions, supervision, motivation, paucity of strategy for safety management, and lack of activity by marine administration. In the phase of system, the behavior of operator can be affected by some systems e.g. wrong alarm, invisibility, hard operation, small endurance, imperfect software, inaccessibility and unavailability (Kobyliński 2009). Regarding this subject, causes of accidents are divided into two groups; namely basic or root causes and immediate causes. In this case, basic or root causes comprised lack of operator knowledge, safety management systems, skills, and ability; on the other hand, human error and failures to use of the correct knowledge of operator, skills, ability, and injury of operator were immediate causes. Injury of operator could be as a result of physical or psychological causes (Grabowski, Merrick et al. 2000). Technical factor involves with problems in valve, design and construction, equipment failure, and electrical failure. External events include some other problems such as environmental issues.
The chain of causes of accidents can be affected largely by some factors like cargo securing and loading (Torstenensson and pålsson 1998). Moreover, the shell cracks or deformations of tanks and pollution within loading or unloading are other major risks of marine transportation of oil and gas (Idelhakkar and Hamza 2011). Flag of the ship, age, and size are three main factors, which contribute to the shell cracks or deformations of tanks and pollution within loading or unloading. Regarding this subject, around less than half of the wrecks, are derived from the ships with the age of more than 15 years. In the case of size, small ships have biggest proportion of problems in compare with the large oil tanker and also using of inexperienced employees with lower costs by convenient flag makes it more risky and dangerous (Idelhakkar and Hamza 2011). Furthermore, other factors such as war, piracy, labor dispute, miscellaneous, ice condition, cold and exceptional weather, and foggy weather are included to aforementioned risks. In this respect, piracy and war can be considered with low probability but posing considerable risks for oil and gas worldwide markets.

Accidents occur when hindrance, successful alleviation and precautionary measures does not work and fail (Torstenensson and pålsson 1998). The most common hazards toward maritime transportation are fire, explosion, grounding, contact, collision, structural failure, hull failure, and external hazards; moreover, other types of accidents also occur more and less; for instance, large ship motions, flooding or water ingress, machinery failure, and payload related accident. In this respect, collision and grounding are most common accidents (Kobylninski 2009) (Soares and Teixeira 2001) (Ellis and AB 2002) (Nikula and Tynkkynen 2007). According to Romer, Haastrup et al. (1995), which is based on 1780 case histories of marine accidents of dangerous goods, collision was the main reason behind the fatalities contributing to nearly all accidents with more than 40 fatalities and also collisions between tankers and ferries resulted in accidents with more than 100 fatalities. In presented accidents dangerous goods were oil.

Consequences can be divided to immediate or delayed impacts. Immediate consequences comprise loss of life, injuries, damaging property, and people in danger; on the other hand, delayed consequences cover damaging environment, financial costs, and further loss of life (Grabowski, Merrick et al. 2000). In the case of oil tankers, the end result of the environmental damage due to the oil spill is the main concern (Soares and Teixeira 2001), which may occur in the shore during loading (with trivial occurrence) or during the transportation of loaded ship in the Sea (UNEP 2007). Regarding the severity of fatalities deriving from accidents in marine transportation of oil and gas, it should be noted that although liquefied petroleum gas (LPG) and similar substances have potential number of fatalities much higher than oil; however, this hypothesis is not proved by analysis due to the fact that oil on the water has potential to float and surround other vessels and igniting. According to IMO, casualties of ship are classified to four main points; namely very serious casualties, serious causalities, less serious casualties, and marine incidents. Moreover, loss of life and lives lost are other most important types of consequences in maritime transportation of oil and gas. Very serious casualties cover the entire loss of the ship and life or severe pollution. Sever pollution refers to making a pollution, which has the main deleterious effect on the environment or resulting this effect on the environment without precautionary action.
Serious casualties is lower than very serious casualties and involve fire, explosion, collision, grounding, contact, heavy weather damage, ice damage, hull cracking, or suspected hull defect. Less serious casualties are lower than serious casualties and comprise marine incidents in a way that marine incidents themselves also include hazardous incidents and near misses (IMO 2008). In part of consequences, it should be noted that affecting environment by some factors has made a difficult job to estimate the consequences of marine transport. These factors can be shoreline, sediment, sensitivity of the marine biotic community, weather, season, etc. (Ellis and AB 2002).

3.5 Risk analysis techniques

Risk analysis techniques, which is the main part of risk assessment and also used regularly in off-shore technology of maritime technology follow three main goals; assessing safety level of technical systems, look into causes of casualties, and discovering most efficient prevention measures (Kobyinski 2009). Alleviation, recovery, and giving recommendations on preventions derive from the output of this part (ICS, OCIMF et al. 2006). Implementing different methods for risk analysis symbolize the importance of flexibility toward techniques, mainly because of not matching all problems to one specific technique and also the limitation of availability of amount of information in some case. However, two techniques; namely fault tree analysis and event tree analysis are more popular and standard for analyzing of transporting dangerous goods (Ellis 2011). When the risk analysis comes to the subject of marine transportation of crude oil and LPG, it deals with four main factors; namely operation, man-machine interface, technique, and environment. Regarding these four factors, operation includes information concerning ship-owners organization, number and competence of crew, trade and cargo. Man-machine interface contain information toward control centers and facilities. Information in terms of speed and types of cargo is related to the part of technique. Environment involves information; for example, visibility, temperature, wind force, tide, wave height, and blockage (Torstenensson and pålsson 1998).

3.5.1 Event tree analysis (ETA)

By this approach, the consequences of failure and accidents are logically analyzed with a diagram, which presents the likelihoods and frequencies of the accident. This model is also connected to the precautionary measures, which can be taken after occurrence of accident or unintended events. In this technique, the starting point of accident stem from initial event (Kyokai 2009). Several branches are existed in this model to growing the initiating event to consequences. This technique can be used both qualitatively and quantitatively, which means that with considering frequency of initiating event and also estimating probabilities on the branches, this technique can be used quantitatively; on the other hand, it can be qualitatively provided that no probabilities or likelihoods are estimated for the branches (Ellis 2011).

3.5.2 Fault tree analysis (FTA)

FTA is another risk analysis technique in bulk maritime transportation. This analysis technique considers the reasons behind the accidents deriving from the logical connection of human error, equipment failure and other external events. This technique has the possibility to investigate before factors considerably affect the probability and contributing to damage the system in a large-scale or resulting in the complexity of system (Lee, Grosh et al. 1985).
As FTA commences from an effect hopping to figure out its causes, it can be viewed as a deductive technique. Its flexibility to use of both qualitative (recognizing the individual scenarios) and quantitative (estimate the frequency of event) analysis is another advantage of this approach (Antao and Guedes Soares 2006).

3.6 Risk control options/measures
Risk control measures are used in order to focus on realms of risk (the areas, which need to be controlled), identification of potential risk control measures, and transforming risk control measures into practical regularity options. Mitigating, preventive, engineering, procedural, redundant, active and passive are examples of risk control measures/options (Kristiansen 2004) (Lois, Wang et al. 2004). Risk control measures are used wishing to reduce the frequency of failures, mitigating the effect of failures, alleviating circumstances where failures may occur, and reducing the consequences of accidents. To reach this goal, a list of countermeasures on the base of people, procedures, and equipment solutions can be used to decrease or keep away from the impact of potential hazards (Lois, Wang et al. 2004). Interventions should be implemented before each step of casual chain. Implementing risk control measures/options may alter the circumstances in casual chain of accidents; for example, removing the overload failures result in reducing the probability of engine failure (Kristiansen 2004). In the case of oil spills, casual chain event starts from situations follow by incidents and after that accident and then results in oil spill and finally damaging the environment, requiring some essential actions; for instance, traffic rules changes before incidents, enhancing escorts requirements before accidents, and double hull requirement before oil spill (van Dorp and Merrick 2011). Hence, it can be finding that appropriately control of potential hazards of marine transportation of oil and gas is necessary in order to prevent of occurring dangerous and unwanted events with severe consequences; for instance, personnel injury, loss of life, loss of goods (oil and gas), and environmental damaging (Plaza 2000).
4 Empirical foundations

4.1 Empirical foundations and analysis on UK territorial waters

In this part, analysis is done on data of marine accident investigation branch (MAIB) from 1991 to 2010 in UK territorial waters focusing on different types of accidents, causes of accidents, consequences, location of accidents and the place of initial cause of accidents regarding crude oil tankers, LPG and LNG carriers.

Analysis of the crude oil tankers, LPG and LNG carriers provided that five groups are involved with the marine accidents of these types of transportation. These groups are ship, safety, deck, import default, and machinery. No injured and dead happened in these types of transportation during 1991 until 2010.

Accidents within maritime transportation of tankers in UK territorial waters happen in these following conditions of ship in the Sea, which are on passage, anchoring operations, entering or leaving port, alongside or moored, mooring operations, at anchor, drifting, other off shore operations, negotiating canal lock, and replenishment at sea operations. In this respect and according to availability of data from MAIB, most of accidents regarding crude oil, LPG, and LNG occurred when the tankers were in the conditions of at anchor, entering or leaving port, alongside or moored, and mooring operations.

Situation of the Sea within accidents concerning crude oil tankers, LPG, and LNG carriers are divided to six different places; namely port/harbor area, high seas, coastal waters, non-tidal waters, and river-canal. In this respect, high seas and port/harbor area shared the main places of happening accidents with 36% for each of them followed by coastal waters with 14%. In this case, non-tidal waters and river canal, which shared the lowest percentage (7% for each of them), were the places of just LNG accident. Number of accidents in different situations of the Sea is presented in Table 4.1-1.

Table 4.1-1 number of accidents in different situations of the Sea in UK territorial waters

<table>
<thead>
<tr>
<th>Tanker</th>
<th>Port/harbour area</th>
<th>High seas</th>
<th>Coastal waters</th>
<th>Non-tidal waters</th>
<th>River-canal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude oil</td>
<td>3</td>
<td>5</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>LPG</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>LNG</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

So, it can be finding that most of crude oil accidents happened in high seas where no LPG and LNG accidents took place. The second main place of happening crude oil accident was in port/harbor area following by one accident in coastal water. LPG accidents occurred just in port/harbor area and coastal waters.

Location of initial event or failure areas during the accidents of crude oil tankers, LPG and LNG carriers is in following places, which is shown in Table 4.1-2.
Table 4.1-2 Location of initial event or failure area in UK territorial waters

<table>
<thead>
<tr>
<th>Tanker</th>
<th>Location of failure area (initial event area)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude oil</td>
<td>Accommodation Space, Machinery Space, Hull plating, Ship’s boat, Complete vessel, Navigation/communication control space, Deck</td>
</tr>
<tr>
<td>LPG</td>
<td>Main engine, Navigation/communication control space, Engine room</td>
</tr>
<tr>
<td>LNG</td>
<td>Engine room</td>
</tr>
</tbody>
</table>

4.1.1 Accidents

During 1991 to 2010, fourteen accidents happened to crude oil tankers, LPG and LNG carriers. In this respect, nine accidents occurred in terms of crude oil, three accidents to LPG carries and two accidents happened to LNG carriers. Figure 4.1.1-3 shows the number of accidents, which happened in every year between 1991 to 2010 in UK territorial waters.

![Fig 4.1.1-3](image)

**Figure 4.1.1-3 number of crude oil, LPG and LNG tankers in accidents during 1991 to 2010 in UK territorial waters**

According to the availability of data from 1991 to 2010 in UK territorial waters, the accidents, which came to the crude oil tankers, LPG carriers, LNG carriers, and other types of tankers (comprising oil tanker, oil/bulk/ore carrier, oil/chemical tanker, tanker barge, and other), were fire/explosion, grounding, collision, machinery failure, flooding/foundering, contact, hull failure, escape of harmful substance, heavy weather damage, cargo handling failure, and pollution. Crude oil tankers and LPG as well as LNG tankers did not give rise to all types of accidents. They just encountered to accident types of grounding, machinery failure, contact, collision, fire/explosion, hull failure, and flooding/foundering. Figure 4.1.1-4 clearly shows the number of accidents and types of accidents, which were in terms of Crude oil tankers, LNG tankers and LPG tankers.
So, it can be finding that accidents regarding crude oil tankers are flooding/foundering, hull failure, fire/explosion, and machinery failure. On the other hand, grounding, contact, and fire/explosion were the accident types toward LPG tankers. LNG carriers were involved with Contact and Machinery failure. In terms of crude oil, Collision shared the biggest proportion of accidents with 34% followed by grounding with 22%. Among presented accidents, expect one accident; other accidents happened in the good visibility. The only accident, which happened in poor visibility, was an oil tanker with crude oil cargo and the accident type was collision. It should be noted that visibility for the accident type of hull failure was not specified. Figure 4.1.1-5 shows the percentages of sharing different types of accidents in terms of crude oil, LPG, and, LNG tankers. As can be seen, collision and grounding were two most common accidents in which each of them shared 22% of all accidents.

4.1.2 Causes of accidents

In the part of crude oil, six types of accident occurred in which collision and grounding were the most common accidents, other types of accidents were hull failure, machinery failure, fire/explosion, and flooding/foundering. Table 4.1.2-3 represents the addressed accidents with their causes and consequences.
Table 4.1.2-3 reasons of Crude oil tanker accidents in UK territorial waters

<table>
<thead>
<tr>
<th>Crude oil accident</th>
<th>Causes</th>
<th>Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grounding</td>
<td>External bodies liaison (Poor regulations, policies or practices), External causes (Uncharted underwater Obstruction)</td>
<td>No damage</td>
</tr>
<tr>
<td></td>
<td>Environment (Low water at tidal berth, berth was not clean of debris)</td>
<td>Material damage</td>
</tr>
<tr>
<td>Collision</td>
<td>Design &amp; construction (Design Inadequate, Characteristic defect, Equipment poorly designed for operational use, Personnel unfamiliar with equipment/not trained in use), Complacency</td>
<td>Minor damage</td>
</tr>
<tr>
<td></td>
<td>Lack of experience and qualification in fogy navigation situation</td>
<td>Material damage</td>
</tr>
<tr>
<td></td>
<td>Cause is not specified but the accident happened when X manoeuvring alongside xx to deliver bunker oil and Liferaft had been left at embarkation position.</td>
<td>Material damage</td>
</tr>
<tr>
<td>Hull failure</td>
<td>Not specified but it can be referred to the age of oil cargo (19 years old), which may due to out of standard</td>
<td>Material damage</td>
</tr>
<tr>
<td>Machinery failure</td>
<td>Material/mechanical defect, Design &amp; construction (Material select defect (eye bolt found to be substandard due to poor quality control and shipyard)), System - External bodies liaison (Non compliance)</td>
<td>Material damage</td>
</tr>
<tr>
<td>Fire/explosion</td>
<td>Unknown but could be electrical fault, arson or careless smoking</td>
<td>Material damage</td>
</tr>
<tr>
<td>Flooding/foundering</td>
<td>System - Crew Factors (Unsafe working practices)</td>
<td>No damage</td>
</tr>
</tbody>
</table>

In the case of LPG carriers, three types of accidents; namely grounding, contact, and fire/explosion happened in which all three accidents contributed to material damage. Causes of types of accidents, which happened to LPG carriers, are shown in Table 4.1.2-4.

Table 4.1.2-4 causes of LPG carriers accidents in UK territorial waters

<table>
<thead>
<tr>
<th>LPG accident</th>
<th>Causes</th>
<th>Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grounding</td>
<td>Fouled fuel valves caused the no 6 unit of the main engine to alarm initiating a slow-down safety function.</td>
<td>Material damage</td>
</tr>
<tr>
<td>Contact</td>
<td>Communication difficult for language or cultural reasons, Communication failure, master/pilot, Inadequate passage planning&lt;sup&gt;7&lt;/sup&gt;</td>
<td>Material damage</td>
</tr>
<tr>
<td>Fire/explosion</td>
<td>Electrical failure after a main switchboard caught fire whilst alongside</td>
<td>Material damage</td>
</tr>
</tbody>
</table>

---

<sup>7</sup> Passage planning or voyage planning is a procedure to develop a complete description of a vessel's voyage from start to finish. The plan includes leaving the dock and harbour area, the en-route portion of a voyage, approaching the destination, and mooring, the industry term for this is 'berth to berth'. According to international law, a vessel's captain is legally responsible for passage planning. The duty of passage planning is usually delegated to the ship's navigation officer, typically the second officer on merchant ships.
Causes of occurring accidents concerning LNG tankers are presented in Table 4.1.2-5. Comparing accident type of machinery failure regarding both LNG and crude oil tankers, reach to the point that failures in the part of design and construction was the initial cause of accident in both cases.

Table 4.1.2-5 causes of LNG carriers accidents in UK territorial waters

<table>
<thead>
<tr>
<th>LNG accident</th>
<th>Causes</th>
<th>Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contact</td>
<td>Status of this accident is open and no cause for this accident is found yet</td>
<td>No damage</td>
</tr>
<tr>
<td>Machinery failure</td>
<td>design &amp; construction (system defect)- System defect</td>
<td>Minor damage</td>
</tr>
</tbody>
</table>

All causes of accidents toward crude oil, LPG, and LNG tankers can be classified to four main parts; namely human factor, technical factor, external factor and other factors. In this part, human and technical factors were the chief culprit behind the accidents, which is shown in Table 4.1.2-6.

Table 4.1.2-6 causes of accidents in UK territorial waters

<table>
<thead>
<tr>
<th>Factors</th>
<th>Causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human factor</td>
<td>System - Crew Factors (Unsafe working practices), System - External bodies liaison (Poor regulations, policies or practices), arson or careless smoking, Lack of experience and qualification in fogy navigation situation, Communication difficult for language or cultural reasons, Communication failure, master/pilot, Inadequate passage planning, Design &amp; construction (Equipment poorly designed for operational use, Personnel unfamiliar with equipment/not trained in use, Complacency), System - External bodies liaison (Non compliance),</td>
</tr>
<tr>
<td>Technical factor</td>
<td>External causes (Uncharted underwater Obstruction), Electrical fault/failure, Design &amp; construction (Design Inadequate, Characteristic defect), Design and construction (Material select defect or System defect), Material/mechanical defect, Design &amp; construction (system defect), Fouled fuel valves</td>
</tr>
<tr>
<td>External factor</td>
<td>Low water at tidal berth, Fogy weather (with poor visibility)</td>
</tr>
<tr>
<td>Other factors</td>
<td>Structural integrity- main cause is not specified but it can be referred to the age of oil tanker (19 years old), Liferaft had been left at embarkation position (cause is not specified)</td>
</tr>
</tbody>
</table>

Figure 4.1.2-6 shows the percentages of sharing causes of accidents. This pie chart obviously demonstrates that human factor was the main reason behind accidents.
4.1.3 Consequences
The consequences as a result of above-mentioned tanker accidents were divided into three groups; namely material damage, minor damage, and no damage. In this case, half of all damages were material damages such as bottom damage, shell damage, and damaging the port wing of Ship Bridge. Other half part was equally divided between minor and no damages. Unlike LPG tankers, which were involved just with material damage, LNG tankers were involved with minor and no damage. Crude oil tankers were involved with all three types of damage. During 1991 to 2010, no dead and injury happen in the accident in maritime transportation of crude oil, LPG, and LNG. In this respect, environment damaged happened one time with pollution type of oil as a result of low water at tidal berth and also not being clean of berth from debris, which resulted to grounding and make a hole in the bottom. The amount of pollution was less than two tonnes and much of it was recovered by skimming equipment.

4.2 Empirical foundations and analysis on the Baltic Sea
In this section, investigations are carried out on data of HELCOM (Helsinki Commission-Baltic Marine Environment Protection) in the Baltic Sea from 1989 to 2010 comprising all types of ships accidents, causes of accidents and the consequences (pollution) they may posed. After that, data was organized and separated in order to reaching related data regarding accidents during the maritime transportation of oil and gas and then analysis carried out in meticulous details. Analysis in this part covers oil tankers, gas tankers, crude oil tankers, oil/products tankers, and other tankers (chemical/oil tankers, chemical tankers) containing oil, gas, and crude oil cargo. It should be noted that tankers with ballast cargo and empty cargo are not included in this analysis and the analysis is just carried out on tankers with oil and gas cargo. Lack of information about causes of accidents and types of cargo made obstacle to analyze data from 1989 to 2003; accordingly, the main focus is done on data from 2004 until 2010. In this analysis, N.i. means no information.

4.2.1 Accidents
On the base of availability of data from the Baltic Sea, number of tankers with the cargo types of oil, crude oil, oil products, and gases from 2004 to 2010 are shown in Figure 4.2.1-7.
As can be seen in 2006 and 2010, the number of accidents regarding aforementioned tankers is lower than other years. The number of accidents plunged moderately from 2008 to 2010.

In this part of study, different types of accidents happened in presented years are analyzed. During the aforementioned years six types of accidents are founded in the marine transportation of oil and gas. These accidents were collision, grounding, pollution, machinery damage, and others. Figure 4.2.1-8 shows the number of each accident per year and the pie chart in Figure 4.2.1-9 displays the percentages of sharing these accidents from 2004 to 2010. According to Figure 4.2.1-8, the number of accidents, which occurred by collision were more than other types of accidents. On the other hand, grounding was the only accident, which happened in all presented years; hence, it can be said that grounding was a prevalent accident amongst other afore-mentioned accidents.

<table>
<thead>
<tr>
<th>Year</th>
<th>Collision</th>
<th>Grounding</th>
<th>Pollution</th>
<th>Machinery damage</th>
<th>Fire</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>2005</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>2006</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.2.1-8 Number of different accidents in the Baltic Sea
The pie chart in Figure 4.2.1-9 displays the proportion of accidents in six broad categories, divided into collision, grounding, pollution, machinery damage, fire, and others. As can be seen collision shared half of the proportion of accidents, which was followed by grounding with percentage of 34%. In this respect, machinery damage and pollution with the same percentage of 6% were other types of accidents. In this classification, fire and others were other two accidents, which happened very low with 2% percentage for each of them.

![Pie chart showing accident proportions](image)

**Figure 4.2.1-9 percentages of sharing accidents in the Baltic Sea**

Collision, which shared the biggest proportions of accidents, occurred in terms of two types: with vessel and with object. Eleven of collisions occurred in type of with vessel and twelve of them happened in type of with object. One collision took place in type of both with vessel and with object. The consequences of addressed accidents are classified into three groups; namely minor accidents, serious accidents, and pollution.

### 4.2.2 Causes of accidents

According to the availability of data, the causes of addressed accidents are recognized. In this case, the causes behind accidents are classified to five factors: human factor, technical factor, external factor, others, and N.I. (no information). Figure 4.2.2-10 provides the numbers of causes of accidents and pie chart in Figure 4.2.2-11 shows the percentage of sharing presented causes of accidents.

Figure 4.2.2-10 demonstrates that expect 2010, human factor and technical factor were the causes of accidents in all years. Technical factor after a moderate drop from 2004 to 2005, followed with a sharp fall to 2006 and it remained unchanged until 2008 and finally it increased gently. Human factor after a slightly plunge in 2004, reached the plateau within two years and then continued with a marked boom and remained unchanged until 2009. External factor, which was another reason of accidents had stable range of causing accidents almost every two years during 2005, 2007, and 2009 but a sudden dramatic shoot up in 2008, was the most noteworthy part of this cause, which was the reason of three accidents in this year. The most interesting point in the addressed figure is decreasing the number of accidents due to technical failure from, which might be as a result of following international standard regulations, especially in the part of design and construction. Reducing the role of technical factor in the accidents was more obvious, particularly in the years of 2006, 2007, and 2008.
Figure 4.2.2-10 causes of accidents in the Baltic Sea

The pie chart in Figure 4.2.2-11 depicts the proportions of sharing presented causes of accidents. The pie chart clearly makes the human factor as the chief culprit with sharing of 33% of total accidents. In this term, technical factor was another big reason with 25% followed by external factor and other factor with the percentages of 13% and 8% respectively.

Figure 4.2.2-11 percentages of different causes of accidents in the Baltic Sea

### 4.2.3 Causes of accidents behind each accident

In last part of analysis, the numbers of each cause, which resulted to every accident, are extracted and considered and it is shown in Figure 4.2.3-12.
As can be seen in Figure 4.2.3-13 and Figure 4.2.3-14, all causes led to grounding and collision. The accident type of Pollution occurred just as a result of three reasons; namely human factor, technical factor and external factor. Machinery damage, fire, and others were
other tree types of accidents caused just by technical factor. Interestingly, albeit human factor shared the biggest proportion of causes of accidents but technical factor was the only cause behind all types of accidents. In this respect, human factor and external factor just resulted in three types of accidents; namely collision, grounding, and pollution. Other factor motivated to collision and grounding. These presented findings are shown in Figure 4.2.3-15, Figure 4.2.3-16, Figure 4.2.3-17, and Figure 4.2.3-18. In the part of technical factor, some failures such as rudder failure, pitch propeller failure, technical fault with loading or unloading device, and fire were reported as the initial cause for four accidents. It should be noted that detailed causes of accidents were not specified for all accidents.

![Human factor](image1)

**Figure 4.2.3-15 percentages of accidents deriving from Human factor in the Baltic Sea**

![Technical factor](image2)

**Figure 4.2.3-16 percentages of accidents deriving from Technical factor in the Baltic Sea**
4.2.4 Consequences

The consequences of aforementioned accidents were not completely specified but they might be classified to less serious casualties, serious casualties, and very serious casualties (pollution). In this case, minor and serious damages to the tug, vessel, hull, rudder and propeller, Canal Bridge, air boom pipe, port facilities, ship’s bottom (deformation), tank (hole in the tank), and harbor quay were reported. During discussed accidents, pollution happened five times, which are summarized in Table 4.2-1.

Table 4.2-1 Accident details resulting in pollution in the Baltic Sea

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of pollution</th>
<th>Cargo type</th>
<th>Accident type</th>
<th>Reason</th>
<th>Pollution type</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>1</td>
<td>Oil</td>
<td>pollution</td>
<td>human factor</td>
<td>IFO over flow</td>
</tr>
<tr>
<td>2005</td>
<td>1</td>
<td>Oil</td>
<td>pollution</td>
<td>technical factor</td>
<td>gasoline</td>
</tr>
<tr>
<td>2008</td>
<td>1</td>
<td>Crude oil</td>
<td>pollution</td>
<td>external factor</td>
<td>crude oil</td>
</tr>
<tr>
<td>2009</td>
<td>2</td>
<td>LPG</td>
<td>Collision</td>
<td>human factor</td>
<td>oil mixed with water</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oil</td>
<td>machinery damage</td>
<td>technical factor</td>
<td>hydraulic oil</td>
</tr>
</tbody>
</table>
Among five above-mentioned accidents resulting in pollution, information about two of them was found. In 2008, an oil tanker containing crude oil as a result of external factor had accident types of pollution and contributed to pollution type of crude oil with amount of 2,2437 tones. The accident detail of this disaster described as when the vessel was moored to the SPM buoy to discharge the oil to the terminal and just after approximately one hour when discharging commenced terminal's one cargo hose lost tightness through connection with ship's cargo manifold. Oil splashed away through the gap in connection and despite the sailor switched off ship's cargo pumps immediately, part of the cargo leaked overboard into the water. The initial cause of the hose connection release found the impact of 2, 5-3 m height sea waves. In this accident oil terminal was responsible for the accident. In 2009, a gas tanker containing petroleum liquefied gas (LPG) due to human factor had an accident type of collision with vessel and resulted in pollution type of oil mixed with water with amount of 3m³ about 0.010 tones. In this accident, the tanker was double hull and collision occurred during the service. In this case, operation of the vessel was reported as offence.
5 Discussion
In this study, the theoretical part extended the purpose in general perspective following with the investigation on data from the Baltic Sea and UK territorial waters. The theoretical part started by describing the importance of maritime transportation system and its vital role in the international trade and world economic growth, especially with oil and gas, which are scarce natural riches. This part continued with definitions of crude oil, LPG, and LNG. Then, Crude oil tankers, LPG Tankers and LNG tankers were described. In this study the analysis started with describing the general casual chain in maritime transportation. This model generally depicts the process in which how likely risks are to happen and how they lead to destructive consequences. After that, risk analysis techniques and then risk control options/measures are described. Finally, the investigation is implemented on the Baltic Sea and UK territorial waters based on collecting and analyzing data.

The main places of occurring accidents in terms of crude oil, LPG, and LNG tankers in UK territorial waters were accommodation space, machinery space, hull plating, ship's boat, complete vessel, navigation/communication control space, main engine, deck, and engine room. In the presented list, Navigation/communication control space, deck, and engine room need to be more considered as the initial hazards took place in these areas more than other addressed places. In the addressed area, accidents occurred in the port/harbor area, high seas, coastal waters, non-tidal waters, and river-canal. In this case, 72% of presented accidents happened in port/harbor and high seas.

Empirical analysis of MAIB revealed seven types of accidents in UK territorial waters regarding crude oil, LPG and LNG carriers; namely contact, collision, grounding, machinery failure, hull failure, fire/explosion, and flooding/foundering. On the other hand, collision, grounding, pollution, machinery damage, fire, and others were the accidents, which occurred in the Baltic Sea. UK territorial waters resemble the Baltic Sea in that collision and grounding shared the biggest proportions of accidents in both areas. In this respect, 44% of all accidents in UK territorial waters equally divided between collision and grounding. In the Baltic Sea collision and grounding shared the biggest proportion of accidents with 50% and 34% respectively.

Causes of accidents for both Baltic Sea and UK territorial waters are classified into four groups; namely human factor, technical factor, external factor, and other factor. In this category human factor was the chief culprit following by technical and external factors. In UK territorial waters, fire/explosion occurred in terms of both crude oil tanker and LPG carrier and in both cases, material damage was the consequences. In this type of accident, two initial causes motivated this accident. One of the initial causes was electrical failure/fault, which can be categorized in the part of technical factors. Another initial cause was arson or careless, which is classified in the part of human factor. Regarding this subject, one accident type of fire/explosion happened in the Baltic Sea due to technical factors. So, it can be that technical factor is the main reason behind the happening of fire/explosion in both Baltic Sea and UK territorial waters. Machinery failure/damage happened two times in the UK territorial waters in the cases of crude oil tankers and LNG carriers. In these accidents, the causes were human and technical factors. In the part of technical factor system defect was the same initial
cause for both LNG and crude oil tankers. This type of accident in the Baltic Sea was as just a result of technical factor. Hence, this type of accident also happened mostly due to technical factor but it should be noted that human factor also had contribution to this accident, which was clear in the UK territorial waters. In this case and regarding technical factors, it can be said that paucity of maintenance might be the main reason behind mechanical failure. In the accident type of grounding in UK territorial waters, human factor, technical factor, and external factors contributed to the accident. These factors were also the causes behind the presented accidents in the Baltic Sea. Collision was another accident, which shared the biggest proportion of accidents in both Baltic Sea and UK territorial waters. In UK territorial waters, collision derived from technical and human factors; while, in the Baltic Sea all factors (human, technical, external, and other factors) were behind happening collision. Contact, flooding/ foundering, and hull failure were other accidents in the UK territorial waters. In this case, contact and flooding/foundering were due to human factors and the cause of hull failure was not specified but the age of tanker was 19 years old; consequently, in this accident (hull failure) the importance and role of the age of tankers was obvious in the chain of accidents.

Importance of the role of human factor to accidents was noticeable in UK territorial waters where human factor recognized as the chief culprit and shared the largest proportion of causes of accidents with 46% following by technical factor with 39 %. Human and technical factors are also recognized as the main causes of accidents in the Baltic Sea with 33% and 25% respectively. In this area external factor shared 13% of causes. Hence, in terms of causes of accidents, the Baltic Sea was similar to UK territorial waters in that human factor and technical factor were the major causes of accidents in presented areas. Analysis of data on the Baltic Sea also displayed that although human factor was the main reason with the largest proportion of sharing accidents, it was the reason behind three types of accidents; namely Collision, Grounding, and Pollution. On the other hand, technical factor, which shared the second biggest proportions of accident, was the reason behind all types of accidents. External factor resemble human factor in that it brought about three types of accidents: collision, grounding, and pollution. Other factors motivated to collision and grounding.

In the part of consequences, 64% of the addressed accidents in UK territorial waters are referred to the part of serious casualties (material damage). In this case, less serious casualties (minor damage) and marine incidents (no damage) shared 14% and 22% of accidents respectively. In this area, one time pollution also happened with the type of oil. In the Baltic Sea, minor and serious damages took place as well. In this area, five times pollution happened in the case of oil and gas tankers. Although detailed causes of releasing gas and oil is not specified in the Baltic Sea but generally they may stem from internal and external causes. Internal causes involve with the problems in valves, being out of standard regulations of tankers and containers and also human errors, especially in the case of over loading; in contrast, external causes derive from inappropriate loading, inadequate safety in the tankers and also the movement of the ship, which is sometimes extreme.

In order to analyze the findings (causes of accidents, accidents scenarios, and consequences) in the previous part, two more popular and standard risk analysis techniques in the maritime transportation; namely event tree analysis (ETA) and fault tree analysis (FTA) are assessed.
Fault tree analyses investigate the combination of circumstances and failures, which lead to the accidental event; on the other hand, event tree analysis looks into the rise potential of accidental event to establish all possible outcomes and their severity. On the base of availability of data related to initial causes of accidents regarding crude oil, LPG, and LNG tankers in UK territorial waters, fault tree analysis is investigated for human, technical, and external factors. Information of the Baltic Sea did not address the initial causes of accidents; hence, it is not possible to investigate fault tree analysis for this area. The investigation of fault tree analysis in UK territorial waters may work and be useful for the Baltic Sea as both areas showed almost the same results in the part of accidents and causes of accidents.

In the part of human factor, causes of accidents derive from operation part of the ship and design & construction. Figure 5-19 shows fault tree analysis in the part of design & construction for the causes of accidents in UK territorial waters.

![Fault Tree Analysis Diagram for Design & Construction](image)

**Figure 5-19 FTA for the part of Design & Construction of human factor**

In the part of human factor, operation part of the ship stem from two elements; namely human error and system & organization. Fault tree analysis for the division of system & organization in UK territorial waters is displayed in Figure 5-20, which demonstrates the causes of accidents in this section of the operation part of the ship.
Human error is the second part of the operation part of the ship. Figure 5-21 demonstrates fault tree analysis for the part of human error in UK territorial waters. In this analysis, inadequate passage planning could be also as a result of lack of training and experiences. Careless smoking is put in the category of negligence because of maybe forgetting the policies of non-smoking or it might derive from other reasons such as alcohol or drugs.

Figure 5-20 FTA for the division of system & organisation in the operation part of the ship

Figure 5-21 FTA for the part of human error in the operation part of the Ship
Technical factor, which was the second biggest causes of accidents, involved with the parts of design & construction, electrical part, and the part of problem in valve. Fault tree analysis for the part of technical factor in UK territorial waters is depicted in Figure 5-22.

**Figure 5-22 FTA for the part of technical factor in UK territorial waters**

External factor was another factor contributed to the accidents in UK territorial waters, which mainly derived from environment but other external cause also motivated in this part. Fault tree analysis is displayed in Figure 5-23 for this part of accident. In the case of low water at tidal berth, although environmental factor was the main reason but not being clean of berth from debris was another reason to make a hole in the bottom of the cargo and resulting in pollution; consequently, this reason incriminates human factor in this part.
Regarding fault tree analysis in UK territorial waters, it can be found that design & construction part played a vital role for the failure in both human and technical factor. In this respect, human error was the chief culprit in the operation part of the ship to result in accidents.

In UK territorial waters, the consequences of accidents in terms of crude oil, LPG, and LNG tankers were classified to no damage, minor damage, and material damage. Among accidents in the presented area, fire/explosion is selected for implementing event tree analysis (ETA) as it is the most significant reason behind the initial event for the accidents of oil and gas tankers. On the base of availability of information regarding the accident type of fire/explosion, an event tree analysis for this accident is implemented and depicted in Figure 5-24. This event tree analysis clearly demonstrates all possible consequences as a result of failures from human and technical factors. One of the main points, which can be found from this accident, might be the importance of specifying main areas and places of occurring fire or being vulnerable for happening fire like accommodation and recreational spaces.

In this part also lack of information (accident details) from Baltic Sea was an obstacle to implement event tree analysis for the accidents but mentioned-figure and its findings can be useful for this area as well.
In the next stage, general casual chains (comprising cause, incident, accident, and consequences) need to be constructed and risk control measures to be identified at each node of the chain. Finally interventions must be implemented before each step of casual chain (van Dorp and Merrick 2011). Interventions should have the potential to remove the cause and put a stop to the situation resulting in lapses because a small lapse can motivate an accident (Lois, Wang et al. 2004). Interventions also should have the capability to reduce the severity of impacts of accidents. Table 5-1 shows some effective interventions before each step of casual chain. Although, most of these interventions are founded on the base of initial causes of accidents in UK territorial waters, but they work for the Baltic Sea as well. Generally these interventions are useful in order to decrease the risks and enhance the safety in the marine transportation of oil and gas.

Figure 5-24 ETA for the accident of fire/explosion in UK territorial waters

<table>
<thead>
<tr>
<th>Arson or careless smoking</th>
<th>Effectiveness of automatic fire/smoke detection and alarm system</th>
<th>Happening fire</th>
<th>Effectiveness of fire extinguishers equipments</th>
<th>Consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td></td>
<td>Yes</td>
<td>Yes</td>
<td>Minor damage</td>
</tr>
<tr>
<td>No</td>
<td></td>
<td>No</td>
<td>No</td>
<td>Material damage</td>
</tr>
<tr>
<td>No</td>
<td></td>
<td>Yes</td>
<td>Yes</td>
<td>Minor damage</td>
</tr>
<tr>
<td>No</td>
<td></td>
<td>No</td>
<td>No</td>
<td>Material damage</td>
</tr>
</tbody>
</table>

Table 5-1: Some effective interventions before each step of casual chain.
## Table 5-1 interventions for casual chain

<table>
<thead>
<tr>
<th>Steps</th>
<th>Interventions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remove the cause</td>
<td>• Appropriate equipments and maintenance&lt;br&gt;• Suitable training to use of equipments&lt;br&gt;• Imposing proper, accurate, and serious regulations and policies&lt;br&gt;• Forbid smoking especially in vulnerable places for fire&lt;br&gt;• Drug and alcohol testing programs&lt;br&gt;• Communication skills training&lt;br&gt;• Not loading tankers with oil hull&lt;br&gt;• Put major safeguards and equipments in place such as vessel tracking system and also escort vessel&lt;br&gt;• Put automatic fire detection and fire alarm system in place, especially in the accommodation spaces&lt;br&gt;• Reliable weather forecast&lt;br&gt;• Installing system for operator to check that the berth is clear of debris&lt;br&gt;• Adequate passage planning&lt;br&gt;• Use of ice breaker in ice condition in winter time</td>
</tr>
<tr>
<td>Before incident</td>
<td>• Check up training&lt;br&gt;• Testing materials, equipments, and system&lt;br&gt;• Testing valves&lt;br&gt;• Testing electrical system&lt;br&gt;• Observe machines and hull&lt;br&gt;• Traffic rules changes&lt;br&gt;• Communications equipments</td>
</tr>
<tr>
<td>Before accident</td>
<td>• Extinguish cigarettes and matches&lt;br&gt;• Clean flammable spills&lt;br&gt;• Not sailing in foggy weather&lt;br&gt;• Enhancing escorts requirements&lt;br&gt;• Fixing and repairing the fouled fuel valve&lt;br&gt;• Changing or fixing the system defect&lt;br&gt;• Changing or fixing the material defect&lt;br&gt;• Fixing electrical failure&lt;br&gt;• Especial procedures for vessel traffic and bad weather (foggy weather)</td>
</tr>
<tr>
<td>Before consequences</td>
<td>• Suitable communication&lt;br&gt;• Move the crew from the fire&lt;br&gt;• Notify outside assistance&lt;br&gt;• Double hull requirement before oil spill&lt;br&gt;• Skimming equipments&lt;br&gt;• Emergency instructions&lt;br&gt;• Emergency equipments such as fire extinguishers, sprinklers, and life saving</td>
</tr>
</tbody>
</table>

In order to increase safety in maritime transportation of oil and gas in the discussed areas, it is necessary to take into consideration some precautionary measures and marine standard regulations such as successful risk and hazard communication in marine transportation, formal safety assessment (FSA), international safety management (ISM) code, and safety
management system (SMS). Here, the addressed measure and standard regulations are described.

- Successful communication of risks during marine transportation of oil and gas

Risk and hazard communications play a vital role in the environment especially where hazards are both sublime and out of personal experience; consequently, successful communication of risks and hazards is the best way to prevent accident, oil spill as well as injury. Visibility, legibility, and Intelligibility are three main factors, which affect the efficiency of risk and hazard communications. The presented factors and their descriptions are summarized in Table 5-2.

**Table 5-2 Main factors affecting risks and hazards communication**

<table>
<thead>
<tr>
<th>Factor</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visibility</td>
<td>Refers to the well viewing something by the human eyes. In the case of visibility, Sufficiency size of text and graphic material facilitate to distinguish them from surrounding environment.</td>
</tr>
<tr>
<td>legibility</td>
<td>It refers to recognizing the characters and symbols as well as graphics, which are displayed. For text, it is connected to the readability of message.</td>
</tr>
<tr>
<td>Intelligibility</td>
<td>It refers to accurate understanding of message, which is influenced by three aspects: namely visibility, legibility and content of text or symbol. So, in this case some factors such as suitable label design and appropriate message content as well as cultural factors help to increase the intelligibility of message and presentation.</td>
</tr>
</tbody>
</table>

Risk and hazard communication is intended to promote situation awareness (SA). Perception, comprehension, and projection of risks in the future are three main parts of situation awareness. Therefore, categorizing and describing hazards, how to avoid consequences and defining the consequences are the main purposes, which are followed by successful risk and hazard communication (Cantwell and Miller 2005).

- Formal safety assessment (FSA)

One way of taking precautionary measures before occurs a disaster is to use a process, which is known as formal safety assessment (FSA). One area where FSA is already being applied is bulk carrier safety. Formal safety management is a structured and systematic methodology intended to improving maritime safety, comprising protection of life, health, the marine environment and property by utilizing risk analysis and cost benefit assessment (IMO 2002) (Lee 2009). FSA follows three main parts; namely recognizing hazards, evaluating risks and making a suitable decision action to handle the risks in a cost-effective way (Trbojevic and Carr 2000). FSA also helps the evaluation of new regulations for protection of the marine environment or in making a comparison between existing and possibly improved regulations with a view to achieving a balance between technical and operational issues, and between maritime safety and costs (IMO 2002).
International safety management (ISM) Code

Every tanker with minimum 500 gross tonnages is required to agree with the international safety management (ISM) Code. With considering ISM Code, safety management processes are based on the risk assessments and risk management approaches (ICS, OCIMF et al. 2006). The main reason of implementing of ISM Code is providing an international standard for the safe management and ship’s operation and also at the same time preventing the pollution. So, to reach this goal, some points and measures should be considered from the operators of ship; for example, providing both safe working environment and safe practices in ship operation, set up appropriate safeguards in place against all identified risks, updating and enhancing the safety management skills of personnel, and preparing for emergencies. Meanwhile, enhancing the safety management system (SMS) of the company is required, which should contain functional requirements, chiefly instructions and procedures in order to following two main goals; namely protection of environment and ensure safe operation of ships. Decreasing the number of oil spill incidents after mid of 1990s is one of the main important effects of considering and consequent implementation of (ISM) Code (Psarros, Skjong et al. 2011).

Safety management systems (SMS)

The role of safety management system (SMS) is providing the efficient installation of the health, safety and environmental protection policy of the company. The subjectivity of SMS to regular audit, paves a way to proof its efficiency and validate its appropriateness to convey the expectations of international safety management (ISM) Code. One of the main roles of SMS can be evident in the operation of the ship when it specifies all activities and situations with possibilities, which bring about affecting the safety of the ship or operation of the ship. Therefore, this function of SMS is essential in order to put the required levels safety management in place (ICS, OCIMF et al. 2006); meanwhile, these activities and possible situation in the operation of the ship contain various types of hazards to environment, personnel, and ship. So, to address the seriousness of the risks, it is required to appropriate assessment of these hazards as well as likelihood of their happening. Finally, implementing risk management tools give rise to reach safe achievement of the work, grantee compliance with the safety management system, and provide the objective proof for conformation such as instructions, procedures, and documented policies. Hence, safe system of work is the ultimate output of an efficient safety management system (ICS, OCIMF et al. 2006). Using appropriate SMS guarantee that risks are recognized and evaluated, suitable controls are carried out in order to handle the risks, and also controls are efficient at any time by line management\(^8\), which is in charge of presented tasks (Trbojevic and Carr 2000).

\(^8\) Line Management is a business term to describe the administration of activities that contribute directly to the output of products or services. The line management function will often cross into other functions vital to the success of a business, such as risk management. Responsibility for risk management is vested with line management.
6 Conclusion
To recap, maritime transportation of oil and gas, through which loads of benefits for international trade and world economic can be found, is involved with many risks and hazards; accordingly, good understanding of these hazards give rise to enhance the safety in this type of transport. In this study empirical analysis in UK territorial waters revealed seven types of accidents regarding crude oil, LPG and LNG carriers; namely contact, collision, grounding, machinery failure, hull failure, fire/explosion, and flooding/foundering. On the other hand, collision, grounding, pollution, machinery damage, fire, and others were the accidents in the Baltic Sea. UK territorial waters resemble the Baltic Sea in that collision and grounding shared the biggest proportions of accidents in both areas. In the Baltic Sea, the results of finding revealed that collision was the main accident type with sharing 50% of all accidents followed by grounding with 34%. Analysis in the UK territorial waters also followed the results of the Baltic Sea by which collision and grounding shared the biggest proportion of accidents with the same percentages 22% for each of them. Analysis of data in UK territorial waters revealed that most of accidents (72%) in terms of crude oil tankers, LPG and LNG carriers happened in port/harbor area and high seas. The analysis in UK territorial waters also displayed that navigation/communication control space, engine room, and deck were three main places of occurring initiating failures, which need to be more considered.

In terms of causes of accidents, the Baltic Sea was similar to UK territorial waters in that human and technical factors were the main reasons behind accidents in these areas. In UK territorial waters, human factor shared largest proportion of causes of accidents with 46% followed by technical factor with 39%. This analysis on data from Baltic Sea also provided that human factor and technical factor shared the biggest proportion of causes of accidents with 33% and 25% respectively. Analysis on the Baltic Sea also displayed that although human factor was the main reason with largest proportion of sharing accidents, it was the reason behind three types of accidents; namely Collision, Grounding, and Pollution. On the other hand, technical factor, which shared the second biggest proportions of accident, was the reason behind all types of accidents. External factor resemble human factor in that brought about three types of accidents: collision, grounding, and pollution. Other factors motivated to Collision and Grounding.

In UK territorial waters where no injury or dead occurred, 64% of the addressed accidents resulted in material damage. In this area, 14% of accidents contributed to minor damage and 22% motivated to no damage. In this area, one time pollution happened while in the Baltic Sea five times pollution occurred.

In the part of risk analysis techniques, event tree analysis and fault tree analysis were implemented. Fault tree analysis applied to investigate the failures motivating to all accidents in UK territorial waters. Regarding this subject, failures in part of design & construction contributed to both human and technical factors. However, operational part of the ship comprising human error and system & organization, was other factor motivation to human factor. In this respect human error recognized as the chief culprit. In the case of technical factor, problem in valve and electrical failure were other factors resulting in accidents. External factor stem from environmental problems and other external causes. Event tree
analysis is applied for one accident type of fire/explosion in UK territorial waters. In this respect, event tree analysis looks into the rise potential of fire/explosion to establish all possible consequences, which were no damage, minor damage, and material damage.

In the last part, in order to prevent or mitigate the finding failures and also reducing the consequences of accidents in aforesaid areas, risk control measures/options were implemented. For this respect, at first general casual chain (comprising cause, incident, accident, and consequences) constructed, then interventions applied before each node of casual chain. In order to increase safety in the maritime transportation of oil and gas, other precautionary measures and marine standard regulations must be taken and considered; for example, successful risk and hazard communication, formal safety management (FSA), international safety management (ISM) code, and safety management system (SMS).
7 References


