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Environmental Risk Minimization of Offshore Transport Systems in Ghana

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Preface

This thesis was written between the periods of January 2019 and May 2019 as a partial fulfilment of the requirement to acquire a master’s degree from Molde University College – Specialized University in Logistics.

I like to acknowledge God for His strength and Grace throughout this period. I am grateful Lord.
I also like to express my deepest gratitude to my supervisor, Johan Holmgren for his support, selfless assistance and encouraging words throughout the period. Thank you, Johan. I would also like want to appreciate Arild Hoff and Katerina Shaton for their assistance when I was in dire need of help.

I finally want to appreciate my parents for their diverse support in every way.

Summary

The study was conducted in order to gain knowledge in environmental risk involved in offshore transportation systems in Ghana, and to develop a system to compute approaches to minimize the environmental emissions associated with offshore transportation in Ghana.

The study started with definitions of environmental risk and identifying the impacts that offshore transport activities have on the environment. It went further to describe the various modes of transportation used for offshore transportation.

This study further analyses the offshore transportation modes in Ghana currently as well as the environmental regulations and policies in the Oil and Gas sector.

The study finally makes use of an optimization tool to reduce the total travel distance and to split the cargo demand on offshore installations such that frequency of travel is reduced.

Results show from the study shows that, reducing the overall travel distance, reducing frequency of visits are initial steps to reducing emissions. Also, as a way to reduce risk of oil spill, factors such as human error, overfilling of tanks, and consistent maintenance of pipelines among others need to be paid attention to.

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List of Abbreviation

Km – kilometer

FPSO – Floating, Production, Storage and Offloading

MMbo – Million barrels of oil

MMcf – Million cubic feet

Bcf – Billion Cubic feet

MDO – Marine Diesel Oil

LSFO – Low Sulphur Fuel Oil

HFO – Heavy Fuel Oil

PM – Particulate Matter

VLCC – Very Large Crude Carrier

ULCC – Ultra Large Crude Carrier

ORF - Onshore Receiving Facility

LNG – Liquefied Natural Gas

WAGP – West African Gas Pipeline

IMO – International Maritime Organization

1.0 Chapter One

1.1 Introduction

Developing and maintaining oil and gas facilities require a fleet of service vessels and other means of transportation to and from the installation, which are designed and well-fitted to the logistics and transport demands of operating offshore. Right from exploration to the deployment and setting up of offshore installations, service vessels are useful in moving crew members, wastes, equipment, and other materials to or from the installation. These offshore vessels include utility boats, supply vessels, seismic vessels, diving supports, anchor tugs, well stimulation vessels, life boats and pipe laying vessels (NPC, 2011). In addition to these support service vessels and boats, helicopters are also commonly used to service a number of offshore facilities, especially in the areas of transporting crew members as well as conducting emergency evacuations. They are also used for transporting other equipment and supplies to offshore installations.

The farther movement of offshore field developments and the increasing complexity and costs accompanying the operations imply an increase in demand for larger and more sophisticated support vessels, with multitasking capabilities, as they may not only be needed for moving only cargo to deep-water facilities, but also for undertaking installation, mooring and firefighting tasks in a wide variety of offshore operational surroundings. Discoveries leading to deep water operations offshore have also contributed to a high demand for advanced helicopter capabilities and capacities. This means that helicopters engaged in offshore support services must have the ability to move faster and farther, carry more crew members at a time, as well as support all weather dynamics.

Ocean vessels and helicopters are, therefore, the two main essential means of transportation systems for offshore petroleum activities and projects, as both are needed in respective situations and roles. However, as noted by the U.S. National Petroleum Council’s September 2011 *Offshore Transportation* report, these ocean support vessels and offshore service helicopters have different sets of potential impacts on the both the operational environment of the installation as well other surroundings (NPC, 2011). Key issues with using helicopters in offshore transportation include noises that affect birds and other ocean mammals, air emissions (hazardous gases), as well as likely cases of the aircraft colliding with birds. Service vessels are also known to emit GHGs, noise disturbances, and liquid (especially oil) expulsions or releases. Moving vessels also sometimes collide with sea mammals, disturb wildlife within the marine habitat and also coastal waterways.

Vessel accidents also cause environmental damage. An example is the 1977 oil /gas blowout on Bravo platform causing sea pollution. Another example is in Alaska; oil spill from tanker Exxon Valdex in 1989 causing severe environmental damage. Deepwater horizon accident among others are examples of accidents causing severe damages to the environment. (NPC, 2011).

1.2 Background of Study

Oil and gas exploration on the African continent started some many years ago, and over the years it has generated environmental effects and the negative aspects of these impacts, both terrestrial and marine is no new happening. Nigeria, which is reputed to be the highest exporter of oil in Africa and the number 8^{th} among world exporters, have engaged in exploration activities and transportation for over a century. Aside the economic benefits reaped by the country through this sectorial development, they have also had their share of the environmental impacts. This makes Nigeria Ghana’s test tube case in identifying and managing the environmental risks within the sector, particularly concerning transportation systems used for offshore operations.

Commercial exploration of oil and gas commenced in Ghana somewhere in the 1950’s, with the establishment of the countries national petroleum corporation – *Ghana National Petroleum Corporation* (GNPC). But, only in July 2007 was commercial quantities of oil and gas discovered in the country’s western region. Three years after the discovery, exploration and production started. The field was named ‘Jubilee Field’ is precisely found in the Deep Water Tano and West Cape Three Point which is approximately 60km offshore Ghana and 130 km lying south-west of Takoradi in the Western region. In march 2009, the ‘Tweneboa field’ was also discovered lying 20 km east of the Jubilee field. In 2011,the Sankofa Gye Nyame field was also discovered lying 55km to 60 km off the coastline of Ghana (Owusu, 2014).

1.3 Research Gap

Numerous studies have provided, majorly, relevant information on other risk components associated with the petroleum sector. A lot more studies have been conducted to identify environmental and health hazards in connection to key activities of involved in drilling, refining oil and gas products. However, not much is found and determined by most research finding in the area of analyzing the environmental risk components related with the various transportation modes employed in offshore activities.

The emphasis of IMO conventions and protocols is only on general maritime transportation, with no specifications relating to transportation related offshore oil and gas operations which includes air transport. This, therefore, leaves the burden of assessing and mitigating environmental risks associated with offshore transport systems on the shoulders of individual countries, and perhaps drilling companies to protect the environment.

To provide essential information for optimizing and improving environmental safety, as well as create an awareness of the potential environmental hazards within the Ghana's Continental Shelf, this study seeks to analyze the environmental risk involved in Ghana's offshore transport systems and how they can be minimized.

1.4 Problem Description

In September 2017, Ghana gained a revenue of US $540.41 million from petroleum products alone. However, despite the millions that the industry generates for the country, the environmental risks associated with the production and transportation process cannot be overlooked. The very obvious risks are those caused accidentally by oil spills or drilling blowouts and emissions from their transportation modes. These accidents and emissions lead to discharge of harmful liquids and gases into the environment which if not managed or controlled, will have negative effects on the environment on the coast of Ghana and possibly even other neighboring countries.

Transportation to and from offshore installations are either done by air (helicopter transport) or by sea (supply vessel), with the regular items in transit being offshore personnel or crew members, instruments for production, spare parts, food and water, crude oil etc. This means support vessels/boats and helicopters are the main modes used in offshore transportation for oil and gas sector. The emissions from these modes of transport contribute to environmental damage. The thesis is going to look at which transport modes are most optimal to use considering the environmental impact of the transportation mode as well as the demand of item being transported.

Ghana's oil is drilled offshore (especially at the Cape Three Point), meaning whenever there is any accident or incident involving support vessels or boats resulting in spillage, the effects can be very disastrous as is evidenced in the *Deepwater Horizon* incident on the Gulf of Mexico in 2010. Some years after Ghana commenced commercial production, there was reported 699 barrels of mud which was spilled. This mud contained heavy poisonous substances that are harmful to the environment, and could affect the nation's ecosystem. Other risks associated offshore activities are passenger and pilot risks in air transport and captain and crew risks in sea transport (Owusu, 2014).

The commencement of drilling and producing oil in commercial quantities in Ghana, beginning 2010, has been marked with great expectations of positive impacts on the nation's economy (Otoo, 2012). This notwithstanding, critical and crucial questions have been raised on how determined the nation and her partner oil and gas companies are with respect to legislating relevant policies, monitoring and regulatory mechanisms to control exploration and production and transportation activities, particularly the environmental safety measures that must be put in place in order to minimize the environmental hazards/risks that come with the production activities offshore.

1.5 Research Objectives

The main objective of this study is to suggest ways to minimize environmental risk associated with offshore transportation that threaten environmental safety. To achieve this, the study aims to:

- Identify factors that contribute to environmental risk in offshore transport.
- Analyze the offshore transportation modes in Ghana.
- Formulate a system to minimize emissions in offshore transport systems

1.6 Research Questions

With increasing drilling and exploration activities happening in deep waters, offshore transportation systems (and facilities) are getting more complex and multipurpose, and as such present increased hazards to territories or environments where oil and gas operations take place. The aim of this study is to reduce the level of risk posed to the environment due to transportation. This study seeks to answer the following questions:

- What factors increases the environmental risk in offshore transport?
- What transportation modes are currently in use in offshore transport in Ghana?
- How can the emissions be reduced in offshore transport in Ghana?

1.7 Significance of the study

Though Ghana's petroleum sector is still young, yet much economic benefit is expected from the sector. Nevertheless, the sector has to deal the problem of environmental safety, as well as the safety of personnel and facilities. Safety of the ecosystem and preserving the ecology or environment has been on the forefront of global concern. Offshore production is one of the highest contributors to environmental pollution globally. Hence, it has become expedient to address some of the environmental risks presented by deep water oil and gas transport operations. This study's significance, therefore, lies in analyzing the environmental risk associated with offshore transport systems, the various transportation modes. The findings of this study will also add up to the existing but limited literature in the area of environmental risk assessment of offshore transportation modes in Ghana and elsewhere.

1.8 Scope of the Study

The scope of this study is to explore the various transportation modes used in offshore transport systems in Ghana, and to analyze and evaluate the transportation modes that pose the greatest risks with respect to their emissions and how these risks can be reduced. The research will evaluate components of modal split models and also identify risk factors. The study also investigated oil spills and the contribution to environmental risk with respect to offshore transport. The study, however, does not directly study how the risk of oil spills as a result of transportation can be minimized. The study mainly focuses on the reduction of emissions from offshore transportations.

1.9 Research Approach

1.9.1 Data Collection

This study examined data from offshore oil exploration and production companies in Ghana, which operates the Jubilee Oil fields, TEN fields and Sankofa Gye Nyame field. The study uses both primary and secondary data. Primary data refers to data collected first-hand by the author of this study while secondary data means data that are already gathered and analysed by someone else. Articles, textbooks, the organisation's publications, annual reports and safety and emergency regulations, historical statistics, etc., were all sources for secondary data used for this study Additional sources of secondary data sources were websites of energy and logistics companies in Ghana, and other academic work.

Data on offshore logistics and transportation modes and demands was obtained from selected skilled workers from companies that operate in Ghana's fields. Questionnaires were principally used to gather data for this thesis. Purposive sampling technique was used in selecting respondents to this questionnaire. Respondents selected were mostly logistics engineers in offshore operating companies in Ghana. Other skilled workers like Mud Engineers, Drillers, and Electrical engineers were also respondents to this questionnaire. The criterion for selecting a respondent was that, the respondent is a frequent offshore worker who has knowledge and are experienced in offshore transport system. Expert values were gathered from the responses to the questionnaires. In total, twenty (20) questionnaires were issued out. Out of the 20 questionnaires issued out, thirteen (14) people responded to this questionnaire. The questionnaire is attached to the appendix below.

This study also reviews literature regarding actual transportation systems currently in use in Ghana's oil exploration and production. There was also a review of literature regarding environmental hazards and an analysis of government documents that relate to management and regulation of oil and gas activities in Ghana.

1.10 Analysis of Data

The quantitative approach is used for analysing the data in this research. The quantitative approach is selected because, this approach simplifies very complex structures to comprehensible and limited variables. For this research, two steps are employed to reduce emissions in transportation. First was to reduce the total transportation distance covered when travelling to and from offshore installation hence reducing the overall emissions. The second step was an adaptation of the modal spilt concept to split cargo demand between helicopter and vessels such that the emission cost of both modes is minimized.

To do this, first of all, emission cost for transporting by vessel and helicopter each is calculated. Data collected on the types vessels and helicopter used on Ghana's offshore waters were used in this calculation. An optimization tool is then used to minimize the emission cost from these two transportation modes. The objective of the modal split is to split transportation modes such that the means that has the least emissions will be more frequently used as the transport means for a period of time. Computations and results are presented in chapter 10 of the study.

2.0 Chapter Two – Environmental Risk Assessment

The chapter outlines the meaning of environmental risk in general offshore operations. It also discusses some environmental impact of oil and gas transport activities.

2.1 Meaning of Environmental Risk

Risk, in general, is a familiar concept due to its application in most aspects of life. But, as a business concept or with respect to the presence of the word in industry, its meaning and applications have evolved in the last few centuries. *Risk,* therefore, as a business and industrial concept has gained great attention. In defining the term *risk*, the International Standards Organization (ISO, 2009) explains that risk is often explained by a combination of the outcomes of an event and the associated likelihood of occurrence. This therefore means that the expression of risk concept is a product of the probability of harmful event happening and the associated numerical value of the consequences of the event (Aven, 2008).

Environment Risk is an important risk element in the petroleum industry (CRAWFORD, 2018)

Williams and O'Connor (1993) state that:

> *"risks to the environment may arise from the release of contaminants into the environment as a result of failure of or discharge of petroleum production transfer or storage facilities. ... These effects may be aesthetic (visual or odour) or may be reflected in distressed vegetation or mortality within a particular population of animals, fish and other organisms"* (Williams, 1993)

Environmental risks, therefore, apply to risks associated with the external environment which may be inflicted by hazards accompanying oil and gas installations for production and other similar operations within the industry. The elements of environmental risk comprise spills of oil from emerging blowouts, shuttle tanker accidents, seepages and leaks from production equipment, ruptures and leaks of pipelines as well as excessive contamination from fluids released from offshore installations. (Vinnem, 2014)

Environmental risk can be characterized as the "real or potential danger of unfriendly impacts on living life forms and nature by effluents, discharges, wastes, resource consumption hence its depletion, and so on, emerging out of industry's activities (CRAWFORD, 2018). Environmental exposures, be it physical, chemical, biological, potentially induces harmful responses to aspects of the ecosystem, and as such may affect soil, water, air, natural resources etc. Environmental risks contribute a huge challenge for offshore oil and gas companies. Risks related to climate and environment concerns permeate more than local regulatory and compliance issues but affect the whole world (Ernst and Young 2013).

In Ghana's case, where most operational activities are offshore, oil spills, terrestrial and other oil-related pollutions and emissions from the different modes of transportation are of great concern. Sakyi et al.,(2012) mentioned that Ghana is probable to experience serious environmental damages, if the operational environments are not managed and protected strictly. They further mentioned that since Ghana's Oil Fields are offshore, oceans, beaches, and the atmosphere are aspects of the ecosystems that are of great concern. Inhabitants of the communities surrounding Ghana's oil field, i.e. around the *Gulf of Guinea* in the west of the country, are known for fishing operations as their main economic activity for livelihood. This places great significance on minimizing potential environmental risks or damages (Sakyi et al., 2012)

2.2 Major Environmental Hazards

ISO (2002) attributed the term environmental risk to any hazard that can potentially result in a damage of any kind to the ecosystem. These hazards may include oil spills, release of toxic gases into the atmosphere, discharge of contaminated production water into the sea, among others. (B. ISO, & IEC Guide, 2002).

Oil spills and gas flaring hazards contributing to the pollution of water resources and the atmosphere respectively are major aspects environmental risks the sector is characterised by. This risk is very high and pertinent as a result of recent happenings within the industry, especially in the Niger-delta region of Nigeria and the North-Sea region of the United Kingdom (UNFCCC, 2010).

According to Woods, Shirley, and Bottelberghs (1991) environmental risks related to offshore operations are traceable to major hazards within the sector such as oil spillage from exploration and transportation operations. The occurrence of environmental risks is linked to drilling and processing operations, transportation involving crude carriers and offshore transport by pipeline. Spills from offshore industry are potential sources for increases in biomass production and accumulation of organic materials leading to algal production; accumulation of toxic materials causing damage to aquatic life (Wall Street Journal, 2008)

Aside water and land pollutions caused by oil spills, air emission hazard is another component of environmental risk as it causes harm to living organisms anthropological and biological sites within the ecosystem. The release of various GHGs, especially CO_2 which is responsible for ozone depletion and climate change contributes to environmental risk (Wall Street Journal , 2008).

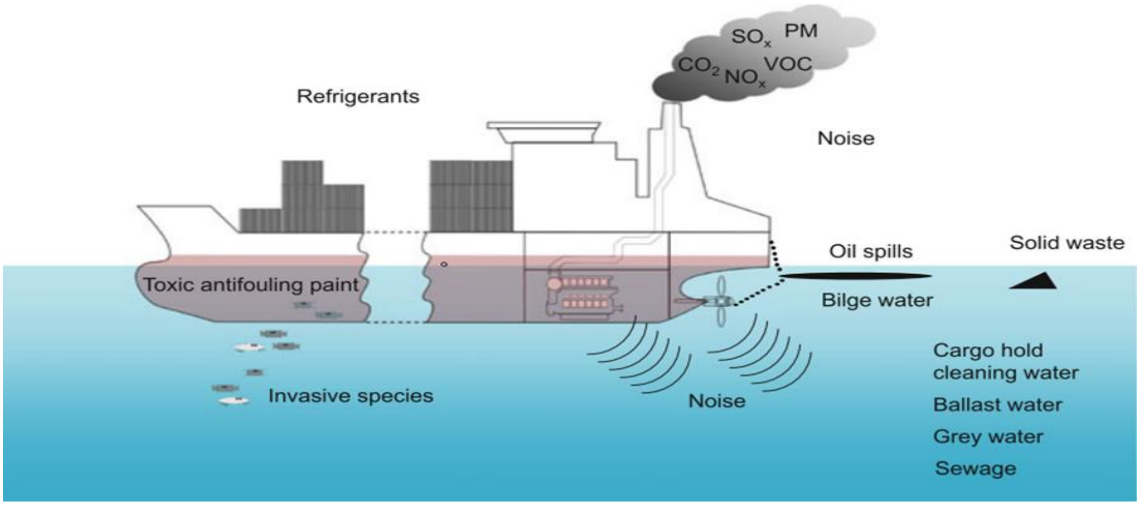
2.3 Environmental Impact of Offshore Oil and Gas Transport Activities

Offshore petroleum operations are categorized into three main sectors: the upstream, the midstream, and the downstream. The upstream activities are those related to exploration and production; the midstream activities involve transporting petroleum products; while the downstream activities comprise refining crude petroleum products. The downstream activities also deal with the distribution and marketing of oil and gas products (Forum/UNEP, 1997). Sectorial operations in Ghana's Jubilee Fields, as is the case elsewhere, is a process of various activities and stages that are usually accompanied by certain intrinsic environmental challenges (Sakyi et al., 2012). Every environmental issue and challenge that emerge from oil and gas activities can be for the most part classified into two: (1) the biological communities (ecosystems) and (2) the human, socio-economic and cultural (Forum/UNEP, 1997).

Air impacts environment by vaporous and particulate emissions. Other than carbon dioxide (CO_2), additionally nitrogen oxides, water vapour, sediment and others add to the environmental effect by air transport. Among the different impacts of air transport on environment, contrails are required to make the biggest commitment worldwide radiative driving of the earth – environment framework, and hence the biggest contributor worldwide environmental change caused by air transport (Schumann, Graf, & Mannstein, 2011).

The figure below shows the environmental impact of offshore sea transport.

Figure 1 Environmental Impact of Sea transport



Source: (Andersson et al., 2016)

The environmental impact of upstream and midstream activities on the operational ecosystems as well as the humans are reviewed below.

2.3.1 Noise

In the process of oil and gas upstream activities related to production and transportation, is the ecological damage of severe noises. Noise disturbances associated aircraft, bulk moving vessels, drilling operational activities etc., have potential negative effects on the operational environment (Sakyi et al., 2012). Noise coming from operational and transport systems, at certain degrees have the potential to affect some biological functions of some marine organisms. Fernández et al. (2005) points out some possible harmful effects of noise, namely, a reduced growth among marine organisms, impaired hearing, stress, and even death have been reported. Whales and dolphin, among most marine mammals and fishes, are especially and gravely affected by the sounds elevated due to offshore production and transportation activities. These mammals are mostly affected due to their reliance on sound either to reproduce, feed, or for safety, i.e. how they avoid danger and other hazards they face in their habitat such as predators and navigation. (McCauley & Cato, 2003; Popper, 2003; Tyack & Miller, 2002).

Noise transmission caused by platform service vessels are normally through both air and water. The most common and dominant source is the propeller cavitation of vessels. Noise intensity are known to be dependent on the vessel size, and speed. Larger vessels have been identified to be noisier as other vessels also increase in noise intensity by increasing moving speed. (NPC, 2011)

Noise is also caused by aircraft transport. The noise generated from aircrafts is fleeting in nature and is mostly variable in intensity. Helicopters often "produce sound forward than backward" (NPC, 2011), and there, their noise radiation underwater is usually brief as compared to their audibility whiles in flight. Factors that influence the radiation and level of noise by helicopters underwater include altitude of the helicopter, the depth of the water, and the bottom conditions in the water (NPC, 2011). Noise disturbances from aircrafts result in increase in heart rate for most terrestrial animals. Noise also has damaging impact on wildlife metabolism and hormone balance. This means that a frequent and long-term exposure of this animals and the entire ecosystem to these noise from aircrafts have potential to lead to excessive stimulation of animals' nervous system, lead to chronic stress, which are all very harmful to wildlife and their reproductive abilities. The response of wildlife to noise greatly depends on how close the animal is to the source of noise (i.e. the moving aircraft or vessel), vessel/aircraft type, abruptness of vessel/aircraft's appearance, overflight frequency (for aircrafts) and also the tolerance level of the species endangered (NPS, 1994).

2.3.2 Air Emissions

The main sources of either continuous or intermittent air emissions from offshore activities include: combustion sources (i.e. from turbines and boilers for as they generate heat and power), pumps, compressors, engines of support vessels and aircrafts. Other sources of emissions include flared hydrocarbons, and emissions that result from testing wells, those that come from exhausts and also fugitive emissions (World Bank Group, 2015).

NPC (2011) identifies that non-platform support vessels including crew boats moving personnel/workers in and out of offshore sites, supply vessels which carry operational supplies, and tugs and barges that carry equipment and other materials are also sources of harmful air emissions. These emissions can mostly be due to the use of diesel engines for vessel propulsion.

Wilson (2010) reported from estimates for all support vessels, pipe laying operations and also seismic studies that major emissions of the pollutants (with exception of sulphur dioxide and other particulate matter) were from offshore petroleum operations. 35% of nitrogen oxide emissions were attributed to platform support vessels. This is attributable to vessel numbers, speed and positioning features. For example, in all, the United States outer continental shelf oil and gas contribution to emissions is about 93% of CO emissions, 74% of all Nitrogen oxide emissions, and 76% of emission of volatile organic compounds. (Wilson, 2010). The table below shows emissions estimates in tons for US outer-continental shelf within the Gulf of Mexico.

Table 1 Total Emission Estimates in Tons of certain outer continental shelf sources in US in 2008

Source Type	CO	NOx	PM10	SO_2	VOC
Support vessels	12,880	135,222	2,342	18,221	2,342
Pipe-laying operations	2,186	10,535	398	1,789	398
Survey vessels	141	1,690	26	204	26
Commercial marine vessels	6,593	79,329	6,603	49,009	2,794
Commercial fishing vessels	681	8,120	124	988	124

Source: (NPC, 2011)

2.3.3 Air Pollution by Biofuels

Biofuels usage for propulsion also adds up to air pollution, just as is the case with fossil fuels. Burning of fuels leads to the production of carbon particulates that are airborne (like CO2, CO) and also nitrogen oxides. The WHO (2018) estimates 3.7million deaths that took place in 2012 could be blamed on air pollution. Brazil is said to "burns significant amounts of ethanol biofuel" (Nguyen et al., 2001). According to Nguyen et al. (2001) gas chromatograph studies conducted in São Paulo, Brazil, and compared studies conducted in

Osaka, Japan (a territory with minimal burning of ethanol fuels), revealed that atmospheric formaldehyde was higher in Brazil to about 160%. Acetaldehyde was also identified to be 260% higher.

According to Haerens (2012), the deterioration in air quality is blamable on the increase in the use of bio-ethanol fuels. It is predicted that nitrogen oxides in atmospheric air are likely to increase as bio-ethanol usage increases. As more fossil fuels are burnt to produce biofuels, it also increases the carbon dioxide level in the atmospheric air, as does nitrogen oxide increase as a result of the use of nitrogen fertilizers for soil improvement. Nitrogen oxide has more effect on the ecosystem, i.e. the air, and is known as an "ozone destroyer" (Haerens, 2012).

2.3.4 Aquatic and Coastal Habitats

Coastal habitats and marine environments have suffered from serious effects of marine transportation. Commercial transportation using the seas and the advancements being made in port establishments in coastal areas are some of the reasons, among others, that contribute to these areas being affected by environmental hazards such as noise, vessels colliding with species, and spills (NPC, 2011). Wakes created by ships, boats, barges, and tanker vessels have potential to wear away unprotected shorelines. This may increase the erosion rate in areas already naturally prone to erosion (NPC, 2011).

2.3.5 Oil Spills

Oil spill as a form of environmental pollution, essentially refers to the release of liquid petroleum hydrocarbons into the environment, i.e. the release is either into water or land. According to World Bank Group (2015), spills from offshore facilities result from equipment failure, leaks, human error or accidents. The release of spilled oils could be from tankers, drilling rigs, offshore platforms, and wells. It can also be from other refined products (like diesel and gasoline), fuels (e.g. bunker fuels) used for large ships, or the discharge of any waste oil or oily refuse. These seemingly small threats in the form of drips and leaks have the potential to turn into serious accidents like fire, slipping etc., if not managed and controlled on time.

As pointed out by Holleman (2004) concerning the Exxon Valdez Oil Spill, spilled oil can enter into the feathers of seabirds and the fur of mammals, reducing its insulating ability, and thus makes these animals more vulnerable to temperature fluctuations and much less buoyant when in water (Holleman, 2004). Oil spills or slicks have a discriminating influence on the environment, i.e. short and long-term impacts. Short-term impacts are visible and quantifiable, depending on the mobility of fishes within the water where the spill occurred and the possibility of escaping toxicity (Cohen, 1995). Long-term impacts on the environment are complicated to estimate, and depend on aquatic animal’s adaptability, feeding habits, and reproductive capacity. Long-term impacts can also be influenced greatly by the capacity of the physical environment to return to normal levels of toxicity. Examples of long-term impacts are mentioned in the observations made of the long persistence of spilled oil in some shores ten years after the Erika spillage of 20,000 tonnes of heavy oil on the coast of Brittany (Jézéquel & Poncet, 2011). Similarly ecologistasenaccion (2013) reported a similar case on the coasts where the Prestige Oil Spill happened in 2002.

According to Broekema (2016), spilled oils have catastrophic consequences for society; environmentally, socially and economically. Oil spills pose serious problems and are greatly harmful, not only to the immediate offshore environment where the oil exploration takes place, but also to general human and animal health, as well as the entire ecosystem. Floating oils resulting from major spills have the potential to reduce the exposure of water to oxygen circulation, which in connection with emulsified oils interfere with photosynthesis.

Figure 2 Oil slick from the Gulf of Mexico, taken on 28 April, 2018

Source: (Darryl, 2018)

Common oil spills known in the industry are the Deep-Water Horizon spill which happened in 2010, the Kuwaiti Oil Fires in 1991, the Exxon Valdez Oil spill, the Gulf War spill and the Taylor Energy spill. The amount of oil leaked through accidents has fluctuated from 100s of tons to 100,000s of tons. This has been the range of volumes spilled during the Deepwater Horizon, Atlantic Empress, and Amoco Cadiz oil spills. However, it is mentioned that the size of oil leaked is an inadequate measure of harm or impact caused the environment when a spill happens. Minor oil spills, like the Exxon Valdez oil spill, have been established to have larger negative effect or harm on ecosystems, for due to the detachment of the site of the spill or how difficult it is to access emergency response.

As reported by Darryl (2018), from 2004, "between 300 and 700 barrels of oil per day have been leaking from the site of an oil-production platform owned by Taylor Energy, situated about 12 miles off the Louisiana coast, which sank in the aftermath of Hurricane Ivan". It is estimated that this oil spill could linger throughout the 21st century, and as such is seen to have a tendency overtake the 2010 Deepwater Horizon incident as the biggest ever (Darryl, 2018). An average of 330,000gallons of oil leak every year from offshore installations and onshore oil tankers (Darryl, 2018).

KOSMOS energy, an exploration company in Ghana, is reported to have spilled 699 barrels of mud in the process of its activities. The mud contained heavy metals which are poisonous and could affect the ecosystem of Ghana. Tullow oil, also an exploration company in Ghana has also been reported to spill some amounts of oil during its operations. (reportingoilandgas, 2011).

According Chang, Stone, Demes, and Piscitelli (2014), when a spill event occurs, one of the most important predictors of impact is its location. Spills closer to shore and human populations have greater economic impacts and are more expensive to clean.

2.3.6 Impact of collision on animals

In their movement, support vessels and other passing vessels to and fro the installation and on –shore site is a potential cause for alarm for large size sea animals. Vessel collisions can cause major injuries or sores that may be very destructive to animals in their movement. All sizes of vessels and types can be involved in collisions with whales and other large sea animals, but the most severe of reported injuries involve vessels that are eighty meters long and those travelling at 14 knots or faster. Majority of these collisions happen near the installation where the whales quite invisible or not seen early enough for preventive actions to be taken (NPS, 1994)

Aircraft overflights can also lead to collision with whales in their speedy dives or any other abrupt behaviours during the aircraft overflight. Also, bird strikes with aircrafts moving to and from installation can also be a source of misfortune for both birds and the aircraft, as this may put the lives of passengers and pilot of the involved aircraft at risk. It is also known that helicopters are highly prone to bird strikes because they fly at lower altitudes and at very high speeds (NPC, 2011).

2.3.7 Hazardous or Radioactive Materials

The offshore production uses chemicals, explosives and other radioactive materials which may be of harm to the ecosystem. The transport of these materials to-and-fro the installation, as well as waste consignments from the installation are potential sources of ecological damage (NPC, 2011).

3.0 Chapter Three – Transport Logistics for Offshore Operations

In developing and maintaining offshore petroleum facilities and installations, fleets of service vessels and aircrafts that are specially well-matched to the operations and demands the offshore activities and operational territories are required (NPC, 2011). This chapter discusses the various transportation modes engaged in offshore transportation.

3.1 Support Vessels

Supply vessels are a new classification of boats. The requirement for this class of vessel emerged the exploration of oil in the mid-1950s. From that point forward, the utilization of supply vessels has been spread around the world. Working principally in the Gulf of Mexico, the North Sea, West Africa, Asia-Pacific, the Middle East, Brazil and different incidental areas within Latin America is greater than 1000 fleet of supply vessels. Fundamentally, supply vessels are utilized to transport supplies forward and backward between the supply base (ports) and the offshore platforms.

Extinguishing fire, oil spill preparedness is among the things that supply vessels are designed to accomplish. Supplies can be partitioned in two principle classifications being the deck cargo as well as the bulk cargo. Everything transported using a vessel's deck is a deck cargo. Also, everything transported in the beneath deck tanks of the supply vessel is known as the bulk cargo. A supply vessel is a vessel which performs multiple tasks and is intended for some distinctive purposes. This makes it very different from the other types of ships we know, which are mainly designed for just a particular kind of cargo.

A critical marker of the decision of supply vessel is generally dependent on the geographical location of the offshore activity. Elements like conditions of the weather, the measure of hardware or equipment required and the distance from the shore are essential for what properties the vessel ought to have. Other factors that determine the nature of support vessels used include increases in the cost and complexity of offshore support services. With farther offshore development, cost and increases in complex services, there will be corresponding increases in the demand for multitasking and even larger capacity vessels, not only for transporting cargo to the deep-water facilities, but also for conducting other operations like installation, mooring, and for fighting fire in a variety of offshore environments. (NPC, 2011).

To have the capacity to work from remote areas, offshore drilling and production units need distinctive sorts of help benefits that are given by specific vessels. Examples of such vessels are Standby/Rescue vessels, Anchor Handling Vessels, Offshore Supply Vessels (OSVs), and Crew Boats. In the upstream sector, it is good to note that, supply vessel is a major component. It is cost intensive to contract and operate a supply vessel. Subsequently, getting the required capacity at the most minimal conceivable rate, and boosting the use of the vessels to its maximum capacity are imperative goals for the oil companies. The use of a vessel's optimum capacity on each routing as well as boosting the number of loaded days at sea are necessary goals that need to be achieved by every oil company. In any case, in light of the tremendous lack costs that can emerge if a platform's needs are not fulfilled, the vessel's ability to be fulfill the need for transport capacity always is only a principal objective. Oil companies mostly do not own supply vessels. They rather charter them. (Aas, Halskau Sr, & Wallace, 2009).

3.2 Aircrafts

The term “offshore operations” is used for aircraft operations when most part of the flight distance is covered by large water bodies and not dry land. Since the demand by the industry is high, helicopters in offshore operations has increased significantly in recent years. This is largely due to the vertical take-off and landing (VTOL) and hover capabilities of helicopters, as they are better alternative for support in operations such as constructing and maintaining offshore platforms. The major offshore functions performed by helicopters may include moving people to and from their workplaces on offshore facilities and vessels, equipment inspection, transporting freight (oil barges), and emergency evacuations. Helicopters are sometimes better options for search and rescue missions. Helicopters are usually quicker means of transportation than vessels. (Skybrary, 2018).

Helicopters are also routinely used in providing needed services to offshore installations. These services, primarily, include conducting emergency evacuations, transporting crew personnel, transporting equipment and supplies from onshore to installation (NPC, 2011).

In recent times, deep water offshore operations have contributed to the high demand of enhanced, multitasking and more complex helicopter capacities and features such as faster and farther travel potential, carry more crew personnel, reduced operational costs and also to have an all-weather capability (NPC, 2011).

3.3 Oil and Gas Transportation Modes and Volumes Transported

Transportation within the oil and gas sector largely entails moving crude oil from the exploration sites (i.e. that is the oil discovery site) to refineries (i.e. for further processing), then to the storage centres and emergency reserves, where final oil and gas products are stored for distribution. With petroleum in its raw state, two primary modes are used for the transportation, namely, the tankers and the pipelines. Tankers are usually used to move crude oil inter-regionally using water routes, whiles pipelines are used for at some part. Transporting and storing oil and gas represent a maze of complex processes that comprise consistent inspections, rigorous compliance to standards, regulations and statutory mandates for designing, constructing and maintaining transport systems (i.e. either tanker fleets and pipeline, etc.). Other major concerns, moreover, include efficiency, safety, tanker hull strength and pipeline integrity. These are of utmost concern in particular, as they are in connection with issues of environmental concern such as fires, oil spills, and oil leaks. (BERA, 2006)

Oil and gas transportation have always known pipelines and tankers as the major means of transporting oil and gas to processing centres or to demanding countries. The Offshore Magazine article in 2000 mentioned that pipelines and shuttle tankers linked to floating production, storage, and offloading (FPSO) vessels are the choices in moving oil to shore. Worldwide, operators select the transport system that best fits their development scheme and economics.(Offshore, 2000)

The United States have millions of miles of pipelines, ten thousand of rail cars, marine vessels, barges, and approximately 100,000 tanker trucks that transport oil and gas from drilling wells to refineries, then from the refinery to the final consumer. These same transportation modes are also mainly used for oil and gas exportation by the United States. Almost entirely, all-natural gas transportation in the United States is done by pipeline, with over 90% of crude and refined petroleum products transported by pipeline (Allison & Mandler, 2018).

Concerning the environmental impact of these transportation modes, (Allison & Mandler, 2018) mentions that, when pipelines very well managed, constructed and maintained , spill and leaks do not occur often. However, it is good note that, no transportation system is completely safe. There is always a risk factor. Oil spills have local, regional and global impacts. When oil spills on the land, it mostly has local impacts but when it spills in the sea, then the scope of impact increases not only regionally but sometimes internationally. When there is leakage of gas methane is emitted, which is a greenhouse gas. Methane gas also contributes to ozone pollution. Pipeline leakages are a waste resources (and therefore money). It can therefore be concluded that, maintaining a safe transportation system is necessary for environmental, public health, and economic benefits

3.3.1 Pipelines

The role pipelines play in the transportation process in the petroleum setor is very crucial and critical as large amounts of oil and petroleum products are moved using pipelines, at least for some part of the transport process. "Pipelines are also integral for landlocked crudes and also complement tankers at certain key locations by relieving bottlenecks or providing shortcuts" (Kennedy, 1993). According to the U.S. Department of Energy, the interregional trade of oil and gas between Russia and Europe solely relies on pipelines linking these two territories (EIA, 2017). Pipelines are reputed to be extremely extensive and important transportation modes. They are mostly "recognized by the general public, mainly due to the fact that, they are buried underground or under the sea as in the case of gas pipelines from North Africa to Europe" (Rodrigue, 2017).

Pipelines are known to be very effective when it comes to moving bulk amounts of oil and gas, especially in cases that no other possible mode of transport (usually by means of water) is in view. Pipes are means of routing or linking isolated production sites to major refining and or manufacturing sites, which is the case with offshore oil and gas installations. Pipelines are used to transport crude and refined, separate from natural gas, either to another transporter or straight to a processing plant for further processing (BERA, 2006).

The construction of pipelines poses environmental risks. Pipeline routes are mostly indifferent to terrain, despite the fact that approval for their construction and installation are frequently delayed by environmental concerns. Thus, in constructing pipelines in highly sensitive areas, especially in the arctic and subarctic areas, there is the need for considerations of its severe impacts on migratory wildlife. Pipelines in these arctic areas pose severe danger to the safety of the natural habitat and environment as the pipes are not be buried due to permafrost. According to Rodrigue (2017) the severity of environmental impacts due to pipelines in arctic areas can be sufficient to deny approval, which was the case with the McKenzie Valley pipeline in Canada, which was proposed in the 1970s. Aside the environmental concerns, it has been established also that the construction and routing of pipelines can be affected by geo-political factors, especially in cases where pipelines routes cross international boundaries.

On the cost of constructing and maintaining pipelines, Rodrigue (2017) mentioned that costs of constructing pipelines differ, depending on the diameter of the pipes and that costs can rise comparably considering the travel distance and viscosity of fluids it carries or transports. Operational costs are often low, though, pipelines are a very important mode for the transport of oil and gas products. A major disadvantage of pipelines is its inherent inflexibility as a transportation mode. Pipelines are not expandable to the expansions in demand once they are constructed, meaning here are restrictions to the carrying capacity. Conversely a lessening of supply or demand will produce a lowering of revenues that may affect the viability of the system. Another disadvantage is that, once a pipeline is constructed to transport a substance from one geographical region to the other, there is no room for changes.

3.3.2 Tankers

Tankers are used in moving oil and gas by transporting oil and refined petroleum products from one country to the other. Tankers are also used when transportation of oil and gas takes place on interregional routes. In the US for example, tankers are used in moving oil along the Gulf coast. In recent times, there have been great improvements in the design of tankers and this has resulted in the development of versatile carriers capable of transporting a wide array of bulk liquid cargoes. In recent times, for transporting large volumes of liquid cargoes, tanker vessels are mainly used.

Primarily, tankers are major movers of imported or exported oil or other refined oil products. The U.S. Coast Guard defines a tank vessel as,

> *"one that is constructed or adapted to carry oil or hazardous material in bulk as cargo or cargo residue*" (BERA, 2006).

The earliest tanker vessels were constructed were said to use single hulls. There are various types of tankers: "*oil tanker, parcel tanker (chemical vessels), combination carrier (designed to carry oil or solid cargoes in bulk), and barges*." (BERA, 2006).

Tanker vessels used for offshore oil and gas, mostly known as crude carriers have different classifications. They are classified as either VLCCs (Very Large Crude Carriers) or ULCCs (Ultra Large Crude Carriers). Irrespective of the classification, Tanker Vessels have designed features that make them efficient in transporting huge quantities of crude oil over very long and heavily travelled ocean routes. The region from where the oil is being shipped determines the economies of scale. (BERA, 2006).

Concerns have been raised on the moving of bulk oil using tanker vessels, among which is the stress on the hull. These concerns are described by three phenomena:

1. **Bending** – This is in the form of sagging, where there is

   "*concentration of excess weight in the mid-section of the vessel causing the deck to be subjected to compression forces while at the same time the keel is under tension."* (BERA, 2006).
2. **Hogging** – Which is a phenomenon that describes

   "*the concentration of weight at both ends of the vessel causing the deck to experience tensile forces while the keel is under compression"* (BERA, 2006).
3. **Shear Force** – This phenomenon occurs

   "*when two forces act in opposite directions parallel to each other, such as at a bulkhead between an empty ballast tank and a full cargo tank. The weight or gravitational and buoyant action experienced on either side of the bulkhead causes the shear force phenomenon"* (BERA, 2006).

These concerns make vessel tankers vulnerable transportation mode that pose high risk to the environment as they stand a high possibility of accidents. In addition to these concerns, there exist international bulk chemical codes that regulates the safe haulage of chemical cargoes, which provides different levels of protection and safety measures against leaks, spills and other uncontrolled release of transported substances that pose the greatest environmental risk (BERA, 2006).

There have been recent increases in the construction of the super tanker vessels, which came about as a result of a number of factors. One of these factors was the closure of the Suez Canal which forced ship owners to travel shipping longer routes. (Huber 2001) VLCCs and ULCCs usually load at offshore platforms or single-point moorings and discharge their contents (mostly liquid cargo) at assigned regions off the coast. With increases in the demand for crude oil worldwide as more oil reserve discoveries are been made and developed in deep water areas such as the Caspian Basin, Latin America and the Middle East, there is an increase in demand for more tankers. (Huber, 2001).

3.3.3 Barges

Traditionally, barges have been used to transport small amounts of oil, as well moving some refined oil products. In recent times, the use of barges has seen dramatic increases in usage especially in the United States. (Allison & Mandler, 2018). According to the U.S. Energy Information Administration, about 46 million barrels of crude oil was moved to oil refineries in the year 2010 using barges (EIA, 2018). This figure was reported to have increased to 244 million barrels in 2014 but in 2016, it reduced to 165million barrels due to the industrial decline. Inland water transportation using barges is reported to use about 75% less energy than transportation by means of trucks and 25% less energy than rail. However, transportation of crude oil is only viable where navigable rivers are close to both the source of oil and its destination. (EIA, 2019).

Another method by which bulk liquid are transported is by the used of barges. Approximately, 15,000 barrels of oil can be carried using barges. Barges, are basically used on rivers and canals.

Globally, barges are involved in different activities in various parts of the world. According to Snieckus (2014) some barges were specially "*designed for grounding and floating operations in the Caspian Sea*". Additionally, two barges named *Nur and Shapagat* were built to shelter 120 personnel.These barges have self-supporting features outfitted with anchoring, mooring, towing and bottom jetting systems. The Russian Maritime Register of Shipping and London's Lloyd's Register have certified these barges as they are specially designed for harsh offshore environments common off Kazakhstan.(Snieckus, 2014)

3.3.4 Trains and Trucks

Trains and trucks are known to be less efficient than barges or pipelines. According a market analysis report by National Tank Truck Carriers about 1.2 billion tons diesel, gasoline, and aviation fuel have been moved using truck tankers (NTTC, 2018).Trucks are known to be one of the most versatile forms of transportation within the oil and gas industry because they don't rely on the presence of railways, pipelines, or water. They are usually used for short-distance transportation of oil and other refined products. However, as noted by Protopapas, Kruse, and Olson (2013) trucks tankers are not mostly energy-efficient. They require three times as much energy as a train to move the same volume of oil and other refined products. This makes trucks not as attractive and economical for transporting oil over, especially over long distances (Protopapas et al., 2013).In terms of mode capacity, trains or railroad tankers range in capacity from 100 to over 1500 barrels of oil and other refined products.

Table 2 Modes Used for Petroleum Transportation

	Pipeline	Marine	Rail	Truck
Volumes	Large	Very large	Small	Large
Materials	Crude/Products	Crude/Products	Products	Products
Scale	2 ML+	10ML+	100kL	50 – 60 kL
Unit Costs	Very low	Low	High	Very high
Capital Costs	High	Medium	Low	Very low
Access	Very limited	Very Limited	Limited	High
Responsiveness	1-4 weeks	7 days	2-4 days	4 – 12 hours
Flexibility	Limited	Limited	Good	High
Usage	Long haul	Long haul	Medium haul	Short haul

Table Source: (Rodrigue, 2017)

3.4 Fuels and Costs of Transport in Offshore Oil and Gas

3.4.1 Aircraft Fuel used in Offshore Operations

Sandhy (2017) identified various types of fuels are used in aviation industry and the fuel used in a particular aircraft depends on the type of engine installed in the aircraft. Fuels used for most commercial aircrafts is kerosene based. This kerosene is said to be very purified with some additives added to enhance the materials used in making the gas turbines in aircrafts from rusting/corrosion, to keep fuels from freezing at higher altitudes and also from other damages. Some these additives include anti-freeze, antioxidants, hydrocarbons, and metal deactivators. In aviation industry, four types of fuel are generally used for aircraft propulsion. These are JetA-1 (kerosene) , Jet B , Avogas 100 LL and Biokerosene. (Sandhy, 2017). The fuel type which is most commonly used is Jet A-1 (Kerosene)

Jet fuel (Jet A/Jet A-1, kerosene)

This is a kerosene type of fuel which is mostly only available in the US produced with American Society for Testing and Materials (ASTM) specifications. The difference between between Jet A (JP-5) fuel and commercial Kerosene is almost insignificant. Jet A is a heavy kerosene which has a higher freezing point than normal kerosene (Sandhy, 2017).

According to Oiltanking (2015) Jet fuel (Jet A-1 type aviation fuel) is used worldwide for turbine engines in civil aviation. It is said to be carefully refined, and is regarded as *light petroleum*.

According to Kollmuss and Crimmins (2009)when aviation fuel (kerosene) is burnt, carbon dioxide is emitted in direct extent to the amount of kerosene used: for every kg of kerosene used, an amount of 3.16 kilograms of carbon dioxide is formed.

Jet B (Kerosene – Gasoline mixture)

This type of aviation fuel is used for military jets. It is made up of a unique mixture of 65% gasoline and 35% kerosene. It has freezing point of -72°C (as compared to -47°C for Jet A-1) hence can be used in very cold regions.(Oiltanking, 2015)

3.4.2 Fuels used for Offshore support vessels

In the history shipping, there is currently more diverse types of fuel than in previous times. (Latarche, 2017). Latarche (2017) suggests that fuel oils will before long be replaced by evidently cleaner such as LNG and methanol despite the fact this opinion has not yet proved to be correct after almost a decade. (Latarche, 2017)

Marine fuels have evolved over time, with the beginning types used being the marine gas oil (MGO) and marine diesel oil (MDO). MGOs and MDOs are the concentrate fuels and used mostly in medium and high-speed marine vessel engines. They are identified to have very low viscosity and flash point. These fuels also are generally cleaner and produce fewer polluting emissions hence highly recommended for use. (Latarche, 2017)

Heavy Fuel Oils (HFOs)

The primary function of a marine engines is to generate energy by burning of fossil fuel so as provide power to propel the ship. The most common type of fuel used to propel ships is the HFO. It is used for commercial purposes. (Anish, 2018)

When crude oil is separated or fractioned, the highly viscous fuel remain as residue and these fuels are known as heavy fuels. Heavy fuels require to be preheated before use because they are highly viscous (thick) in nature. If not preheated, they cannot be pumped into the fuel system. They are also only used in low speed and medium speed engines. Heavy fuels have a higher energy content by volume. They however hold many more of the pollutants from the crude oil. (Latarche, 2017)

Biofuel and EcoFuel

Modern organic procedures such as agriculture, and anaerobic absorption are used in the production of biofuels. Unlike fossil fuels which are produced by long term decay of organic matter Biofuels are one of the recent developments of fuels used for powering vessel propulsion. The term *bio-diesel* is an all-inclusive name for fuel from a wide variety of products. Biodiesel can be either be produced from animal substance, plant substance or a blend of the two substances. A little amount of bio-diesel can be blended with mineral diesel to deliver an increasingly stable fuel (Latarche, 2017). Biofuels have been identified as one of the best candidates to aid in attaining the industry's target of low emissions. Derived from sources as algae, by-product of waste, jatropha, biofuels have proven to minimize up to 80% the carbon footprint of aviation fuel.(atag, 2018)

EcoFuel, which is likewise known to be without sulfur, is perfect for use by the ships working in the Baltic and North Sea SECAs. EcoFuel can either be mixed with fossil diesel or directly used as heavy marine fuel, or it can be processed to light marine fuel. Ecofuel is also used as less environmentally harmful heating oil. The crude materials of VG Marine EcoFuel are reused vegetable oils and fish processing residues. (Latarche, 2017).

Low-sulphur fuel oil (LSFO)

The International Maritime Organization (IMO) reports that in 2020 a further reduction in the permissible sulphur level in fuels will be finalized. (Latarche, 2017)

According to Latarche (2017), there are some low sulfur fuel oils (LSFO) accessible today despite the fact that he amounts accessible are not high enough. There are some more current ultra-low sulfur fuel oils (ULSFO). These ULFSO are sometimes called to as hybrid fuels. They are formulated to meet the 2015 sulphur reduction level of 0.1% in ECAs.

Generally, LSFO is considered to have a sulfur content of 1.0%. This is unreasonably high for use in an ECA yet ULSFO with a sulfur content of 0.1% which meets the necessary ECA requirements at some ports. (Latarche, 2017). This makes ULFSO a preferable type of fuel to be used.

Non-oil fuels

According to Latarche (2017) liquefied natural gas (LNG) is the only option to oil that is currently in use to power the propulsion systems of vessels. LNG has a higher energy content for every volume. For every litre of LNG,600 litres of natural gas is contained approximately. LNG is used as fuel to power some offshore vessels, some ferries, and are also used for the purposes of steaming turbines. Using LNG as fuel is less environmentally harmful than the other types of fuel.

3.4.3 Fuel Costs

Rodrigue (2017) estimates that fuel costs accounts for about 40-50 percent of air operating costs of a single flight. Air transport operating costs are estimated to depend largely on the type of plane used (i.e. economies of scale and fuel efficiency). Since 2000, there have been an environment characterized by much higher fuel prices and volatility. Between 2005 and 2016, fuel prices varied between 20-35% of the operating expenses of an aircraft company. Meanwhile in the 1990s, aircraft fuel prices were very stable. The surge and large fluctuations in fuel prices is claimed to mark the beginning of the 21st century. In the 2010s, fuel prices for aircrafts stood at six times the level seen in the 1990s. This makes the long-term planning of air operations more complex, with the priority in aircraft design focusing on fuel efficiency (Rodrigue, 2017).

Below is a graphical representation of the fuel prices recorded in the United States, between 1990 and 2018.

Figure 3 Aircraft Fuel Prices, 1990-2018

Source: (EIA , 2018) US Energy Information Administration, U.S. Gulf Coast Kerosene-Type Jet Fuel Spot Price FOB, USD per gallon.

3.4.4 Impact of emissions from sea and air transportation

Emissions from the fossil engines have adverse effect on both the environment and the quality of air. Pollutants in their gas phase as well as airborne pollutant that can influence environment are emitted by aviation. When carbon dioxide (CO_2) is emitted, it warms the atmosphere, so does nitrogen oxide warm the atmosphere through the formation of tropospheric ozone (O_3). Tropospheric ozone (O_3) behaves as a greenhouse gas as well as cool climate by means of a reduction in the lifetime of the well-blended greenhouse gas methane (CH_4) through increments in the OH radical (Holmes, Prather, Søvde, & Myhre, 2013) Sulfur dioxide emissions (SO_2 and NO_x) from aviation forms sulfate and nitrate aerosols through adjusted atmospheric oxidants, lead to a cooling, and dark carbon (BC) emissions leading to a warming.

Also, the production of straight contrails as well as contrail-cirrus from aircraft prompts warming. Generally, emissions from aviation are thought to have a warming effect on climate. Emissions from flight or air transport systems can raise the atmospheric concentration of fine particulate matter which has diameter of < 2.5 μm ($PM_{2.5}$). Being exposed to $PM_{2.5}$ for a short period of time can aggravate respiratory and cardiovascular afflictions, while being exposed for a long period can result in perpetual respiratory and cardiovascular illnesses, cancer of the lungs, incessant changes in physiological capacities as well as mortality. Particulate matter concentrations are particularly increased at airports, and in the case of offshore air transport, it is increased at supply bases or ports due increased emissions during taking off and landing (Kapadia et al., 2016).

Sulphur Dioxide Emissions

Sulfur dioxide (SO_2) has a place with the group of sulfur oxide (SO_x) gases. Group of SO_x are formed when fuel containing sulfur (which for the most part is coal and oil). When concentrations of SO_2 is high, it causes numerous health conditions as well as environmental impacts. The locations of industrial facilities record the highest concentration of SO_x. SO_2 discharges are an imperative environmental issue since they are a noteworthy precursor to surrounding (Particulate Matter) $PM_{2.5}$ concentrations.

Adverse health effect is related to the exposure to airborne SO_2. Multiple human clinical investigations, epidemiological examinations, and toxicological examinations bolster a causal connection between momentary introduction to airborne SO_2 and respiratory morbidity.

According to U.S EPA (2008), some observations made proved that, some health impacts SO_2 have been hospitalizations for every respiratory reason, which includes airway inflammation among others. These examinations further propose that asthmatics, kids, grown-ups, and individuals who spend most of their time outdoors where exerted levels are high, are at high risk of these health dangers.

In addition, SO_2 responds with other air toxins to form sulfate particles, from which fine particulate matter ($PM_{2.5}$) are made. Breathing in or inhaling $PM_{2.5}$ has been related with different cardiovascular and respiratory health impacts. Numerous other environmental impacts are related with concentrations of SO_2. For instance, airborne SO_2, alongside NO_x, adds to acidic rain.

As mentioned earlier, SO_2 is a noteworthy precursor to $PM_{2.5}$ and SO_2 adds to vision impairment. SO_2 likewise can hurt vegetation by expanding foliar damage, diminishing plant development and yield, and diminishing the number and assortment of plant species in a given network. Lastly, SO_2 can quicken the corrosion of materials (e.g., metals, solid, limestone) that are utilized in structures, statues, and landmarks. (U.S EPA, 2014) hence weakening buildings/structures.

One of the means by which SO_2 is produced is when fuel is combusted. Industrial processes like chemical production, petroleum refining and different modes of transportation (trucks, boats, ships, cars, buses, motorcycles, aircrafts, construction and farm equipment, lawnmowers etc.) are examples of processes that fuel combustion. Plants powered by oil, coal and gas produce SO_2 when combusted.(U.S EPA, 2014)

CO_2 Emissions

On a global scale, emissions from transport accounted for 23% of the world's emissions in 2010.(WHO, 2019)

Transportation by ship, cars, trucks, planes among others is engineered mostly by the burning of fossil fuels or petroleum products (EPA, 2017). Out of the total shipping CO2 emission in the world, 13% of the emissions is from oil tankers (Olmer, Comer, Roy, Mao, & Rutherford, 2017) Consumption of petroleum products like gas and diesel discharges carbon dioxide, an ozone harming substance (also a greenhouse gas), into the environment. The development of carbon dioxide (CO_2) and other ozone depleting substances like methane (CH_4), nitrous oxide (N_2O), and hydrofluorocarbons (HFCs) is making the Earth's environment warm, bringing about changes to the atmosphere we are as of now observing today (EPA, 2017).

Climate change has its effect on plants, marine ecosystems, human health among others. The change of climate has very great effects such as weather conditions which are extreme like great flooding, rise in sea levels, catastrophic storms, among others. It also has its economic effects on countries. Governments for example have had increasing healthcare bills as the effects of global change have increased the number of people who are going to the hospitals. Properties are being destroyed, there is an increase in the prices of food which are all burdens to governments. (Environmental Defense Fund, 2019) Most countries have carbon prices per ton of carbon released into the atmosphere. This strategy is helpful as it encourages industries to use cleaner fuels which emit less CO_2.

Nitrogen Oxides (NOx) Emissions

To depict the entirety of nitric oxide (NO), nitrogen dioxide (NO_2), and different oxides of nitrogen a term "Nitrogen oxides" (NOx) is used. Basically, non-renewable energy source burning, activity of engine vehicles, industrial operations are sources of most airborne NOx. In many critical environmental and human health effects, NO_x is a key factor. Scientifically, it has been proven that, there are different health impact with respect to the span or amount of time one is exposed to the gas.

Additionally, NO_x reacts with volatile organic compounds (VOCs) when there is sunlight which results in the formation of ozone. Ozone is related with human wellbeing and environmental impacts. Like SO_2, there is a reaction between NO_x and other pollutants to produce compounds which contribute to acid deposition. Acid deposition can destroy forests as well as causing water bodies such as streams, lakes etc. to acidify. Also, the discharge of NO_x influences nitrogen cycles and can add to unwanted development of green (algae) growth that can disturb the nutrients in water bodies by disrupting the chemical balance particularly in coastal estuaries. Lastly, NO_x is a factor in many other environmental problems such as forming particulate matter, climate change globally as well as reduced visibility (EPA, 2014).

Emission factor for the gas components is shown in the table below;

Table 3 Emission factor for gas components

Gas Component	Carbon monoxide (CO)	Methane (CH_4)	Nitrous oxide (N_2O)	Carbon dioxide (CO_2)	Sulphur dioxide (SO_2)	Particulate matter (PM)[b]

Emission Factor (kg emitted per ton fuel**)**	7.4	0.3	0.08	3170	54	7.6

Source: (Endresen et al., 2003)

The emission factor for carbon dioxide is used later in chapter 5 to calculate the emission cost for transportation by sea and transportation by vessel.

4.0 Chapter Four – Offshore Ecology and Environmental Regulations of Ghana

4.1 History of Oil and Gas in Ghana

The historical background of the Ghanaian oil and gas activity can be followed back to the twentieth century. The Keta and Tano Basins had little scale production in the mid-1900s, and the Saltpond field has been working since the 1970s. Ghana was noted as a commercial oil and gas producer when it disclosed the offshore Jubilee field in 2007, which has an assessment of 700 million barrels of oil (MMbo) and 800 billion cubic feet (Bcf) of gas.

Jubilee field produced its first oil in 2010, and since then two new projects have been started in the offshore of Ghana's. Production commenced in the Tweneboa, Enyenra, and Ntomme (TEN) fields (has an expected volume of 240 MMbo and 396 Bcf of gas) in August 2016.The Sankofa Gye-Nyame fields (with an expected volume 500 MMbo and 1.45 trillion cubic feet of gas) commenced its production in May 2017. Jubilee Field is located 60km off the coast of Cape Three Points which is in the western region of Ghana. It has a water depth of 1100m to 1700m. The unrefined petroleum which is produced from the Jubilee field is sent out to Europe. The gas is, however, conveyed by means of pipeline to Ghana's coastal processing gas plant.

The TEN fields are positioned 20 km west of the Jubilee field. The Jubilee field and the TEN fields are connected by means of subsea infrastructure which aids in the transportation of gas to Ghana's coastal gas processing plant. The most recent oil and gas project is the Sankofa field also known as Offshore Cape Three Points Integrated oil and gas development project. (Skaten, 2018).

4.2 Ghana’s Offshore Ecology

Ghana’s offshore ecology is estimated to boast of 89 species of marine animals found within 1,100 – 1,700m water depth of the jubilee oil fields. These include pelagic stocks and demersal species which are the most abundant species offshore of the Cape Three point, the centre of Ghana’s oil field. The distribution and abundance of small pelagic species are highly dependent on or affected by coastal upwelling in the area. Organisms in these areas that are of biomedical importance are phytoplankton, zooplankton, pelagic fishes, offshore benthic invertebrate fauna, as well as other sea mammals and sea turtles(Ganapathiraju & Pitcher, 2006). Figure 7 shows Ghana's offshore activities map.

Figure 4 Ghana's offshore activity map, showing the offshore sedimentary basins

Source: (Skaten, 2018)

4.3 Ghana's Onshore ecology

Armah (2005) mentioned that the sandy shores around Ghana oil field are known for nesting sea turtles and serves as habitat for other species such as ghost crab, isopods, amphipods, mysids, mole crab and polychaetes, bivalves and gastropods. There is also strand vegetation including creepers and grasses, coconut palms and dwarf palms along the sandy shores.

Also, rocky shores are seen there and also serve as important habitat for macro algae, barnacles, and littorinid snails. These animals use the rocks as substrates.

The coastal belt of the Cape Three Points also hosts a forest reserve, rainforest around the Ehunli and Akpulu lagoons. There is also an estuary along the western coastline, where the Yile and Kpani rivers meet. These places have 141 species of 58 diverse plant families, made up of trees, grasses, shrubs, and surges. The forest also boasts of 263 species of animals, from birds, elephants, bongo, turtles and primates (Armah, 2005).

Therefore, due to the importance of the above-mentioned species in Ghana's offshore and onshore ecology, great importance must be attached to the regulation of activities of offshore operations to ensure that damage is not done to the habitats and breeding grounds of flora and fauna. (Sakyi et al., 2012).

4.4 Environmental and Social Assessment and Management System in Ghana

Eni Ghana is the operator of the OCTP block in Ghana. Eni developed two studies in Environmental, Social and Health Impact Assessment (ESHIA). The ESHIAs meet the necessities of the Performance Standards. Quantitative studies were completed by the use of numerical modelling of emissions to environment and noise at the ORF amid activities, submerged noise levels, measurement of project discharge, including cutting discharge as well as modelling of oil spill situations. This was completed in the first study.

Laying of the subsea pipeline, drilling activities, introducing the pipeline from the shoreline to the ORF, and clearing the areas for the ORF, base camp and helipad (to be utilized just if there should be an occurrence of restorative departure) are the fundamental wellsprings of potential environmental effect amid development. This covers the second study.Amid production activities, the most critical occasion that could influence the marine and beach environment is an unrefined petroleum spill from the FPSO, which handles oil and related gas from the oil field improvement just as non-related gas from the gas field advancement, or from the crack of a stream line from an oil well to the FPSO.

Inadvertent occasions or accidents evaluated include a blowout from an oil well or a gas well, leakages of gas, fire or blast at the FPSO or the ORF or its pipelines. Wastes and cuttings from drilling, solid waste and dangerous waste, air emissions as well as noise are measures tended to in the ESHIAs. Management of risk, HSE management, environmental control, management of water resources, ozone depleting substance computing and reporting, biodiversity and biological systems(ecosystems) among many others are areas covered by the Eni HSE IMS. The IMS has been created and is executed as per ISO 14001 Environmental Management System and OHSAS 18001 Occupational Health and Safety Management.(Eni S.p.A, 2015)

4.5 Environmental Policies and Regulations on Offshore Oil and Gas in Ghana

4.5.1 The Marine Pollution Bill

With recent developments in commercial production of oil and gas, Ghana's Maritime Pollution Bill was introduced in Parliament with the core purpose of enacting the bill as a way of ensuring the protection and safety of the nation's marine environment. The Bill primarily seeks to legislate a prevention and control framework to put in check marine pollution sources in general through consolidating the International Maritime Organization's International Marine Pollution Conventions. The IMO's conventions that were integrated into the MPB consists the areas of control and prevention, preparedness and response, liability and compensation for accidents resulting in pollution. The Bill also has other important provisions concerning the control and prevention of pollution to environment from marine sources. These provisions, regarded to be non-conventional, cover these areas: (1) a duty to report oil discharges, (2) an insurance for oil rig and platform operators, and (3) provisions to regulate the movement of oil and gas, (4) as well as a provision mandating the minister of Transport to make other relevant regulations. In effect, the Bill applies to both Ghanaian and foreign ships, and also installations within Ghana's maritime jurisdiction (Owusu, 2014).

The core aim of the MPB is to provide the guideline, the prevention as well as marine pollution control within the regional waters of Ghana. The Bill's sole concern was with pollutions that result from oil ships and tankers. However, it does not make any specific provisions on such issues related to operational pollutions that are brought about as result of offshore oil and gas activities. Nonetheless, the Bill considers it an offence *"to cause pollution from the exploitation of a natural resource"* (Owusu, 2014). The Marine Pollution Bill affects these following, in its attempt to protect the environment of Ghana's waters:

- "*Imposing strict liability on owners of oil tankers and ships that cause pollution and the payment of prompt compensation,*
- *Preventing pollution from sewages from ships,*
- *Preventing pollution of the air by ships through emissions,*
- *Preventing of pollution caused by noxious liquid substances.*
- *Discharge of oil or oily mixture by oil tankers or foreign ships was also prohibited.*
- *Chemical discharges such as ballast water, tank washing water, etc. produced by ships are also prohibited.*" (Ghana Maritime Authority, 2017).

4.5.2 Oil in Navigable Waters Act - 1964 (Act 235)

The Oil in Navigable Waters Act (Act 235) was enacted in 1964 to enforce Ghana's treaty obligations under the International Convention for the Prevention of Pollution of the Sea by Oil. The Act 235 was implemented as a direct regulation of oil and gas pollution by ships on the nation's territorial waters. The Act made it a crime to pollute Ghana's waters. Ships that use oil as fuel in its engines or for boilers is required in the Act to be fitted with machines so that the oil does not leak into the sea. Every master of a ship is also required to keep a record of times when oil was discharged from a ship to secure its safety and when oil leaks from a ship.(Ghanalegal, 2019).

The Oil in Navigable Waters Act seems to only have regulations concerning transportation systems, either with oil and gas movements or with respect to general maritime transport. It is focused on oil pollution caused by ships and therefore affords little help in regulating offshore operational pollution caused by petroleum activities (Owusu, 2014).

4.5.3 Environmental Impact Assessment under Act 490

The Environmental Impact Assessment (EIA) procedure is enshrined in the Environmental Assessment Regulations (Legislative Instrument 1652) enacted under Act 490 (The Environmental Protection Agency Act). The Act specifies that all petroleum exploration and production activities can only be undertaken after the issuance of an environmental permit issued by the Environmental Protection Agency (EPA). In accordance with LI 1652, petroleum production is listed as an activity that requires completion of a mandatory EIA before an environmental permit will be issued (Owusu, 2014).

The EIA process is listed in a scoping report which sets out the scope or extent of the EIA to be carried out and includes a draft term of reference indicating the exact issues to be addressed in the EIA, as follows:

- *"a description of the undertaking;"*
- *"an analysis of the need for the undertaking;"*
- *"alternatives to the undertaking including alternative situations where the undertaking is not proceeded with;"*
- *"matters on site selection including a statement of the reasons for the choice of the proposed site and whether any other alternative site was considered;"*
- *"an identification of existing environmental conditions including social, economic and other aspects of major environmental concerns;"*
- *"information on potential, positive and negative impacts of the proposed undertaking from the environmental, social, economic and cultural aspect in relation to the different phases of the development of the undertaking;"*
- *"the potential impact on the health of the people"*
- *"proposals to mitigate any potential negative socio-economic, cultural and public health impacts on the environments;"*
- *"proposals to be developed to monitor predictable environmental impact and proposed mitigating measures; contingency plans existing or to be evolved to address any unpredicted negative environmental impact and proposed mitigating measures;"*

- *"consultation with members of the public likely to be affected by the operations of the undertaking;"*
- *"maps, plans, tables, graphs, diagrams and other illustrative material that will assist with comprehension of the contents of the environment impact statement;*
- *a provisional environmental management plan; "*
- *"proposals for payment of compensation for possible damage to land or property arising from the operation of the undertaking;" and*
- *"an indication whether any area outside Ghana is likely to be affected by the activities of the undertaking*." "(EPA Act 490, 1999)

The EIA procedure requires operational pollutions within offshore oil and gas production and transportation to be considered and measures to implemented to address them. However, Owusu (2014) mentions that due to the absence of local regulations detailing either prescriptive or performance-based standards, the foreign oil and gas companies are not required in the EIA process to meet the best possible standards.(E.A.R, 1999)

5.0 Chapter Seven – Environmental Risk Modelling

This chapter presents details on the basis and the elements of the model used in this study.

<u>Mathematical Formulation and Description for finding Shortest Distance in One Route</u>

$\min \sum_{(i,j)\in A} D_{ij} Z_{ij}$

$$\sum_{i,j)\in A} Z_{ij} = 1 \ \forall \ i \ \in N$$

$$\sum_{(i,j)\in A} Z_{ij} = 1 \ \forall \ j \ \in N$$

$\sum_{(i,j)\epsilon A} Z_{ij} = \sum_{(j,i)\in A} Z_{ji} \qquad \forall i \in N$

$\sum_{(i,j)\in A(S_k)} Z_{ij} \le |S_k| - 1 , \forall \ S_k$ C N

$Z_{ij} \ \in \{0,1\} \ \forall \ (i,j) \in A$

(LOG820, 2018)

Set	ARCS $i - origin(i = 1 \dots n)$ $j - destination(j = 1 \dots n)$
	SUBE - set of edges in sub-cycle
	set of nodes in sub-cycle S_k
Parameters	**Description**
D_{ij}	Distance of travel from installation i to installation j

K	Number of subcycles.
|S|	Cardinality / size of set
Variable	**Description**
Z_{ij}	Route used from installation i to installation j that gives optimal minimum travel distance. 1 – if arc *(i, j)* is used 0 – if otherwise

Description

The objective function of this model is to find the shortest distance.

The second constraint expresses that exactly one arc that moves into an installation node.

The third constraint expresses that there is exactly one arc that moves out of an installation node.

The fourth constraint ensures that no sub-cycles are formed .in the route.

(LOG820, 2018)

Mathematical Formulation and Description for finding Shortest Distance in Two Routes

$\min \sum_{(i,j)\in A} D_{ij} Z_{ij}$

$\sum_{(i,j)\epsilon A} Z_{ij} = 1 \quad \forall\ i \ \epsilon\ N$

$\sum_{(0,j)\epsilon A} Z_{0j} = m \qquad \forall\ i \ \epsilon\ N$

$\sum_{(i,j)\epsilon A} Z_{ij} = \sum_{(j,i)\in A} Z_{ji} \qquad \forall\ i \ \epsilon\ N$

$Z_{ij} \in \{0,1\} \ \forall (i,j) \in E$

$Z_{ij} = 1 \ if \ arc(i,j) is \ used$

$0 \ otherwise$

(LOG820, 2018)

Set	ARCS - $i - origin(i = 1 \ldots n)$ $j - destination(j = 1 \ldots n)$
Parameters	**Description**
D_{ij}	Distance of travel from installation i to installation j
M	Number of routes to be taken.
Variable	**Description**
Z_{ij}	Route used from installation i to installation j that gives optimal minimum travel distance for two routes. 1 – if arc *(i, j)* is used 0 – if otherwise

Description

The objective function expresses the minimum transportation distance to visits all three installations in two separate route.

The second constraint expresses only one arc exists between installation i and installation j .

The third constraint defines how many routes that needs taken which in this scenario is two routes.

The constraint expresses that the number of arcs into an installation should be equal to the number of arcs out of the node ensuring continuity of the solution (LOG820, 2018)

5.1 The Modal Split Theory

In transportation, modal split is characterized as dividing quantities that need to be transported between different modes of transportation (Sierpiński, Staniek, & Celiński, 2015). According to (Sathish, Jagadeesh, & Kumar, 2019) ,modal split is the way of separating an individual's trip by the method of travelling. Generally, modal split alludes to the trips made by private vehicle rather than public transport. Public transport, because of its capacity to transport more people in one trip compared to private vehicles are considered to be less environmentally harmful. Policies are made to encourage people to shift their modes of transportation from private cars to public transport. Modal split keeps on getting essential consideration from examiners keen on modelling of urban transportation. Modal split is of the most concern while settling on choice transportation mode.

The number of transportation trips made by the different transportation modes to offshore installations are dependent mainly on demand that is placed. Main transport to offshore installation is the transport of personnel's to and fro. Modal shift in this context implies replacing less environmentally friendly methods for transport with another to make less environmentally harmful. Modal split accordingly makes it possible to transport offshore supplies and personnel in higher volumes and urgent demands as well as reduce emissions as most as possible (greenmodal, 2018).

Hydrocarbons, Nitrogen oxides (NO_2), Sulphur Oxides (SO_2), Carbon dioxide (CO_2), Carbon monoxide (CO), particulate matter (PM), methane are examples of gases released when a supply vessel or helicopter travels to an offshore installation. However, this study mainly focuses on CO_2. Additionally, though only calculations for CO_2 are computed in this study, it can be noted that, when CO_2 emissions are reduced, the other gases emitted are also directly reduced.

5.2 Calculation of emissions from offshore air transport

The Total Emission in transport can be calculated from the Emission Factors (EF) and energy utilized. Energy utilized can be measured in fuel consumption when taking off and landing or the distance covered. The formula used is shown below;

$TE_i = EF * C$

where

$TE_i = Total\ emission\ of\ subtance\ i$
$EF = \ Emission\ Factor\ for\ substance\ i$
$C = Fuel\ consumption.$
$i = CO_2$
(Zadek & Schulz, 2010)

The parameters (being the emission factor and fuel consumption) used in this calculation depends on the model of helicopter used for transportation as well as the type of fuel that is used to operate the helicopter. For the purposes of this study, Sikorsky S92 model of helicopter is used. The fuel type used is Jet A kerosene. The emission factors depend on the fuel used.

There are also softwares available for computing the emissions depending on the estimated process parameter. (regjeringen, 2008)

5.3 Calculation of emissions from offshore sea transport

The emission model is given calculates the exhaust gas emissions from the engines and the fuel consumptions for ship types. The model is given by:

$M_{i,s} = \ c_{gk}\ F_{i,s}$
where
$M_{i,s} \ = \ quantity\ of\ pollutant\ emittedof\ ship\ of\ type\ i, engine\ type\ s$

$c_{gk} = emission\ factor\ for\ fuel\ type\ g\ , pollutant\ type\ k.$

$F_{i,s} = fuel\ consumption\ of\ vessel\ of\ type\ i, with\ engine\ type\ s.$

Source: (Endresen et al., 2003)

For the purposes of this study, the model of platform supply vessel used is the Vos Partner. The engine type used for this type of PSV is 2 x Diesel Engines, 1630 kW. It is propelled by diesel electric. For the purposes of this calculation, the fuel consumption was determined by the engine type, fuel used and the speed of the vessel. For the Vos Partner, the fuel consumed at a speed of 10 knots is 7 MT/day while fuel consumed at a speed of 13 knots is 15.5 MT/day.(vroonoffshore, 2018).

Emission can also depend other factors such as the condition of loading, the condition of the engine (old engines are more environmentally unfriendly than new engines), and how rough the hull of the vessel is. Back-up engines also emit gases into the atmosphere, accounting for the total gas emitted by a vessel. However, these additional factors are not considered in our computations. (Endresen et al., 2003).

Emission factor for the gas components is shown in the table below;

Table 4 Emission factor for gas components

Gas Component	Carbon monoxide (CO)	Methane (CH_4)	Nitrous oxide (N_2O)	Carbon dioxide (CO_2)	Sulphur dioxide (SO_2)	Particulate matter (PM)[b]
Emission Factor (kg emitted per ton fuel**)**	7.4	0.3	0.08	3170	54	7.6

Source: (Endresen et al., 2003)

Various countries have their differing carbon pricing. Some countries have relatively high carbon pricings, while others have low carbon prices. In Canada for example, the carbon pricing is at $15 - $30 per metric ton of CO_2. In Britain, the current price is at $ 25 per metric ton of CO_2. In the 9 northeastern states of the United States, a metric ton of CO_2 costs $5. (NYtimes, 2019) Most countries do not have carbon pricing. In Africa, South Africa has a carbon pricing of $8.48 per ton of CO_2 (Reuters, 2019) For this computation, the emission cost of $8.4 per ton of CO_2 is used

Results from the above computation is tabulated below;

Table 5 Values for emission and emission cost for CO2

Transportation Mode	**Fuel consumption** (tons /hr)	**Emission** (for CO_2) (tons / hr) (Emission factor for CO_2 * fuel consumed.)	**Emission Cost** ($ / hr) (Emission*$8.4/ton)
Transport by Sea (Vessel Transport)	0.71	2.26	19.16
Transport by Air (Helicopter Transport)	0.697	2.21	18.74

Source: *Author's own computation*

The table 5 above shows values for emission and emission cost for CO_2. By using the emission factor of the different gases components shown in Table 5 above, calculations can likewise be made for the other pollutant gases released as a result of transportation.

Emission cost is based on the carbon pricing of a country, and the fuel consumption of the engine being used. As a result, when these parameters are altered, the emission cost will also change.

5.4 The formulation of the modal split model

One of the models to be used in this thesis is the modal split model. This multi-period mixed integer programming model will aid in determining the mode of offshore transport which will reduce the overall emissions into the environment in offshore transport. The model will take into account the demand and capacity of transport mode. Emissions can be considered by two means; the distance travelled (a shorter distance travelled implies less emissions) and the load utilization.

The model shown below is a Just in Time (JIT) model formulation for helicopters (air transport) and vessels (sea transport) in a planning horizon of a one week. Model also assumes that a supply vessel and helicopter capacity are fully utilized in every travel.

Objective Function:

$$\text{Min} \sum_{i \in A} \sum_{t \in T} A_{i,t}^{R} C_i^{R} + A_{i,t}^{S} C_i^{S}$$

Constraints:

$$\sum_{i \in A} X_{i,t} + \sum_{i \in A} Y_{i,t} = \sum_{i \in A} D_{i,t}^{c} \qquad \forall\, i \in N, t \in T$$

$$\sum_{i \in A} Q_{i,t} = \sum_{i \in A} D_{i,t}^{p} \qquad \forall\, i \in N, t \in T$$

$$\sum_{i \in A} X_{i,t} \leq \sum_{i \in A} A_{i,t}^{H} \ K^{H} \qquad \forall\, i \in N, t \in T$$

$$\sum_{i \in A} Y_{i,t} + \sum_{i \in A} F_{i,t} \leq \sum_{i \in A} A_{i,t}^{v} K^{v} \qquad \forall\, i \in N, t \in T$$

$$X_{i,t}, Y_{i,t} \geq 0 \qquad t \in T$$

$$A_{i,t}^{H}, A_{i,t}^{v} \quad \text{integer}$$

(Norlund, 2015)

Table 6 Description of parameters and variables

Set	N – Set of installations
Parameter	**Description**
C_i^H	Emission cost per helicopter visit to each installation i
C_i^S	Emission cost supply vessel visit to each installation i
$D_{i,t}^c$	Demand of cargo at installation i in time period t
$D_{i,t}^p$	Demand of personnel installation i in time period t
K^H	Vessel cargo capacity
K^v	Helicopter cargo and personnel capacity
Variables	**Description**
$A_{i,t}^H$	decision variable of number of vessels visiting installation i at period time t.
$A_{i,t}^v$	decision variable of number of helicopter visiting installation i at period time t.

$X_{i,t}$	Total quantity of cargo arriving installation i at a time period t by helicopter.
$Y_{i,t}$	Total quantity of cargo arriving installation i at a time period t by vessel.
$Q_{i,t}$	Total number of personnel arriving at installation i at a time period t by helicopter.

Source: *Author's own tabulation*

5.5 Description of Model

The objective function reduces the emission cost of helicopter and vessel travel. The model does this by splitting the cargo and personnel demanded between sea and air transport such that, the transportation mode with the higher emission cost is less frequently used while ensuring that, the demand of cargo is met. This objective function reduces the emission cost from sea transport and air transport thereby minimizing the environmental threat posed by the frequent offshore transportations.

The first constraint ensures that the demands of the installations are fully met by both the vessel and helicopter transport modes in time period *t*.

The second constraint in the formulation ensures that the personnel demand at each of the installations are fully met by the helicopter transport mode in time period *t*.

The third constraint expresses that, the amount of cargo being transported by vessel must not exceed the total vessel capacity.
The fourth constraint expresses that, the amount of cargo being transported by a helicopter and the number of personnel being transported by helicopter must not exceed the total helicopter capacity.

5.6 Analysis of Oil Spill Risk

DNV and Norsk Hydro developed a method for environmental risk analysis known as 'MIRA'(Vinnem, 2014).

Vinnem (2014) describes an approach which is carried out on three levels of details dependent on the input data available. These are;

- Source based analysis: This is the basic form of approach which is dependent on the distance from installation to shore, the duration, as well as the rate of release.
- Exposure based analysis: This approach, like the source-based analysis is based on duration and the quantity of spill. In addition to these, this is also based on oil drift simulation. The effect of spills is analyzed in more details by segmenting the affected area.
- Damage based analysis: This approach is more comprehensive. Analysis is done depending on the duration of travel, the consequence of a spill, oil drift simulation. Effects of spill is mostly associated with vulnerable populations such as beach habitats.

The 'MIRA' approach, gave much consideration to the time it takes for the environment to recover from the damage caused by the spill. Recovery time is only calculated quantitatively in the damage-based analysis. The source based and exposure based are used more fore indirect assessment. It is observed that, most of the oil spill on waters are mostly caused during transportation. Transportation by tankers or by various types of vessels. Oil spills that have had longer impacts on the environment have been caused by vessels.

An overview of recovery times of some oil spills in history is shown below;

Source of Spill	**Calculated total spill (bbls)**	**Observed recovery time(years)**
Exxon Valdez	375–500,000	Approx. 10

Mercantile Marcia	--	4
Oil pipeline, Louisiana	--	1
Oil pipeline, Texas	--	2
Amoco Cadiz	20,000	5 -10
Esso Bernica	--	9
Ekofisk B platform	22,000	1
Tsesis	--	5 – 10
Arrow	7,000	5 – 10
Santa Barbara	>8,500	1
Torrey Canyon	30,000	5 – 10

(Vinnem, 2014)

From the table above, it can be noticed that, there is no direct connection between the total quantity of oil spilled and the time it takes to recover. It can also be noted that, the shortest recovery time for a spill according to this table presented is one year. The level of risk is often measured by the "order of magnitude" of the damage caused. (Vinnem, 2014).

Ghana as a country, has not recorded any major oil spills since it started commercial exploration and production of oil and gas in 2007. In May 2018, an oil tanker vessel which contained 1200 tons of light crude oil split into two on the Tema Port. However, according to reports, authorities worked at best to ensure there is no spillage (News, 2018).However, as mentioned earlier, an oil and gas exploration and production company in Ghana, known as KOSMOS energy spilled 699 barrels of oil based mud into the region of offshore operation in 2009. Tullow Oil, another exploration and production company in Ghana is also reported to have spilled small quantities of oil during its offshore operations in the Jubilee field. However, the quantities spilled are not mentioned (ghanabusinessnews, 2012).

6.0 Chapter Eight – Environmental Risk Influencing Factors

6.1 Definition

A Risk Influencing Factor (RIF) is characterized as,

“an aspect (event/condition) of a system or an activity that affects the risk level of this system/activity” (Øien, Utne, & Herrera, 2011).

Øien (2001) further explains that risk influencing factors are theoretical variables which do not always have a specified value of measure. Risk influencing factors sometimes may be environmental, organizational, regulatory, human or even technical (Rausand, 2013).

Risk influencing factors are usually identified with risk indicators within a risk system. They are connected in a sense that suggest that risk indicators become the measurable representations of the risk influencing factors. As such risk influencing factors are termed theoretical variables whiles the risk indicators are termed operational variables.(Øien, Utne, & Herrera, 2011).

Rausand (2013) defines a risk indicator as *“A parameter that is estimated based on risk analysis models and by using generic and other available data”*. (Øien et al., 2011). The risk influencing factors identified here uses mainly available and generic data.

6.2 Risk Factors

6.2.1 Tanker Accidents and Collision

Accidents involving oil and gas tanker vessels have been reported to be among the most harmful accidents in the marine world. This is due to the nature of the materials being transported, the distances in transit and the high-level effects of the materials in transit on the environment. As identified by Musk (2012), the most frequent sources of tanker accidents are the tankers running aground and into shore reefs, tankers colliding with other vessels or offshore installations, hull failure, and fires or explosion of the cargo. Accidents frequently occur in proximity to the coast and may lead to shores being affected by large amounts of spilled oil.

Historically, a huge percentage of oil and gas transport accidents involving tanker vessels that occur worldwide takes place in European waters, resulting in major environmental damages. However, the majority of recent transport incidents are said to have had only minor or moderate effects on the environment except for the case of Prestige accident in 2002 (Gomez & Green, 2013). The Prestige Oil Spill accident left impacts of the oil spilled on the affected shores, even ten years after the accident. Oil spilled from the sunk tanker for several months after the accident, where three main “black waves” arrived to the coast in the first month, and polluted more than 1300 km of coast. Although by summer 2003 most of the affected shores were officially clean, the impact of the spill on some beaches is still visible ten years after the accident (ecologistasenaccion, 2013). By summer 2003 most of the affected shores were officially clean, the impact of the spill on some beaches is still visible ten years after the accident. However in 2004, 11,000 oil tonnes were recovered from the tanker. (ecologistasenaccion, 2013). The Galician littoral, a coast near the location of the prestige oil spill accident was closed to fishing when the oil arrived to the coast, for periods between two to eleven months due to the damage caused to the environment. (ecologistasenaccion, 2013).

The prevailing weather conditions within the areas of operation or the territories that are regular routes for offshore oil and gas transportation is one of the influencing factors of environmental risk. The environmental risks associated with transporting oil and gas is reported to be significantly higher on the Russian continental shelf compared with other regions, as mentioned in the Bellona Foundation’s Oil and Gas Industry Report. According to the report, the region’s weather, which is one of the worst in the world, is a contributing factor to the high environmental risk associated with oil and gas production and transportation within the region as it leaves tanker vessels more prone to accidents. Large local temperature differences and snowstorms contribute to the difficulty in giving or predicting a reliable weather forecast before or during transportation. In areas where ice covers oceans, temperatures can be as low as minus 50 degrees Celsius while open areas sometimes do have temperatures ranging from 4 to 6 degrees Celsius. These differences in weather conditions do create polar lows and snowfalls that result in almost no predictability of weather when it relates to transport decisions (Bellona Foundation, 2006). In the arctic regions, drifting icebergs are reported to be a major source of challenge for offshore transportation, and installations, both under and over water. The phenomenon of icing of tanker vessels and also offshore installations caused by a combination of waves, wind and extremely low temperatures in the arctic are factors that influence the high environmental risk associated with transportation within these areas (Bellona Foundation, 2006).

Turkina (2005) evaluated the risk of oil spills in relation to transportation of oil and gas, and reported that the probability of tanker vessel accidents or collisions resulting in oil spills can be influenced by:

- *"the relatively small average length of the transportation routes" (less than 1,000 km compared with an average global distance in excess of 4,500 km);*
- *"the large number of freight operations – loading on to a shuttle tanker, transfer from shuttle tankers, via waterborne terminals, to export tankers, unloading at the destination port";*
- *"the great discrepancy in displacements between the tankers used" - from 10,000 to 100,000 tonnes and above; and*
- *"the difficult navigation conditions in places like the Arctic"* Turkina (2005).

An examination of data regarding accidental spillages in Russia over the periods 1974-2004 reveal that the main problems identified with environmental risk in offshore transportation, occur during bunker operations or loading/unloading at terminals. These problems are sometimes due to violation of safety standards and spillages during bunker operations and loading/unloading (Bellona Foundation, 2006).

The International Marine Organization (IMO) also identifies that large-scale oil spills that happen as a result of accidents during transportation pose high environmental risks. Large-scale oil spills can be triggered by elements such as:

- technical failure,
- grounding and collisions,
- fires and explosions

It is, however, noted that the most hazardous situations from the viewpoint of oil spills resulting from tanker accidents or collisions are fires and explosions, although the frequency with which they occur does not exceed 1% (Bellona Foundation, 2006).With reference to above discussion, the following points are identified in this study as the risk influencing factors in relation to environmental risks associated with offshore transportation involving vessel tankers:

- technical failure,
- grounding and collisions,
- fires and explosions,
- prevailing or territorial weather conditions of the transportation routes, i.e. the specific climatic conditions of the offshore environment,
- average length of transportation routes used in moving oil and gas, i.e. the distance between the source and destination,
- number of freight operations –loading on to a shuttle tanker, transfer from shuttle tankers, via waterborne terminals, to export tankers, unloading at the destination port
- discrepancies in displacements between the tankers used.
- navigation conditions within the offshore route used.

6.2.2 Oil Spill factors

The impact of oil spills on the environment largely depends on many factors, including (1) the size and nature of the spill, (2) the season of year, (3) the weather conditions of the territory where the oil spill happened whiles in transit, (4) the closeness to physical environment and biological communities, (5) the effectiveness of the response, and (6) the density of the oil product being transported. Factors which cause oil spill include human error or equipment failure, during operations of diesel transfer from supply vessels, and overfilling of tanks (Gomez & Green, 2013). Light oil is easily dispersible and has a less harmful effect than dense products. Ritchie (1993) observed that the Braer oil spillage which happened during winter of 1993 on the Shetland shores caused by grounding was partly due to the lightness of the oil involved. The persistence of extreme weather conditions, a source of huge waves and water currents that accelerated the breaking up and dispersion of the oil particles were also identified as some of the factors contributing to a wider spread of the oil spill.

As remarked by Den Hartog and Jacobs (1980), spills of hydrocarbons leave traces of dissolved and dispersed residues in the water where the spill happened. This poses environmental danger to fish populations. The level of environmental risk is higher with denser residues, on sandy beaches as well as on enclosed sea waters. With denser residues deposits are made on the seabed or shores and sometimes smothering habitats. This affects the spawning, nursing and feeding of some aquatic species. (Den Hartog & Jacobs, 1980) The impact a spill makes on sandy beaches that easily get soaked with oil pollutants is presumably more durable and damaging than the same spill reaching hard rock cliffs, that is if the spilled oil gets dispersed in contact with rocks. Enclosed seas like the Mediterranean Sea, the Black Sea, or the Baltic Sea suffer more harmful impacts than an open ocean, as the water recycling rate is far lower (Den Hartog & Jacobs, 1980).

Payne, Driskell, Short, and Larsen (2008) also described a stable and extremely low contaminated environment in Prince William Sound and the Northern Gulf of Alaska, which were strongly affected by the Exxon Valdez spillage twenty years before. The consequences of offshore accidents involving spillages are especially severe when they happen near the shore, in shallow waters or in areas with slow water circulation. (Gomez & Green, 2013).

The table 7 below shows a summary of the level of risk of oil spill on the environment.

Table 7 Factors that determine the level of environmental risks posed by oil spills

Factors	**Lower Risk**	**Higher Risk**
Size of spill	Small	Large
Nature of spill	Light oil	Dense crude
Season of year	Non critical	Reproductive period Leisure time
Weather conditions	Storminess	Calm atmosphere

Physical Environment	Open ocean Rocky cliff	Enclosed water Sand beach Sensitive ecosystem (coral, mangrove)
Response	Fast and adequate	Inadequate

Source*:* (Gomez & Green, 2013)

6.2.3 Pipeline Accidents

Underwater pipeline systems used in transporting oil and gas are often considered major environmental risk factors identifiable within the offshore oil and gas operations (Bellona Foundation, 2006). These pipelines are well stretched over thousands of kilometres under water. Pipeline accidents are usually caused by ruptures in the pipeline. Damages that take place in the marine ecosystem during pipeline ruptures are have enormous consequences to animal life in the marine world. Although pipeline ruptures are extremely hazardous, the severity of the damage caused largely depends on the size of the rupture, hence the size of the leaks due to the rupture. With overland pipeline systems, ruptures of the pipelines can also result in accidental oil and gas discharges into nearby marine or coastal ecosystems. The impact of these leaks or discharges into close by rivers have the potential to contaminate or later impact other estuarine sea or river areas (Bellona Foundation, 2006)

A second factor considerable in relation to environmental risks associated with pipeline systems is identified during the construction of underwater pipelines. Embankments as a result of excavations during pipeline constructions are also major sources of damage to the marine ecosystem. These damages result from operations such as creating access channels, sinking trenches, backfilling and deepening pipelines, and dumping of soils. These things increase the contents of suspension within the water, intensifies the grounding of deposits formed by fine fractions underwater. They basically alter the hydro-geochemical features and composition of the marine ecosystem as a result of the pollutants being released from the muds. (Bellona Foundation, 2006)

Changing pipeline temperatures also contribute to impact of pipeline transportation on the environment, especially the marine environment. During transportation of oil and gas through pipelines over long distances, pipelines temperatures alternate which also induces the near-bottom water temperature; i.e. the region around the pipeline. The waters in the near-bottom area either heats or cools down, depending on the pipeline's temperature as oil and gas moves through. According Bellona Foundation (2006), it is not likely that these temperature alterations will be significant enough to contribute to temperature changes in the water. Nevertheless, it cannot be entirely ruled out that there is the possibility of these changes inspiring impacts which can communicate warning signals to fishes that dwell underwater, especially at the bottom of waters, to migrate.

Statistics from the "Transneft" Joint Stock Company, show 31% of pipeline accidents in Russia for example happen due to structural defects, 22% result from pipeline defects as pipelines come from factories, and 22% of accidents because of corrosion. Another factor is the intensive and overloading of pipelines, which result in pipelines easily wearing out and without good and timely maintenance poses great risk to the environment. Additionally, improper construction technologies also lead to low construction quality, coupled with defects in the metals used for pipeline walls, reduces safety when transporting oil using pipelines (transneft, 2015).

Accidents from pipeline are mainly caused by:

- External factors – i.e. earthworks close to the pipelines, rock slides, which contribute to about 45.3% of accidents,
- Defects in pipeline construction and assembly work, causing about 20.8% of all accidents,
- Technological and technical reasons – which comprise failures of cut-offs, flawed valves, and faulty products from the factory. This has resulted in about 5.6% of all pipeline accidents,
- Bad management caused 11.3% of all accidents,
- Corrosion caused 13.2% of all accidents. Bellona Foundation (2006)

Other causes or factors considered by Gazprom on the gas transport system include (1) imperfections in the pipes and other equipment, and (2) disregard for the guidelines concerning technical operation of gas pipelines caused by inexact and unrealistic data on technological parameters relevant in operating oil and gas pipelines (Gazprom, 2005).

7.0 Chapter Nine – Analysis of Offshore Transportation Modes in Ghana

This chapter presents a discussion on findings regarding the various transportation methods used my most companies operating in Ghana's offshore fields. It also presents a brief analysis of the methods identified.

7.1 Offshore Transportation Modes Used in Ghana

Crude oil from Ghana's Jubilee Fields is generally moved by ships to refineries outside the country (mainly in Europe) since the nation's Oil Refinery – Tema Oil Refinery (TOR) – was not originally calibrated to refine oils with high Sulphur content as being produced from the jubilee field. As such, pipelines are not the major transport system that links refining systems to offshore production sites. Aside the vessel tankers used to move oil from offshore to onshore in Ghana, there exist also pipelines which are mostly used for gas transportation. Road tankers are also commonly used in transporting LNG and other processed petroleum products in Ghana but not much of the railway system is used(Sakyi et al., 2012)

According to secondary data collected (World Bank Group, 2015) the distance from the supply base to Jubilee field offshore installation is 55km to 60km.Also, a 63km long pipeline is in place to connect FPSO to onshore and a 1.5km long pipeline from shore to the onshore receiving facility (ORF). According to TullowOil (2019), the TEN field lied 20km west of the Jubilee field while the TEN field lies 45km off the mainland. Sankofa Gye Nyame field lies 55km from Ghana's mainland.

As such, transport in Ghana's offshore oil and gas is generally with systems that use air (aircrafts), land (pipelines and road trucks) and sea (vessel tankers and supply vessels).

7.1.1 Air Transport - Aircrafts

PHI Century is a joint endeavor between PHI Inc. a worldwide innovator in helicopter transportation and Century Aviation Company Limited, overseen by leaders in aviation in Ghana. PHI Century was established to help the extending necessity for transportation to offshore production platforms in West Africa. PHI Century is the body in charge of providing helicopter transportation services for offshore productions in Ghana presently. . (PHI Century, 2013)

Three main models of helicopter are used in transportation to offshore petroleum installations in Ghana. These being the Sikorsky S-76s C++ and A++ model as well as Sirkorsky S-92.

The Sikorsky S-76s C++ and A++ models function by double turboshaft engines. The S-76 can fly at a most extreme speed of 287 kilometers per hour. With the knowledge that, the distance between mainland and offshore platform is 60 km, this implies that, the time taken to travel from the mainland to the offshore platform is approximately 12.5 mins that is 0.2 hours. The type of fuel used by the S-76s C++ is Jet A1.(wikipedia, 2019) The maximum take-off weight of this model of helicopter is 5306 kg. When empty, the helicopter weighs 3177 kg. This implies that, the carrying capacity of the helicopter is 2129kg. This model is built to carry both cargo (equipment) and personnel.(aerospace-technology, 2019).

The Sirkorsky's civil product line has Sirkorsky S92 as one of the cutting-edge aircrafts. The passenger capacity of Sirkorsky S92 is 19 passengers. It operates at a cruise airspeed of 143 knots. Fuel consumption is noted at 1394 Ib/hr. This is equivalent to 0.697 tons /hr. Among other things, the Sirkorsky S92 is equipped with a "Traffic Collision Avoidance System". As the name implies, the traffic collision avoidance system reduces the risk of collision which thus lessens the risk of accidents. Accidents that happen during transportation are often environmentally damaging. (erahelicopters, 2019).

7.1.2 Transport by Sea – Supply Vessels and Oil Tankers

As mentioned earlier in Chapter Three (3.1) supply vessels are most chartered for a period of time. The specifications of PSVs chartered greatly depends the operations happening offshore and the demand for frequent transportation. As a result, different models of Platform Supply Vessels are contracted to be used on Ghana's Offshore waters in different time periods. Examples of vessels used on Ghana's offshore waters are Posh Fulmar, Pacific Harrier, Pacific leader, Vos Partner, Posh Sincero, Lewek Scarlet, and Siem Louisa. In most cases, the latest manufactured vessels are more environmentally friendly than vessels that are being driven by old engines. Most of the vessels used on Ghana's offshore waters were manufactured between 2009 and 2016. Posh Sincero for example is vessel which was manufactured in 2010. Lewek Scarlet was manufactured in 2009. Pacific leader was manufactured in 2014. Vos Partner is the most recently manufactured vessel. It was manufactured in 2016.The common type of fuel used in the vessels mentioned is diesel. Contamination of water, air, and soil, climate change, poor visibility, advancement of cancer, cardiovascular as well as other respiratory diseases are all effects of diesel emissions as discussed earlier.(Lloyd & Cackette, 2001). The Vos Partner vessel is one of the vessel types mentioned. It operates at a maximum speed of 13 knots and a normal speed of 10 knots. When it is operating at its maximum speed of 13 knots, the fuel consumption is 15.5MT per day. When it is operating at its normal speed of 10 knots, the fuel consumption is 7 MT per day. It has a deadweight tonnage of 4200 and a deck area of 850m^2. (vroonoffshore, 2018).

Logistics operating companies provide oil tankers which are used to transport oil produced to other countries most in different continents. International sea routes are used when transporting.

7.1.3 Pipeline Systems in Ghana

The pipeline framework utilized for oil and gas transportation in Ghana is certainly not an enormous one. Despite its limitation in coverage and mileage, pipeline framework has assumed a fundamental job in the advancement of the oil and gas industry. Generally, pipelines are mainly used in gas transportation in Ghana. One company responsible for operating, managing and maintaining pipelines in Ghana is the Bulk Oil Storage and transportation Company Limited (BOST). BOST manages a framework of storage capacities and pipelines running from Accra to Akosombo then between Buipe as well as Bolgatanga. The overall distances covered by these pipelines is 370 kilometers. The table below shows the depots managed by BOST and the storage capacity for petroleum products. (BOST, 2018).

Table 8 Depots managed by BOST and the storage capacities

Distribution Depots	Gasoline	Gasoil	Kerosene	Total Storage Capacity
Accra plains	101250	10925	No Storage	210500
Kumasi	34000	43000	10000	87000
Buipe	13500	37600	No Storage	51100
Bolgatanga	12500	35000	No Storage	47500
Akosombo	5000	7000	No Storage	12000
Mami-water	5000	12500	No Storage	17500
Total	171250	244350	10000	**425600**

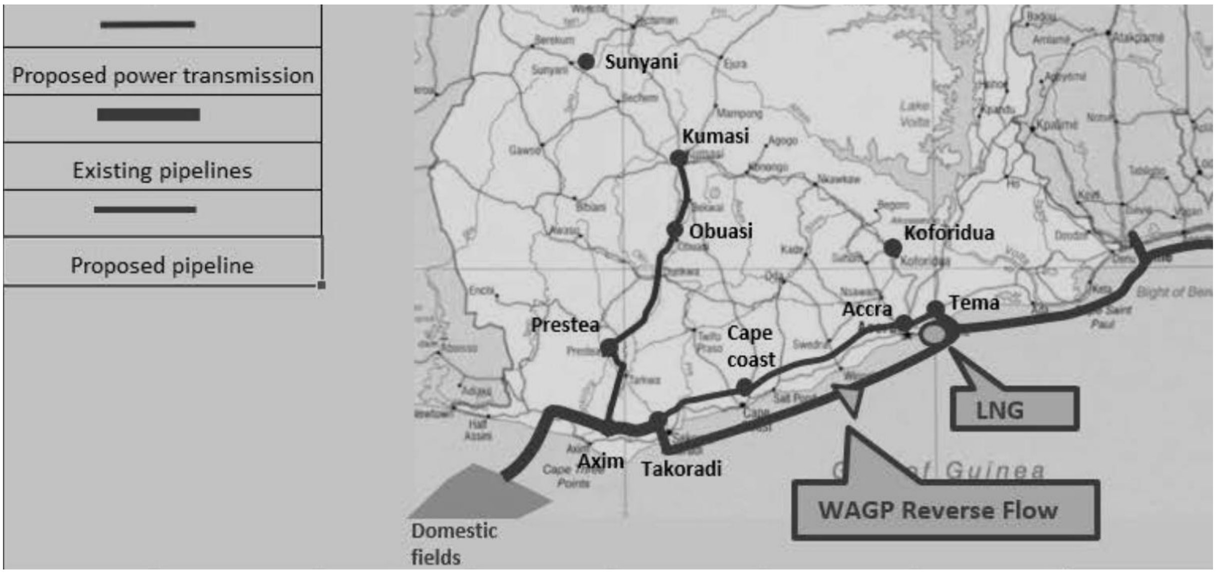
Source: (BOST, 2018)

7.1.4 Gas Pipelines in Ghana

Ghana boasts of a meaningful offshore gas reserve which are found in the nation's western zone i.e. the Jubilee field with estimated gas reserve of about 335 billion cubic feet (Bcf), the TEN1 fields with about 353 Bcf gas reserve, and the Sankofa field with non-related gas stores of 1,168 Bcf. Gas flows from the Jubilee field where gas is produced to power generators for use of electricity production in the country by the infrastructure that has been built. The Western Corridor Gas Infrastructure Development project was initiated to integrate offshore and onshore processes. (Memorandum 2015).

In 2015, a 59 km pipeline was constructed to move gas from Ghana's Jubilee Fields to a Gas Processing Plant in a place called Atuabo. Another 111km pipeline, of 508mm diameter was also constructed onshore to move gas from the Gas Processing Plants to the Power Generators. This pipeline transmission framework comprises of a starting or initiating station, a Gas Distribution Station, a Two-block Valve station and a Terminating Station. The outside diameter of the 111km pipeline is 20 inches. This pipeline has a minimum wall thickness of 10.31 mm and a normal depth of cover of 1.2m. (Memorandum 2015)

Figure 5 Current and Proposed Pipeline Routes in Ghana



Source: (PETROLEUM, 2016)

About 15 km of the existing pipelines in Ghana were constructed in level territory and generally lay parallel to the coast of the Gulf of Guinea, with some swampy and muddy territories. The rest 96km of pipeline runs in uneven hilly territory with substantial vegetation (palm, elastic and other crops) (Memorandum 2015).

The ECOWAS Trans-Country Pipeline System

The Economic Community of West African States (ECOWAS) in 1982 proposed a plan to build natural gas pipeline networks all throughout its member states. This project, named the West Africa Gas Pipeline (WAGP) was expected to attain the objective of easing transportation of natural gas produced in Nigeria in commercial quantities to Benin, Ghana and Togo. The WAGP crosses 520 miles (1,033 kilometers) both onshore and offshore from Nigeria`s Niger Delta district to the coastal belt of the west of Ghana.

The Gas Transmission framework prolonging from Nigeria to Benin, Togo and Ghana has an initial System Capacity of 170 Mmcf/d (without addition of compression) and a final system capacity of 474 Mmcf/d (with the addition of compression). The maximum operating pressure of pipeline is 150 bar. (BARANDAO, 2012).

7.2 Demand Frequencies and factors of Use of Transport Modes

Offshore exploration and production platforms need to receive regular supplies in order to ensure progressive or continuous production. On an offshore platform, several employees/workers are needed to ensure smooth operation. As a result, several supplies are needed; ranging from supplies for basic living (such as food, water, clothes), equipment needed to perform drilling operations (such as drilling pipes, casing etc.). The amount, types and sizes of equipment needed vary greatly.

Offshore installations do not only receive supplies from onshore but, they also return goods from the platforms. Cargoes being returned often contains waste, empty load carriers, back-up equipment, rented equipment etc. Frequent visits to offshore installation are expedient because the storage capacity on these platforms is mostly limited. Frequent visits help to avoid shortage of supplies as well as reduce the amount of return cargo on the platform.

Also, frequent transportation is necessary because, most of the highly specialized equipment such are used in drilling and well operations are rented at very high rates on a daily basis. Therefore, in order to reduce overall production cost, it is important to return the equipment quickly. The main modes of transport to offshore platforms are transportation via sea and via air. (Aas et al., 2009).

Data gathered reveal that, at any point, a great number of personnel with different skills are required for successful production of oil and gas. There is approximately one hundred and sixty-five (165) personnel that work on an offshore installation in Ghana. Rig workers spend approximately 14 to 28 days offshore or on the rig. Geologists, Welders, Radio Operators, Cement Hand, Utility personnel (housekeeping), Chef, Baker, Floorman, Storekeeper, Electrician, Casting Hand, Safety Officer Trainee, engineers (subsea engineers), offshore installation manager, medics among others are examples of skilled personnel that are transported to offshore rigs regularly.

Averagely, a supply vessel visits an offshore installation two to three times in a week, while the helicopter visits the installation as often as two to three times in a week summing up to approximately ten times in a week.

In conclusion, there are two aspect or parts of transportation when offshore installation platforms are considered. First is the transportation of supplies / cargo and personnel to the offshore platforms. The other part is the transportation of oil and gas produced from the offshore platforms to their destination markets.

Accidents which threaten our environment are less frequent when pipelines are used in transportation. Especially when these pipelines are managed and maintained well. Hence, it will be more environmentally friendly for Ghana to construct pipelines which transport oil to nearing countries in which they are sold. This way, the risk of accidents such as collision of tankers and oil spills will be greatly minimized.

Also, transportation to offshore installations must be less frequent, and vessels and aircraft models used for transportation must be up to date with systems that protect the environment. For example, Ghana can explore the option of hiring vessels that are only powered by LNG. LNG powered vessels emit less dangerous gases into the environment.

8.0 Chapter Ten – Discussion of Quantitative Results

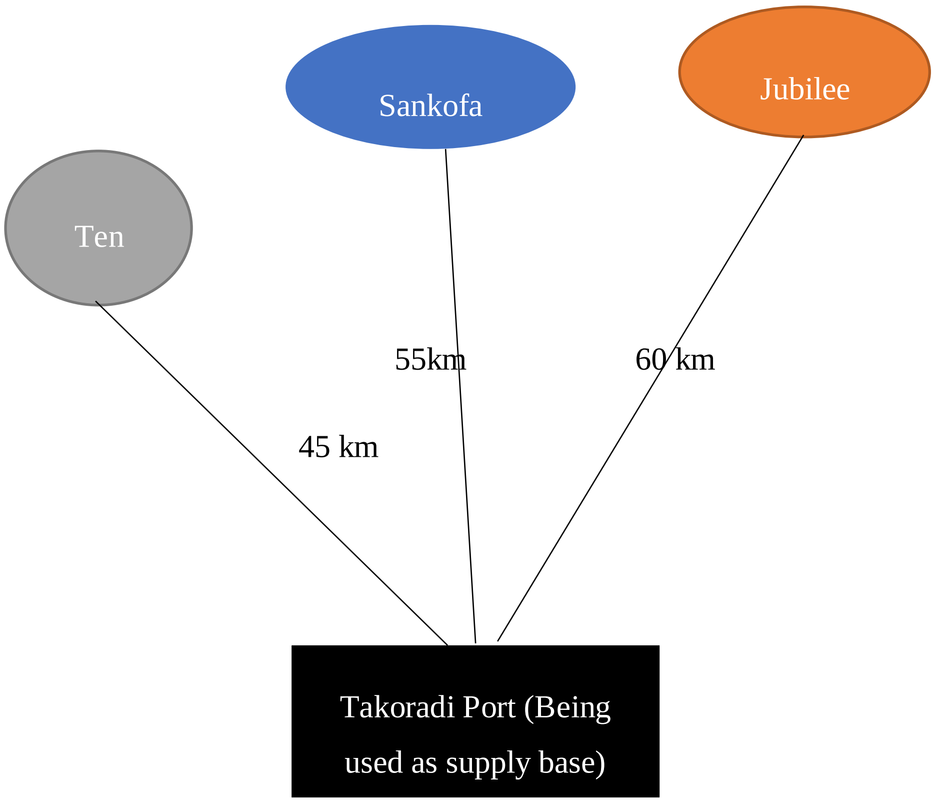
This chapter presents the results and a discussion of computations using the mathematical model.

8.1 Results

Shorter transportation distances and modal shift are ways to reduce emissions which occur as a result of frequent transportation in offshore transportation. Reducing emissions in turn reduce the risks that frequent transportation pose to the environment. In Ghana currently, there are three different oil fields or three different installations.

The figure below shows the distances between the supply base and the three offshore installations.

Figure 6 distances between the supply base and the three offshore installations



The formula (n-1)! is used to calculate the number of possible routes, given the number of nodes (n). There are four nodes (n = 4) being used in this case.

Hence, number of possible routes = (4 - 1)! = 3! = 3 * 2 = 6

Hence there are 6 possible routes to be taken either by the vessel or the helicopter. The mathematical formulation presented above was coded in AMPL. (AMPL is an optimization tool). The results provided below is the optimal route to be taken to attain the minimized total transportation distance to each installation.

Results 1

The objective is to reduce the total travel distance hence the total travel cost

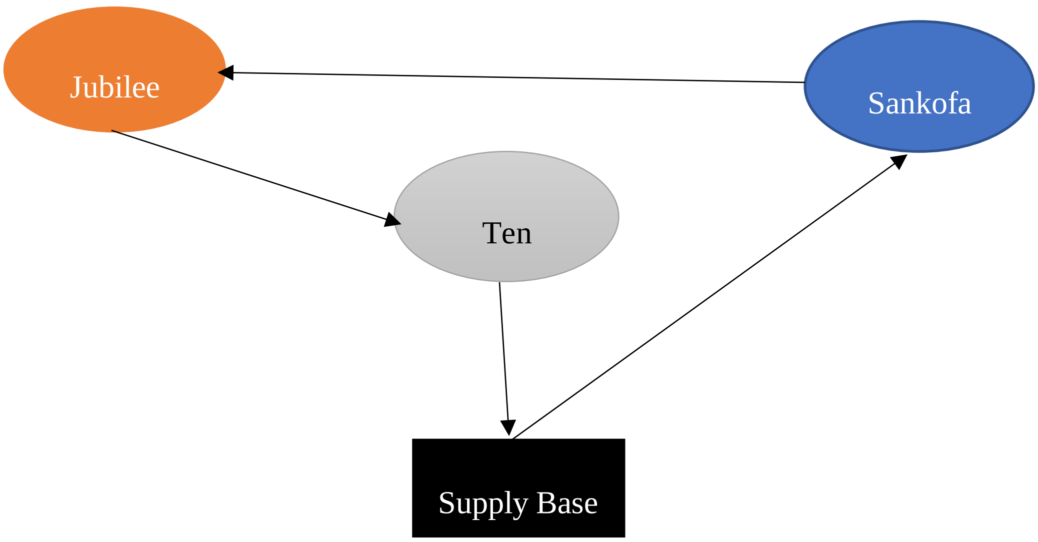
For shortest travel distance, to all installations in one route,

Optimal total travel distance = 155 km

Optimal route = 0-3-1-2-0

This figure below illustrates the optimal travel route for visiting all three installations one route.

Figure 7 optimal travel route for visiting all three installations one route



For shortest travel distance, to all installations in two routes,

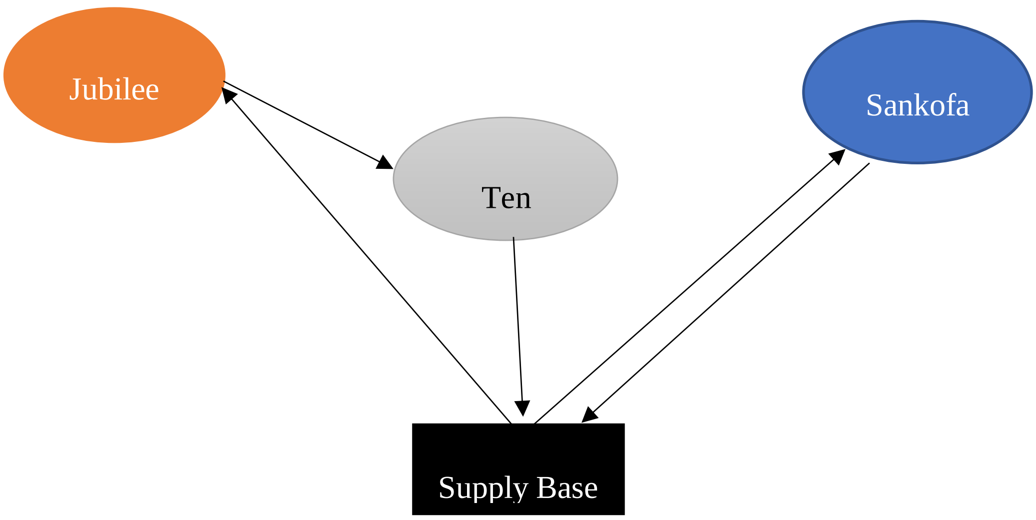
Total travel distance = 235 km

Route 1 = 0-1-2-0

Route 2 = 0-3-0

This figure below illustrates the optimal travel route for visiting all three installations two routes.

Figure 8 Optimal travel route for visiting all three installations two routes



Results 2

The objective of this model is to split cargo being transported between the helicopter and vessel such so as to minimize emissions.

Total minimal emission cost = $ 23,831

The table below shows the results of the amount of cargo to be transported by vessel and the amount of cargo to be transported by helicopter in each time period to each installation.

Table 9 Amount of cargo to be transported by vessel and aircraft

Installation	**Period (week)**	**Cargo transported by Vessel (ton)**	**Cargo transported by Helicopter (ton)**	**Personnel transported by Helicopter (ton)**
1	1	2544.6	10.4	3.45
	2	3289.6	9.9	3.95
	3	2911.84	8.16	5.69
	4	3276.12	8.88	4.97
2	1	3642.32	147.68	4.67
	2	2588.63	9.37	4.48
	3	1379.14	9.86	3.99
	4	3649.12	7.88	5.97
3	1	3982.14	7.86	5.99
	2	2579.82	8.18	5.67

	3	2891.13	8.87	4.98
	4	3190.7	9.3	4.55

The table below shows the sum of cargo transported by vessel and helicopter in every time period. It also shows the number helicopter and vessels needed for a time period.

Table 10 Sum of cargo transported by vessel and helicopter

Period (week)	**Total Cargo transported by Vessel (ton)**	**Total Cargo and Personnel transported by Helicopter (ton)**	**Number of Vessel Used in a period**	**Number of Helicopter Used in a period**
1	10169.06	180.3	3	13
2	8458.05	41.55	3	3
3	7182.11	41.55	2	3
4	10115.94	41.55	3	3

8.3 Discussion

One of the aims of the study is to reduce the total emissions that results from the frequent transportation to offshore installations. The first step to reducing total emission is to reduce the total travelling distance. For a vessel or helicopter to visits three offshore installations in one route, there are six (6) possible routes it can take. To find out which of the six (6) routes will give the shortest travel distance an optimization tool was used. The results obtained shows that, the shortest distance travelled either by vessel or helicopter to visit all installations is 155km. *Figure 11* above shows the optimal route to be taken to achieve this result.

However, the three installations are not being visited in one route. They are being visited on two separate routes because the three installations are being operated by two different companies. The results obtained shows that, to visit all three installations in two different routes, the shortest distance will be 235 km. *Figure 12* above shows the optimal route to be taken to achieve this result. The difference in travel distance between travelling one route and two routes is 80km.Assuming that, every 1 km travelled is equivalent to 1 unit of emission.80 extra units of emissions are released every time the two routes are used. Reduced transportation distance also means less risks of accidents such as collisions, helicopter crash among others. These accidents pose a lot of threat to the environment. Assuming a vessel or helicopter has the capacity to service three installations simultaneously, it has not only economic benefits but also safer environmental benefits to deliver demand to all three installations simultaneously.

The second step to reducing total emission is to reduce the frequency of visits. A mathematical model is formulated and run with AMPL for this purpose. The model achieves this by splitting the cargo demand on every installation and for every time period such that the transportation mode that has the higher emission cost is not used as often as the transportation mode that has the least emission cost. It is assumed here that, the vessel is operating at a speed of 13 knots which is equivalent to 24 km/h. The results as shown in table 8 above shows the amount of cargo that needs to be transported by each helicopter and a vessel so as to attain the minimal emission cost. It also shows the frequency of visits by both helicopter and vessel so as to meet the cargo demand on the offshore installations.

When the mode of transportation is split as suggested by the model, the number of times a vessel visits an offshore installation remains approximately the same as with the data collected.

Averagely, according to the data collected, in every time period, a vessel visits each installation at two (2) to three (3) times. However, the solution from model suggests that number of helicopter visits can be reduced 3 times in a week and still have all of the cargo demands on all installations met. This result proves that, a helicopter can meet the demands of all offshore installations by travelling less time than collected in data. According to the data collected, a helicopter travels approximately ten (10) times to an offshore installation in every time period. Less frequent visits imply less helicopter emissions. Less frequent visits also imply that transportation cost is less. Splitting the cargo demand as suggested by this model gives a win-win scenario. Though the objective of this model is to reduce emissions, it is noted that, when emissions are reduced, transportation cost is reduced as well since frequency of visits is minimized.

The supply vessel can operate at a speed of 13 knots or at 10 knots. The mathematical model was run a second time, this time, assuming the vessel was operating at a speed of 10 knots. The emissions cost greatly reduced to $ 9970. The emission cost when the supply vessel is operating at 13 knots is $23,831. The difference in the costs is $13861. Economically and environmentally, it is beneficial for the supply vessel to operate at a speed of 10 knots.

In the course of this study, it was noticed that, there is a contrast between minimizing emission cost and simultaneously minimizing transportation cost. Oil and gas companies' ultimate aim to make profit. Therefore, if maximizing emissions will lead to minimal transportation cost, most oil and gas will rather take that option. This is the reason environmental regulations are necessary. As outlined in chapter 5 of this study, most environmental regulations in Ghana are strict in protecting Ghana's offshore environment against oil spill events and any other damages that other offshore activities cause to the environment. There are regulations regarding flaring of gases on production sites and emissions of gases which result from exploration and production activities.

The Marine Pollution Bill and the Oil in Navigable Waters Act – 1964 (Act 235) have laws which cover environmental damage arising from transportation especially transportation by ship and pipelines. However, according to Owusu (2014) local regulators do not demonstrate same level of strictness in enforcing the regulations when it comes to the foreign oil and gas companies that operate in Ghana's waters. Regulations enforcement systems at local levels needs to be strengthened across aboard within the sector, to ensure standards and all necessary protocols enshrined within the nation's Environmental Impact Assessment procedures.

Ensuring that all oil and gas companies meet standards set by the regulators of the country will challenge foreign companies to reduce their frequency of visits and travel distance hence causing them to reduce emission cost even if this will mean a slightly higher transportation cost. It will also challenge oil and gas companies to charter vessels and helicopters that use less environmentally friendly fuels. For example, vessels which use LNG as a propulsion system emits less harmful gases that vessels that use diesel.

Other environmental risk element posed by offshore transport systems is oil spills from vessels, tankers, barges and leaks from pipelines. Fortunately, Ghana has not recorded any major oil spill hence there has not been a major environmental effect resulting from oil spill. However, factors that influence oil spills as mentioned in Chapter six (6) need to avoided to reduce the risk of oil spills.

9.0 Chapter Eleven – Conclusion & Further Study

9.1 Conclusion

Increasing damage to the environment has not only been of concern to individual countries but a global issue. For this reason, this study was conducted with the aim to minimize the risks posed to the environment as a result of the frequent offshore transportations. Three final conclusions were made after this study was conducted. Firstly, to reduce the emissions that arise from transportation to offshore installations in Ghana, the three offshore installations in Ghana's offshore waters must be visited in one route. When they are visited in two different routes, a longer distance is covered which implies that, more emissions are released into the environment. Secondly, by splitting cargo demand appropriately between vessels and helicopters, the number of times a helicopter needs to visit an installation is greatly reduced. Reducing the frequency of visits does not only reduce emissions into the atmosphere, but also, it reduces the risk of accidents which often have very great environmental consequences. Finally, local regulators must enforce the environmental regulations and policies.

9.2 Further Study

The modal split concept used in this study does not include time sensitive demands. As mentioned earlier, a lot of investment is made into oil and gas exploration and production. Rigs and equipment used in production are hired at very high costs hence when production has to be paused because of the unavailability of equipment or personnel, it constitutes great loss. For this reason, some equipment or personnel that must be transported offshore need to arrive immediately so the production process is not halted. In such cases, they are transported as fast as possible. More research can be done into how to reduce air emissions even when considering time sensitive cargo. Considerations must be given to load utilization of transportation mode used when considering time sensitive cargoes.

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11.0 Appendix

Questionnaire

The questionnaire was used in gathering data needful for conducting this research

This form is aimed at gathering data for a research on "Environmental Risk Minimization in Offshore Transport Systems In Ghana" at the Molde University College-Specialized University in Logistics, Norway.

Any response provided is confidential, and will be used for academic purposes only.

Kindly provide answers to the questions you have answers to, and leave blank questions you do not have answers to.

Thank you in advance.

1. What is the name of the company you work for?
2. What is your role or position in this company?
3. The helicopter to offshore rigs transport other goods and equipment apart from offshore rig workers.

- True
- False

4. How often does a helicopter visit an offshore rig in a day?
5. What is the full capacity of helicopter used for transportation?
6. How many people are transported per trip by the helicopter to the offshore rig?
7. If you have had any visibility of platform support vessels, what are some of the models of vessels used in Ghana? (The names of the vessel is written on the vessel)
8. How often does a platform supply vessel visit an offshore rig in a week?
9. There are three fields in Ghana offshore waters, being the jubilee field. TEN field, and the Sankofa fields. Which of these options below best describe the transportation of Platform Supply Vessels (PSVs)?

- One platform supply vessel visits all these three field in one trip.
- One platform supply vessel visits only one field in one trip.

- One platform supply vessel visits at least two fields in one trip.
- Other

10. Platform Supply Vessels transport skilled rig workers.

- True
- False

11. Are platform supply vessels loaded to their full capacity before they leave the port to the offshore rigs?

- Yes
- No

  If no, by which percentage in your opinion is capacity of vessel fully utilized?

- Sometimes

12. What is the approximate cargo demand at offshore rigs in a week? (The number of items needed to be sent)
13. What is the approximate personnel demand at offshore rigs in a week? (The total number of skilled workers needed to be sent)

MOD File 1

The codes (mod file) for the finding the shortest route when one travel route is taken is given below

```
param n;

param K;

set ARCS := {i in 0..n, j in 0..n: i<>j};

param m;

set S {k in 1..K}; # nodes in subcycles

set SA {k in 1..K}:={i in S[k], j in S[k]: i<>j};   # arcs in
the subcycles

param travel_distance{ARCS}>=0;

var travel_route {ARCS} binary;

minimize Total_Distance:

sum {(i,j) in ARCS}travel_route[i,j]*travel_distance[i,j];
```

```
subject to Out_Of {i in 0..n}:

sum {(i,j) in ARCS} travel_route[i,j] = 1;

subject to In_To {i in 0..n}:

sum {(j,i) in ARCS} travel_route[j,i] = 1;

subject to Route_Continuity {i in 0..n}:

sum {(i,j) in ARCS} travel_route [i,j] = sum {(j,i) in ARCS}
travel_route[j,i];

subject to SEC {k in 1..K}:

sum {(i,j) in SA[k]} travel_route[i,j] <= card (S[k]) - 1;
```

MOD File 2

The codes (mod file) for the finding the shortest route when two routes are taken is given below

```
param n;

param K;

set ARCS := {i in 0..n, j in 0..n: i<>j};

param m;

set S {k in 1..K}; # nodes in subcycles

set SA {k in 1..K}:={i in S[k], j in S[k]: i<>j};   # arcs in
the subcycles

param travel_distance{ARCS}>=0;

var travel_route {ARCS} binary;

minimize Total_Distance:

sum {(i,j) in ARCS}travel_route[i,j]*travel_distance[i,j];

subject to Route_Continuity {i in 0..n}:

sum {(i,j) in ARCS} travel_route [i,j] = sum {(j,i) in ARCS}
travel_route[j,i];
```

```
subject to Start_Depot:

sum {(0,j) in ARCS} travel_route[0,j] = m;

subject to Depot{i in 1..n}:

sum {(i,j) in ARCS} travel_route[i,j] = 1;
```

APPENDIX C

The codes (mod file) for the modal split model is shown below.

```
param n >= 0;                       # number of nodes

param K;

set A := {i in 0..n, j in 0..n: i<>j};        # set of arcs

set S {k in 1..K}; # nodes in subcycles

set SA {k in 1..K}:={i in S[k], j in S[k]: i<>j};   # arcs in
the subcycles

param T>=0;

param Cargo_Demand{0..n,1..T}>=0;             #cargo demand at
installation t

param Personnel_Demand{0..n,1..T}>=0;         #personnel
demand at installation t

param Helip_Capacity>0;

param Vessel_Capacity>0;

param m>=0;

param Heli_emiss_cost{0..n}>=0;

param Vess_emiss_cost{0..n}>=0;

param travel_cost{A}>=0;

#variables

var vess_cargo{0..n,t in 1..T}>=0;
```

```
var Helip_cargo{0..n,t in 1..T}>=0;

var travel_route{A,t in 1..T} binary;

var Helip_personn{0..n,t in 1..T}>=0;

var Helip_Numbr {0..n,t in 1..T} integer >=0 ;

var Vessel_Numbr{0..n,t in 1..T} integer >=0;

minimize Total_Cost:

sum {i in 0..n,j in 0..n,t in 1..T}Helip_Numbr[i,t]*Heli_emiss_cost[i] + sum {i in 0..n,j in 0..n,t in 1..T}Vessel_Numbr[i,t]*Vess_emiss_cost[i];

subject to Amt_of_Cargo_demanded{i in 0..n,t in 1..T}:

sum {j in 0..n}vess_cargo[i,t]+ sum {j in 0..n}Helip_cargo[i,t] = sum {j in 0..n}Cargo_Demand[i,t];

subject to Amt_of_Personnel_demanded{i in 0..n,t in 1..T}:

sum {j in 0..n}Helip_personn[i,t] =sum {j in 0..n} Personnel_Demand[i,t];

subject to Capacity_of_Vessel {i in 0..n,t in 1..T}:

sum {j in 0..n}vess_cargo[i,t] <=sum {j in 0..n}Vessel_Numbr[i,t]*Vessel_Capacity;

subject to Helicop_Capacity{i in 0..n,t in 1..T}:

(sum {j in 0..n}Helip_cargo[i,t] + sum {j in 0..n}Helip_personn[i,t]) <=sum {j in 0..n}Helip_Numbr[i,t]*Helip_Capacity;
```