Master's degree thesis

LOG950 Logistics

Risk Analysis in Supply Vessel Operations in Ghana

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Preface

This dissertation is submitted in partial fulfillment of the requirement for Master of Science in Petroleum Logistics at Molde University College – specialized University in Logistics. It was conducted from January 2018 to October 2018.

The study was conducted in order to acquire a theoretical knowledge in offshore risk assessment so that further studies can be done.

This study was successfully completed with the support and recommendations from my advisor, Yury Redutskiy. I would take this opportunity to express my gratitude to him

Summary

The main objective of the was to investigate a collision risk model, identify weaknesses and suggest some improvements that can be used in Ghana,

This study began with definitions of collision and risk concepts to help introduce the research theme. Statistics on collision was also presented and discussed. The study centered on collision, defined by Kristiansen (2004). as the *impact between two moving objects;* and the term ‘moving’ seen as very significant

The study considered the COLLIDE collision risk model and discussed the key challenges with quantification and some collision risk influencing factors as well their associated risk indicators were reviewed. Human error was analyzed using technique for human error rate prediction (THERP) and was incorporated into the collision risk model.

It was revealed that vessel collisions account for 13-28% of all ship accidents. Vessel accidents and collisions causes are human factors, technical and organizational factors; with the most common ones being lack of lookout or watch-keeping failure, lack of sleep, bad communication, and bad maintenance routines as authors suggested by some authors

Contents

LIST OF FIGURES

LIST OF TABLES

1.0 Introduction

Most of the energy and resources needed to run the society is provided by oil and gas extraction. Energy demand keep increasing, signaling that more of oil and gas products will keep on being demanded because the sector is a major contributor to the world's energy sector (Azad 2014). International Energy Agency (IEA)'s gahered information for the two decades (1984-2004) on world energy consumption trends shows that primary energy has grown by 49 percent. Current forecasts also show that this growth will continue. Oil, the most dominant fuel globally, accounts for 32 percent of world total primary energy supply (TPES) in 2015 (International Energy Agency (IEA) 2017). To accommodate the rapid iincrease in demand requires oil and gas production to increase consistently. A review of current industry praactices and literature proposes that offshore activities will move into more profound water from shore and thus, supply requirements will rise significantly (Clarkson 2012, Williams 2011). One of the ways to do this is by using supply vessels that represent one of the largest cost elements in the upstream supply chain of oil and gas installations (Aas, Halskau Sr, and Wallace 2009). These supply vessels achieve an assortment of tasks. Their core logistic function is transportation of products, tools, equipment and personnel to and from offshore installations. The challenge of ensuring constant supplies to offshore platforms has been a key concern within the sector, making it a very important subject in oil and gas logistics. Thus, logistics has been a composited problem as it is influenced by several factors with lots of important uncertainties (Rose 2011). Since production and generation logistics within the petroleum sector is very expensive and capital intensive and the high costs connected with production loses on offshore platforms, it is imperative to ensure uninterrupted provision of needed supplies and other needful services.

Exposure to dangers and other threats at sea have made suppliers within the industry to sometimes pause operations for ample periods of time. And, in order to ensure smooth deliveries, an effective and critical evaluation of all possible risks must be practiced. Risk may simply mean uncertainties on achievement of set objectives. These uncertainties can be positive or negative in effect. Risk then, according to z-013 (2001), *"is the combination of the probability of occurrence of harm and the severity of that harm";* whereas the risk analysis process can be described as making use of available information on risk and uncertainties in identifying hazardous incidents, and to estimate and quantify the risk probabilities and consequences of the hazardous events (z-013 2001).

1.1 Background: Offshore Operations in Ghana

Following the sale of licenses for offshore oil exploration and production in 2004, oil was discovered in commercial quantities in the western coastal of Ghana by Tullow Oil and Kosmos Energy. The area was named “Jubilee Field”. Development of the production site started right away and in December 2010, commercial oil production was officially launched. Since 2007, further discoveries have been made. Ghana is believed to have up to 7 billion barrels of petroleum in reserves, and 6 trillion cubic feet of natural gas in reserves (Opong, Klaas, and Benson Lamidi).

Offshore installations are located off the coast within a distance of about 60 km where the density of shipping lanes and other traffic is relatively high. Following the exploration and production of oil, supply vessels that arrive at the Port of Ghana have seen an upward trend in recent times in the region which has resulted in a rise in maritime activities(Ghana Ports and Harbour Authority 2017). From Underwater Technology Conference (2018), it is further predicted that, offshore activities particularly, oil production will double in the couple of years. This makes maritime safety, within the surroundings of Ghana’s offshore installation a matter of great concern. According to Dai et al. (2013), the focus of several studies have been on researching the level of collision risk involving passing vessels and offshore installations, with respect to maritime transportation, military activities and fisheries.

Likewise, little studies on offshore risk management have been undertaken and to contribute to Health Safety Environment (HSE), create awareness of potential uncertainties, and to provide essential information for improving and optimizing vessels on the Ghanaian Continental Shelf, a study of risk analysis in offshore supply vessel operations must be undertaken.

1.2 Research Gap

Available research provides relevant information on the collision risk involved when there is collision between offshore installations and visiting vessels. Ship (2003) records 557 shipplatform collisions on the United Kingdom Continental Shelf from 1975 to 2001. More than 90% of these collisions involved service vessels (representing 514 service vessels). Collisions involving service vessels are *low-energy collisions* as they lead to minor damages. However, five colisions involving either a supply or standby vessel, have been reported to have resulted in serious damages (Vinnem 2007).

For over two decades, the COLLIDE risk model is the known model used for determining risk level in vessels colliding with offshore installations on the North Sea . The COLLIDE model is the standard model used in determining and quantifying the probability of collisions. The development of the model relied on initial vessel mapping and movement data, like the Automated Identification System (AIS) data.

It is, therefore, the aim of this study to review the current COLLIDE model, and to identify its weaknesses for more holistic perspective and approach may be considered and incorporated in the new risk model.

1.3 Problem Description: Offshore Collisions

The Mumbai High North (MHN) complex witnessed a collision in the year 2005, where an installation waas hit by a passing support vessel. The multipurpose vessel drifted having lost control, which resulted in the collision. The incident resulted in severe fire (see figure 1). Two hours after the collision, the complex had collapsed with only a stump of jacket above sea level. The support vessel which collided had also sunked some four days after it had caught fire. 22 people were confirmed dead, whiles 362 were rescued (International Association of Oil & Gas Producers (IAOGP) 2010). This MHN accident is a pointer to how catastrophic vessel-platform collisions can be.

Figure 1 Mumbai High North (MHN) complex after vessel collision

Source: Bailey (2010)

The Petroleum Safety Authority (2011), reports 26 collisions cases between 2001 and 2011 involving visiting vessels and offshore installations or facilities, which happened on the Norwegian. 6 out of these accidents had great potential for severe hazard. From a study conducted by (Oltedal 2012), vessel-platform collisions are divided into two groups: powered collisions and drifting collisions: *powered collisions are vessels moving under power towards the installation and include navigational/manoeuvring errors, human/technical failures, watch-keeping failures and bad visibility/ineffective radar use.* Meanwhile, *a drifting vessel has lost its propulsion or steerage and is drifting only under the influence of environmental forces* (International Association of Oil & Gas Producers (IAOGP) 2010). According to the (International Association of Oil & Gas Producers (IAOGP) 2010), a powered collision can only happen in these three situations: (1) there must be a vessel and platform on collision course; (2) unawareness of the watchkeeper/navigator of the situation long enough till the vessel reaches the installation; and (3) the installation was also not aware of the collision course situation or is not able to signal a warning to the approaching ship to “normalize” the situation.

To provide essential information for improving and optimizing vessels, contribute to Health Safety Environment (HSE), and create awareness potential dangers in the Ghanaian Continental Shelf, the study seeks to analyse risk in offshore supply vessel operations.

1.4 Significance of the Study

The Ghanaian oil and gas industry is still an infant industry in the sense that the discovery and exploration of oil was achieved in just about half a decade ago. However, there is a high public expectation of the economic benefits of the discovery within the shortest possible time. Meanwhile, the industry has to deal with the issue of safety of personnel and properties in their operations.

This study's significance lies in analysing collision between supporting vessels and offshore production installations, identifying collision risk influencing factors and suitable indicators. The result of the study would be added to the limited studies in risk assessment of offshore activities in Ghana and further studies may also be suggested.

The study is a starting point in exploring and clarifying the complex and multi-dimensional research field of investigating the associated risks with Ghana's offshore activities, to facilitate future research.

1.5 Study Objectives

- To review relevant literature on vessel/ship collision and its causal factors
- To present a collision risk model and identify the weakness with respect to risk quantification
- To describe the concept of risk influencing factors (RIFs) and safety indicators. To give an overview on the various classification of risk and safety indicators
- To suggest ways collision risks in Ghana can significantly be reduced based on the literature reviewed.

1.6 Scope of the Study

The scope of this study is to make an analysis of the collision risk that may hinder the realization of the core functions of logistics with respect to the Ghanaian oil and gas industry. The research will tend to evaluate the existing collide risk model and tries to incorporate human and organisational factors which previously were not considered enough.

1.7 Structure of the Study

The research work is categorized into eight (8) main chapters.

- Chapter 1 gives the introduction and within it are brief background, research problem, research questions, the objectives and scope of the study and others.
- Chapter 2 gives the approach adopted by the author in writing this thesis. It describes how relevant literature is obtained and also, the steps used to quantify the COLLIDE risk model.
- Chapter 3 introduces main definitions of risk concepts, vessel collisions, collision hazards, risks and their assessment. It also presents statistics on vessel collisions as well as causes.
- Chapter 4 introduces the COLLIDE risk model from a theoretical perspective, its construction as well as the challenges with quantifying and modeling of human error.
- Chapter 5 explains collision risk influencing factors and indicators. It also presents different categorizations of indicators.
- Chapter 6 gives the identified suitable RIFs and indicators.
- Chapter 7 discusses of the results of the study and makes suggestions on how collision risks in Ghana’s oil and gas sector can be reduced significantly.
- Chapter 8 presents a summarizes and concludes the study, and gives recommendations for further research.

2.0 CHAPTER TWO – APPROACH

ment, risk indicaThis thesis is a literature study. It is based mainly on a the review of theory and relevant literature. The core objective is to obtain knowledge through studying necessary theory and also to delve into the conclusions and findings by other researchers or writers, on the subject of collision risk, and how they can be applied in the peculiar case of Ghana’s infant offshore oil and gas sector.

In gathering literature, the main focus was on the core objectives of this thesis and the necessary theories specified in the design of the work. The search for relavant information were from textbooks, reliable research databases such as ScinceDirect, ProQuest, ABI

Infrom, SP Shipbase, Transport OVID, among others. The keywords used in searching for literature for this study were, ship/vessel collision, collision causes, the COLLIDE model, risk influencing factors, collision risk assessment, risk indicators, safety indicators, vessel navigation etc. More than 600 literatures was found in relation to the theme for this literature study from 1980 to date, but the author could not review all due to time limitations, and also considering the relevance of discovered related literature.

Because there is high variation in information, the author was not very strict in what journals to review, websites to read, as well as other articles. Again, the author combined search words as guide words for the study.

Table 1 Key Search Words

Ship/vessel collision	Collision causes	Collision statistics
Maritime safety	Collision risk	Collision frequency
Human factors	Human errors	Organizational factors
Technical factors	Risk influencing factors	Risk indicators
Collision risk modelling	Vessel Safety	Safety Indicators
Collision course	Offshore installations	Sea State

The search terms were used in different combinations, which gave lots of results. These results were mostly research articles, but come were also books and webpages. The books and articles were selected depending on the relevance of the topics found in the book or article. These were futhure reserached by reading and evaluating the summaries. This cut down the number of relevant literature sources. Relevant articles were analysed, reading the whole article. However, with books, only those parts relaated and relevant to this study were read and analysed. The results from this analysis therefore formed the theoretical part of this study, as they presented a good overview of various topics relevant to this study.

3.0 CHAPTER THREE – VESSEL COLLISION, CAUSAL FACTORS AND RISK ASSESSMENT

3.1 Meaning of Risk

Risk has been a familiar notion in all civilization. But as a business concept, it has evolved in only the last few centuries. In modern business, it has received great attention. The complexities of commerce and shipping provide much meaning and depth to this word and its concept.

The source of the word *risk* has been a linguistic bone of contention for years, among scholars in the English language. However, *risq* (the Arabic version of the word, *risk*) and *riscum* (the Latin word) are two of the commonly recognized origins of the word, *risk*. The Arabic word *risq* which communicates "anything from Allah to his people and from which they draw profit" (Kedar 1970). But *riscum* in Latin originated as a maritime term in describing the circumvention of danger, especially barriers. In the Arabic origin, there is a clear and distinct linkage to prosperity, whereas the Latin origin shows greater focus on negative consequences. With these two meanings of risk, it is no surprise that the modern meaning of risk has both positive and negative connotations, especially with regard to trade and therefore business (Walker 2013).

Risk and different types of risk concurrently increases with its development. Research activities become more complex and interconnected, and then new technologies are introducing new risks (Ouédraogo, Groso, and Meyer 2011). To establish an integrated and common strategy for assessing risk, it is important to develop a "common language" relating to this concept (Azad 2014). The very common definitions of *risk*, are:

- *"Risk is often expressed in terms of a combination of the outcomes of an event and the associated likelihood of occurrence"* (International Organisation for Standardization (ISO) 2009).
- z-013 (2001) defines risk as "*combination of the probability of occurrence of harm and the severity of that harm*."
- Risk is "*combination of the probability of an event and consequences of the event.*" (ISO 2002).

The concept of risk is expressed by multiplying the probability and numerical value of the consequence as represented below:

$$Risk = probability\ of\ occurrence\ X\ Consequences \qquad (1.1)$$

From this concept, Aven (2008) explained that an initial event can result in different consequences. These consequences can be positive or negative and mostly, much concern is drawn to the negative outcomes. He furthered that the probability factor expresses the likelihood of such event happening, thus the probability factor and expected factor applies to express risk. According to z-013 (2001) risk can be expressed qualitatively or quantitatively.

3.2 Dimensions of Risk

At the point when accident consequences are considered, they may be related to personnel, the environment, and assets and production capacity. These are sometimes called risk dimensions (Vinnem 2014a).

3.2.1 Personnel risk

According to Vinnem (2014a), personnel risk is considered only risk for employees. This type of risk was historically known as second party, but now called first party, whereas risk for the public (third party) is not applicable. This risk type is subdivided into fatality (risk of death) and impairment (risk of injuries).

3.2.2 Environment risk

ISO (2002) explained that any hazard that may cause potential harm to the ecosystem is attributed as environment risk. These hazards may include oil spills, release of toxic gases into the atmosphere, discharge of contaminated production water into the sea, among others.

3.2.3 Assets risk

Asset risk usually have non-environment and non-personnel consequences. These risks may have potential threats on an organization's properties. The following types of hazards are examples of assets risks:

- Ignited or unignited hydrocarbon gas leaks or liquid leaks, such as glycol, diesel, jet fuel, etc.
- Fires from electrical systems
- Fires in accommodation, utility areas, etc.
- Crane accidents
- External impacts such as vessel collision, helicopter crash, etc.

3.3 Risk Management

It is recognized that risk cannot be disposed of, however, should be managed. There is a tremendous drive and eagerness in different industries and society in general these days to execute risk management in organisations.

The ISO (ISO and Guide 2002) "d*efine risk management as coordinated activities to direct and control an organization with regards to risk"*. The process of managing risk is explained as, a *"set of components that provide the foundations and organizational arrangements for designing, implementing, monitoring, reviewing and continually improving risk management throughout the organization"* and this, according (ISO and Guide 2002), is termed the risk management framework.

ISO 31000 incorporates eleven (11) principles which it asserts are required to achieve effective risk management; of which the first three are considered the crust of the importance of setting a process for risk management.

- *Risk management creates and protects value*
- *Risk management is an integral part of all organisational process*
- *Be part of decision making.*

3.4 Risk analysis

According to (Ayyub et al. 2002), in order to accurately assess and evaluate the uncertainties that may result from an accident event, risk may be defined as "the potential for loss as a result of a system failure, and can be influenced by a pair of factors, one being the probability of occurrence of an event, and the other being the potential outcome or consequence associated with the events occurrence".

3.4.1 1.4.1 Common Risk Analysis Techniques

3.4.1.1 1.4.1.1 Hazard Operability study (HAZOP)

HAZOP is an analytical technique used to identify hazards and operability problems. This technique is being applied generally to identify in detail sequence of failures and conditions that may cause accidents. In HAZOP analysis, a team of interdisciplinary experts adopts a systematic approach in identifying hazards and other operational problems that are caused by deviations from the supposed range of process conditions. The team leader who must be very experienced systematically coaches his team members, shows them the complete plant design, using "guide words" which relate to specific "process parameters" at "discrete locations" or "study nodes" within the process system. For example, the guide word "High" combined with the process parameter "level" raises questions that concern possibilities of "high-level" deviations from range intended in the design of the system. Sometimes the leader will use checklists or process experience to help the team develop the necessary list of deviations that the team will consider in the HAZOP meetings. The analyses the effects of any deviations at the point in questions and determines possible causes for the deviation (e.g. navigator error, improper lifting, etc.), the consequences of deviations (e.g. Collision, falling material, etc.), and the safeguards in place to prevent deviations. If the causes and consequences are significant and the safeguards are inadequate, the details are recorded so that follow-up action can be taken.

3.4.1.2 1.4.1.2 The Bow-tie Analysis

The Bow-tie method of analyzing risk involves processes that are meant to demonstrate with effectiveness how the Safety Management System designed within a facility can be enforced. Companies and operators find it handy in analyzing and managing peculiar hazards and risks their business or operations are exposed to, and with the use of graphical presentations and displays in the Bow-Tie method, they are able to illustrate the relationships between identified hazards, hazard controls, measures to reduce risk and their business's HSE activities in a diagrammatic form. According to (Vinnem 2013), Bow-ties have become a preferred tool in many circumstances, in order to illustrate the relationship between factors.

The figure below is the structure of a Bow-tie diagram.

Figure 2 An example of a bow-tie diagram. Source: (Taleb 2007)

3.4.1.3 Fault Tree Analysis (FTA)

The Fault Tree Analysis is a deductive failure analysis method that models the pathways within a system that can lead to failures or undesired results. It is a top-down method which starts at a single point and then branches out downwards to display the different states of the system using certain logic symbols. The starting point is fault or undesired event, which is resolved downwards to show the causes of the undesired event and the causes of such event (TechnoPedia 2018).

This top-event is evaluated using Boolean logic (event, gate, transfer symbols) to explore the interrelationships between the critical event and the causes of the incidence. According to Tartakovsky (2007), Fault Tree Analysis is a reliable tool that helps in identifying weaknesses and effects, provide an assessment for reliability, and also quantify future probability. Below is a figure of the structure of Fault Tree Analysis diagram.

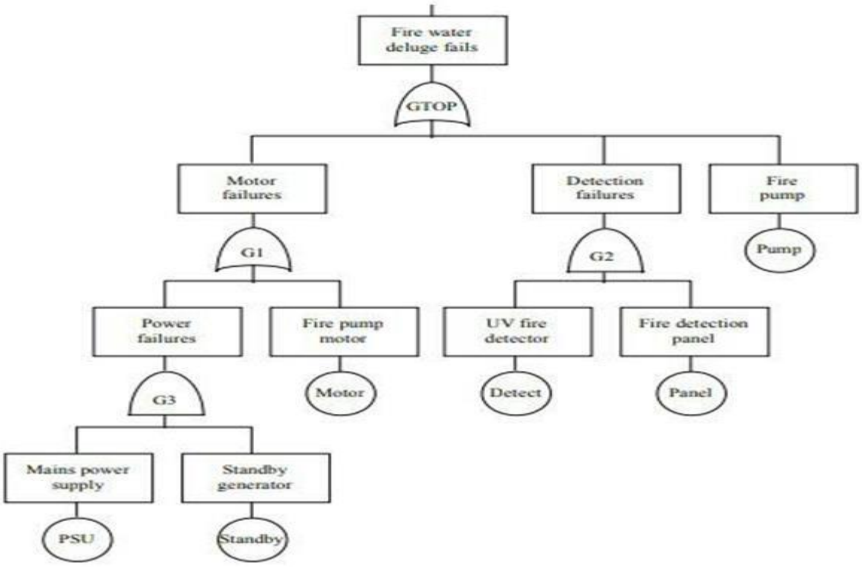


Figure 3 Fault Tree Analysis diagram Source (Spouge 1999)

The Fault Tree Analysis tool is constructed using 'logic gates' (mainly AND or OR gates) to show how basic events combine to cause the main critical event. The construction uses several standard symbols, among which the typical ones are as shown in the diagram below.

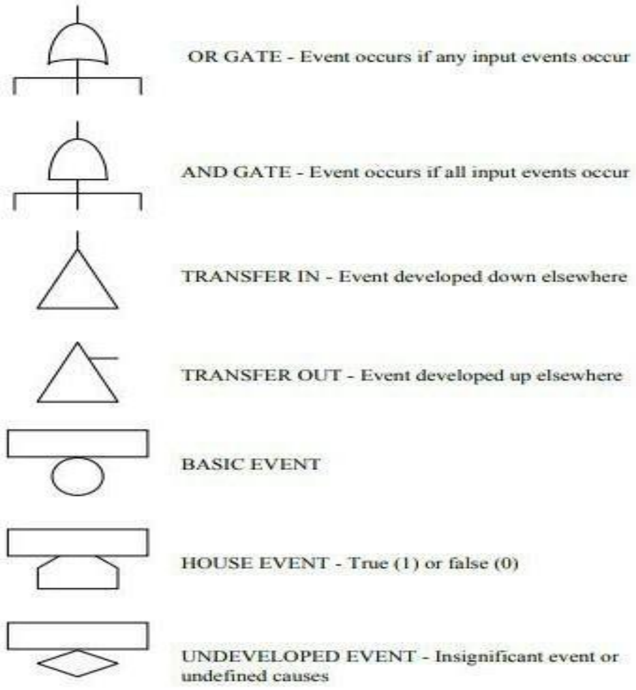


Figure 4 Typical Symbols of FTA Source: (Spouge 1999)

Although the Fault Tree Analysis tool has key potential usage benefits, Spouge (1999), mentioned some strengths and weaknesses of the Fault tree which are noteworthy.

Some strengths:

- It has a wide usage and is well accepted.
- The analysis is well-suited for lots of hazards in QRA, arising from combinations of several adverse circumstances.
- It is a clearer and more logical form of presentation.

Some weaknesses:

- The format of diagrammatic presentations discourage analysts from stating expressly the various assumptions and the conditional probabilities for every gate.
- It soon becomes complicated, time consuming, and difficult to follow for larger systems.
- There's a high tendency of analysts overlooking future modes and common cause failures.
- The assumption that all events are independent, making leads to loss of clarity in the analysis, in its application to systems that cannot be categorized as simple failed or working (e.g. human error, adverse weather).

3.4.2 1.4.2 Limitations of risk analysis

- The applicability of results is influenced greatly by how deep the analysis was done using consequence and escalation modelling. Typically, these are concerns made for when considering systems and functions that are involved in escalation analysis. If, for instance, the modelling of passive fire protection is very coarse, then the study should not be used to determine what the optimum choice of passive fire protection should be. This may seem as an obvious fact, but failures to observe such limitations are not rare.
- There must be sufficient and relevant data to be used as a base for quantifying the frequencies of accidents or the associated causes of the accidents.

- Data used in analysis are mostly from distinct stages and operational phases, and as such results of analysis cannot or may not be used for other phases or operations.

3.5 1.5 Supply Vessels

Vessels engaged in offshore oil and gas, typically, are meant for specific and varied operational purposes. These include construction works on the high seas, exploration operations and other support services. Different vessels are used during explorations and drilling activities. There are also special vessels meant specifically to provide necessary supplies to and fro the construction and excavation or exploration and drilling units on sea.

Other vessels involved in offshore activities are purposed to transport crew personnel who transit to and fro the operational areas on the high seas, when needed. Vessels are thus, classified based on the operation or activities they are purposed for or used for: support vessels for offshore activities, vessels involved in exploration and drilling oil, vessels for offshore production of oil and gas, and other special purpose or construction vessels. Each of this groupings comprise varied types of vessels.

3.5.1 1.5.1 Oil Exploration and drilling vessels

As depicted in the name, this vessels are used when exploring and drilling oil at high seas. They include are drill ships, Jack Up ships, Semi-submersible vessels, offshore barge, floating platforms and tenders

3.5.2 1.5.2 Offshore Support Vessels

These vessels are used in keeping and commuting technical and manpower reinforcements needed for continuity of operations on the high seas, without any form of undesired interruptions.

3.6 1.6 Supply vessel operations

A supply vessel is designated to provide supplies for offshore installations. The vessel loads it’s supplies from onshore base, and then sails to one or more offshore platforms to unload cargo and load up return cargo before it sails back to the onshore base. Most modern vessels use Dynamic Positioning (DP) system for the operations close to the platform,

which is a computer-controlled system to automatically maintain the vessel's position or heading, considering the effects of wind and currents (Kongsvik et al. 2011). The DP system will not be turned on during the voyage to the platform but is prepared during the approach outside a 500-metre safety zone around the installation Northwest European Area (NWEA 2009).
When sailing to the platform the vessel will instead use autopilot to navigate to a predetermined destination close to the installation.

Since the vessel is sailing to the installation and thus will have a high probability of being on collision course with its destination, a safe and standardized set of procedures and industrial guidelines for the supply vessel operations have been made by Northwest European Area (NWEA 2009).

3.7 Major Supply Vessel Operations Hazards

Vessels play a substantial role in the transportation within the oil and gas industry. Consequently, marine and offshore activities present many unique risks and hazards which require special considerations in order to control them. Major operational hazards to supply vessels include those associated with dealing with hydrocarbons in the marine environment and also, other hazards associated with the oil and gas industry including potential collisions. Many offshore installations are located in or near busy shipping lanes, which exasperate the problem of vessels straying into the exclusion zones surrounding each of these installations (Wise Global Training 2015). As hazardous as passing vessels are, majority of collisions with offshore installations also involve *attendant vessels*. Attendant vessels cause roughly ten times more fatal damage collisions than passing vessels, and this can result in grave catastrophic losses.

Major hazards associated with supply vessel operations include collision hazards, oil spill hazards, hazards with greenhouse gases, and few others, as reviewed in sections 2.7.3.1 to 2.7.3.4.

However, some other hazards associated with vessels according to Wise Global Training (2015) are:

- Breakdown, loss of power or loss of steering

- Anchoring over pipelines, wells, and submerged cables. This leads to rupture of the pipelines, wells and cables.
- Explosion during loading/unloading operations
- Pollution – spillage and leakages
- Man overboard (MOB). The personal hazards associated with someone who falls into the water during operations: drowning, hypothermia, being struck by debris or vessel or becoming entrapped by debris.

3.7.1 Collision hazard

Most offshore installations are designed to withstand collisions from supply vessels at moderate speed. They are quite unlikely to withstand collisions from larger merchant vessels at full speed or from large support vessels such as flotels if they come adrift in severe weather. Such events have been extremely rare, but the result may be total collapse of the installation, making them a significant risk. As ships pose risks to offshore installations, the presence of the installation is a hazard for passing merchant shipping, and collisions involve risks to their crews as well as to platform personnel. This is one of the few areas where offshore installations impose risks on third parties (Spouge 1999).

Collision hazards are of one of the design factors that must be carefully considered for the risk of collision during operations of ships and offshore structures. Ship collision has been identified as a major accident hazard (MAH) with potential collision scenarios detailed in the major hazard register. (Koo 2018) identified that ship collisions with offshore installations may involve three different categories of colliding vessels:

- **Passing Vessels –** such collisions involve shipping traffic where the voyage is not related to the FLNG installation activities. The impact by a passing vessel including merchant ships, passenger vessels, navy vessels, fishing boats and other offshore related traffic operating to/from other installation.
- **Visiting Offloading Vessels** – such collisions involve large carriers approaching the installation to remove cargo products.
- **In-field Support Vessels** – such collisions involve smaller vessels that serve the installation as standby vessels, tow vessels for offtake tankers, personnel transfers, and supply and maintenance activities.

Other classification of vessel collisions are based on how the collision takes place at the time of the accident:

- **Powered** (head-on) collisions occur when the colliding vessel is under power of its engines when colliding with the installation, and may be due to navigational errors, watch keeping failure or poor visibility. The 'errant' vessel may be unaware of the proximity to the installation or in the case of visiting vessels, may fail to reduce its approach speed sufficiently to avoid the collision.
- **Drifting collisions** occur when the colliding vessel drifts into the installation due to loss of steerage or towline failure.

3.7.2 Oil Spill hazard

The term oil spill is a form of pollution which essentially means a release of liquid petroleum hydrocarbons into the environment, especially into large water bodies. Oil spills are common accidents within the industry, and can happen while transporting, dispensing and or storing oil in industrial and mining operations. According ProjectLink (2016), the seemingly small threats in the form of leaks, drips, or spill can turn into major accidents, such as fire hazards, slipping etc., if not controlled and managed on time.

Oil spills pose serious harms and are greatly hazardous to not only the immediate environment of the oil production but it also has a much more extensive effects. Oil spills cause immediate and long term harm to both human and animal health, and their ecosystems. Oil spills endanger wildlife as it affects oxygen availability in water, which can suffocate them. Oil emulsions stick to fishes' gills, or coat and this destroys algae or other plankton. Again, floating oils from major oil spills reduces exposure of water to circulating energy, and together with emulsified oil can interfere with photosynthesis. Oil spills can contaminate food sources; reduce plant and animal reproduction and also their nesting habitats. Spilled oils can under oxidation and polymerisation reactions tend to form tars with potential to tarry in the environment for years.

Transocean Settlement, a legal agreement between the United States and Transocean Holdings, about the *2010 Deepwater Horizon* oil spill in the Gulf of Mexico, laid a demand on Transocean Holdings to reconsider the safety of their drilling activities and to improve their preparedness and response to oil spill. The agreement was enetered into as a means of preventing the likelihood of oil spills in the future, as well as minimize the severity of effects of soil spill, when it happens (US Environmental Protection Agency 2017).

3.7.3 Green-house gases emission hazard

According to United States Environmental Protection Agency (US EPA), 22% of the total greenhouse gas emissions in 2016 are produced in the industrial sector. Direct greenhouse gas emissions are ‘produced by burning fuel for power or heat, through chemical reactions, and from leaks from industrial processes. According to (US Environmental Protection Agency 2017) , roughly a third of these emissions in the United States come from leaks from natural gas and petroleum systems, the use of fuels in production (e.g. petroleum products used in making plastics), and the reaction of chemical during chemical mixes.

Globally, 21% of gas emissions are attributed to the industrial sector (Intergovernmental Panel on Climate Change (IPCC) 2014).

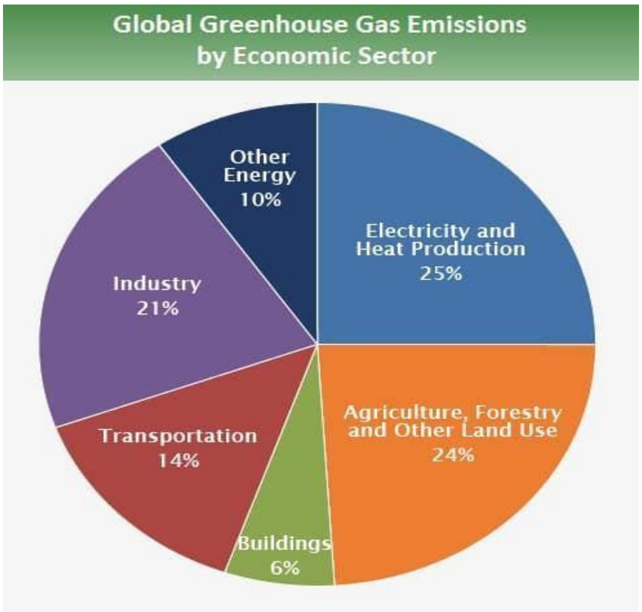


Figure 5 Greenhouse gas emissions, 2014 *Source: US Environmental Protection Agency*

In 2009, US EPA gave a public notice and declared greenhouse gases harmful to people and the environment (ABC News 2009).

3.7.4 Risk of sinking

Capsizing of vessels is a worst case happening in offshore operations and martime sector. Different kinds of hazards or risks are known in these industries, but when vessels sink or ship capsizes, the results are devastating. These kinds of events lead to injuries, illnesses, and in worst situations drownings and fatal hypothemia (Maritime Injury Center 2018).

According to (Actuarial Eye 2014), two large ships sink every week on average worldwide. Carsey et al. (2011) suggest that though these statistics seems exaggerated, she noted however that, ‘every year, on average, more than a dozen large ships sink, or otherwise go missing, taking their crews along with them’. According to an annual analysis reported by Allianz Insurance, 94 ships 9over 100 gross tonnes) were completely lost in 2013. Several reasons attribute to these loses. However, ‘foundering’ (which means sinking or submerging) caused the vast majority of most vessel losses. (Allianz 2014).

In 2018, an Iranian vessel carrying 136, 000 tonnes of crude oil sunk and burst into flames.

“The tanker has burst into flames and sunk, eight days after a collision with a cargo ship off the coast of China. The *Sanchi,* carrying 136,000 tonnes of oil from Iran, had been in flames since colliding with the *CF Crystal*, a Hong Kong registered bulk freighter”. 30 crewmen on board the vessel had no hope of saving. (The Guardian 2018).

Figure 6 Smoke and flames coming from the Sanchi at the sea off China’s coast.

Source: The Guardian (2018)

A review of an article published by *New Scientist* revealed the possible main cause of most vessels sinking. *"Methane gas is the culprit" It further explained, "Organic matter deep under the seabed generates methane which works its way up through the sediment over thousands of years. Pockets of gas can build up beneath the surface. Every once in a while, the pressure gets too much and the gas explodes. Gas below the surface is not just a theory, it is a known hazard for oil rigs. If they hit a gas pocket while drilling, the resulting blowout can sink the rig* (The New Scientist 2000).

Very destructive accidents happpening at sea prove that vessels/ ships, regardless the size, can sink when the conditions for sinking are in place (Maritime Injury Centre 2018). Marine Injury Centre identified 5 conditions or causes of vessel sinking: (1) *Bad weather – which is a major cause; (2) Collisions with other ships or running aground; (3) Human error; (4) Flooding – when the vessel takes on water and hence becoming less buoyant; and (5) Shifting cargo.*

3.8 Collision and Statistics

Collisions can be defined 'as the impacts on installation from ships or other marine vessels, including submarines, and mobile offshore platforms working close to the installation (Spouge 1999). Collisions that involve visiting vessels or other passing vessels and offshore facilities are notable across the world petroleum space. According to the Norwegian petroleum Safety Authority, the Norwegian Continental Shelf have witnessed 26 of these kind of collisions, between the years of 2001 and 2011. Hazard potential was reported to be very high for 6 of these accidents. In 2001, 13% of all vessel related accidents in the world fleet were collisions. Collisions account for 16% of all the severe maritime or vessel accidents over the years of 1980 to 1989 (Kristiansen 2005).

According to Allianz Global Corporate & Specialty (2017), 1,186 vessel losses have been reported over a decade, from 2007 – 2016. 72 of these losses, representing 6% of the total losses, were caused by collision.

Other noteworthy collisions are the *Far Symphony's* collision with West Venture Semi vessel in 2004; the *Ocean Carrier's* collision with the bridge at Ekofisk in 2005; the *Bourbon Surf's* collision with Grane jacket in 2007; the *Big Orange XVIII's* collision with the Ekofisk in 2009; and the *Far Crimshader'*s collision with Songa Dee Semi in 2010 (Oltedal 2012).

3.8.1 Significant Collisions

According to the WOAD^R database, (DVN, 1998a) there have been six cases of total loss of a platform recorded from 1980 until 1988 due to collision or 'contact' (impact by vessel in close attention):

- Two jack-up structures in US Gulf of Mexico have been lost to collision as the initiating event
- One jack-up structure in Middle East waters has been lost due to collision as the initiating event
- One jack-up was lost in US Gulf of Mexico during movement, due to listing, structural damage, contact with platform, and finally loss of buoyancy
- One jack-up structure was lost in the North Sea, due to collision with a pier. This is a non-representative case, involving a small jack-up, which was lost due to severe weather. The jack-up was engaged in tunnel drilling and was standing only a few metres from the waterfront. The jack-up was small and not representative of offshore jack-ups. The accident is disregarded from further discussions.
- One jack-up structure was lost in South American waters (Atlantic coast) due to contact with attending vessel.

It is worthwhile noting that none of these occurrences have taken place in the Ghanaian Continental Shelf.

3.8.2 Collision causal factors

Reviewing studies on vessel collision, two words stand out: "encounter" and "probability". These, according to Mou et al (2010) are the key concepts when considering vessel collisions. They describe an *encounter* to be when two vessels come close enough to each other, that this increases the collision *probability*. Each ship has its safety zone, and whenever another vessel crosses this zone, it is considered an encounter. A vessel's safety zone is the surrounding effective waters as determined by the navigator, to keep clear of other passing vessels or fixed objects or platforms. Usually, the safety domain is often estimated by using the length of the vessel, meanwhile the approximation should be decided by dynamic parameters such as the navigator's skills and capabilities, weather, encounter angle and speed of the vessel Hänninen and Kujala (2009).

Collisions between ships and platforms are divided into: (1) powered collisions and (2) drifting collisions (Oltedal 2012). Powered collisions include vessels moving under power towards the installation and include navigational errors, human or technical faults, watch keeping failures and bad visibility due to weather or ineffective radar use. But, with drifting collisions, the drifting vessel losses its propulsion or steerage and drifts only under the influence of environmental forces (IAOGP, 2010). The loss of steerage may also be related to failure stemming from human interface with technical arrangements such as inadequate maintenance. According to IAOGP 2010, three conditions are necessary power collision: (1) the vessel must have been on a collision course with the installation; (2) the watch keeper must have been unaware of the collision course long enough for the ship to reach the installation; and finally (3) the installation must either be unaware of the developing situation or unable to warn the vessel to normalize the situation.

The common causes of most ship-platform collisions, according to Oltedal (2012), can be identified as (1) unmonitored approach related to inadequate transfer of command and (2) human deficiency in detecting or interpreting a technical state or error. These underlying causal factors are related to violations of operational procedures that have drifted into normalized operational behavior. With reference to reported collision accidents, some common causes of the collisions identified or classified as: *(1)equipment failure (2) weather, (3)misjudgment of captain, (4) human control failures (5) poor understanding and training in advanced technical equipment*. Health and Safety Executive (HSE) determined that the primary cause of most collisions was due to human error in 45% of the cases, followed by equipment failure in 33% of the cases, and 22% for other external factors.

Again, Kristiansen (2005) specified that a collision between two vessels can mainly be in three ways: *(1) it can be head on collision, (2) collision caused by overtaking, and (3) collision caused by crossing*. In this regard, Goerlandt and Kujala (2011) indicated that the highly common among these three ways is the overtaking collision while the head on collision is not very frequent.(Mou, Van Der Tak, and Ligteringen 2010), in their investigation of historical data of vessel collision causality, have revealed that collisions caused by crossing encounters are the most dangerous while those by overtaking are considered the lowest risk.

Vessel collisions, like every other accident, are the outcome of a chain of several numbers of failures and or mistakes. According to Rothblum (2000), every accident is a result of causes ranging from 7 to 53 factors. Originally, one would only classify a failure cause resulting in an accident as human failure or technical failure but recent developments of accident models help in explaining that accident can be identified by considering other underlying causes such as crew working conditions, management and competence of crew, training and safety relations within the organization.

From the above mentions, one can conclude that vessel accidents causes, and collisions (for purposes of this thesis), are due to human factors, technical and organizational factors; with the most common ones being lack of lookout or watch-keeping failure, lack of sleep, bad communication, bad maintenance routines etc. (Olsen 2017).

3.8.2.1 1.1.1.5 Collision Course

A definition of collision course is *“a situation in navigation in which a vessel will collide with another vessel unless one or both vessels alter course, or stop”* (SeaTalk Nautical Dictionary). Vessel encounters are, thus, related to collision course. Figure 7 shows how vessel encounters can be classified in relation to collision course.

Figure 6: Classification of ship encounters in relation to collision course. Source: (Goerlandt et al. 2015)

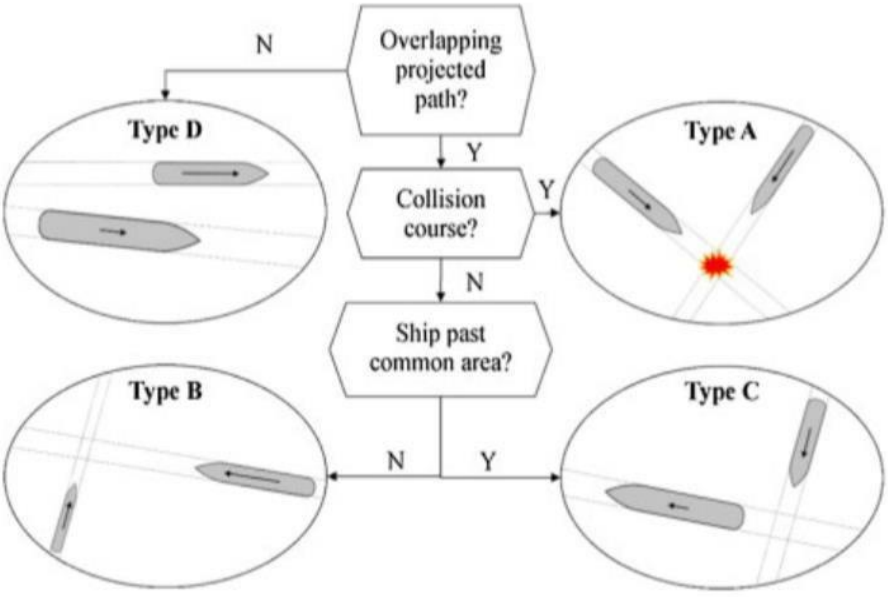


Figure 7 Classification of ship encounters in relation to collision course. Source: (Goerlandt et al. 2015)

Goerlandt et al. (2015) explained that a collision course from which no escape is possible is the final phase before a vessel-vessel collision. The model, as seen above, presents four types of projected paths in relation to collision course. Type A depicts a projected path where two colliding vessels will reach a common spatial zone simultaneously and then collide if no action is taken. Type B and C depict projected crossing courses where the common spatial zones for the moving vessels are reached at different times, leading to no collision. However, Type B and C may evolve to a Type A situation if one of the vessels in question changes its course or adjusts its speed. A Type D path is where ships' paths don't overlap and hence no collision. Goerlandt et al. (2015) also noted that despite the projections of the above model, collisions can happen even though vessels are not on collision course at the given time, as changes in the spatial zones and/or temporal relation between the concerned vessels may cause the vessels to be on collision course. And according to Kristiansen (2013), the risk of collision is a function of traffic density and the distance of the fairway. According to him, the probability of a collision between two ships is the product of losing navigational control and the likelihood of having an accident, given that you have the occasion of losing navigational control.

3.8.2.2 1.1.1.6 Human Factors

Goodwin (2007) defined *human factors* as the scientific discipline encompassing theories and knowledge about human behavioral and biological characteristics, that are validly applicable for specification, design, evaluation, operation and maintenance of products and systems, in order to promote safe, effective and satisfying use by individuals, groups, and organizations. Thus, human factors may be regarded as including a wide range of issues, i.e. human perception, physical and mental capabilities, individuals' interactions with their job and work environment (surroundings), human performance under influence by equipment and system design, as well as the influence of organizational characteristics on safety related work behavior (Skogdalen and Vinnem 2011). Human factors have become major considerations in the area of vessel collision accidents. Despite new models can be used to explain and identify underlying causes of collisions, the human and technical failure classifications are still widely used (Olsen 2017). Another argument is the view that almost all accidents (both vessel collision accidents and general accidents) are mostly due to human actions. All machines are designed and operated by humans. Humans decide on machine and system maintenance requirements and frequency, humans decide which materials to use in designing and maintaining machines. Much more, humans determine the safety cultures within an organization. For this reason, Rausand (2013)writes that human errors account for 60-90% of all accidents in industry and transport. Out of all ship collisions reported to have occurred in the Gulf of Finland, 52.6% were noticed to be due to human factors, this includes routines, communications and organization. Trucco et al, further report that 70-80% of all maritime accidents are due to one form of human mistake, or other events influenced by human behavior.

3.8.2.3 Human Error

Often, the terms ‘human error’ and ‘human factor’ appear in literature where they are synonymously used. A distinction between the two is needed. Human factors are not the same as human errors as human errors are the immediate cause of accidents while the human factors are the underlying causes, or the so called latent errors (Goodwin 2007). Horberry, Grech, and Koester (2008) describes human error as inappropriate or undesirable human decisions or behavior, resulting in, or having the potential for adverse results. Human error is identified as one of the main contributing elements in numerous maritime accidents and incidents (Lundborg and Erik 2014). Rothblum (2000) reports a study on 100 accidents. The study revealed that common to all 100 accidents was that in every causal chain there was at least one human error, and that if the human error had not occurred the whole accident wouldn’t have occurred. It would have been avoided, as the causal chain would be broken. It can therefore be concluded that prevention of human errors or an increase in the probability of discovering human errors, could lead to greater maritime safety and fewer vessel accidents (Rothblum 2000).

Rothblum (2000) argues that technological, environmental or organizational factors are the main influencers of the way humans perform and therefore also influence the human errors. This makes human errors an indication of deeper and more sophisticated problems in organizational systems, even though they are often blamed on simple inattentions or mistakes by the systems operator. As many technical systems are designed without thought to the user, most technical or technology designs does impact the way humans perform at task. Human performance and behavior – human errors – are influenced by organizational work schedules, crew size, company policies, hierarchical command structure, etc. These, therefore, are to extent incompatible with optimal human performance, as they set up the individual to make mistakes (Rothblum 2000). To resolve this, Rothblum (2000) writes that systems will have to be adapted to the humans that will operate them, instead of the of the other way around as is common in the maritime industry. The human centered approach for designing system technologies will increase efficiency, effectiveness, morale, and while decreasing errors, accidents, training costs, personnel injuries and lost time (Rothblum 2000)Organizational Factors (and Human Errors)

A good definition of human factors encompasses the effect individual, group and organizational factors have on organizational safety (Gordon, 1998), and this also means that organizational factors are key influencers of human factors, which also influence human errors. The organizational factors are often overlooked in accident investigations, but they influence how individuals and groups behave and perform (Rausand, 2011), and therefore, are significant to be investigated. Organizational causes for accidents are often linked to the organizations safety culture (Olsen, 2017).

Today, International Maritime Organization (IMO) has recognized that although human errors are commonly found to be primary causal contributors to accidents, investigators should not explicitly focus on the organization's personnel directly involved in the accidents (sharp-end personnel), but rather take into consideration the conditions surrounding the sharp-end personnel and the organization, that permitted the hazardous conditions to exist (Chen et al, 2013). People and their work their environments are usually subject to and influenced by the organization, the job and other personal factors, and these, as (Stranks,
2005) writes, are further directly influenced by the organization's communication systems, training systems, and operational procedures. These surrounding conditions are called the organizational factors.

An organization's design of job positions, work and task divisions, as well as the selection, training, cultural indoctrination and coordination of the workforce defines organizational factors. With respect to the oil and gas industry, the key safety related aspects include factors in relation to the complexity, size and age of installation, and factors determining the organizational safety performance, e.g. communications, coordination, leadership, manning (Skogdalen and Vinnem, 2011)

3.8.3 Consequences of Collision Accidents

The consequences of collision accidents can be: (1) damages to the installations resulting in loss of structural integrity, (2) loss of stability or buoyancy, (3) oil outflow or oil spill resulting in environmental pollution, (4) loss of entire installation, and (5) loss of life.

(Wang et al, 2003). According Silveira et al, vessel collision consequences may depend on: (1) Ship striking or being struck (2) The angle of encounter, relative to speed, (3) The type of ship, cargo, age of ship and the loading condition of the vessel (4) The extent of damage; i.e. breach of hull, or loss of watertight integrity (5) The location of the collision (in port, coastal waters, open sea, or near environmentally sensitive areas), (6) Availability and distance to means of rescue and, (7) The weather conditions.

3.8.4 Vessel-Platform Collision risk analysis

QRA for vessel platform collisions have proven conservative in many cases, and most effort in response to them has been related to improving the predictions by collecting better data, rather than reducing risks. However, for some platforms in busy shipping areas, QRA's have been used to help select risk reduction measures, (Spouge, 1999).

According to Spouge (1999), six (6) classes of potentially colliding vessels are noteworthy for vessel-platform collision analysis. These collisions are reviewed in turn.

3.8.4.1 Visiting Vessel Collisions

Visiting vessel collisions vary from relatively frequent minor bumps to rare but highlydamaging full speed collisions. The frequency is strongly dependent on severity f collisions included. Few incidents have been documented to sufficiently help define the severity of such collisions in terms of impact energy. According to Spouge (1999), for better risk analysis, three main visiting vessel collision types can be classified:

- On arrival – where the visiting vessel fails to stop when it reaches the platform, hitting it in full speed. These are potentially the most severe.
- Maneuvering – where the vessel captain misjudges a turning and hits the platform a relatively low speed.
- Drifting – where the vessel losses power or suffers failure of dynamic positioning, drifting into the platform due to wind and waves.

Collisions involving ships alongside a platform such as supply vessels and anchor-handling tugs, in practice, can cause extensive local damages to both the vessel and the platform.

However, the impact will rarely impair the structural integrity of the platform (*Van der Tak and Glansdorp, 1992)*

3.8.4.2 1.1.1.9 Passing Merchant vessel collisions

Passing vessel collisions are relatively rare (amounting to 5% of all reported collisions) but are potentially the most damaging (Spouge, 1999). The main cause appears to be vessels that have suffered watch-keeping failure due to some human errors or other technical factors, or are entirely unaware of a platforms presence.

3.8.4.3 1.1.1.10 Fishing Vessel Collisions

These pose a collision hazard to platforms in general, and bottom-trawling gear poses a particular risk to subsea installations and pipelines. They are frequent offenders in entering platform safety zones, since fishes tend to congregate around installations. Because fishing vessels are small, they cause low energy impacts, though some may be as large as small merchant ships.

3.8.4.4 1.1.1.11 Naval Vessel Collisions

Naval vessels tend to approach platforms during exercises or for intelligence gathering. The Norwegian sector has witnessed a naval submarine colliding with a fixed platform, and various infringements of safety zones. According to Spouge (1999), no traffic data is available for security reasons, and that they are usually omitted from collision risk calculations or are treated negligible compared to other passing vessels.

3.8.4.5 1.1.1.12 Offshore Tanker collisions

Tankers approaching offshore moorings or off-loading installations may collide with them due to misjudgment or machinery failure.

3.8.4.6 1.1.1.13 Collisions between fixed and floating platforms

Collisions from flotels or other large support vessels anchored close to the platform are likely to result from the progressive loss of anchors, followed by failure of tugs and/or thrusters to prevent the collision.

3.8.4.7 1.1.1.14 Vessel-Platform Collision Risk Impact

Analysis of vessel-platform collision risk consequences and impacts is usually dependent on the principle of conservation of energy. On this basis, Spouge (1999) categorized two types of collisions that may be considered:

- Glancing blows – where the ship brushes against the platform but retains most of its incident kinetic energy. These events mostly cause negligible damage to the platform.
- Full-on Collisions – where the ship is stopped by the platform while its kinetic energy is absorbed in plastic deformation of the ship's and the platform's structure.

Historically, vessel-platform collisions result in fatalities among the crew on tankers carrying highly flammable cargoes. Fatalities among platform crew from vessel-platform are almost non-existent, but this may be due to anonymity of the platforms that are hit most often. However, the risks can be estimated by theoretical evaluation models, combined with judgments about the time available before collapse, and the evacuation methods that can be used (Spouge, 1999).

3.8.4.8 1.1.1.15 Limitations to Vessel-Platform Collision Risk Analysis

Spouge (1999) identified five limitations/weaknesses:

- The lack of data on high-energy collisions such as from flotels or tankers

- The lack of shipping traffic data for many areas of the world (and even in the North Sea for some types of ships) which is needed to use the theoretical models
- Substantial uncertainty in theoretical collision frequency predictions due to changes in shipping lanes with time
- Limited understanding of how installations affect shipping lanes, and hence how collision risk varies with time.
- Lack of knowledge of how installations would respond to high-energy collisions, and how evacuations would be affected.

4.0 CHAPTER FOUR – COLLISION RISK MODELLING

4.1 Basis of the Collision Risk Model

The Model used in the study is primarily based on the probability theory as (Ostrom and Wilhelmsen 2012) stated that probability is an integral part of risk assessment and they move hand in hand. Probability is used in this model to determine the likelihood of supply vessel collide with a stationary offshore installation.

4.2 Probability Theory

Probability may be explained as the chance that an incident may happen. Probability ascertains the degree of uncertainty connected to the outcomes of an event. Probability is usally expressed as a fraction with the denominator representing the total number of ways things can happen and the numerator representing the number of things one is hoping to occur. It is always a number from 0 to 1 or between 0% and 100%. Zero means there is no possibility of an even occuring whereas 1 or 100% shows that an event will surly occur.

When dealing with probabilities, there are two common used terms: mutually inclusive and mutully exclusive. The former means that events are simultaneously happen whereas the ladder is the other way round. The basic rule of probability is that mutually exclusive events

(eg A and B) can never happen at the same time. This can be written as $P(A \text{ or } B) = P(A) + P(B)$.

Even though, these rules are few and easily understood, they are very important in application (Ostrom and Wilhelmsen 2012).

4.2.1 Combining Probabilities

To ascertain the final probability of events, events' probabilities are combined using the rules, the Boolean algebra. The two most commonly used Boolean Algebra terms include the logical "AND" and "OR" (Ostrom and Wilhelmsen 2012).

When two probabilities are combined using "AND" logic, these probabilities are multiplied together and when two probabilities are combined using "OR" logic, they added together.

4.2.2 Conditional Probability

Conditional Probability is explained by (Ostrom and Wilhelmsen 2012) as "a probability whose sample space has been limited to only those outcomes that fulfil a certain condition. In other words, conditional probability is a chance of an event happening only when certain actions are satisfied. It can be represented as

$P(A/B = n(A \cap B)$

In general when working with probabilities, "AND" means multiply and "OR" means add, care must be taken with compound probabilities (Ostrom and Wilhelmsen 2012). There are three important rules that must be considered.

- If A and B are independent and that the occurrence of one does not affect the other, then P(A and B) = P(A) x P(B)
- If A and B are dependent and that the occurrence of one affects the other, then P(A or B) = P(A) + P(B)
- P(A or B) = P(A) + P(B) – P(A and B). P(A and B) may equal to zero if A and B are "mutually exclusive".

4.3 Elements of the Collision Risk Model

The Collision risk model is made up of several large fault trees with a fairly simple equation trying it all together. The top level equation (1) calculates the annual probability of collisions from passing vessels and other parameter descriptions are shown below (Vinnem 2007):

$$p^{cpp} = \sum_{i=1}\sum_{j=1}\sum_{k=1} N_{ijk} \sum_{l=1} \left(P_{jkl}^{cc} * P_{jkl}{}^{FSIR} * P_{jkl}{}^{FPIR}\right) \qquad Eq.\,(1)$$

i = number shipping

routes/lanes j = types of vessel

categories k = size group of

vessels l = traffic groups

Where m is the number of shipping lanes/ routes identified to pass the installation with a relevant distance, j is the types of vessel categories, k is the size group on the type of vessel and l is the traffic groups.

P^{CPP} = Annual probability of collisions from powered passing vessels

N_{ijk} = Annual number of vessels of type j and size k passing the installation in route i

P_{jklcc} = the probability that the vessel of type j in size group k and traffic group 1 travelling in route i is on collision course at the point when the vessel should be able to observe the installation visually or on radar.

$P_{jklFSIR}$= the probability that the vessel itself does not initiate action to avoid a collision with the installation (Failure of Ship Initiated Recovery)

P_{ccjkl} = the probability that the installation or its external resources fail in diverting the vessel on collision course, given that the vessel has not initiated such action (Failure of Platform Initiated Recovery)

The model above consists of four different elements which include traffic pattern, the probability of being on a collision course, probability of vessel initiated recovery and failure of platform initiated recovery.

4.3.1 Traffic pattern

Quantitative risk models of ship collisions perpetually utilize some form of traffic data as the basis for further computations (Hassel, Utne, and Vinnem 2014). The contribution to the impact Model is traffic and vessel data, portraying the traffic pattern and all vessels required, alongside installation data and climate data. The model output is the probability of a vessel collision with a stationary installation, along with corresponding total impact energies (Hassel, Utne, and Vinnem 2014). As seen in equation (1), the first component (N_{ijk}) is traffic pattern and it is not really modeled, but simply is the result of traffic pattern assessment.

In this research, Automatic Identification System (AIS) is processed to determine traffic patterns and the tracks are linked to ship databases to retrieve additional data on type, size and other relevant information. AIS has been the data source most commonly used to document ship traffic since its introduction in 2005. (International Maritime Organization (IMO)) regulation requires AIS to be fitted aboard all ships of 300 gross tonnage (GT) and upwards not engaged on international voyages.

4.3.2 The probability of being on a collision course

The next component of equation (1) is the probability that a vessel is on a collision course, P^{cc}. this parameter is mainly calculated based on the way the vessel is assumed to navigate, with the following set of equations (Hassel, Utne, and Vinnem 2014):

$$P_1^{cc} = (1 - P_k) * F_1^D * F^{NS} \qquad Eq.(2)$$

$$P_2^{cc} = \mathrm{P_k} * (1 - P_A^P) * (1 - P_{PF}^P) * F_2^D * F^{NS} \qquad Eq.(3)$$

$$P_3^{cc} = \mathrm{P_k} * (1 - P_A^P) * \mathrm{P_{P,PF}} * F_3^D * F^{NS} \qquad Eq.(4)$$

$$P_4^{cc} = \mathrm{P_k} * \mathrm{P_{P,A}} * F_4^D * F^{NS} \qquad Eq.(5)$$

P_{cc2} = Annual probability of a vessel being on collision course at a distance of 12 nm

1 signifies unknown vessel (vessel unaware of the existence of the installation)

2 signifies non-planning vessel (vessel has not planned evasive action)

3 signifies position-fixing vessel (vessel passing closer to help position-fixing)

4 signifies avoidance vessel (vessel taking evasive action to increase distance)

P_{PA} = probability of vessel being aware of the existence of the installation

P_{PPF} = probability of vessel planning evasive action

$P_{PF}{}^{P}$ = probability of vessel using installation for position-fixing

$F_1{}^{D}$= fraction of vessels heading towards the installation

F_{D2} = shielding factor

4.3.3 Failure of ship initiated recovery

The F_{NS} component of equation (1) is calculated from a fault tree, and the collision project identified three main modes of failure:

- Watchkeeping/navigation failure/failure to act
- Erroneous action by navigator
- Equipment failure/technical error

The last two items were considered negligible by the collide project, with the exception of a radar failure. The argument was that equipment failure that would lead to a collision was highly unlikely and should be disregarded. Similarly, the action needed to avoid collision was simply to alter course, an action deemed so simple that erroneous action was highly unlikely and thus disregarded. This is further represented in the fault tree below.

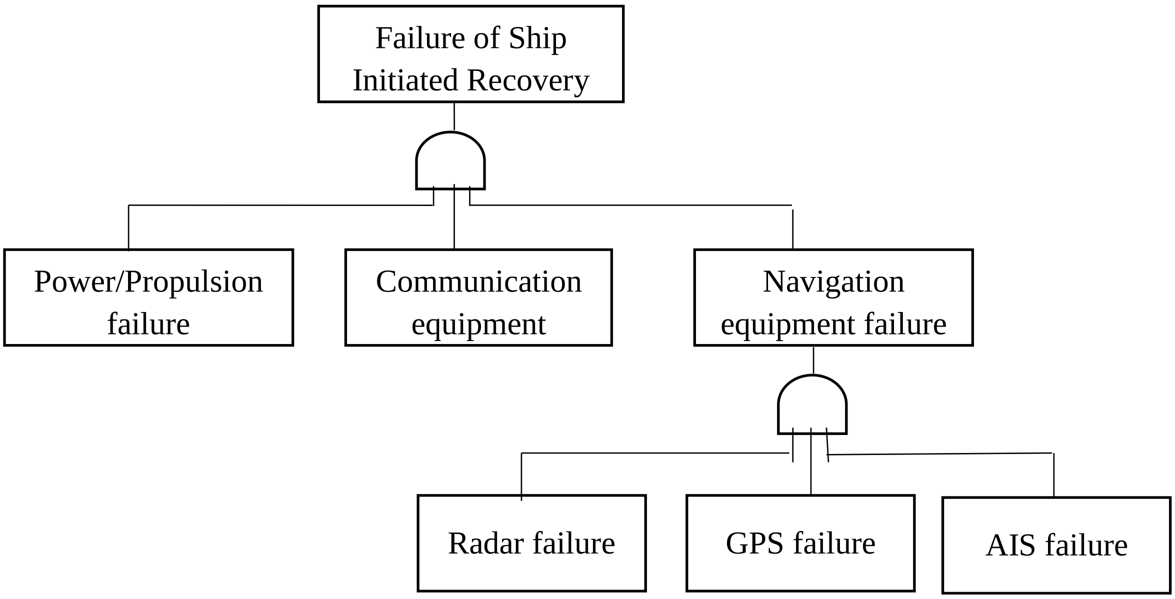


Figure 8 Fault tree for Failure of ship initiated recovery

Source: Hassel, Utne, and Vinnem (2014)

4.3.4 Failure of platform initiated recovery

The last component of equation (1) is the P^{FPIR} component. It is also the result of a fault tree, considering factors such as realization that a vessel may pose a threat, establishing successful communication with the vessel and having the standby vessel to intercept. The efficiency and success of platform initiated actions will be highly dependent on the reasons behind a failure of ship initiated recovery. According to (Hassel, Utne, and Vinnem 2014), the approaching vessel is not regarded as a threat to the platform unless it reaches the 20min limit and can also be assumed that there will be limited difference between the planning, non-planning and unknown vessels. They further explained that the ability to perform such task (i.e. Platform Initiated Recovery) is based on whether the actions including the following are performed in time: identification of the vessel as a possible threat; attempt to call the vessel on Very High Frequency (VHF); position the standby vessel alongside the vessel; and undertaken correct avoidance action by the standby vessel.

4.3.5 Modelling of Human Errors

Human Reliability Analysis (HRA) is an necessary factor to consider in risk modelling. According to Swain and Guttmann (1983), the most exploited tool for analyzing human reliability data is the Technique for Human Error Rate Prediction (THERP). THERP was proposed by Swain and Guttmann (1983) in their report. Since 2002, THERP has been liste as to be practical methods for marine industry (Formal Safety Assessment (FSA) (IMO 2002).

This model tries to identify operator's actions and modelled as an equipment item. From the THERP Handbook, Swain and Guttmann (1983) identified four steps to follow:

- Identifying of the system component that may be influenced by human error
- Analyzing the related human operations
- Estimating the relevant human error probabilities (HEPs) using the data that are available or expert values.
- Estimating the extent of effects of human errors.

Swain and Guttmann (1983) futher explained that the probability of operator's action can be determined using the following equation:

$$P_{EA} = \sum_{k=1} HEP_{PSF} \cdot W_k$$

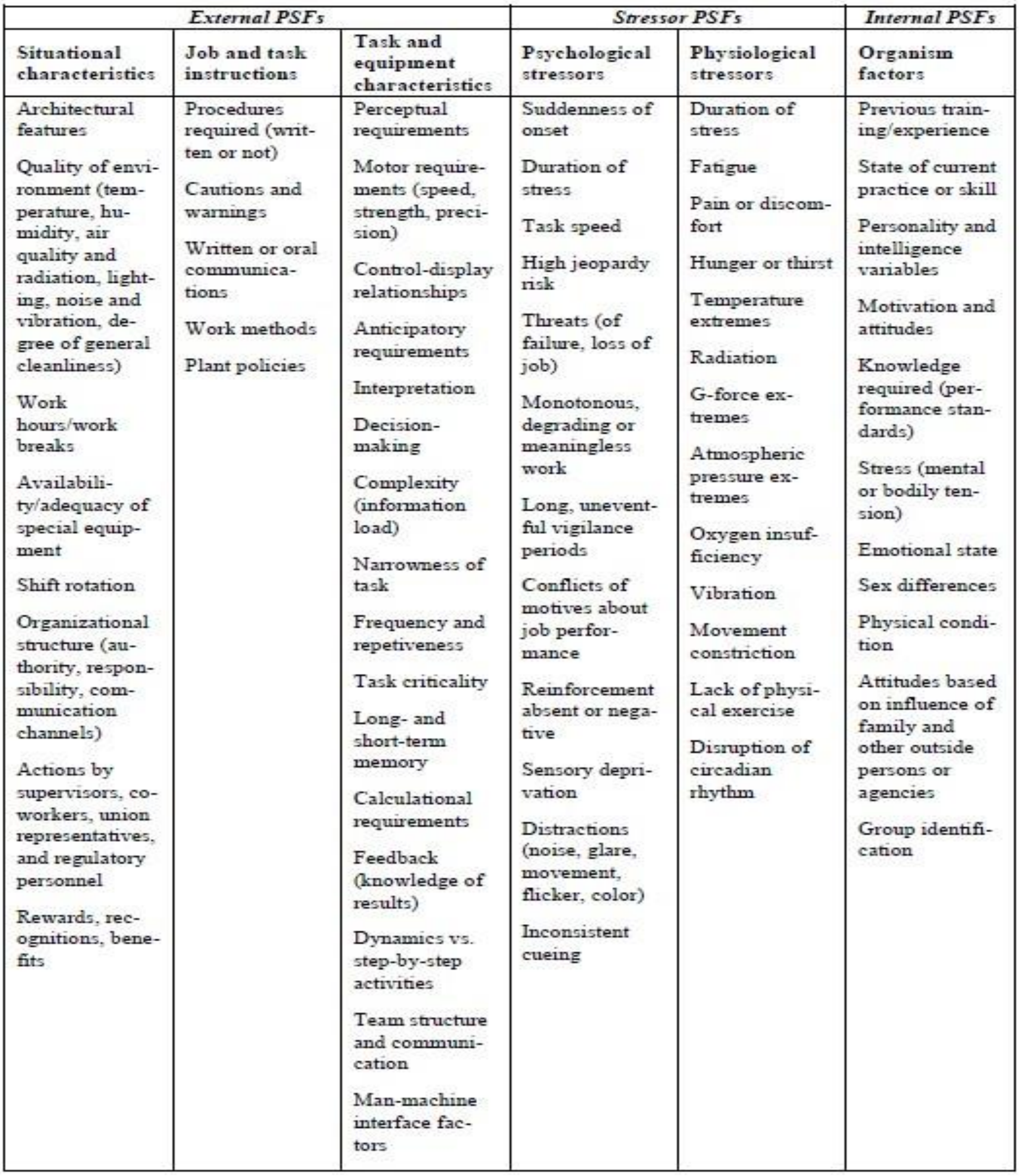
Where

P^{EA}	is the probability for a specific erroneous action
HEP^{EA}	is the basic operator error probability
W^k	is the weight of PSF^k,

The basic HEPs are predefined values of human error probabilities and they are listed in the Handbook. These are assumed to be independent of their context so they can be applied to different domains (Brown and Haugene 1998). The perfomance shaping factors describe the effect of context on the basic human error probability (Hollnagel 1998). they furthered that these PSFs are classified into external, stressors and internal as shown in table 6

Table 2

Table 2 PSFs in THERP. Source (Hollnagel 1998)



External PSFs			*Stressor PSFs*		*Internal PSFs*
Situational characteristics	**Job and task instructions**	**Task and equipment characteristics**	**Psychological stressors**	**Physiological stressors**	**Organism factors**
Architectural features Quality of environment (temperature, humidity, air quality and radiation, lighting, noise and vibration, degree of general cleanliness) Work hours/work breaks Availability/adequacy of special equipment Shift rotation Organizational structure (authority, responsibility, communication channels) Actions by supervisors, co-workers, union representatives, and regulatory personnel Rewards, recognitions, benefits	Procedures required (written or not) Cautions and warnings Written or oral communications Work methods Plant policies	Perceptual requirements Motor requirements (speed, strength, precision) Control-display relationships Anticipatory requirements Interpretation Decision-making Complexity (information load) Narrowness of task Frequency and repetiveness Task criticality Long- and short-term memory Calculational requirements Feedback (knowledge of results) Dynamics vs. step-by-step activities Team structure and communication Man-machine interface factors	Suddenness of onset Duration of stress Task speed High jeopardy risk Threats (of failure, loss of job) Monotonous, degrading or meaningless work Long, uneventful vigilance periods Conflicts of motives about job performance Reinforcement absent or negative Sensory deprivation Distractions (noise, glare, movement, flicker, color) Inconsistent cueing	Duration of stress Fatigue Pain or discomfort Hunger or thirst Temperature extremes Radiation G-force extremes Atmospheric pressure extremes Oxygen insufficiency Vibration Movement constriction Lack of physical exercise Disruption of circadian rhythm	Previous training/experience State of current practice or skill Personality and intelligence variables Motivation and attitudes Knowledge required (performance standards) Stress (mental or bodily tension) Emotional state Sex differences Physical condition Attitudes based on influence of family and other outside persons or agencies Group identification

5.0 ILLUSTRATIVE CASE STUDY

As an illustration, let's consider the input parameters for the FPSO, John Agyekum Kufour. The FPSO is considered as recently installed and below are the details:

Name:	*John Agyekum Kufour*
Vessel Type:	*Floating Production/Storage*
Position(latitude/longitude):	*4.468095°/-2.554095°*
Dimension:	*333.07m x 58.04m*
Flag:	*Singapore*
Status:	*Moored*

Now let's assume that for vessels which pass up to at least once a year:

- 80% know about the installation
- 40% exercise avoidance planning with a safe distance of 2nm
- 15% use the FPSO as a fixed navigation point
- 90% collide with the installation when position fixing with a 2nm distance

169 vessels per year traffic in both directions, all year seasons

1.35nm distance to the FPSO John Agyekum Kufour

The width of the installation is 58meters. In a normalized Gaussian distribution, the following data is given for further calculation:

1.35nm	~ 0.225 standard deviation
1.35nm+58m	~ 0.22662 standard deviation

Probabilities obtained from accident history for individual factors that were assumed to be the cause failure of ship initiating recovery are:

Alcohol	0.11%
Asleep	0.23%
Distracted	0.95%
Radar failure	0.98%
Power/propulsion failure	0.12%

And probabilities of factors that may cause failure of FPSO initiated recovery include:

failure to realize that a vessel may pose threat 0.00144
failure of establishing communication with the vessel 0.18

failure of having standby vessel to intercept 0.2

Results

PROBABILITY OF FAILURE OF SHIP INITIATED RECOVERY

failure probabilities for recovery by ship	
Alcohol	0.0011
Asleep	0.0023
Distracted	0.0095
Radar failure	0.0098
Power/propulsion failure	0.0012
	2.82652E-13

PROBABILITY OF FAILURE OF FPSO INITIATED RECOVERY

failure probabilities for recovery by installation	
failure to realize that a vessel may pose threat	0.00144
failure of establishing communication with the vessel	0.18
failure of having standby vessel to intercept	0.2
	0.00005184

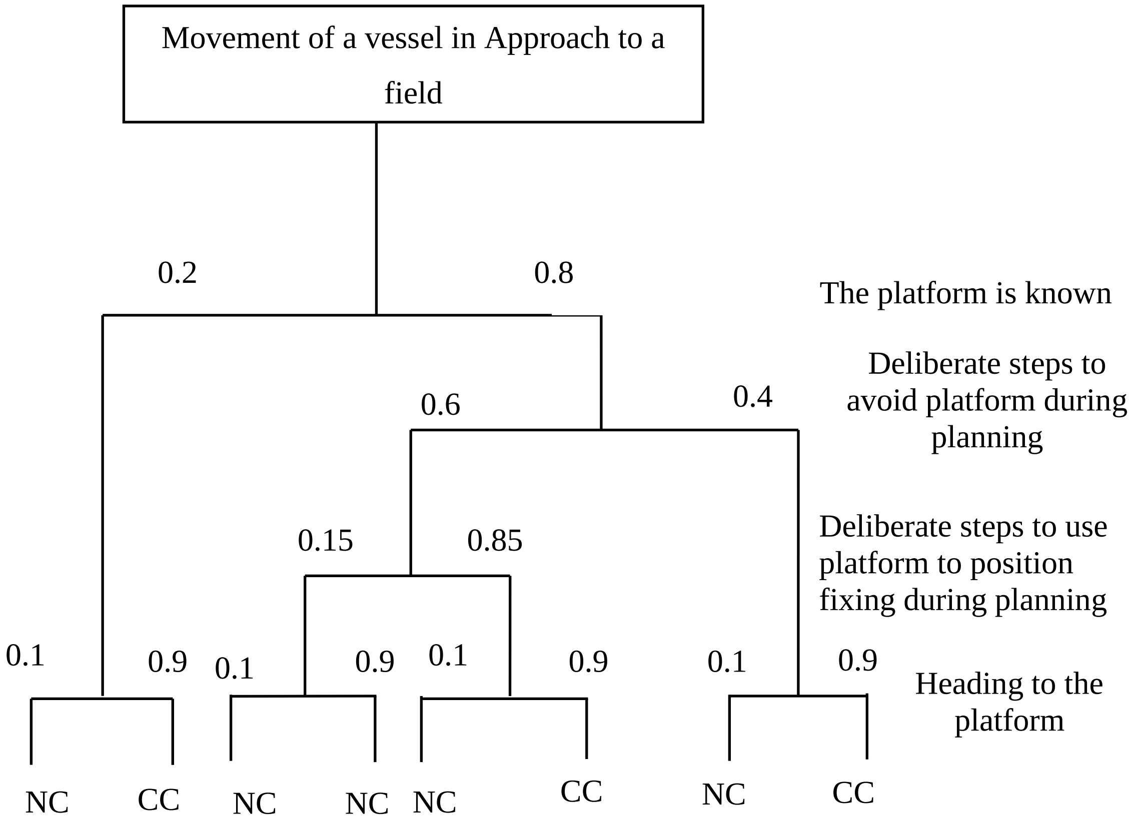
PROBABILITY OF VESSEL ON COLLISION COURSE

	YES	NO
The platform is known	0.8	0.2
Deliberate steps to avoid platform during planning	0.4	0.6
Deliberate steps to use platform to position fixing during planning	0.85	0.15
Heading to the platform	0.9	0.1

Probability of collision course(unknown vessel)	0.18
Probability of collision course(non-planning vessel)	0.3672
Probability of collision course(position fixing vessel)	0.288
	0.019035648

TRAFFIC PATTERN

Mean distance of shipping lanes away from FPSO	1.35nm
Standard deviation (1.35nm range)	0.225
Standard deviation (1.35nm+58m range)	0.22662
conditional Probability of vessel hitting the FPSO	**0.00063**
ANNUAL PROBABILITY OF COLLISION	**1.20251E-05**



HUMAN ERROR PROBABILITY

Erroneous action	PSF	Weight (w)	Probability(P)
Navigational error	Procedures	2	0.06
	Training	3	0.09
	Feedback	1	0.03
Watch-keeping error	Fatigue Asleep	1	0.08
		3.5	0.28
	Alcohol	0.5	0.04
Personnel Incompetence	Training	2	0.2
	Recruitment	3	0.3
Total HEP			**5.22547E-10**

ANNUAL PROBABILITY OF COLLISION INCLUDING HUMAN ERROR 6.28369E-15

Interpretation

The results obtained from the illustration above shows, the probability that a vessel on collision course hits the FPSO John Agyekum Kufour is 0.019, probability that the vessel fails to initiate recovery is 2.826×10^{-13} , the probability that the FPSO fails to initiate recovery is 5.184×10^{-5} and the probability vessels passing hit the FPSO is 6.3×10^{-4}. The annual probability is 1.20251×10^{-5}. This implies that for every 100000 vessels that pass in a year, one vessel will hit the FPSO considering that all the conditions stated.

After incorporating human error, the annual probability is 6.28369×10^{-15}. A difference of 50225407×10^{-10} between the two. This indicates the influence human error contributes collision in the offshore activities.

Decision-making:

Operating in an environment where risk of collision is as low as 6.28369×10^{-15}, implies that some preventive measures may be avoided, and this may reduce costs. The indication of human error on the annual probability depicts that employee actions should not be undermined. (Vinnem 2014) suggested some ways which may reduce human error in navigation:

- Navigation chart should be updated regularly
- Effective and regular training, seminars and workshops should be organised for worker in order to improve their efficiency
- Effective communication should be encouraged.

6.0 CHAPTER FIVE – COLLISION RISK INFLUENCING FACTORS (RIFs) AND INDICATORS

6.1 RIFs

Stornes (2015) explains Risk Influencing Factors (RIFs) as "any factor that affects an undesired event". Øien (2001) also defines RIF as "an aspect (event/condition) of a system or an activity that affects the risk level this system or activity". Since the influence of an RIF is indirect, it is mostly assumed that the RIFs work through parameters in a risk model (Vatn, 2013). For instance, the performance of watch keeping as a risk factor can be influenced by bad weather conditions, personnel competence, workload and so on (Dai et al, 2013). According to Lundborg (2014), RIFs are identified through the process of grouping comparatively steady conditions that influence risk into sets, a single RIF representing the level of one set of conditions. These sets may, moreover, be improved through specific actions. (Vinnem et al, 2013b) categorized risk influencing factors, with corresponding definitions as presented below:

- Operational RIFs – These are activities essential to ensuring the safety and efficiency in operations on daily basis.
- Organizational RIFs – These are related to the organization's management philosophies, policies, and strategic choices in relation to the technical and operational foundation, along with the control, support and management of daily activities.
- Regulatory RIFs – These are related to institutional requirements and regulatory activities from authorities.

As noted by Lundborg (2014), risk influencing factors are very important tools in identifying which factors that interact and influence risk. To further investigate and identify these other factors, (Lundborg, 2014) proposed using sociotechnical system model. This model uses a systematic methodology in assessing the human, organizational, and technological factors, as well as how the interaction of these factors influence system performance. The seven main areas of this model (Grech et al, 2008) is presented and explained below.

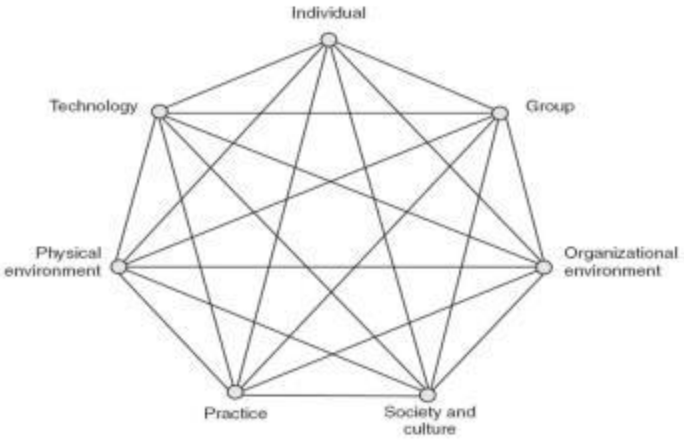


Figure 8: Sociotechnical system model by Thomas Koester (Grech et al., 2008)

- **Group** – these are factors relating to interpersonal interaction of the crew, e.g. teamwork, communication and leadership.
- **Individual** – relates to humans as individuals, i.e. individual physical or sensory limitations, physiology, psychological limitations of individuals, individual workloads and management experiences, skills and knowledge.
- **Practice** – factors that relate to the interaction between individual and practice, i.e. how the humans obtain system knowledge through practice.
- **Physical environment** – relating to the physical surrounding working environment, i.e. physical workspace, weather and visibility conditions, and lighting conditions.
- **Technology** – factors relating to the interaction between humans and technology, e.g. equipment usability and human machine interaction
- **Society and Culture** – the socio-political and economic surroundings of the organization.

6.2 Risk Indicators

Rausand (2011) defines risk indicator as a ‘parameter that is estimated based on risk analysis models and by using generic and other available data’. As RIFs are theoretical variables and have no specification as to how to measure, indicators allow RIFs to be measured. This makes RIFs and risk indicators connected. Indicators are, therefore, measurable representations of an RIF, and are also operational variables (Øien et al, 2011). This means that one or more indicators can represent a RIF; e.g. “years of experience” and “years of education” could be two suitable risk indicators for the RIF “competence”.

6.2.1 Characteristics of good risk indicators

According to Kjellén (2009), a good indicator should have the following characteristics:

- **Validity** – The indicator must be a valid measurement, and the further we move in the casual chain of an accident the less certain we can be on the validity of the measurement.
- **Reliable and robust measurement techniques** – It is important that under-reporting of accidents and incidents doesn’t exist, and the indicator should be robust against manipulation.
- **Feedback on changes** – the indicator has to provide relevant statistics in a relevant time period, indicate the current level of safety, indicate whether the safety level is improving or not
- The indicator must be transparent and easily understood.

6.2.2 Classifications of Risk Indicators

6.2.2.1 Risk indicators and safety indicators

An indicator may be classified as a risk or safety indicator depending on the inclusion of its corresponding RIF in a risk model. According to Øien et al (2011) changing the risk indicator value for a given RIF will determine its effect on the total risk. These risk indicators are developed using a risk-based approach. An indicator is called safety indicator when corresponding RIF is not included in a risk model but affects some other safety measures. These indicators are often selected based on their assumed effects on safety, through correlation, and are often based on the safety performance – incidence – or resilience-based approach (Øien et al, 2011).

6.2.2.2 Personal and Process Safety Indicators

These indicators are differentiated based on whether they are indicating factors about personal safety or system process safety. Process safety accidents potentially result in multiple fatalities or harm to the system or plant as they are incidents in the process plant. Such incidents can be explosions or toxic gas leakages. Personal safety indicators, on the other hand, indicate hazards that may affect human safety. They usually have nothing, or little, to do with processing activities, but are rather accidents like falls, trips, electrocutions, and vehicle accidents (Hopkins, 2009a).

6.2.2.3 Leading and Lagging Indicators

Hopkins (2009a) explains lagging indicators to refer to injury and fatality rates, while lead indicators are those incidents that directly measure aspects of the safety management system, which could be frequencies or timeliness of audits. With respect to process safety, lag indicators are a kind of "after-the0event" indicators, which suggest that one can count the number of accidents or incidents that have already happened. Leading indicators, on the other hand, considers the underlying conditions of the factors that lead to the accidents. This means that these indicators are proactive and can provide feedback on performance before an incident occurs, and as such they serve as early warning signs (Øien et al, 2011). This is because, as noted by Kjellén (2009), leading indicators change before actual risk levels change. Hopkins (2009b) highlights that differences between the two indicators are not clear-cut, and that as such the meanings of them should be indicated and specifically defined every time they are used to avoid confusion. Øien et al (2011) and Hopkins (2009) demonstrated the use of the Swiss cheese model to illustrate a distinction between leading and lagging indicators. In describing the Swiss model, the 'holes' are used to indicate a series of failings in the defence layers, risk barriers and safeguards. In this illustration, it is argued that the holes within the cheese are identified by all leading indicators, and the lagging indicators reveal the holes as a result of an accident.

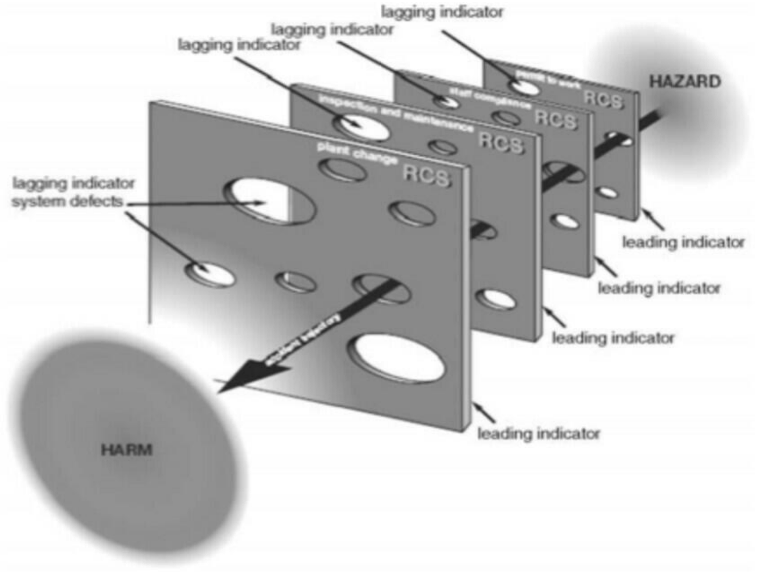


Figure 9 Swiss Model illustrating leading and lagging risk indicators (Source: Hopkins 2009a)

A more detailed discussion is presented in Chapter Seven of this thesis.

6.2.2.4 Risk barriers and analysis

Here, the author presents relevant theories on risk barriers and its relation to managing and assessing risk in the oil and gas industry. For this thesis, key barrier analysis methodologies relevant to offshore installations are considered.

Barriers are measures for mitigating risk in systems as the whole concept of barrier analysis is about separating valuables from a hazard or hazardous event occurring by installing a barrier between the two (Lundborg, 2014). A definition of the various aspects of the barrier concept is indicated below, as presented by (Vinnem, 2013, Skogdalen and Vinnem, 2011, NTS, 2010).

- **Barrier function** – these are intended functions to prevent, control or mitigate undesired or actual events. The functions are intended because among its purposes is risk reduction. Examples include preventing leaks or ignition, reducing fireloads, ensuring acceptable evacuation and preventing hearing damage (PSA, 2013).

- **Barrier system** – system designed and implemented to perform one or more barrier functions
- **Barrier element** – this is a component of the barrier system, which when isolated is not capable of working or performing the required functions.
- **Barrier influencing factor** – these are factors that influence the performance of barrier elements.

6.3 Safety barriers

PSA (2013) defines safety barriers as 'technical, operational and organizational elements which individually or collectively reduce opportunities for a specific error, hazard or accident to occur or which limits its harm/drawbacks'. These are defences implemented in complex systems to protect assets, people and both operational environment and surroundings from hazards. In other words, safety barriers are put in place to minimise the probability of hazardous even from occurring or to limit the impacts/effects of such events. According to Xue et al (2013), these barriers can either be proactive or reactive, and that depends on whether the intended barrier function is to provide protection after the hazardous event or before it. Sklet (2006b) presents an energy model which views a safety barrier as a defence or a means of protecting humans from an energy source, as shown below.

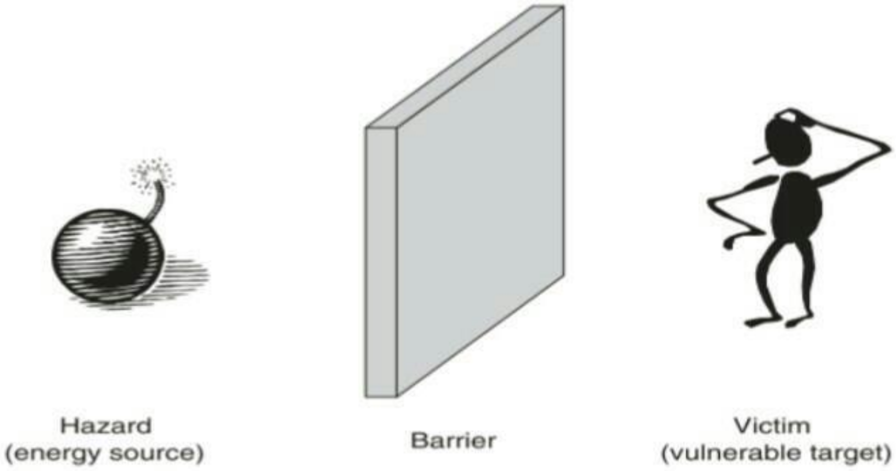


Figure 10 Energy Model for barriers (Sklet 2006)

Sklet (2006) further illustrates the relationship between the various aspects of a barrier system, classifying them in relation to safety barriers. He presents that the system can either be active or passive, where passive barriers refer to those built into the system and are able to perform their functions independent of input from external control systems, i.e. an operator or control system. But, active barriers, he claims, depend on such controls.

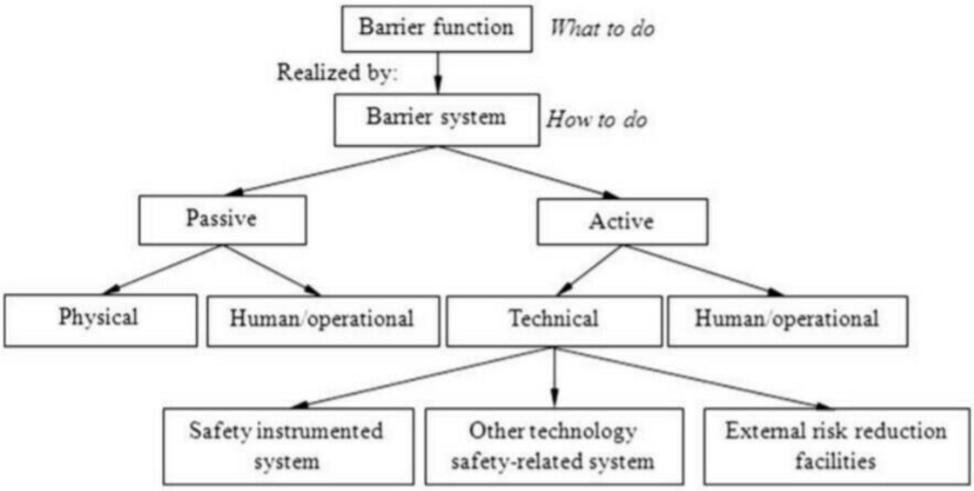


Figure 11 Safety barrier classification (Sklet, 2006)

6.4 Barrier analysis

The Bow tie method and the Swiss cheese model can be used for barrier analysis in most cases. This thesis presents theories on both. Details on the Bow-Tie model is presented in section 3.5.2 of this thesis. However, the author presents more discussion on how the Swiss cheese model is used in barrier analysis.

According to Lundborg (2014), the Swiss cheese model provides a more illustrative method for communicating how accidents happen in complex systems. The model is known for a conceptual framework that helps risk analysts discover that accidents are not only caused by isolated failures, but are rather the outcome of several related failures, on different system levels but occurring simultaneously. As depicted in the Diagram above (insert figure number), the arrow shown in the model illustrates breaches in the system's defences. The arrow imitates the accident trajectory. The accident trajectory is created when the Swiss cheese 'holes' align together, which happens in certain circumstances (Grech et al, 2008), and this is unlike the normal situation where the defence walls/layers are depicted to 'interacting' and supporting each other.

7.0 CHAPTER SIX – ESTABLISHING SUITABLE RIFs AND INDICATORS

7.1 Approach

Several studies have been made, in which attempts to identify and structure relevant RIFs and how to establish these RIFs and risk indicators have been done. Geijerstam and Svensson (2008) listed four reasons that fulfill a collision: intentional failure, technical problems, lack of awareness and handling error. These four excluding intentional failure correspond to technical failures, failure to keep watch, and human failures respectively.

Øien (2001a, 2001b) developed two approaches for establishing suitable RIFs and associated indicators; one is the technical approach for technical factors, and the other is organizational for organizational and human factors. Øien (2001b) argues that the use of these approaches to establish indicators provides a good tool for risk control during operations.

7.2 Technical Approach

This approach was developed with main purpose of monitoring risk during operations of offshore petroleum platforms. However, the method has also proven applicable in any industry given that the risk in concern is modeled and quantified in a risk analysis, since the risk influencing factors are generated from quantitative risk analysis methods (Øien, 2001a).

For a quantitative analysis, Øien (2001b) further elaborated the technical approach as follows:

- A categorical selection of all accidental or hazardous events that contribute most to the risk. Criteria for selecting the categories are that, the selected category of accident event must (1) *have a large accident potential*, (2) *give a significant contribution to total risk of potential loss of lives*, and (3) *there must be room to exercise control over the development of the risk represented by the chosen hazardous events category.*
- An identification of the RIFs contributing to each of the selected categories above must be made.

- Potential changes in identified RIFs must be assessed during the time period between each updating of the QRA.
- Effects of each level of change of each RIF on total risk must be assessed. This is done by conducting sensitivity analysis using the model values.
- Significant RIFs, i.e. those with highest effect on risk, are selected and put under surveillance.
- Initial selection of the associated risk indicators for each selected RIF.
- Testing and selecting a final and appropriate set of indicators. Øien (2001a) identifies that, from experience, it is difficult to select appropriate risk indicators without testing if they are suited.
- Finally, there must be a routine structure set for use of the indicators.

7.3 Organizational Approach

Olsen (2017) writes that developing an organizational RIF and associated indicators is important since the organization may go through changes in the areas of staff training and quality procedures or during operations. Again, because personnel get affected by the organization during operations, most accidents can be termed as organizational accidents (Øien, 2001a) Just like technical framework or approach, Øien (2001b) presents an approach for organizations to establish organizational RIFs with their associated indicators. This includes an organizational model, organizational risk indicators and a quantitative methodology. The organizational approach is both qualitative and quantitative. Below is the organizational framework by Øien (2001b).

- *Organizational Model* – the risk model used by the organization has to be reasonably holistic, practically usable and much more, it must fit for the purpose.
- *Organizational factors must be rated* – there must be assessment of the quality of organizational factors within the model, and this is done by rating them based on expert judgment, qualitative tools or indicators set and a measure must then be set for the state of every given factor. Øien (2001b) noted that it is not sufficient to a scale that distinguishes ‘good’ and ‘bad’ states, but the scale must make it possible to distinguish between the various states in a credible way, and therefore the scale should not be too fine-graded either. Øien (2001b) suggested a five graded scale for rating.

- *Weighting or scoring the factors* – weights must be assigned to each of the organizational factors through data-driven approaches or expert judgment. These assigned weights reveal the effect/impact/strength of each identified factor has on total risk, directly or indirectly through intermediate factors in the model.
- *Propagation method/algorithm* – the ratings and weights assigned earlier must be combined and are then aggregated. This is done to reflect the total impact or effect on total risk, or just the impact or effect on a particular parameter in the risk model.
- *Risk Modeling Technique* – the risk model considered in this thesis by the author is the COLLIDE model, which is well defined and presented in Chapter 4 of this thesis. (Refer to chapter for details)
- *Establish the link of factor to risk model*
- *Adaptation of risk model*
- *Re-quantification of risk factors.*

7.4 Suitable Indicators for identified RIFs

This section presents a review of suitable RIFs that are identified in literature, along with their associated indicators, as seen in literature and proposed by studies made in the area of collision. With the Collide Model as the chosen model for this thesis, the author, herein, analyses the identified influencing factors of the model as presented in earlier chapters of this thesis. These factors (human, technical, organizational and environmental factors) are selected considering their closest link to the main accident event discussed in this thesis – collision. This section discusses existing literature on identified indicators for the RIFs previously mentioned above.

7.4.1 Vessels on collision course

As earlier on quoted in this work, a working definition for vessel collision course has been one by Sea Talk (Nautical Dictionary): *"A situation in navigation in which a vessel will collide with another vessel unless one or both vessels alter course, or stop".* This definition notwithstanding, it is argued that vessels being on course for collision does not that pose any serious threat or that not is great significance to warrant alarm if the vessels said to be on collision course are several hours away/apart. It is therefore noteworthy that, being on collision course is not a sign that collision is imminent. Therefore, in valuing the indicator for collision course as a collision risk influencing factor, time duration and distance between the vessels must be considered (Olsen, 2017). Distance between colliding vessels determines the value of an indicator of this factor. Olsen (2017) presents that the distance prior to maneuvering is a necessity and as such could be set as a standard distance applicable for every ship type and size, e.g. one nautical mile. A second alternative has to do with the variation with the size and speed of the current vessel. This is because the smaller the vessel the easier it is to maneuver away from the meeting vessel. This is unlike the case with larger vessels. Olsen (2017) mentions that the distance is set so that the vessel personnel have time to evaluate and adjust moving course safely. According to Mou et al (2010), this distance, CPA value (closest point of approach) should be set to 2 nautical miles. A critical situation therefore is "when two ships come to close quarters – crossing within half a nautical mile of each other" (Fowler and Sørgård, 2000).

The most significant influencing variable determining whether there will be collision between vessels on course, or not, is whether or not the vessels on course collision alter their course after knowing they are on collision course. If both vessels alter their course, the probability that there will be collision is 0.00001, whiles if none of the vessels involved alters course, it increases the collision probability to almost 1.0 (Hänninen and Kujala, 2012). For vessel reaction time to be quick, or for vessel to take required action on time, it depends partly on the time the operator observes the potential collision and this also depends on the operator's expertise and experience in interpreting information and signals from various sources (Olsen, 2017). Vessel maneuverability is also an influencer of vessel response time when possible collision is observed, as high maneuverability could mean avoidance of collision than lower maneuverability.

Thus, suggested indicators for 'collision course' factor include the maneuverability of the vessel, whether there's other vessel on collision course, and whether meeting vessel takes action in time or not.

7.4.2 Technical and Human factors

7.4.2.1 Navigational indicators

Vessel navigation is determined to move a vessel from one place to another as safely as possible, under prevailing circumstances (Nilsson, 2009). Kulaja et al (2009) studied accidents in the Gulf of Finland and revealed that 32% of all vessel collisions are due to navigational failures, and that this mostly is the case of own ship. Also, technical failures were found to be responsible for 4.67% of all vessel accidents reported on the Gulf of Finland. In navigating through a fair way, vessel positioning, steering and control of speed are actions that need to be supervised repeatedly (Nilsson et al, 2009). This therefore means that speed, course, and maneuverability key components in defining navigational indicators.

This clearly means that level of safe navigation depends partly on ability of the operator (competence and his/her awareness of situation) in relation to these three key components. Though these influences navigational safety, they however, cannot be used in measuring navigation as an influencing factor to vessel collision. Rothblum, (2000) identifies that errors in navigation are mostly because of a lack of, or incorrect, information from one of the navigational systems. As such, it is important that vessel operators check to verify the available information with other sources before decisions are made or altered.

Suggested indicators for the navigational factor could be: frequencies of controlling speed, correct steering, positioning, and frequency of search for other vessels. Others can be whether there is use of multiple information sources or not and also the mean time to corrective actions after a deviation has been identified.

7.4.2.2 Loss Steering Function

When a vessel loses steering it loses the ability to navigate in safety and also maneuver when other vessels are in proximity. Mohovic et al (2013) identified grounding of a vessel as the number consequence of loss of steering function, but same, undoubtedly, can lead vessels into collision. Loss of steering function is therefore a significant indicator and must be considered in weighing and valuing factors influencing collision risk. Generally, in literature, steering loss is presented together with failures in propulsion. Nevertheless, it must be noted that it is not stated that propulsion failure is the cause of steering failure.

Mohovic et al (2013) has shown that even after vessel’s propulsion fails the vessel can still continue to move because of inertia at the instance of the propulsion failure. Therefore, if the vessel steering system is working well the vessel can still continue on the planned trajectory. However, after some time of continued steering after propulsion failure, it will no longer be feasible to steer and control vessel movements as the flow of water around the rudder begins to decrease, which affects rudder deflection. When this becomes the case, the vessel continues in motion but not under the control of crew, but movement is rather determined by the remaining inertia and other external forces (Mohovic et al, 2013).

System failure of the command transmission between the navigation bridge and the rudder, cuts in power supply to the steering system and failure on the steering device have been noted as the main possible causes for loss of steering function.

7.4.2.3 Indicators for Effective Watch-keeping

Kristiansen (2004) identifies vision as the main source of information for vessel watchkeeping staff. This means that a distortion of a watch-keeper's vision will distort information received, because all the influencing factors that affect watch keeping are connected to the human eye. Several factors influence the effectiveness of lookout. Olsen (2017) wrote that when observing a uniform field is prolonged, without pause, it may result in the watchkeeper blanking out. Blanking out may happen after 10-20mins of effective lookout. This is largely so because performance of watch-keepers at post tend to reduce drastically after about the first 30mins of attentiveness and watchfulness. In one study, Kristiansen (2004) explains this further that the probability of noticing a visual signal during lookout is a direct function of the initial probability of detection and the duration of the lookout.

Factors that cause visibility challenges or visual illusions could be refractions, the texture of an object, or fogs and hazes (Kristiansen, 2004) and also fatigue, which increases operator reaction time and hence reduces vigilance (Akhtar and Utne, 2014). Refractions, which refer to breaks in the direction of light due to the interference of other media like water, can cause watch-keepers to wrongly interpret the relative direction of objects or other vessels on collision course. Similarly, when it gets foggy and hazy object visibility gets distorted, in that they appear smaller than they actually are. This makes the objects appear further away than they actually are, which poses threats of serious consequences. Also, the texture of the object impacts the watch keeper's estimation or judgment of how distant the object is. This is because the object texture as observed by the watch keeper informs his judgment of the distance (Olsen, 2017). Similarly, watch keepers' knowledge of the remaining time for assignments requiring vigilance has been shown to have a positive impact on performance of vessel operators (Kristiansen, 2004). Olsen (2017), therefore, believes that engaging more than one personnel for watch keeping can reduce the probability of visual illusions.

Other indicating factors that may influence lookout, as identified by Kristiansen (2004) include watch keepers' ability to observe well under dark conditions. Night blindness and the adaptability of the eye to darkness may negatively impact the watch keeping function.

Therefore, in view of the above, suggested indicators for this factor are: watch-keeping hours/duration, number of watch-keepers at post at a time or working concurrently, operator's knowledge of remaining watch time, knowledge of watch-keepers night blindness condition, age of watch-keeper, hours of sleep of watch-keepers as well as sleep problems/conditions of keeper, duration off voyage, and the hours/duration per standing watch (Olsen, 2017).

7.4.2.4 Loss of propulsion function

Propulsion failure has been identified as a category of the severe hazardous events in vessel operations (Brandowski, 2009). Aspects of loss of propulsion function include a loss of the propeller, failure of the turbine or low fuel. A computation using facts from DAMA database revealed that nearly 2.8% of all collisions that happened in good visibility were as a result of steering and propulsion failures. Also, a probability of 4.5E-6 is estimated for steering or propulsion failure in a critical situation; where a critical situation as explained earlier in this thesis, refers to a situation where both vessels on collision course are only half a nautical mile (lesser) apart (Fowler and Sørgård, 2000).

The probability of propulsion failure of a vessel is discovered to be dependent on *the reliability of the propulsion system and also the operator* (Brandowski, 2009), whiles the frequency of failure is found to be dependent mainly on the type of propulsion system in use as well as the vessel operation mode (Olsen, 2017). Nothing is mentioned by (Fowler and Sørgård, 2000) on how operator performance impacts propulsion failures, which suggest that their computations from DAMA database only show directly the failure of propulsion function.

The consequences that result from failure of propulsion system have been divided into: (1) *immediate catastrophic failure* and (2) *delayed catastrophic failure*. The first is of greater concern because it induces a forced stoppage of the vessel and this creates the risk of complete damage or loss of vessel. In another study, Eide et al (2007) believes that the probability of loss of propulsion function will be lower for ships that have double main engines, due to redundancy. They further stated that propulsion failure rates are influenced by frequency of maintenance, skills and experience of crew, as well as other operational factors.

In view of the above, indicators for this factor can be determined considering the vessel type and size, type of propulsion system used by ship, the operational speed mode of the ship, the frequency of maintenance of propulsion system, and whether or not there is *immediate catastrophic failure*. According to Olsen (2017), assuming the '*immediate catastrophic failure'* indicator has a value of a "yes", all the other indicators, as mentioned here, are irrelevant.

7.4.2.5 Personnel Competence

Personnel competence is a necessary factor for ensuring safety during navigation. Competence cuts across both technical and non-technical competence. Hetherington et al (2006) wrote that non-technical competence covers the skills of crew members in the areas of human behaviour and crisis management, but the types of human behaviour skills and adequate level of competence have not been indicated. A study referred to by Rothblum (2000) reveals that 35% of all vessel casualties were as a result lack of general technical knowledge, with the main contributor to this being no knowledge and expertise concerning proper use of technology. Errors in equipment usage such as when operators base their judgments wrong information or depend on wrong equipment whiles there is another source for better information, are all as a result of personnel competence. As indicated by Olsen (2017) many seafarers or mariners lack understanding in how vessel automated systems work, neither do they have adequate understanding concerning the settings under which these systems and equipment are designed to work effectively.

Another aspect of competence issues identified is personnel lacking knowledge when it comes to specific ships and their varied technicalities. This also contributes to most accidents in shipping, as validated in a study by Rothblum (2000) where 78% of mariners interviewed mentioned this as a problem. The mariners found this to be a problem because they work on different types and sizes of vessels with different equipment setup and automation settings, and also carry different types and weights of cargo. The limited memory capacity of humans also causes problems, making it difficult for crew members to make swift adjustments. To take care of this problems that affect crew competence, it is proposed that mariners are made to work on lesser number of vessels and also vessel shifts well-coordinated, as this is believed to be ideal and may enhance crew knowledge of current vessel of deployment. Rothblum (2000) also suggests a more holistic training and standardization of vessel equipment designs to be possible solutions for this problem.

It should also be noted that competence issues covers vessel traffic guides and vessel traffic service personnel at harbours as they are known to be providers of useful information upon request to vessel operators in conflict situations (Wiersma and Mastenbroek, 1998). This is noteworthy for consideration as these traffic systems are frequently updated and new equipment developed.

Therefore, as discussed above, some indicators for this factor include the frequency of vessel shifts or switches, number of relevant qualifications for crew personnel, level of training of personnel and frequency of upgrades made on systems and equipment.

7.4.2.6 Vessel Navigation System

Recent developments in technology have influenced operational systems in all industries including shipping, as new computerized systems for navigation are being developed, e.g. with bridge systems. One of these new computerized systems in shipping and vessel navigation is the Electronic Chart Display and Information System (ECDIS). The ECDIS is proven more effective than the use of traditional navigational charts. The system has also reduced collision risk influenced by navigational failures as it has helped reduce the amount of work involved in route planning, positioning and monitoring (DNV, 2007). The ECDIS is also effective for displaying and monitoring route plans without paper charts and also helps to access information concerning other vessels easily (Nilsson, 2007). However, it is realized that the ECDIS is new, which means that not all vessels have it installed or implemented, though it can be a better replacement for other instruments (Nilsson, 2007). Moreover, only a handful of vessel operators and crew have knowledge of the ECDIS and also how it works. They have little or no knowledge of how to properly make use of it, neither do they have understanding of the benefits and demerits of using the system (Jie and Xian-Zhong, 2008).

Other systems for vessel navigation that are normally used on the bridge are the AIS, GPS, RADAR, vessel passage plan, nautical charts, modes of communication, depth indicator, compass and speed indicator (Olsen, 2017).

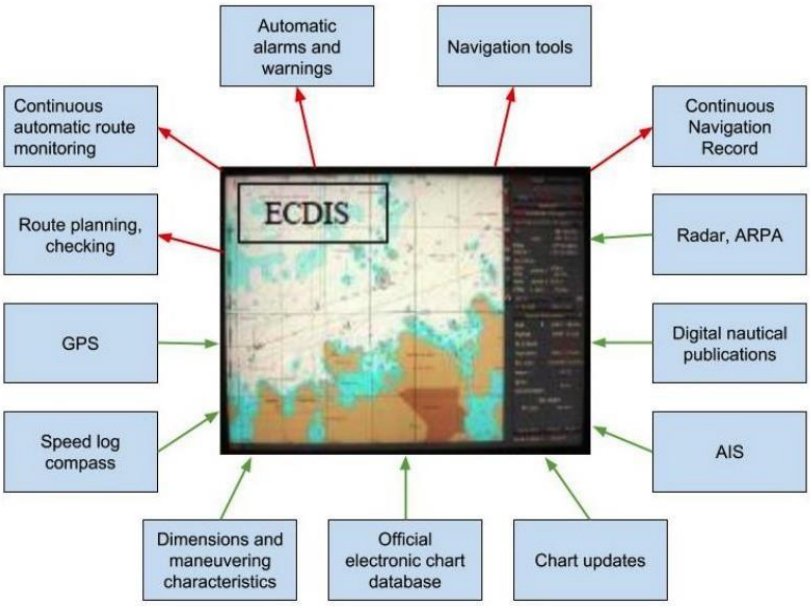


Figure 12 ECDIS; information flow and functions. [Source: Nilsson, 2007)

GPS, i.e. Global Positioning System, is a *radio navigational system, which is based on satellite signals and a receiver on the ship that determines the positioning of the ship* (Olsen, 2017). Unlike the GPS, which is used only for navigation, the RADAR is used for navigational purposes and also as traffic control and it works using radio waves. Another version of the GPS, called Differentiated GPS, gives more accurate information about vessel position that the normal GPS. Differentiated GPS uses additional stations onshore (on land) that traffics information about reliability and corrections concerning satellites in space. Due to the limitations of the GPS in giving accurate positioning information, the AIS (Automatic Identification System) can be used for additional information (typically the name of ship, speed, course, destination and depth), as the AIS is able to transmit position information between vessels and also between vessel and land (Nilsson, 2007).
The author would want to indicate that in avoiding collision caused by navigational failures, it must be noted that own ship visibility to other vessels is as crucial as the visibility of other ship to own vessel.

Therefore, indicators proposed for this factor include, whether or not all navigational equipment and navigational lights are functioning properly, and whether, or not, all the lights are correctly placed. Other indicators can be the frequency of chart and software upgrades, frequency of deviations and lastly, how regularly equipment are tested.

7.4.3 Environmental Factors and Indicators

Environmental factors that influence collision risk can be described as factors that cannot be controlled by vessel operators, but influence their actions and how they handle various situations. These include traffic density, area of operation, weather etc.

7.4.4 Weather

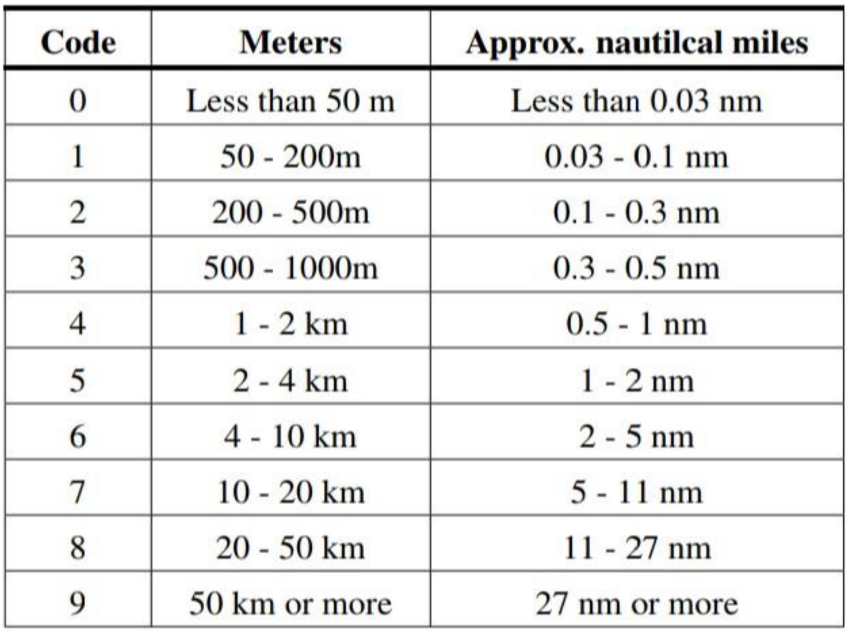
Historical data on accidents show that most accidents happen under dangerous weather conditions, though the relationship with the accidents and weather condition have not been quantified (Fowler and Sørgård, 2000). After reviewing 857 marine accidents recorded by the Portuguese Maritime Authority over a ten year period, Antao et al (2009) found that sea state and weather conditions caused 23% of all accidents recorded over the period.

Two things must be considered when discussing weather conditions as an influencing factor to collision risk: effects on visibility and sea state.

7.4.4.1 Visibility

World Meteorological Organization (WMO) defines visibility as *the greatest distance at which a black object of suitable dimensions located near the ground can be seen and recognized when observed against a scattering background of fog, sky, etc.*. Rømer et al (1995) have shown in a study that collision frequency increases as visibility and brightness decreases. Kristiansen (2004) also revealed likewise, that risk of collision increases with decreasing visibility. This notwithstanding, other authors also have disagreed on the importance of visibility and darkness on marine accident risk assessment. The table shown below presents various visibility codes developed by WMO. These codes can serve as indicators for this factor, though it must be noted that there is difficulty in concluding the impact of visibility on collision risk, due to varying views presented in literature.

Table 3: Horizontal Visibility. Source: (Olsen, 2017)



Code	Meters	Approx. nautilcal miles
0	Less than 50 m	Less than 0.03 nm
1	50 - 200m	0.03 - 0.1 nm
2	200 - 500m	0.1 - 0.3 nm
3	500 - 1000m	0.3 - 0.5 nm
4	1 - 2 km	0.5 - 1 nm
5	2 - 4 km	1 - 2 nm
6	4 - 10 km	2 - 5 nm
7	10 - 20 km	5 - 11 nm
8	20 - 50 km	11 - 27 nm
9	50 km or more	27 nm or more

7.4.4.2 Sea State

Sea state refers to the varying states of the sea resulting from different wind conditions, and the speed of wind is important in measuring wind condition. Tofoli et al (2005) wrote that inasmuch as human errors are known causes for accidents, it must be noted that the accidents happen also due to unexpected and dangerous sea states, which result in affects the operator’s control of the vessel. Wave height and wave period are parameters in describing the state of the sea, though Tofoli et al (2005) believe otherwise because according to them, wave height and wave period cannot with sufficiency be used in ascertaining the risk involved with dangerous wave events. Tofoli et al (2005) introduces wave steepness (defined as ratio between wave height and length) as another parameter, since the steeper the sea the more danger it yields. They wrote that accidents happen mostly under relatively lower wave heights, and that 2 of 3 accidents happen under wave heights lesser than 4. With regards to wave steepness, they wrote that 3 of 5 accidents happen in sea states where the steepness of prevailing wave was between 0.03 and 0.45.

Relevant indicators as suggested by author include, the visibility codes by WMO, wave height, wave steepness, and wave length as well as wind speed.

7.4.4.3 Operational area

The geographical area of operation for a vessel is worth considering in establishing suitable indicator for the risk of collision. The oceans are the main operational areas for vessels. All of the world's oceans have been divided into thirty-one main navigation zones and these zones were determined considering their effect on safety of ships that operate there (Li et al, 2014). The most dangerous zones are not necessarily those that have recorded more accidents, but those that have large numbers of passing vessels, because passing vessels increases traffic density. Zones like the Southern China sea and the Eastern Asia oceans are known for frequent accidents but they are not reckoned zones of high risk (Olsen, 2017). However, the Suez Canal is regarded a dangerous zone, by reason of the large number of vessels that pass the canal. The high number of passing vessels within this zone makes the zone an important consideration in maritime safety levels. As confirmed by Kujala (2009), navigational zones with higher traffic intensities pose high threats of vessel-vessel collisions. Therefore, the various navigational zones can be considered indicators for ship-ship collision risk. Also the water level of the areas (example whether the operational area is a port area, inner coastal area, open coastal area, outer coastal area, or the open sea) can be measured as indicators.

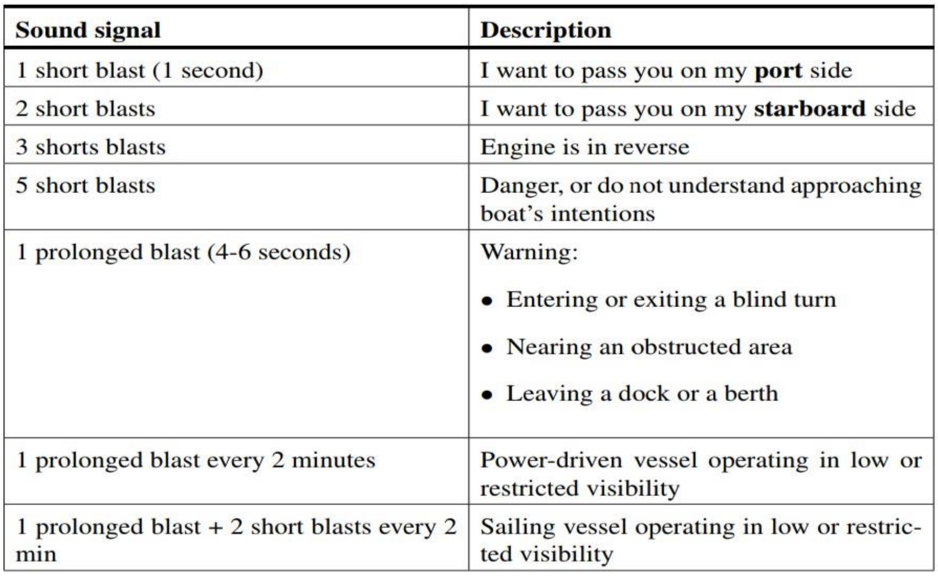
7.4.4.4 Other Vessel Action

Hockey et al (2003) write that clarity of the intended actions of others minimizes uncertainty and also helps in anticipating potential worst-case events that may happen. From their study, it is clear that the uncertainty of how other vessels will act or respond in collision situations increases the probability for collision. This is because the uncertainty of what to do affects and reduces time used for information gathering and also decision making in a collision situation. Goerlandt et al (2015) further argues that unexpected turns by meeting vessels, which may either result from human error or technical failures, also increases collision risk.

The inertia of own vessel's turning might also increase the risk of collision, if the other vessel turns unexpectedly (Goerlandt et al (2015).

To reduce the level of uncertainty and unexpected turns, it is proposed that ships who encounter each other and are within half a mile apart must communicate their intended actions using sound signals. In this case, the vessel sounding the signal makes a maneuver or a turn to which the other vessel must respond. The responding vessel needs to either agree or disagree.

Table 3 Sound Signals [Source: Olsen, 2017)



Sound signal	Description
1 short blast (1 second)	I want to pass you on my **port** side
2 short blasts	I want to pass you on my **starboard** side
3 shorts blasts	Engine is in reverse
5 short blasts	Danger, or do not understand approaching boat's intentions
1 prolonged blast (4-6 seconds)	Warning: • Entering or exiting a blind turn • Nearing an obstructed area • Leaving a dock or a berth
1 prolonged blast every 2 minutes	Power-driven vessel operating in low or restricted visibility
1 prolonged blast + 2 short blasts every 2 min	Sailing vessel operating in low or restricted visibility

Moreover, considering the CPA (Closest Point of Approach) analysis made by Mou et al (2010), reveals that own ship does not influence the CPA value as much as the meeting vessel. In other words, the CPA value is strongly influenced by other vessel. Inasmuch as this is logical, concerns as to how to mirror its effects and create a measure for it as an indicator(s) cannot be concluded on in this thesis by the author. Thus, the indicators for meeting vessel include, whether or not the sound signals are used correctly, whether meeting vessel turns within sufficient time frame or violates the signal rule by own vessel.

8.0 CHAPTER SEVEN – DISCUSSION

8.1 Discussion

In this literature study, the author aimed to describe the concept of risk influencing factors (RIFs) and indicators relevant for analyzing vessel collision risks, and to further on suggest ways the collision risk can be significantly reduced in Ghana Oil and Gas industry, based on the literature reviewed. The author presents a discussion of key findings in this section.

Literature reviewed revealed the common collision risk influencing factors in vessel operations. Factors that influence collisions among vessels range from human factors to technical factors. The degree to which these factors impact the out of vessel-vessel encounters were found to be varied. RIFs are categorized as (1) operational RIFs – which are activities essential to ensuring the safety and efficiency in operations on daily basis; (2) organizational RIFs – which are related to the organization's management philosophies, policies, and strategic choices in relation to the technical and operational foundation, along with the control, support and management of daily activities; and lastly, (3) regulatory RIFs – which are related to institutional requirements and regulatory activities from authorities. These categorizations are found be relevant because, as discovered, most factors influence collision risk indirectly, therefore categorization helps to assign parameters to each factor within a collision risk model. These parameters will help determine what other factors that further influence an identified risk factor. A typical example is how 'watch keeping' as a risk factor is influenced by other factors such as bad weather conditions, personnel competence, workload and so on.

To investigate and further analyze these other factors, a proposition to adopt a sociotechnical model in categorizing collision risk influencing factors was found to be ideal and impactful. This socio-technical system helps to identify other aspects such as culture, society, working teams or groups etc. and how they influence risk.

Collision causes were found to range from seven to fifty-three in every incident presented in literature. Human factors were found to influence 52.6-90% of all collision accidents. This high percentage was found to be due to the fact humans cannot be separated from the other factors. Humans design everything about vessels, and they determine how it works and is maintained. Humans also decide on the culture within the organization that owns vessels. Human causes of collision are not only tied to the vessel operator, but there are other aspects of human causes apart from the primary operator. These include lack of sleep for crew, lack of lookout, bad communication among crew, which makes understanding the main language among crew members a factor of great concern.

In determining indicators for the RIFs identified in this thesis, it was realized it was easy to set indicators for certain factors, as they were discovered to have more evident indicators than others. The reason for this was found to be that all identified factors have different complexity levels. The author discovered that human factors can be the hardest factors to develop indicators for. The main reason for this being the behavioral dynamism of the human mind and actions; and these are known to be affected by numerous factors than thought of in the initial stages of analysis. For this reason, the author believes that to ascertain a more specific indicator for human factors, human behavior experts or people with adequate understanding of how humans behave should have been included in this literature study. The author thinks their input would have helped define more specified indicators. Also, in relation to technical factors, an increase in the knowledge of technical systems and also understanding how they work would improve the quality of findings when studying collision risk factors.

Concerning establishing suitable technical and organizational RIFs and indicators, it is discovered that the final stage in the process must include a testing procedure for identified indicators. This is necessary to overcome the complexity of difficulties in selecting suitable indicators. The testing procedure, however, is not the focus of this work; hence it is possible that some of the suggested indicators may seem not suited for the respective factors.

The scope and outcome of this study may pose a limitation to a general application of the suggested indicators, but the author, in an attempt to minimize these deficiencies to the study findings, tried all means possible to be extensive in this research.

9.0 CHAPTER EIGHT – STUDY SUMMARY AND CONCLUSIONS

9.1 Summary and Conclusions

This study began with definitions of collision and risk concepts to help introduce the research theme. Statistics on collision was also presented and discussed. The study centered on collision, defined as the *impact between two moving objects*; and the term ‘moving’ seen as very significant (Kristiansen, 2004).

It is revealed that vessel collisions account for 13-28% of all ship accidents. Vessel accidents and collisions causes are human factors, technical and organizational factors; with the most common ones being lack of lookout or watch-keeping failure, lack of sleep, bad communication, and bad maintenance routines (Olsen, 2017). These causes can be further classified into (1) equipment failure (2) weather (3) misjudgment of captain, (4) human control failures (5) poor understanding and training in advanced technical equipment.) The primary cause of most collisions was found to be human error in 45% of the cases, followed by equipment failure in 33% of the cases, and 22% for other external factors (Health and Safety Executive (HSE).

The number of collisions per accident was found to range from 7-53 factors (Rothblum, 2000). Human factors contribute to 52.6 – 90% of all vessel accidents, and this is because humans cannot be separated from the other factors since they design the vessels and systems, determine how it works and is maintained, decide on the culture within the organization that owns vessels. Human causes of collision are not only tied to the vessel operator, but there are other aspects of human causes apart from the primary operator. These include lack of sleep for crew, lack of lookout, bad communication among crew, which makes understanding the main language among crew members a factor of great concern.

When investigating collision accidents, organizational factors that influence risk are usually not taken into detailed consideration, yet they have been proven to influence individual and corporate behavior, thus making them important during accident investigations. These

factors include safety culture, organization’s management, working environment/conditions, training etc. (Olsen, 2017).

Concerning technical factors, technical failures were found to be responsible for 4.67% of all vessel accidents reported on the Gulf of Finland. Recent developments in technology have reduced the frequency of equipment failure causing accidents. However, these technological advancements have also contributing, relatively, to increases in human errors, leading to more accidents (Hetherington et al, 2006).

The study considered the COLLIDE collision risk model and discussed the key challenges with quantification.

The study also reviewed collision risk influencing factors as well their associated risk indicators. Risk indicators are explained as measurable representations/parameters of the identified RIFs, because RIFs are not measurable in themselves. Each identified risk factor is represented by one or multiple indicators. Developed indicators may be categorized into safety/risk indicators, personal/process indicators, and then lagging/leading indicators (Øien et al, 2011; Hopkins, 2009).

The study also attempted to present some suggested indicators for identified RIFs. Developing indicators for some RIFs was realized to be easier than others. In determining collision probability, whether or not action is taken by vessels on collision course, knowing they are on collision course, is a variable considered most influential. In case both ships take responsive action, collision probability drops to 0.00001, whiles if none of the vessels involved alters course, it increases the collision probability to almost 1.0 (Hänninen and Kujala, 2012). This makes the 'vessel action' very significant.

32% of all collision accidents were found to be due to navigational failures, mostly resulting from own ship, with very small number of these accidents resulting from misjudgments of turns by the meeting ships (Kujala et al, 2009). Most navigational failures were found to be caused by inadequate or incorrect information and operator's preference of operational equipment (Rothblum, 2000). Mariners must, therefore, validate any information received with other sources before making final decisions or making any changes in navigational plan. The ECDIS is found to be the most efficient navigational system, but it also has downsides in implementation, as not all vessels have it installed and implement. Another challenge is operators' inability to understand the system and how it works, since the ECDIS is a relatively new technology.

Vessel operator's incompetence and inexperience was found to contribute to 35% of all collision vessel accidents (Rothblum, 2000), with the main contributor to this being no knowledge and expertise concerning proper use of technology. This suggests that implementing new technologies and systems are not absolute solutions for minimizing accidents, since operators may not have the know-how to execute it. This makes more holistic trainings and equipment standardization possible solutions to this problem.

Vessel type and size was also noted to have great influence on collision risk. Safety levels of vessels differ per vessel type (Li et al, 2014).

Finally, considering the fact that human factors (human errors) and its accompanying organizational factors contribute largely to causes of collision, and thus are high influencers of collision risk, the author in this study, therefore, concludes that to reduce collision risk in Ghana's oil and gas industry, there needs to be more concentration on human and organizational factors than technical factors, within the industry. Efforts should be made to devise measures to reduce human errors.

10.0 CHAPTER NINE – STUDY RECOMMENDATIONS

10.1 Recommendations for further study

Developed indicators needs to be tested to validate them accordingly with their respective RIFs before they are selected and categorized as a set of suitable indicators for specific factors. A collaborative study with a typical vessel owner company will bring practical considerations.

The author recommends further studies to be conducted on all the factors of the COLLIDE collision risk model, to generate more indicators. This will help contribute to more precise representation of the collision risk picture.

Human behavior experts as well as experts in the area of organizational factor should be included in further studies, as existing relevant literature may not be substantial and may even be hard to find.

Finally, a sensitivity analysis may also be conducted when assessing the impact of each identified RIF on collision risk, within the COLLIDE risk model.

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