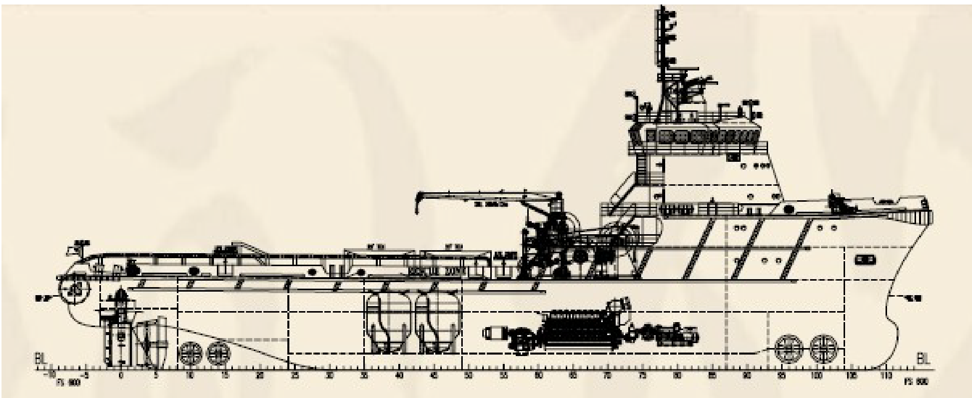
University of Stavanger

Faculty of Science and Technology

MASTER'S THESIS

Study Program/Specialization: Offshore Technology/Asset Management	Autumn Semester, 2012 Restricted access
Author: Huan Liu	------------------------ (Signature Of Author)
Faculty Supervisor: Professor: Ove Tobias Gudmestad	
Title Of Thesis: **Design trends for Offshore Support Vessels**	
Credits (ECIS):30 ETCS	
Key Words: Trend OSV Deepwater Risk	Pages: +enclosure:

Design trends for Offshore Support Vessels (OSV)



A thesis submitted to

University of Stavanger

In partial fulfillment of the requirement for the degree of

Master of Science

March, 2013

Acknowledgement

First, I would like to express much appreciation and gratitude from the deepest heart to my supervisor Professor Ove Tobias Gudmestad for his professional guidance and patience. Without his support it would be impossible for me to complete this thesis.

Second, I would like to thank COSL, who had provided such precious opportunity to have a further education, 6 years after I graduated from university.

Third, I also thank to UIS PLUSS, especially Mr. Frode Leidland, for giving me assistance with regards to studying at UiS.

Finally, I want to say “thank you! I love you!” to my wife, without her understanding and supports, I could not finish the study at UiS. Even more, I could not be with her when she gave birth to the baby, so she is the greatest mother and wife in the world in my heart. Absolutely, I have to thank all my family because they have always been encouraging me and looking after my wife and son during the one year of my leaving.

Yanjiao Beijing

March, 2013

Huan Liu

刘欢

Abstract:

Nowadays, with the rapid development of the offshore oil and gas industry and the important role on the sea, offshore production and support vessels are getting more and more advanced to fulfill the requirements of offshore operations during oil and gas exploration, project developing and production.

The main objective of this thesis is to summarize the design trends of OSVs, based on the needs of the physical environment and recent regulations, and then look into South China Sea and suggest some requirements for OSVs design in this area for the future. Risk analysis shall be carried out as well.

Thesis Supervisor: Gudmestad, Ove Tobias

Abstract in Chinese：

如今，随着近海油气行业的高速发展，以及船舶在海上作业扮演的重要角**色**，近海支持船的发展越来越高端、先进，以满足海上油气行业在勘探、开发以及生产各阶段的要求。本文主要是基于海上作业环境，规则等，对近海支持船的设计趋势进行总结，并就中国南海海域未来作业提出近海支持船的设计要求。同时，就海上作业风险展开讨论。

论文指导老师: Gudmestad, Ove Tobias

Contents

List of figures:

1. Introduction to offshore oil and gas industry development trends

1.1 Physical environment of offshore oilfields

1.1.1 Water depth

As the development of the offshore oil industry fields accessible by shallow water drilling has largely be exploited, most of the new developments are being made in deepwater fields like in Brazil, Gulf of Mexico, North Sea, as well as in the South of the China Sea. Figure 1.1.1.1 shows how the numbers of worldwide annual subsea wells on stream by water depth have increased from 2004 to 2014.

Note: Shallow water is defined as <500m, deepwater is defined as 500-1500m, and ultra deepwater is defined as >1500m (Zijderveld et al., 2012).

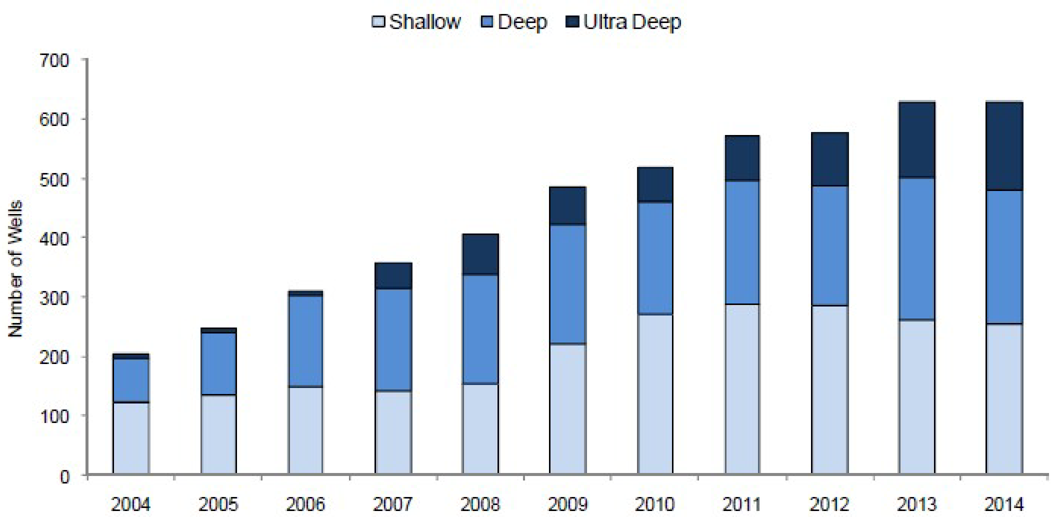


Figure 1.1.1.1 Number of subsea wells brought on-stream by water depth 2004-2014. (Zijderveld et al., 2012)

There is a regional spread of the subsea producing wells as shown on figure 1.1.1.2:

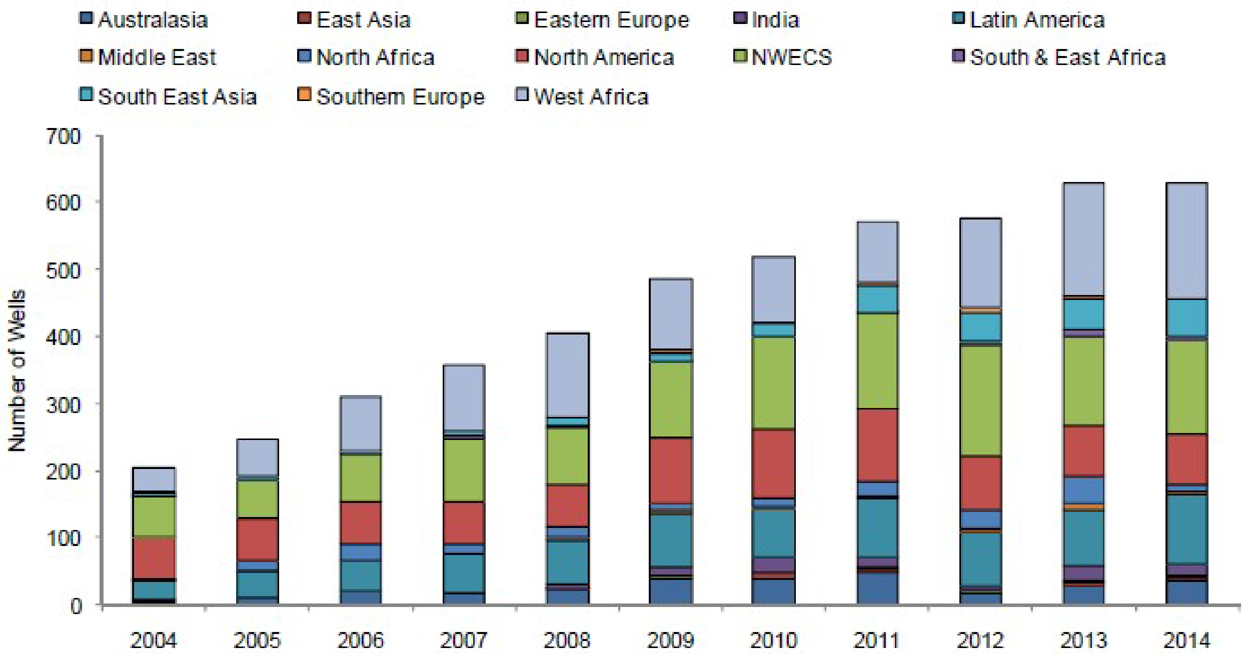


Figure 1.1.1.2 Number of subsea wells brought on-stream by region 2004-2014. (Zijderveld et al., 2012)

Based on historical averages of executed work, a future demand on subsea well intervention is projected for the various water depth ranges. The demand is shown as "vessel days" on figure 1.1.1.3.

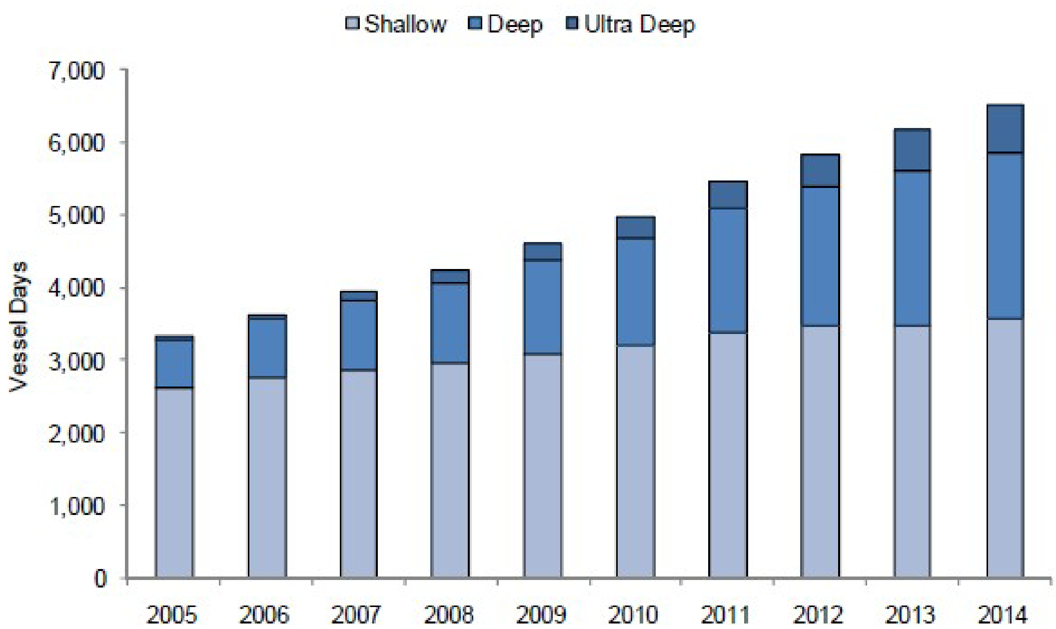


Figure 1.1.1.3 Global well intervention demand (vessel days) by water depth 2005-2014. (Zijderveld et al., 2012)

A further analysis shows that the requirement for subsea well intervention vessel days varies by region as shown on figure 1.1.1.4.

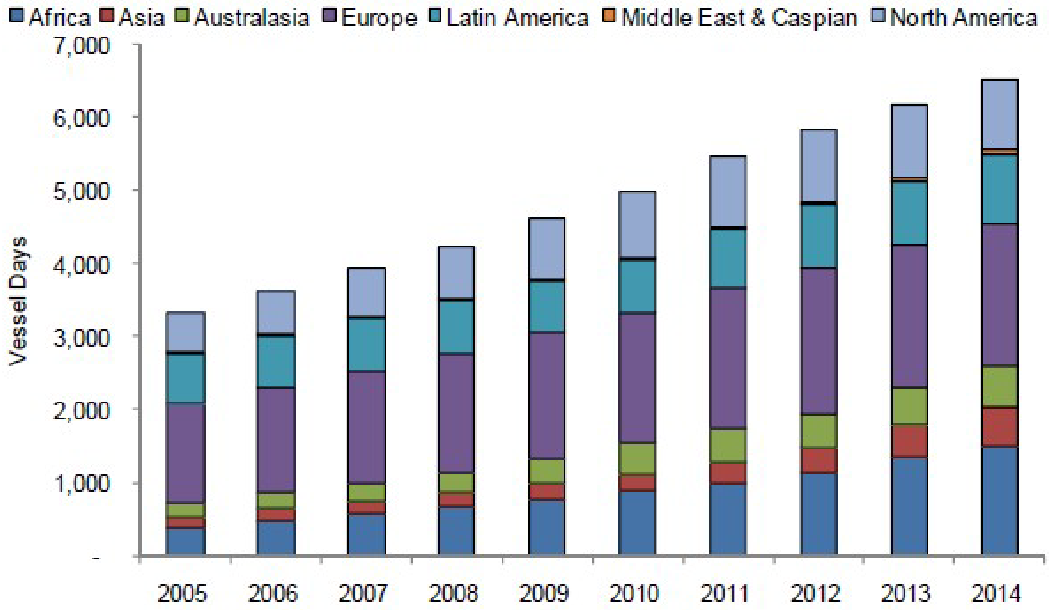


Figure 1.1.1.4 Global well intervention demand (vessel days) by region 2005-2014. (Zijderveld et al., 2012)

1.1.2 Weather conditions

As mentioned above, the water depths of operations in the future would increase to meet the requirements for oil and gas production. With the increase in water depth, the sea condition would be harsher and harsher, that is, higher waves, which brings threat to vessels' stability.

In some area, which has been attacked by typhoons, for example, the South China Sea, the Beaufort wind scale always keeps at 5-6. So the designers of the vessels for such an area should consider how to keep the vessels' stability, how to ease crews' seasickness, and how to ensure the necessary life-saving equipment in case of emergency evacuation due to typhoon's coming.

With the increasing of the requirement, people begin to touch into the Barents Sea and polar area for oil and gas. For operating in such cold areas, winterization becomes the key word, which has been the factor designers take into account.

1.1.3 Distances from the logistic base

Normally, deep water means a long distance from an onshore logistic base, with the increase of water depth, the distances from offshore work sites to onshore logistic bases are getting longer and longer.

MMS (The Minerals Management Service) Planning Areas differ considerably based on both water depth and distance from shore. (See MMS website 2006 Resource Assessment Maps at http://www.mms.gov/revaldiv/NatAssessmentMap.html). For example, in the North Atlantic, over half of the potential oil and gas might be located in water depths of 200 meters or less, whereas in the South Atlantic, over 70% of the oil and gas is located between 200-800 meters of water and, based on MMS maps, appears to be more than 50 miles from the coast. Because of the narrow shelf off the California coast, most of the potential oil and gas resources would likely be found within 50 miles of the coast and in water depths between 0-800 meters. The eastern Gulf of Mexico is vastly different than both coasts in that the vast majority of the potential oil (84%) and gas (68%) resources are beyond 2,400 meters of water depth and beyond 100 miles from the coast. Estimates show that only about 15% of the potential oil and 22% of the potential natural gas might be found in less than 200 meters of water (which could also be beyond 100 miles from the coast)(Humphries, 2010).

1.2 Safety & environmental friendly design

1.2.1 The role of OSV in perspective of safety and environmental friendliness

Due to the high risk of operations offshore, the OSVs play one of the most important roles during the offshore oil and gas fields' exploration, development and production phases. Historical events associated with offshore oil production, such as the large oil spill off the coast of Santa Barbara, CA, in 1969, caused both opponents and proponents of offshore development to consider the risks and to weigh those risks against the economic and social benefits of the development(Humphries, 2010). People began to consider safety and environmental friendliness more and more during the design phase, before the construction. For instance, a DP system keeps the vessels' stability especially in harsh sea conditions, and reduces the probability of collision between the vessel and the offshore facilities; FIFI system ensures the capacity of vessel's fire fighting, in case of fire accidents happening on the rig or platform during the operation.

With the development of the industry, the environmental pollution has become the most troublesome thing for human, and most of countries have issued regulations and laws with regard to environmental protection. For offshore oil and gas operations, the most threat to the environment is spilled oil, so oil recovery equipment and storage tanks are taken into account during the vessel design. Meanwhile, air pollution is always of concern, and in some countries, especially in Europe, the governments have begun to impose carbon tax to encourage less emission design for engines. For OSVs, the electric propulsion design becomes more and more popular.

1.2.2 Case study (Emergency response after loss of Deepwater Horizon)

For a better understanding of the importance of oil recovery design, we take the example of the Deepwater Horizon oil spill. In fact, the disaster of Macondo well blowout was nothing to do with the vessels, so we just talk about the emergency response for oil spill after loss of the Deepwater Horizon rig.

The April 20, 2010, explosion of the Deepwater Horizon offshore drilling rig led to the largest oil spill in U.S. waters. Federal government officials estimated that the deepwater well ultimately released (over 84 days) over 200 million gallons (or 4.9 million barrels) of crude oil. For such a huge amount of spilled oil, the government and BP took many actions to dispose of thee oil, for instance, direct recovery, burning, skimming, use of chemically dispersion, etc (Ramseur, 2010).

No matter which kind of method used, the vessels played the most important role as the disaster happened offshore. So some recovery equipment, storage tanks or oil dispersant should be considered during the phase of an OSV vessel's design.

2. Brief introduction of OSVs

2.1 Types and functions

Sano et al. (2012) explained that the global OSV fleet for offshore operational support has become increasingly diversified as shown below:

- **Offshore Supply** – Transport materials, equipment and/or personnel to, from and between offshore installations.
- **Anchor Handling & Towing** – Handle anchors of offshore floating installations and/or towing operations.
- **Firefighting** – Carry out firefighting operations.
- **Diving & ROV Support** – Provide support for diving systems and underwater remotely operated vehicles (ROVs).
- **Oil Spill Recovery** – Recovery of oil from the water and near shorelines in response to an oil spill in the marine environment.
- **Safety Standby Rescue** – Adapted with special features for evacuating and receiving personnel from an offshore installation, these vessels are also used in the rescue and care of people from another vessel at sea.
- **Pipe Laying** – Used in subsea pipeline installations.
- **Heavy Lift** Vessels – Lift heavy loads in oil drilling and production operations, offshore construction and/or salvage operations.
- **Well intervention, Stimulation & Test** – Designed and equipped, either permanently or temporarily, to carry out well intervention, well stimulation and/or well test services.
- **Escort** – Provide assistance to disabled vessels in emergencies involving impaired maneuverability due to loss of propulsion or steering or both.
- **Wind Turbine Installation, Maintenance & Repair** – Used for installing,

maintaining and repairing wind turbines. (Sano et al., 2012)

2.2 State of Art

2.2.1 ROV system and vessels with moonpool

An ROV system is designed to be capable of accommodating a wide range of user equipment without modification from the outset. Ample space is available within the vehicle frame for accommodation of scientific payload, numerous survey ports are available for a wide variety of equipment including multi-beam, CTD (Charge -Transfer Device), nutrient sensors as well as numerous spare serial and I/O ports which have been incorporated into the system to allow a wide range of scientific sensors to be deployed.

The vehicle is equipped with a high level of auto control features including auto hold which is invaluable in the completion of delicate scientific tasks. The vehicle is also equipped with the latest underwater camera equipment including a HDTV camera and recording system to allow the capture of high definition footage for a variety of uses.

The system is a fully contained system including launch and recovery systems and whilst primarily designed to operate from the vessel and it is readily capable of mobilization from a range of suitable vessels as required (Institute, 2012).

ROV systems (Figure 2.1) can support a variety of missions, including:

- Inspection, Maintenance, and Repair
- Mooring and Buoy Installation
- Rig and Drilling Support
- Accident and Forensic Investigations
- Recovery Operations
- Route and As-Built Surveys
- System Installation
- Optical Documentation

- Biological and Oceanographic Sampling
- Sub-sea Cable Installation and Maintenance Support

Figure 2.2.1.1 Types of ROVs (Subsea7, 2011)

C. Daw (Daw, 2012)described *the moon pool (figure 2.2.1.2) as an opening area that is located in the hull of a sailing vessel that permits easier and safer access to the water. It permits sailors, divers and researches to reach the water easily, and allows those in the oil drilling business to safely bring tools and instruments into the water. This opening area makes it easier to enter the water, especially when there is ice on the water or when the sea condition is rough.*

This specially engineered pool originated in the oil drilling business and is commonly found on marine drilling platforms or drill ships. A moon pool can also be located on marine or underwater research ships, as well as underwater habitats. There are four different types of moon pools that are used.

The first type of moon pool is an above water style and is located inside a chamber in the vessel that is above sea level. With this type of pool, there is open air found above and below the chamber. The chamber is easily accessed through open hallways and stairways. This type is most commonly found on oil and gas drilling platforms.

The second style is the at water level style where the hull of the ship is below sea level but the opening is located right at the water level. This will make it look like there is a swimming pool in the hull of the vessel. The sides of the moon pool are built up to a height that is well above the sea level to prevent the ship from sinking. Doors found near the hull will allow for the opening area to be sealed shut while the ship is moving, or if it encounters stormy weather.

The third type is the below the water level style where the opening area, just as the name suggests, is found below the water level. The only way this style of pool can be built in order to prevent the ship from sinking is if the chamber which houses the moon pool is airtight. This means that the chamber will not be exposed to the air at all. To gain access to this chamber the person entering will have to go through an airtight door.

The final style is the underwater habitat; in which the entire pool is under the water in a uniquely designed underwater habitat, similar to the diving bell. This can provide divers and researches a dry underwater place to go. They will be able to work and rest without the need to climb their way to the surface of the water. These habitats are connected to the bottom of the sea and the opening area of the pool is the only entrance or exit into the chamber(Daw, 2012).

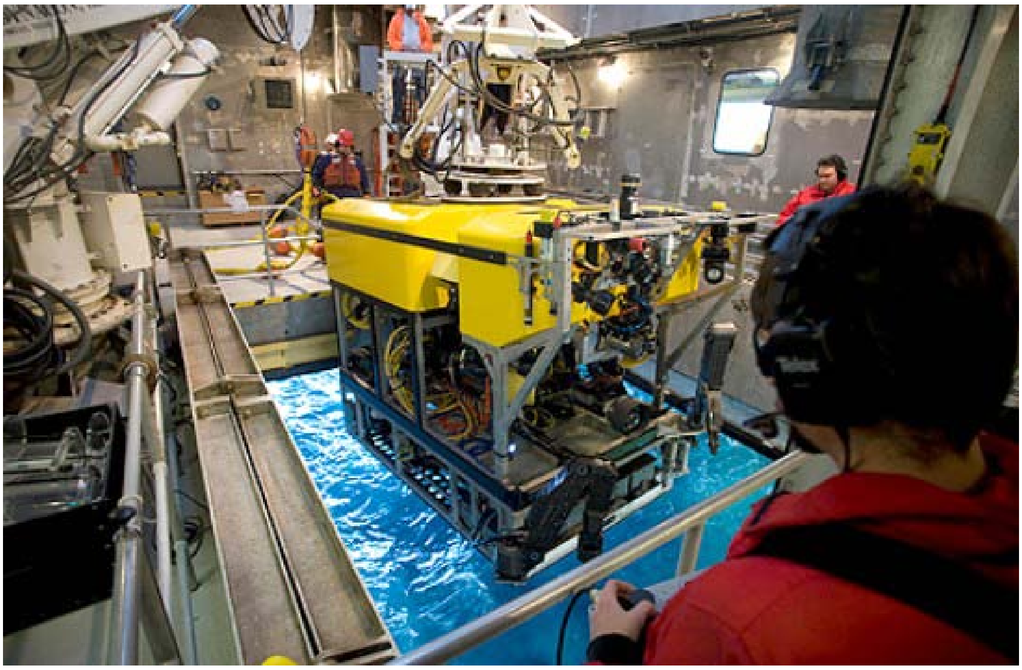


Figure 2.2.1.2 ROV operation from a Moonpool (Walsh, 2009)

2.2.2 X-bow vessel

The X-BOW design is a backward-sloping bow that starts at the extreme front of the vessel. This allows for the sharpest possible bow shape. A continuous and sharp bow shape can smoothly divide both waves and calm water. Increased volume above and up front allows the vessel to efficiently respond to large waves.

A conventional bow has a forward-sloping bow shape that starts at the extreme front of the vessel and drops down and back. The actual start of the bow at the waterline is moved back, and the bow shape at the start of the waterline is less sharp. Thus, a bow pushes the waves down and forward - this absorption of energy slows the vessel (ULSTEIN, 2011).

Figure 2.2.2.1 Comparison between X-bow and conventional bow(ULSTEIN, 2011)

The bow shape ensures soft entry into waves, thus reducing speed loss, pitch and heave accelerations, as well as eliminating slamming and vibration problems associated with conventional bow flare, the figure 2.2.2.1 shows the comparison between X-bow and conventional bow, and the figure 2.2.2.2 is X-bow design OSVs.

Extracts from *X-BOW Hull Line Design* (ULSTEIN, 2011), X-BOW advantages are listed as following:

- Higher transit speed in calm water due to low angles of entry and increased waterline length
- No bow flare, eliminating bow impact and slamming in foreship
- Lower pitch and heave accelerations due to foreship volume distribution and slender hull water line
- Reduced noise and vibration levels in foreship due to soft entry into waves
- Less spray
- Negligible occurrences of green water on bridge deck

- Working deck and deck equipment better protected due to hull extended to full beam in accommodation area
- Higher transit speed in head and following sea, giving reduced power consumption and/or higher fuel efficiency in waves and still water(ULSTEIN, 2011).

Figure 2.2.2.2 The OSV with X-bow (ULSTEIN, 2011)

2.2.3 Well intervention vessels

Following the drilling and completion of deepwater wells (with hundreds of deepwater wells completed per year), one of the upcoming needs is the intervention on deepwater wells.

Zijderveld et al.(2012) explain that there are two basic reasons for intervention:

1. To execute maintenance on existing wells when production is interrupted.

2. To increase the extraction rate (ultimate recovery) from subsea fields to the same level as is done from more conventional offshore fields.

In order to address this matter, a ship shaped Well Intervention Vessel (WIV) was developed for the intervention on deepwater wells. The design is developed utilizing the extensive experience gained over the last 40 years with the design of mobile offshore drilling units whilst at the same time taking into account the specifics of well intervention (Zijderveld et al., 2012).

3. Authorities and Regulations

3.1 Regulations

International Maritime Organization (IMO)

The offshore regulatory regimes begin on an international level with the International Maritime Organization (IMO), which develops and maintains a comprehensive international regulatory framework for the maritime and offshore industries. The IMO establishes regulations with the main focus on providing for safety at sea, and protection of the marine environment. This is accomplished through various regulations such as:

- International Convention for the Safety of Life at Sea (SOLAS).
- Convention on the Prevention of Maritime Pollution (MARPOL).
- The International Convention of Loading (ICLL).
- International Convention on Tonnage Measurement of Ships.
- International Ship and Port Facility Security Code (ISPS). (Sano et al., 2012).

The following IMO documents are specifically applicable to OSVs:

- *Adoption of the guidelines for the design and construction of offshore supply vessels, 2006, IMO Resolution MSC.235(82), which supersedes IMO Resolution A. 469(XII).*
- *Guidelines for the transport and handling of limited amounts of hazardous and noxious liquid substances in bulk on offshore support vessels, IMO Resolution A. 673(16) 1989 as amended by MEPC.158(55) Oct 2006 and IMO MSC.236(82) Dec 2006.*
- *Code of safety for special purpose ships, 2008, IMO Resolution MSC. 266(84).*

Flag Administration and Coastal State Requirements

Each Flag Administration and Coastal State has unique regulatory requirements which must be met.

3.2 Main classification societies (DNV, ABS, LR, CCS, etc.)

With reference to IACS:

The International Association of Classification Societies（IACS）makes a unique contribution to maritime safety and regulation through technical support, compliance verification and research and development. More than 90% of the world's cargo carrying tonnage is covered by the classification design, construction and through-life compliance Rules and standards set by the thirteen Member Societies of IACS. Extract from IACS (2012), the member societies are listed as follows:

DNV: Det Norske Veritas (Norway)

ABS: American Bureau of Shipping

LR: Lloyd's Register Group (England)

CCS: China Classification Society

BV: Bureau Veritas (France)

CRS: Croatian Register of Shipping

GL: Germanischer Lloyd

IRS: Indian Register of Shipping

KR: Korean Register of Shipping

NK: Nippon KaijiKyokai (Japan)

PRS: Polski Rejestr Statkqw (Poland)

RINA: REGISTRO ITALIANO NAVALE (Italy)

RS: Russian Maritime Register of Shipping

The main societies are introduced as below:

DNV

Stiftelsen “Det Norske Veritas” (DNV) is a classification society organized as a foundation, with the objective of "Safeguarding life, property, and the environment". The organization's history goes back to 1864, when the foundation was established in Norway to inspect and evaluate the technical condition of Norwegian merchant vessels. DNV describes itself as a provider of services for managing risk.

Together with Lloyd's Register and American Bureau of Shipping, DNV is one of the three major companies in the classification society business. DNV has its headquarter in Høvik, Bærum, just outside Oslo, Norway. It has 300 offices in 100 countries, and over 10,000 employees. Important industries where the company operates include ship transport, energy (including wind and solar), aviation, automotive, finance, food, health care and information technology. It also conducts research in several fields where it operates (Wikipedia, 2012).

For the offshore support vessels, DNV has published a series of standards and rules for classification of newbuildings of OFFSHORE SERVICE VESSELS, TUGS AND SPECIAL SHIPS, which have introduced different kinds of offshore support vessels, included anchor handling and towing vessels (AHT), platform supply vessels (PSV), stand-by vessels and so on, hull arrangement and strength, systems and equipment, stability and watertight integrity of the vessels have been described as well. The detailed information could be referred to PART 5 CHAPTER 7 of RULES FOR CLASSIFICATION OF SHIPS (DNV, 2011).

ABS

The American Bureau of Shipping (ABS) is a classification society, with a mission to promote the security of life, property and the natural environment, primarily through the development and verification of standards for the design, construction and operational maintenance of marine-related facilities. At the end of 2006, ABS was the third largest class society with a classed fleet of over 10,000 commercial vessels and offshore facilities. ABS' core service is the provision of classification services through the development of standards called “ABS Rules”. These Rules form the basis for assessing the design and construction of new vessels and the integrity of existing vessels and marine structures.

Extract from Wikipedia (2012), “*ABS was first chartered in the state of New York in 1862, to certify ship captains. It has been involved in the development and improvement of safety standards. Born out of a need for industry self-regulation, ABS published its first technical standards, Rules for Survey and Classing Wooden Vessels, in 1870. When the era of wooden ships gave way to iron, ABS established standards for these structures, published as Rules for Survey and Classing of Iron Vessels. Similarly, when iron gave way to steel, the first ABS Rules for Building and Classing Steel Vessels were established and published in 1890. These Steel Vessel Rules continue to be revised and published annually.”*

ABS first established Rules specifically for smaller vessels with the publication in 1973 of *Rules for Building and Classsing Steel Vessels Under 61 Meters (200 Feet) in Length*. In 1997, the Rules evolved into *Rules for Building and Classing Steel Vessels Under 90 Meters (195 Feet) in Length*. Besides extending the length of vessels covered, the Rules specified more functional equipment and arrangement requirements as well as introduced optional classification notations for specific functions and services.

Considering design trends and challenges of the new generation deepwater support vessels, the Guide for Building and Classing Offshore Support Vessels (OSV Guide) was developed in 2011 with standards for design and construction of modern OSVs. *(Sano et al., 2012)*

GUIDE FOR BUILDING AND CLASSING OFFSHORE SUPPORT VESSELS, 2011, consisting of the eight (8) booklets as shown in Table 3.2.1.

Notices and General Information		1 May 2011
Part 1:	Rules for Conditions of Classification*	1 January 2011
Part 1:	Conditions of Classification (Supplement to the ABS *Rules for Conditions of Classification*)*	1 May 2011
Part 2:	Rules for Materials and Welding Rules for Testing and Certification of Materials Rules for Welding and Fabrication	1 January 2011
Part 3:	Hull Construction and Equipment	1 May 2011
Part 4:	Vessel Systems and Machinery	1 May 2011
Part 5:	Specialized Vessels and Services Chapter 1 General Chapter 2 Offshore Supply Chapter 3 Anchor Handling and Towing Chapter 4 Fire Fighting Chapter 5 Diving and Remotely Operated Vehicles (ROVs) Support Chapter 6 Oil Spill Recovery Chapter 7 Safety Standby Service Rescue Chapter 8 Pipe Laying Chapter 9 Heavy Lift Chapter 10 Well Intervention Chapter 11 Well Stimulation Chapter 12 Well Test Chapter 13 Escort Chapter 14 Wind Turbine Installation, Maintenance and Repair (Wind-IMR) Chapter 15 Special Purpose	1 May 2011
Part 7:	Rules for Surveys After Construction	1 January 2011

Figure 3.2.1 Applicable Editions of Booklets Comprising 2011 Guide(ABS, 2011)

Lloyd's Register

Extract from Wikipedia (2012), *“the Lloyd's Register Group is a maritime classification society and independent risk management organization providing risk assessment and mitigation services and management systems certification. Historically, as named Lloyd's Register of Shipping, it was a specifically maritime organization. During the late 20th century, it diversified into other industries including oil & gas, process industries, nuclear and rail. Through its 100% subsidiary Lloyd's Register Quality Assurance Ltd (LRQA), it is also a major vendor of management system quality certification to ISO9001, ISO14001 and OSHAS18001. Lloyd's Register is unaffiliated with Lloyd's of London*

The Society printed the first Register of Ships in 1764 in order to give both underwriters and merchants an idea of the condition of the vessels they insured and chartered: ship hulls were graded by a lettered scale (A being the best), and ship's fittings (masts, rigging, and other equipment) was graded by number (1 being the best). Thus the best classification was "A1", from which the expression A1, or "A1 at Lloyd's", is derived, it first appeared in the 1775 – 76 edition of the Register. The Register, with information on all sea-going, self-propelled merchant ships of 100 gross tonnes or greater, is published annually. A vessel remains registered with Lloyd's until it is sunk, wrecked, hulked, or scrapped. The Register was published formerly by the joint venture company of Lloyd's Register-Fairplay, which was formed in July 2001 by the merger of Lloyd's Register's Maritime Information Publishing Group and Prime Publications Limited. Lloyd's sold its share of the venture to IHS in 2009."

Related to offshore oil and gas industry, Lloyd's Register published Rules & Regulations for the Construction & Classification of Submersibles & Underwater Systems

CCS

Extract from web site of CCS (2012), *"CCS was founded in 1956. China Classification Society (CCS) is the only specialized organization of China to provide classification services. CCS aims to provide services for the shipping, shipbuilding, offshore exploitation and related manufacturing industries and marine insurance by furnishing reasonable and reliable classification requirements and providing independent, impartial and integral classification and statutory services to ships and offshore installations, for the promotion and safeguarding of the safety of life and property at sea and for the prevention of pollution to the marine environment.*

CCS is one of the thirteen full members of the International Association of Classification Societies (IACS), and chaired IACS Council respectively in 1996 - 1997 and 2006 - 2007. Its highest class notation has been included in the Classification Clauses of the Institute of London Underwriters (ILU). Up to the end of 2011, CCS had been authorized by governments of 29 countries *or regions to perform statutory surveys for the ships flying their flags. CCS is also the associate members to the International Association of Dry Cargo Ship owners (INTERCARGO) and the International Association of Independent Tankers Owners (INTERTANKO). CCS has established 60 branches/offices both at home and abroad, forming a global service network. By the end of 2011, the CCS classed fleet is 2654 ships, totaling 50.30 million gross tonnages.* "

4. Design trends

With the development of offshore oil and gas exploration and production activities, today's OSVs are required to be larger, more powerful, sophisticated, and to combine multiple capabilities within the vessel design. Extract from Sano et al.(2012), following is a listing of the features or capabilities (Sano et al., 2012):

Size - The average length, beam and work deck space has increased dramatically over the last 10 years due to work taking place in deeper waters at increased distances from shore. Today's vessels are expected to be self-sufficient for longer periods and carry increased quantities of all types of materials, drilling fluids, chemicals, etc.

Power - The larger OSVs today have a correspondingly large increase in horsepower and power generation for all the additional equipment they are outfitted with.

Propulsion Types - Traditionally OSVs had direct drive diesel engines, but the requirements of more complex and efficient layout of machinery combined with focus on power management and fuel consumption have made diesel electric design favorable to owners.

Dynamic Positioning Systems (DP) - OSVs required to remain on station in deepwater and conduct subsea operations, are fitted with DP systems which are driven by various thrusters and rotary propulsion system.

Rail Mounted Deck Crane - This crane type both services the work deck and can be used for alongside loading operations. It allows for work deck flexibility as it can be moved forward or aft and stowed out of the way for other work deck operations.

Deck Cranes - Large capacity, high lift cranes to support offshore construction and maintenance activities.

Knuckle Boom Crane - Active and passive heave compensated with heavy lift capability. It is designed for deepwater subsea construction and support activities.

Moon Pools – A through the hull opening in the work deck which provides shelter and protection from the open sea to allow subsea, ROV and diving operations to take place.

ROV Bays - Enclosed spaces from which ROVs are launched and recovered, also equipped with ROV maintenance equipment and features.

Helidecks – Positioned forward, high mounted and cantilevered designs that may include onboard refueling capabilities.

Table 4.1 shows a comparison between legacy boats and new generation deepwater OSVs on the terms of dimensions, horsepower, winch capacity, and DP.

Feature	Legacy Boats	New Generation Deepwater OSV
Length (m)	57m – 70m (190'–235')	67m – 130m+ (220' – 427'+)
Brake Horsepower	4,000 – 15,000	8,000 – 28,000
Winch Rating (Tons)	80 – 300	250 – 600
Dynamic Positioning	None	Yes – DP-2
Source: Seacor, Tidewater, Clarkson's Research, Fortis Bank Equity Research Estimates		

Figure 4.1 Evolution of OSVs (Sano et al., 2012).

4.1 Hull design

Nowadays, the hull of OSV is designed to be strengthful, less resistance and high stability, listed below are the major trends of hull design:

- Double hull design

- X-BOW design (refer to 2.2.2 X-Bow vessel)
- Dedicated anti heeling and anti-rolling tanks

4.2 DP system

Balchen et al. (1980) explain that dynamic positioning (DP) is a computer-based system to automatically control a vessel's position and heading by using its own propellers and thrusters. The main purpose of a dynamic positioning system is to keep a floating vessel on a specified position by proper action of the propulsion system of the vessel. A DP system is required in many offshore oil and gas field operations such as drilling, pipe-laying and diving support. (Balchen et al., 1980) With the development of the deepwater oil and gas fields, more and more activities are going to deeper waters, which also means harsh sea conditions and difficulty to control the vessels or MODUs, therefore DP system becomes standard configuration for such deepwater trends.

The IMO publication 645 (IMO645, 1994) explain the three equipment classes as:
"• Equipment Class 1 has no redundancy. Loss of position may occur in the event of a single fault.
• Equipment Class 2 has redundancy so that no single fault in an active system will cause the system to fail. Loss of position should not occur from a single fault of an active component or system such as generators, thruster, switchboards, remote controlled valves etc., but may occur after failure of a static component such as cables, pipes, manual valves etc.
• Equipment Class 3 which also has to withstand fire or flood in any one compartment without the system failing. Loss of position should not occur from any single failure including a completely burnt fire sub division or flooded watertight compartment."

Nowadays, in most of ITB (Invitation To Bid) with regard to OSVs of oil companies, especially for the projects of deepwater, DPII has become the key factor. Furthermore, some other facilities like FPSOs, shuttle tankers, rigs and crane engineering vessels are all equipped with DP systems.

The advantage of a dynamic positioning system:

- Maneuverability is excellent; it is easy to change position.
- Rapid response to weather changes is possible (weather vane)
- Rapid response to changes in the requirements of the operations
- Versatility within system (i.e. track-follow, ROV-follow and other specialist functions)
- Ability to work in any water depth
- Can complete short tasks more quickly, thus more economically
- Avoidance of risk of damaging seabed hardware from mooring lines and anchors

4.3 Automation

Nowadays, with the development of technology, everything becomes advanced with high-tech, even an automobile can drive by itself automatically. The design of automation has become the trend; OSVs are typically designed to minimum manning standards by staying below 6000 GRT. Even OSVs are getting significantly more complex, outfitted with DP systems, advanced liquid cargo handling systems, Diesel Electric propulsion and unmanned engine rooms. While the number of crew stays constant or decrease, automation is playing an increasingly important role in vessel design. Attached is main equipment's providers and specification of HAIYANGSHIYOU 681 in appendix A.

In fact, a large portion of the price increase for a standard PSV from USD 3-4 million in the 1970s to USD 30-40 million today can be attributed to the increase in vessel automation. Modern vessels often have integrated fuel-tracking, onboard maintenance-tracking systems, and DP systems. (Rose, 2011)

4.4 Environmental friendly design

The term Environmental friendly vessel has two main components: reducing emissions from fuel consumption, and reducing the probability of pollution by oil or chemical spill. In general, reducing emissions helps operating costs when it means reduced fuel consumption, but hurts operating costs when it means burning more expensive fuels. That is the reason of Diesel Electric propulsion getting increasingly popular. At the same time, hull design could be the main factor of fuel consumption; as mentioned above, X-bow design became trend because of economic fuel consumption when comparing with conventional design. From the economy's prospect, LNG-fuelled designed vessel is getting more mature, such as the Eidesvik VS489 PSVs running on dual-fuel Wartsila engines and delivered at first quarter of 2011. (Rose, 2011).

For the other component, reducing the probability of pollution by oil or chemical spill, regulations have changed the requirements for OSVs carrying certain amounts of fuel or Noxious Liquid Substances (NLS). For instance, MARPOL regulations will force "protectively located fuel tanks for all ship with an aggregate oil fuel capacity of 600 m^3 and above" for ships delivered after August 2010. Furthermore, MARPOL regulations cover vessels carrying more than 800 m^3 of NLS. Complying with these regulations effectively forces PSVs to become double-hull vessels, which significantly reduces their fuel, mud and bulk capacities. (Rose, 2011)

Besides the two main components of environmental friendliness, the design for oil recovery could be the other important factor with regard to protection of oil pollution, especially after the disaster of Deepwater Horizon in GOM. So oil recovery capacity or recovery oil tank capacities are getting increasingly important in the design of OSVs.

4.5 Safety concept

Due to the high risk of offshore oil and gas industry, safety is always being concerned, especially after the disaster of Deepwater Horizon. Here we mainly talk about design for personnel evacuation in case of emergency.

For the offshore structures (for instance, FPSO or platforms), normally they use helicopters, standby vessels, or lifeboats to evacuate persons in case of typhoon or something emergency, while how to evacuate crew or passengers on vessels? There are not so many choices. Lifeboat normally is the only way to escape, so lifeboat plays the most important role during the evacuation for the OSVs.

Normally, the designers of lifeboat consider the following factors when design a lifeboat:

- Major explosions and major fires, toxic gas releases and oil or gas blowouts (recognizing the possibility of H2S);
- Loss of stability due to ship collisions;
- Loss of stability due to extreme ice events, storm waves, earthquakes, etc.;
- Loss of stability due to unexpected structural failure, equipment malfunction, etc. (Wright et al., 2003)

Recently, free-fall lifeboats are becoming popular due to the fact that many life threatening accidents have occurred with conventional lifeboat systems. Most of the accidents happened during launching and after lowering the lifeboat into the rough seas in high wind and wave. During launch, the lifeboat may hit the sides of the distressed vessel, become severely damaged and crews may fall into the sea causing injury and even death. It is impossible to launch the lifeboat if the parent vessel is listing significantly or if the falling becomes tangled. After lowering the boat into the water, it may be unable to move away from the distressed vessel if high seas and winds continually push the lifeboat towards the parent vessels or due to the inability of the engine to start. These situations become even more dangerous during fire or when the potential for an explosion exists. Many of the risks associated with conventional lifeboat systems have been substantially reduced by the free-fall lifeboat system.(Hwang et al., 2012)

With regard to the design of free fall lifeboats, DNV has published OFFSHORE SEANDARD DNV-OS-E406 “DESIGN OF FREE FALL LIFEBOATS”.

4.6 Design for easy maintenance (condition monitoring)

Predictability is a valuable virtue in many areas of life, which could be also used in offshore marine domain. HEMOS (health monitoring on ships) system designed by Rolls-Royce has been designed for the OSV. (http://www.oilpubs.com/oso/article.asp?v1=7864)

Sensors on the equipment collect data on various parameters. Some are in the control loop for operating the equipment. Others capture a wider range of information, ranging from oil quality to navigation and meteorological data, and HEMOS transmits this information flow to land for analysis. A data center is established by the ship companies, from a large amount of data the correct conclusions must be drawn, involving both intelligent software and people able to make correct diagnoses. And from these conclusions can be derived advice on servicing and preventive maintenance.

The advantages of HEMOS:

Firstly, it is the real-time advice on maintenance. Secondly, it is planning work to be done during docking, port visiting as well as platform arriving. By analysis those monitoring data, what spare parts and exchange units are likely to be needed can be known in advantage. The process also helps with maintaining an optimal level of parts in stock, reducing the cost of parts storage, and rationalizing production of spares, with economic advantages to all parties.

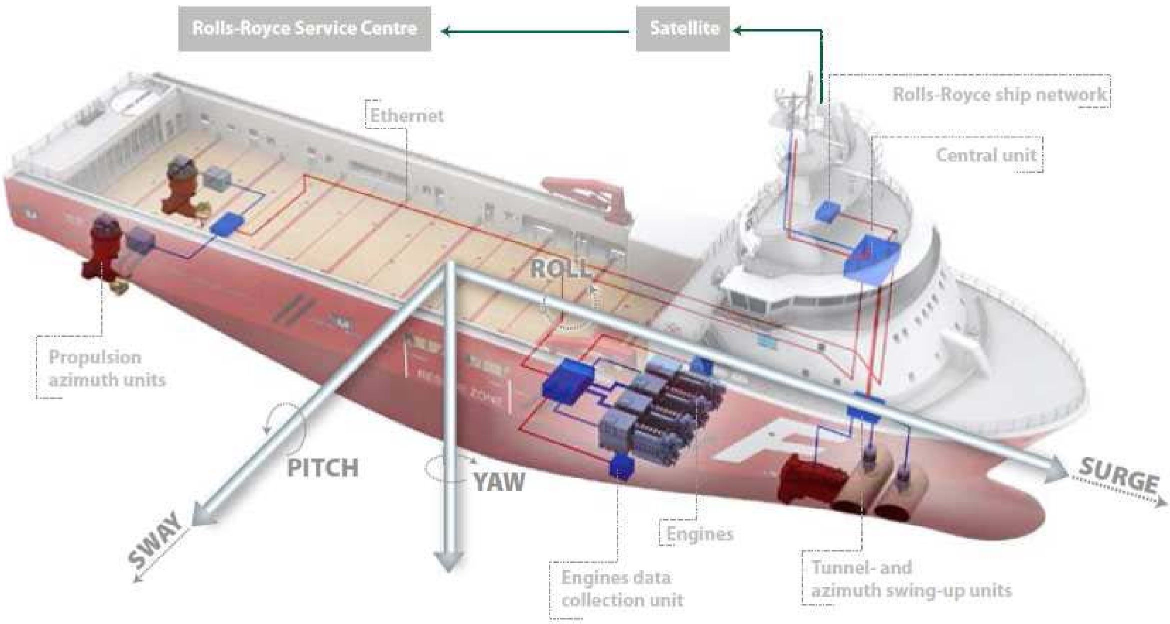


Figure 4.6.1 OSV equipment monitoring system (Backwell, 2012)

The system can also give a workable basis for total care package. The thruster, for instance, in one vessel may experience quite different lives from those in an apparently similar vessel. HEMOS can be helpful in assessing what risk is being transferred.

The Farstad vessel “Far Searcher” (Figure 4.6.2) working in the North Sea, has had an installation for the past year and a half, with useful results. One is improved maintenance planning, what might be termed the conventional benefit of continuous condition monitoring. Another, with considerable long-term possibilities, is combining machinery data such as power and fuel consumption, with navigation and weather data to improve the vessel’s overall operating efficiency and thus cut exhaust emissions. (Backwell, 2012).

Figure 4.6.2 Far Searcher in North Sea (Backwell, 2012)

4.7 People oriented design

At present, less and less people wants to working on boast, due to the high risk and uncomfortable working condition, especially for the OSVs crew, they often bear seasickness for 24 hours a day and 7 days a week, which also represents potential risks for the offshore work. In order to attract good crew and keep their level of performance and safety high, OSV operators are expecting vessel designs that are more comfortable and appealing to mariners. Newbuildings are increasingly conforming to class society comfort notations, and designers have made a number of conscious design decisions to increase habitability. Such improvements include increased engine room insulation, more spacious cabins, and moving accommodations higher to avoid bow thruster noise and vibrations. Comfort improvements not only attract quality crew, but also reduce crew exhaustion and thereby increase vessel operational safety. (Rose, 2011)

5. OSV market in China

5.1 Main OSV companies in China

With the development of offshore oil and gas exploration and production in China, people began to invest their money into offshore support vessels 5 years ago. Consequently, more than 40 OSVs were put into market during the past 3 years, but the marketing need did not increase, so most of those owners, who were not familiar with the OSVs industry, bareboat or chartered their newbuildings to the major companies, for example, COSL (China Oilfield Service Limited). The following OSV owners are main competitors of COSL in China: Huawei (Shenzhen Huawei Offshore Shipping Transport Ltd.), CNPC (China National Petroleum Corporation), Sinopec (China Petroleum & Chemical Corporation), as well as China Rescue and Salvage Bureau (CRSB). The total number of OSVs working in the Chinese offshore oil and gas industry is about 220, of which 170 are working and 50 are idle. The following pie chart (Figure 5.1.1) shows the number of vessels of the owners in China.

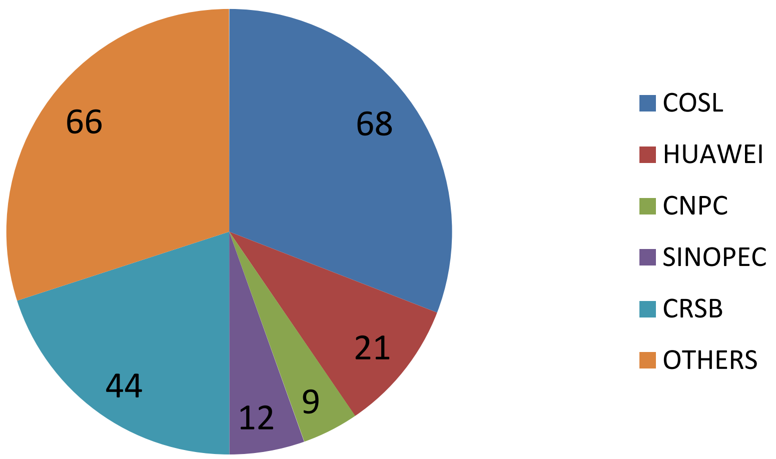


Figure 5.1.1 Numbers of OSVs in China

Note:

“OTHERS” (including 28 owners) here means the small owners which have less 8 vessels each.

CRSB (China Rescue and Salvage Bureau) includes 3 Rescue subsidiaries and 3 Salvage subsidiaries in China, the number of 44 is the part of its fleet, which have gotten involved in the offshore oil and gas industry.

COSL

The OSVs business of COSL is under the management of the Shipping division of COSL. Based on over forty (40) years working experience in the offshore oil and gas industry, COSL now is owning and operating 98 OSVs, which includes 68 owned and 30 chartered vessels from small owners, the fleet of COSL comprises AHTS (Anchor Handling Towing Supply vessel), PSV (Platform Supply Vessel), Standby vessels and Crew boats. The average horsepower of the fleet (self-owned) is 7638, and the average age of the vessels is 16 years old.

For running such huge fleet, COSL has established 3 logistic bases (Tanggu, Shenzhen and Zhanjiang) and 6 support offices (Huludao, Longkou, Shanghai, Zhoushan, Weizhou and Sanya) in China.

Huawei

The full name of the company is Shenzhen Huawei Offshore Shipping Transport Ltd, which is the strongest competitive owner to COSL in China. It operates 21 vessels, of which 15 are working in the South China Sea. The average horsepower of the fleet is 7804, and the average age of the vessels is about 20.

CNPC (China National Petroleum Corporation)

As the biggest oil companies in China, CNPC has tried to go offshore in recent years. So the fleet size is relative small, the total number of OSV is 9, and the fleet is really young, the average age of the vessels is only 4years.

Sinopec (China Petroleum & Chemical Corporation)

As one of top 3 oil companies in China, Sinopec has more experience than CNPC in the offshore sector, it operates more than 20 vessels for its own offshore oilfield in shallow water (named the ’Shenli Oilfield’ in China). The number of 12 vessels listed above is only the number of vessels which has experience of working for other oil companies. The average age of the vessels is about 23 years.

China Rescue and Salvage Bureau (CRSB)

The main business of China Rescue and Salvage Bureau is rescue and salvage. Thanks to most of vessels in the fleet have the function of towing, they could play the role of tugs to tow rigs or other offshore facilities. With the development of the offshore oil and gas industry in China, some of its subsidiaries began to build vessels dedicated for offshore oil and gas in recent years. The total number of 44 listed above is the part of its fleet, which has the capacity to work for offshore oil companies. Based on the new buildings recently, the average age of the vessels is about 10 years.

5.2 Fleet and composition

According to incomplete statistics, as of the end of 2012, the total number of OSVs working (or in idle) in China is 220, and most of them are AHTS, most of which normally play the role of standby and supply. Comparing with the number of AHTS, the number of PSV and crew boats is relatively small. The pie chart below (Figure 5.2.1) shows the composition of the fleet in China.

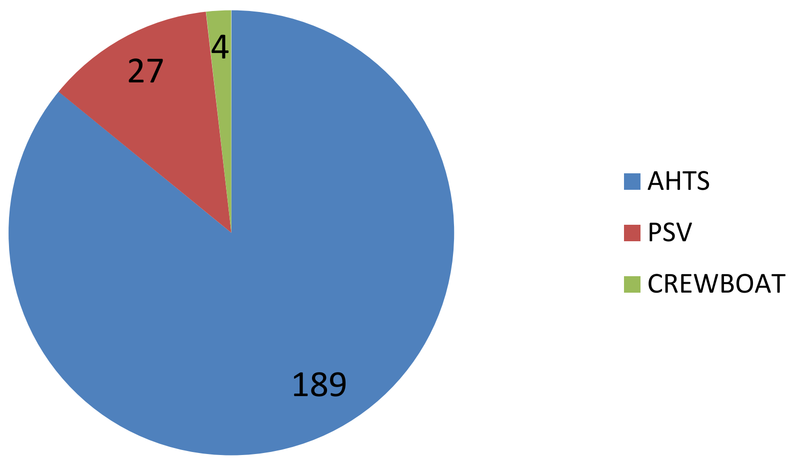


Figure 5.2.1 Compositions of OSVs in China

The average horsepower of those 220 vessels is 7445, from the following distribution (Figure 5.2.2) of horsepower, the vessels are mainly with 6000-8000HP.

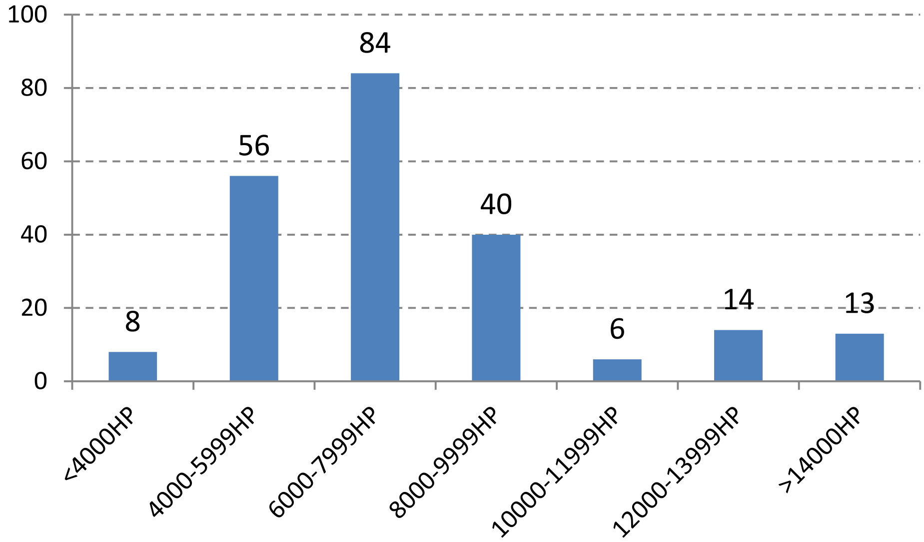


Figure 5.2.2 Horsepower distribution of OSVs in China

Thanks to boom of new buildings, the average age of those 220 vessels is only about 12 years, and about half of the 220 were put into the market in the past 5 years, Figure 5.2.3. But in the coming couple of years more than 20 vessels would be retired, because the vessels working in China should be scrapped after 34 years old as per the policy.

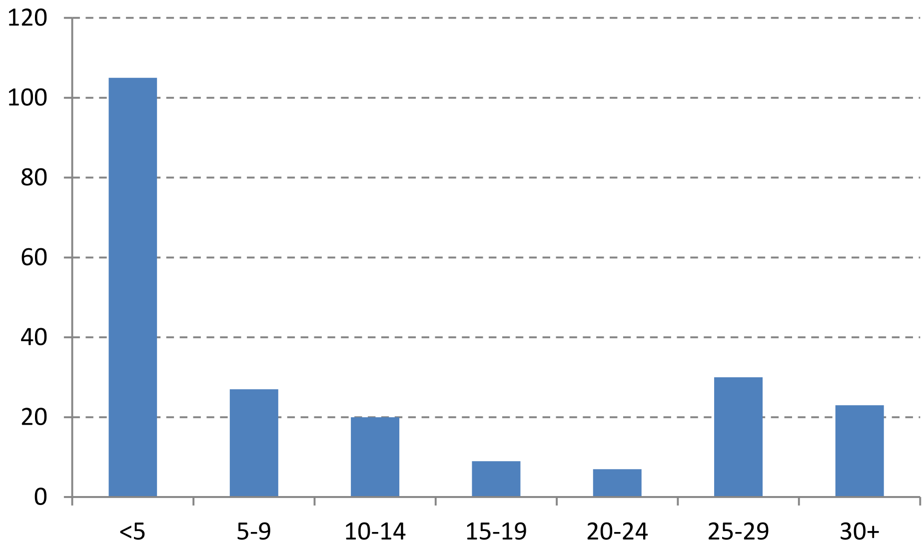


Figure 5.2.3 Age distribution of OSVs in China

5.3 Possible worldwide application of vessels built for the Chinese market

As we have shown above, the types of OSVs in China is relatively simple. Most OSVs are designed to be AHTS, but actually they just play the role of standby or transportation vessels for offshore facilities, and the function of anchor handling is mostly wasted.

Some of mature design worldwide could be applied in the Chinese OSV market, for instance, the UT755 designed PSV, is one of the most popular PSVs, and more than 200 vessels of this model has been built or are under construction.(Rolls-Royce, 2013)

Figure 5.3.1 UT755CD designed PSV(Rolls-Royce, 2013)

6. Looking into South China Sea

6.1 Physical environment

6.1.1 Description

The South China Sea (SCS) is claimed by China as a semi-enclosed tropical sea located between the Asian land mass to the north and west, the Philippine Islands to the east, Borneo to the southeast, and Indonesia to the south (Fig. 6.1.1.1), a total area of 3.5106 km^2. It connects to the East China Sea (through Taiwan Strait), the Pacific Ocean (through Luzon Strait), the Sulu Sea, the Java Sea (through Gasper and Karimata Straits), and to the Indian Ocean (through the Strait of Malacca). All of these straits are shallow except the Luzon Strait whose maximum depth is 1800 m. The elliptical shaped central deep basin is 1900 km along its major axis (northeast-southwest) and approximately 1100 km along its minor axis, and extends to over 4000 m depth. (Chu et al., 2004).

Figure 6.1.1.1 Maritime claims in the South China Sea (America, 2011)

6.1.2 Weather forecasting

Comparing with activities on land, offshore oil and gas exploration and production activities are influenced by the weather factor. Besides the factors of temperature, humidity and wind, wave and current should be taken into account when working on the sea. Weather always changes like a baby's face, so weather forecasting is the basis of offshore activities.

Let's go back to 25th November 1979; The Bohai No. 2 jack-up encountered a storm with force 10 winds and sank on the way from China to Korea in the Bohai Bay while under towing, resulting in the deaths of 72 out of the 74 personnel on board. After such a disaster people began to pay more attention on weather forecasting and operators follow standard tow procedures with regards to weather strictly. (Refer to http://home.versatel.nl/the_sims/rig/bohai2.htm)

Nowadays, according to the COSL's standard of rig towing in China, towing work must be done below force 7 wind, and the professional weather forecaster should be onboard during the whole towing job, and every time of towing work should be done by two boats, one is main tug, and the other plays as the escort ship.

With the increasingly more respect for the nature and more attention on weather forecast, OSVs are equipped with more and more advanced weather forecast instruments, for instance, weather facsimile, wind indicator, wave detector. Meanwhile, weather forecast information is included in the navigation warning every day, which is received by NAVTEX (Navigational telex) on board.

6.2 Challenges

Frequent typhoons in the South China Sea

Globally, about 79 typhoons form each year, with the greatest force and largest number occurring in the northwestern Pacific Ocean and South China Sea region. Between 1965 and 2008, this area saw the formation of 1,189 typhoons, an average of 27 to 35 per year; more than half occurred in July, August and September, with most occurring in August. Typhoons are generally stronger and more frequent than hurricanes, and their maximum wind speeds can reach 120 knots (138 miles per hour). The Hagupit Typhoon, which occurred in the South China Sea region on 24 September 2007, is characteristic. Fig. 6.2.1 shows a satellite photo.

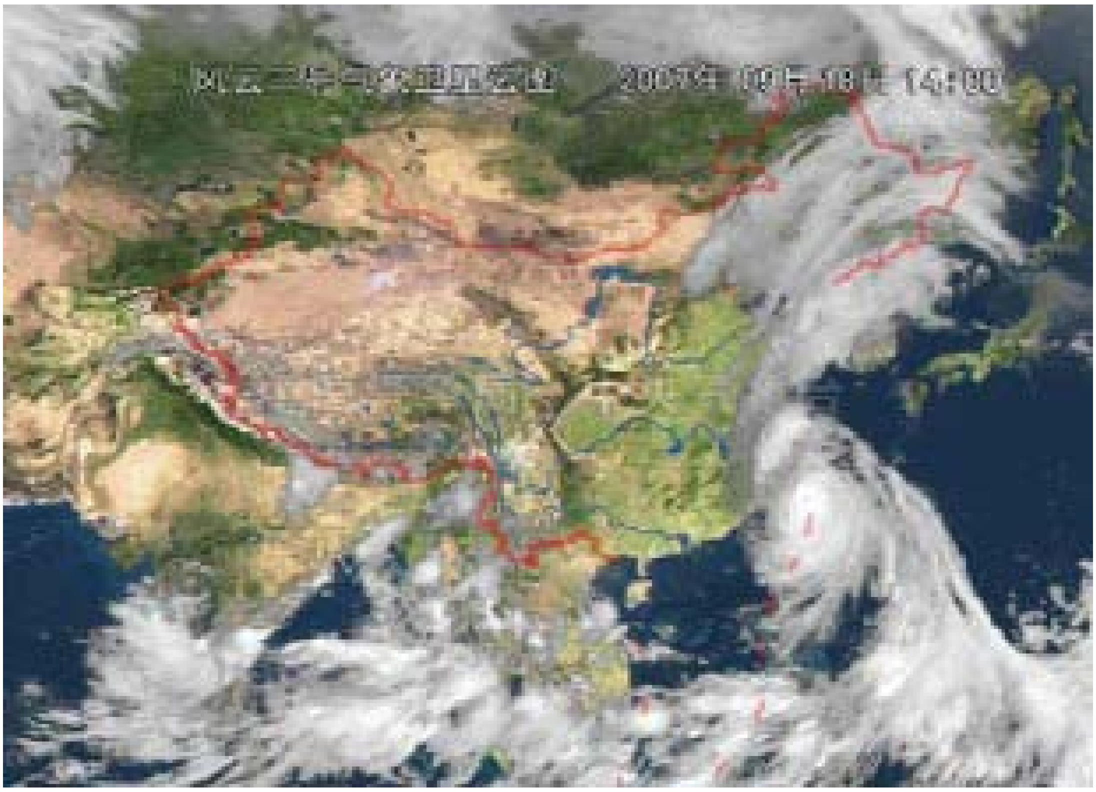


Figure 6.2.1 Typhoon cloud satellite photo (Chen, 2009)

Typhoons have resulted in great damages to offshore installations and are a principal hazard to offshore operations and platforms in the South China Sea. Serious damage even leads to stoppage of oilfield production; and a stricter design standard is under consideration. (Chen, 2009).

6.3 Activities in the future

According to the deepwater strategy of offshore oil and gas fields, the government has begun to issue permits for exploration and development in the block of deepwater in South China Sea, and some of them have been prospected and drilled.

Take the example of the BAIYUN and LIWAN deepwater block in South China Sea, more than 60 wells have been drilled in the past 3 years, and in 3 blocks nature gas is found. Moreover, more than 20 wells would be drilled in 2013. The following map shows the exploration state of the BAIYUN and LIWAN deep water block, which located about 350KM southeast of Hong Kong.

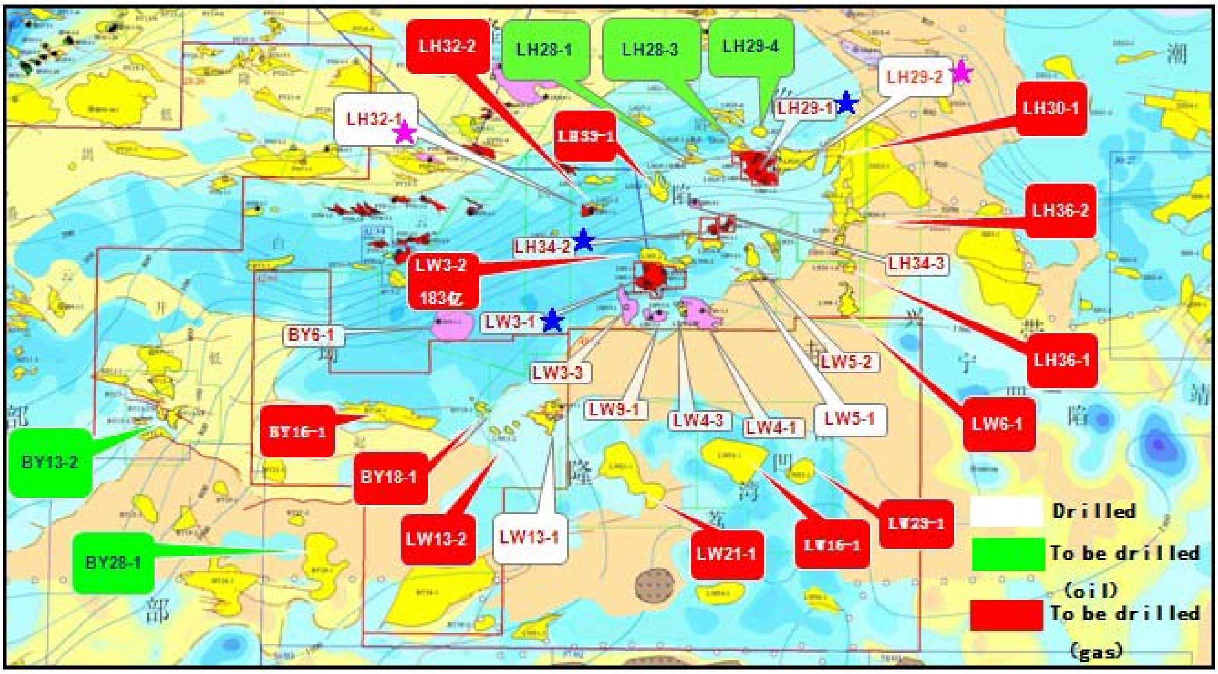


Figure 6.3.1 Exploration state of the BY&LW deep water block (from the department of development & production of CNOOC)

6.4 Requirements for OSVs

With the increasing activities in deepwater in the future, the requirements for OSVs dedicated for deepwater is increasing accordingly. For the east of South China Sea only, the OSVs requirements from 2013 to 2015 are listed in Table 6.4.1 below:

Table 6.4.1 OSVs requirements from 2013 to 2015 in the east of South China Sea (from the department of development & production of CNOOC)

year	No. of blocks	Requirements of OSV for production	No. of rigs	Requirements of OSV for drilling support	Total No. of requirements
2013	23	**27**	3	**7**	**34**
2015	37	**36**	4	**9**	**45**

Actually, besides the most advanced rig in China “HAIYANGSHIYOU981”, the Drilling division of COSL has begun to purchase or lease semi-submersible rigs from Malaysia and Namibia since last year, the first rig has been put into the market at the end of 2012, and the second one would be used in March of 2013, both two rigs are planned to work in South China Sea.

In order to match with rigs' development, the owners of OSVs have begun to purchase or build new vessels designed for deepwater. In 2012, HUAWEI purchased a UT755 designed PSV, which is named "HUAZE" which is working for HUSKY now. A new building AHTS with 16000HP, designed by HAVYARD, "KANTAN225", which belongs to Sinopec, was delivery in the end of 2012 and would be used from the first quarter of 2013.

To keep the pace of deepwater's developments; Shipping-COSL has launched a new round of purchase and building. 4 PSVs designed by KCM Singapore, which would be delivered on March/May/June/September of 2013, will be purchased by COSL in the first quarter of 2013. In addition, Shipping-COSL has public invited bids for 15 deepwater designed OSVs construction vessels, and those vessels would be put into the market in 2015.

7. Risk analysis

7.1 Main risks during operations

Risks on oil and gas production have been increased with the trend of deepwater and cold region developments; due to harsh environment and long distance to land. The main risks are related to the physical environment, human factors and equipment on vessels.

Physical environment

As discussion above, offshore activities are always restricted on the basis of the physical environment. According to the Gudmestad, 2012 the key factors of the physical environment of the cold regions are waves, polar low pressures, sea spray icing, winterization, visibility, sea ice conditions, and so on. (Gudmestad, 2012)With regard to deepwater, the risks mainly focuses on the waves, there are potential risks of collision between OSV and offshore installation when cargo is transferring because of less stability of vessels due to high waves and strong currents.

Human factors

A Human error is sometimes described as being one of the following: an incorrect decision, an improperly performed action, or an improper lack of action (inaction).(Rothblum, 2000).

Studies have shown that human error contributes to:

- 84-88% of tanker accidents
- 79% of towing vessel groundings
- 89-96% of collisions
- 75% of allisions
- 75% of fires and explosions

The most important human factors challenges facing the maritime industry are mainly *fatigue, inadequate communications, inadequate general technical knowledge, inadequate knowledge of own ship systems and decisions based on inadequate information.*(Rothblum, 2000).

Reliability of equipment on vessels

Like all types of equipment or their components, equipment on vessels have their own failure rates during the life cycle, and the reliability of the equipment is relevant to failure rates directly. Based on discussion with our captains and chief engineers on boats, they said they dislike new built vessels, although all things on the vessel are new, because they were too tired and nervous when working on those kinds of vessels due to there were always problems during the first 2 years after delivery. But after a couple of years, the vessels conditions' are getting better and better, normally 3 years after vessel delivery, the captain and chief engineer are very confident to manage and control the vessels. But after 15 years, the problems arise again due to wear out failures, and more and more spare parts are required to be stored on boat. The following figure 7.1.1 shows the life cycle of components.

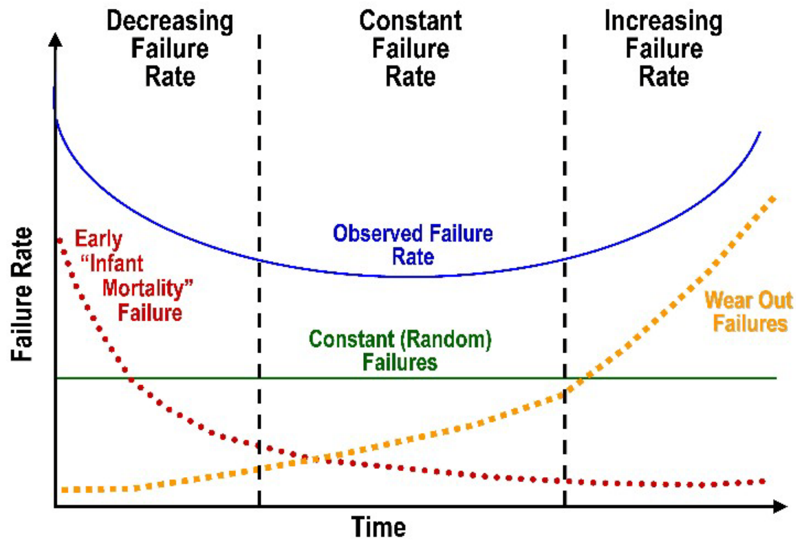


Figure 7.1.1 life cycle of components

(http://upload.wikimedia.org/wikipedia/commons/6/6e/Bathtub_curve.jpg)

7.2 Qualitative risk analysis

With regard to the risks mentioned above, especially in the aspect of reliability of equipment on vessels, it is necessary to conduct reliability analysis during marine operations. Here we introduce three important tools for risk analysis: FMECA, FTA and ETA.

"FMECA is a methodology to analyze and discover all potential failure modes of a system, the effects these failures have on the system and how to correct and or mitigate the failures or effects on the system" (Markeset, 2012). A FMECA is a formal and systematic approach to identify potential system failure modes, the causes and effects of the failure occurrence on the system operation. It provides the basis for establishing corrective action priorities. In order to avoid or reduce failures as much as we possibly can during the phase of operation and production, a FMECA is necessary to be performed during the design and operation phase of a system. The FMECA worksheet for an electric winch on the deck is presented in Appendix B, in which the reducing risk measures are enclosed in column 11.

A FTA (Fault Tree Analysis) is one of the most used reliability and risk analysis methods, which uses a logical diagram to show the relation between system failures. An ETA (Event Tree Analysis) is used to study the consequences of the initiating event (failure) by providing a picture of the possible scenarios. The simulation of ETA and FTA is presented in Appendices C and D.

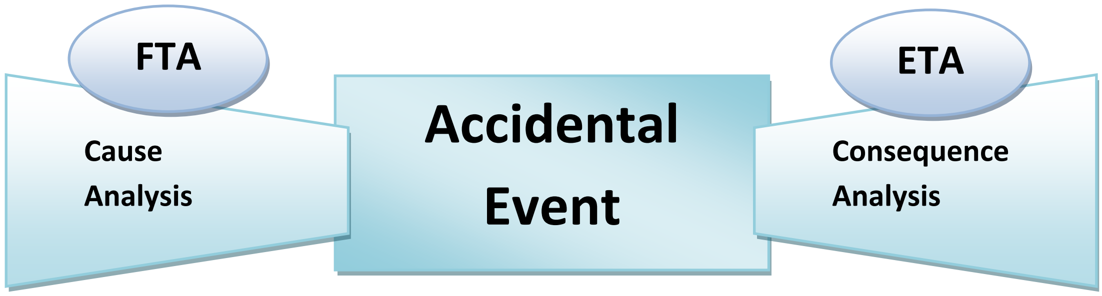


Figure 7.2.1 Demonstration of where to apply FTA and ETA

7.3 Methods to mitigate the risk

Besides reliability analysis during marine operations, the following methods could be necessary to mitigate the risk:

- Improve the accuracy of weather forecast, and study the meteorological condition of the work site before commencement of work.
- Equip advanced devices for weather forecast, for instance, wind indicator, wave detector, echo sounder, and so on.
- Orientation and training are always the most important for employees.
- Condition monitoring and periodical check of equipments are important for vessels' maintenance.

7.4 Case study (the loss of "Bourbon Dolphin")

OSVs seem safer and higher stability, when comparing with conventional cargo ship, because of easy maneuverable design. Actually, it is more dangerous than cargo ship when carry out the job of anchor handling or towing. The accident of Bourbon Dolphin's capsizing was one of the most serious cases within the offshore oil and gas industry in the past decade. Extracts from the police report (Police, 2008) of the Bourbon Dolphin is shown in table 7.4.1.

Time and date:	17:08 on Friday 12 April 2007.
Place:	Rosebank, West of Shetland. (Water depth: ~1100m)
Vessel name:	Bourbon dolphin (12000KW DP-2 AHTS)
Rig:	Transocean Rather (semi-submersible rig with 8 anchors)
Company:	Chevron
The accident: The ocean depth in the area concerned is 1,100m. The rig is moored with eight anchors. The distance between the rig and the mooring positions was around 3,000m. The mooring lines were about 3,500m, of which about 900m was of 84 mm chain and about 920m of 76 mm chain, plus 1,725m of 96 mm wire. Deployment of anchors was done by means of the vessel running out the rig's chain, connecting it to chain that the vessel had on board, whereupon the rig ran out wire. The anchor that was fastened to the vessel's chain was thereafter lowered down to the seabed with the aid of the vessel's winch and wire. During the last part of the deployment, another vessel participated by grabbing hold of (grappling) the chain so as to distribute the weight of the mooring and relieve the strain on the rig. Around 09:00 on Friday 12 April 2007 the "Bourbon Dolphin" began to run out chain for the last anchor (no. 2). Around 14:45 all the chain was out. The "Bourbon Dolphin" then drifted considerably off the mooring line and asked the rig for assistance. The "Highland Valour" was sent to assist the "Bourbon Dolphin", but did not succeed in securing the chain. The "Bourbon Dolphin" drifted eastwards towards the mooring of anchor no.3. The rig instructed the vessels to proceed westwards, away from anchor no. 3. During an attempt to manoeuvre the vessel towards the west, at the same time as the chain's point of attack over the stern roller shifted from the inner starboard towing-pin to the outer port towing-pin, the vessel developed a serious list to port. The engines on the starboard side stopped. The vessel at first righted herself, but soon listed again and at 17:08 rolled over on her port side. The "Bourbon Dolphin" had a crew of 14 persons. Also on board was the master's 14-year-old son. Seven persons were saved. The bodies of three persons were found in the sea, the remaining five persons are still missing. Key conclusions: ● The vessel's stability-related challenges were not clearly communicated	

from shipyard to company and onwards to those who were to operate the vessel.

- Under given load conditions the vessel did not have sufficient stability to handle lateral forces. The winch’s pulling-power was over-dimensioned in relation to what the vessel could in reality to withstand as regards to stability.
- The anchor-handling conditions prepared by the shipyard were not realistic. Nor did the Norwegian Maritime Directorate’s regulatory system make any requirement that these be approved.
- The company did not make sufficient requirements for the crew’s qualifications for demanding operations. The crew’s lack of experience was not compensated for by the addition of experienced personnel.
- The master was given 1.5 hours to familiarize himself with the crew and vessel and the ongoing operations. In its safety management system the company has a requirement that new crews shall be familiarized with (inducted into) the vessel before they can take up their duties on board. In practice the master familiarizes himself by overlapping with another master who knows the vessel, before he himself is given the command.
- The vessel was marketed with continuous bollard pull of 180 t. During an anchor-handling operation, in practice thrusters are always used for maneuvering and dynamic positioning. The real bollard pull is then materially reduced. The company did not itself investigate whether the vessel was suited to the operation, but left this to the master.
- In specifying the vessel, the operator did not take any account of the fact that the real bollard pull would be materially reduced through use of thrusters. In practice the “Bourbon Dolphin” was unsuited to dealing with the great forces to which she was exposed.
- The mooring system and the deployment method chosen were demanding to handle and vulnerable in relation to environmental forces.
- Communication and coordination between the rig and the vessel was defective during the last phase of the operation.
- There was lack of involvement on the rig when the “Bourbon Dolphin” drifted.
- The roll reduction tank was most probably in use at the time of the accident.

- The inner starboard towing pin had been pressed down and the chain was lying against the outer starboard towing pin. The chain thereby acquired a changed angle of attack.

Table7.4.1: Extracts from the police report of the Bourbon Dolphin (Police 2008)

7.5 Hazard identification for OSV vessel operations

We discussed risk related to three main aspects: physical environment, human factors, and equipment on vessels. There are many kinds of marine operations with regard to the offshore oil and gas industry, and we will just identify the risks existing in the operation of *supply job* for platform, which is the most frequent job the OSVs carry out in daily work.

7.5.1 Method of hazard identification

The hazard identification in a maritime operation can be analyzed qualitatively. In practice, a Risk Assessment Matrix is a good tool to determine which risks we need to develop a risk response for. In this method, the risk is defined by the product of two factors related to the operation:

1) The likelihood of the accident occurring (L); and

2) The impacts of consequences (C), which include the factors of personal injury, environmental pollution, and property loss.

Every factor will be rated in a seriousness grades. The final result of the risk assessment (R) is the product of the grade of two factors, that is, R = L *C.

First, we define the rating scales for likelihood and impact of consequences.

Here's Likelihood Scale definition, Figure 7.5.1.1:

Rating (grade)	Likelihood	Description
1	Very Low	Highly unlikely to occur. May occur in exceptional situations.
2	Low	Most likely will not occur. Infrequent occurrence in past projects.

3	Moderate	Possible to occur.
4	High	Likely to occur. Has occurred in past projects.
5	Very High	Highly likely to occur. Has occurred in past projects and conditions exist for it to occur on this project.

Figure 7.5.1.1 Likelihood Scale definition

Here's an Impact Scale definition, Figure 7.5.1.2:

Rating (grade)	Impact	personal injury	environmental pollution	property loss
1	Very Low	No person injury	No impact to environment	＜10 thousands USD
2	Low	No person injury	Slight impact to environment	10 -100 thousands USD
3	Moderate	1 person injury	Slight impact to environment	100 thousands -1 million USD
4	High	2 or more person injury	Medium impact to environment	1 – 10 million USD
5	Very High	1 or more person dead	Heavy impact to environment	Over 10 million USD

Figure 7.5.1.2 Impact Scale definition

Risk classification, Figure 7.5.1.3:

R=L*C	Risk level
Minor	Level 1
Moderate	Level 2

Major	Level 3
Severe	Level 4

Figure 7.5.1.3 Risk classification

Note:

Level 1: Normal risk, attention.

Level 2: Significant risk, needs rectification.

Level 3: High risk, rectify immediately.

Level 4: Very dangerous, stop work.

Risk Assessment Matrix:

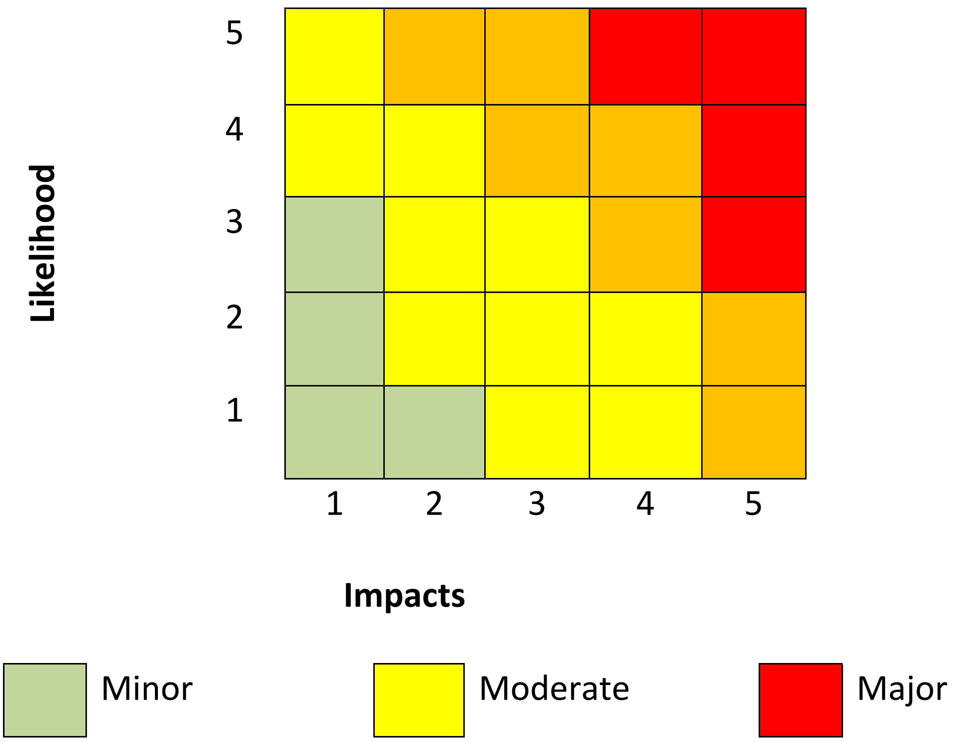


Figure 7.5.1.4 Risk Assessment Matrix

7.5.2 Risk assessment of marine operations

Figure 7.5.2 Risk assessment of marine operations

No.	Operation/ activities		Risk resource	Possible consequence	Likelihood (L)	Impacts of consequence (C)	Risk grade (R)	Risk level
1	Supply job	Berth to platform	Harsh sea condition or Captain's technology shortage	Collision with platform	1	1or 2 (no person injury, No impact to environment, Below 100 thousands USD's property loss)	1 or 2	Level 1
2		Transfer deck cargo to platform	Harsh sea condition or unsmooth communication between captain and crane driver	Cargo hit against the deck, Cargo loss into the sea, Person injury	2	3 (1 person injury, Slight impact to environment, Below 1 million USD's property loss)	6	Level 2
3		Transfer liquid mud from tank to platform	Harsh sea condition or poor skill of sailor	Liquid mud spilled into the sea	1	2 (no person injury, Slight impact to environment, Below 100 thousands USD's	2	Level 1

						property loss)		
4		Transfer fuel oil from tank to platform	Harsh sea condition or poor skill of sailor	Fuel oil spilled into the sea	1	5 (no person injury, Heavy impact to environment, Much money to get rid of fuel oil)	5	Level 3
5		Transfer fresh water from tank to platform	Harsh sea condition or poor skill of sailor	Fresh water spilled into the sea	1	1 (no person injury, No impact to environment, Below 10 thousands USD's property loss)	1	Level 1
6	Towing & positioning job	Connect towing line between MODU and main tug	Unsmooth communication between captain and MODU, Poor skill of deck operation	Failure of getting connected	2	1 (no person injury, No impact to environment, Below 10 thousands USD's property loss)	2	Level 1
7		Towing	Harsh sea condition or high speed for towing	Towing line break	1	3 (1 person injury, No impact to environment, Below 1 million USD's	3	Level 2

						property loss)		
8		Positioning	Harsh sea condition or poor skill of captain	Failure to position on right point	1	4 (No person injury, No impact to environment, Below 10 million USD’s property loss)	4	Level 2
9		Avoid typhoon during towing job	Weather forecast receiver’s failure or wrong decision from captain	Damage of ship, Persons injury or death	1	5 (Persons injury or death, huge impact to environment, over 10 million USD’s property loss)	5	Level 4
10	Anchor handling job	Deploy anchors of rig	Failure of shark jaw or deck crew’s poor skill	Anchor missing, Persons injury	1	4 (Person injury, no impact to environment, below 10 million USD’s property loss)	4	Level 3

7.5.3 Risk reduction measures of marine operations

Figure 7.5.3 Risk reduction measures of marine operations

No.	Operation/ activities		Risk resource	Possible consequence	Risk grade (R)	Risk level	Risk reduction measures
1	Supply job	Berth to platform	Harsh sea condition or Captain’s technology shortage	Collision with platform	1 or 2	Level 1	Study sea condition on the location of platform before berth job, including wind, wave, current; Send the captain who has rich experience doing such job.
2		Transfer deck cargo to platform	Harsh sea condition or unsmooth communication between captain and crane driver	Cargo hit against the deck, Cargo loss into the sea, Person injury	6	Level 2	Do this job in good sea condition; Keep smooth communication between captain and crane driver; Safety training to deck crew before operation.
3		Transfer liquid mud from tank to platform	Harsh sea condition or poor skill of sailor	Liquid mud spilled into the sea	2	Level 1	Do this job in good sea condition and strictly following the working plan and procedure; Making the emergency plan for such operation.

4		Transfer fuel oil from tank to platform	Harsh sea condition or poor skill of sailor	Fuel oil spilled into the sea	5	Level 3	Do this job in good sea condition and strictly following the working plan and procedure; Making the emergency plan for such operation. Prepare anti-pollution equipments before such job.
5		Transfer fresh water from tank to platform	Harsh sea condition or poor skill of sailor	Fresh water spilled into the sea	1	Level 1	Do this job in good sea condition and strictly following the working plan and procedure
6	Towing & positioning job	Connect towing line between MODU and main tug	Unsmooth communication between captain and MODU, Poor skill of deck operation	Failure of getting connected	2	Level 1	Training before such operation; Keep smooth communication between captain and MODU; Deck equipments check before operation
7		Towing	Harsh sea condition or high speed for towing	Towing line break	3	Level 2	Pay attention on tension condition of main towing line; Keep a safety and economic speed; Careful double check on towing line before towing job.

8		Positioning	Harsh sea condition or poor skill of captain	Failure to position on right point	4	Level 2	Study the right location point of positioning; Have a check on the GPS receiver;
9		Avoid typhoon during towing job	Weather forecast receiver's failure or wrong decision from captain	Damage of ship, Persons injury or death	5	Level 4	Pay attention on weather forecast and ensure the weather forecast receiver is in good condition; Avoid the typhoon as per the planning and procedures, as well as experience of captain
10	Anchor handling job	Deploy anchors of rig	Failure of shark jaw or deck crew's poor skill	Anchor missing, Persons injury	4	Level 3	Training for deck crew before anchor handling job, Careful double check on deck equipments before job, Keep safety distance when operation.

8. Conclusions and Recommendations

Conclusions

Offshore support vessels always play a most important role in the process of offshore oil and gas exploration and production. In this paper we have introduced the types and functions of OSV, relevant regulations and Main classification societies, relevant development trends in the offshore oil and gas industry, as well as design trends for OSV. In addition, we were looking into China OSV market and South China Sea. Risks during operation were analyzed as well. It is the hope that the information presented will be helpful in the design of vessels, especially for the Chinese market.

Recommendations

"Deepwater" would be the key word in the offshore oil and industry in the future, so harsh physical environment and long distances from the logistic base, would be taken into account during the phase of a vessel's design. Meanwhile, as people pay more and more attention to the safety and environment protection, oil companies look for advanced boats to meet the requirements of offshore facilities. The following technology and design would be increasingly popular:

DP-2 or DP-3 systems now have become standard configurations in the requirements of the Oil Company, for the reason of high reliability and economical fuel consumption.

Diesel Electric propulsion, which could obviously reduce fuel consumption, is welcomed by the Oil Company, because of relevant low use-cost of vessels.

Azimuth propulsion system, comparing with conventional propulsion system, it is easier for the captain to control the boat, and provide safer services for Company.

FIFI-1 system, which could pump water 2400m^3/hour for firefighting, is getting more welcomed, especially after the accident of DEEPWATER HORIZON.

Automated work deck systems, which remove crew or deck personnel from hazardous areas, thereby reducing risk and injuries by way of crewmembers operating remote controls.

Concept of subsea, such as design for ROV or well intervention equipment, is getting increasingly important, because after decades of production or operation, more and more subsea facilities of oilfield (especially for old oilfield) are facing frequent maintenance and repair work.

Reference list

ABS 2011. GUIDE FOR BUILDING AND CLASSING. *OFFSHORE SUPPORT VESSELS.* HOUSTON: American Bureau of Shipping.
AMERICA, V. O. 2011. *Maritime claims in the South China Sea* [Online]. wikipedia. Available: http://en.wikipedia.org/wiki/File:South_China_Sea_claims.jpg [Accessed 2013].
BACKWELL, G. 2012. *Advanced Power & Propulsion Monitoring System – 'HEMOS'* [Online]. Available: http://articles.maritimepropulsion.com/article/Advanced-Condition-Monitoring-System-by-Rolls-Royce-5368.aspx [Accessed 2012].
BALCHEN, J. G., JENSSEN, N. A., MATHISEN, E. & S LID, S. 1980. A dynamic positioning system based on Kalman filtering and optimal control.
CHEN, W. 2009. Going Deeper: China's Offshore Oil and Gas Industry. Osaka, Japan.
CHU, P. C., QI, Y., CHEN, Y., SHI, P. & MAO, Q. 2004. South China Sea Wind-Wave Characteristics. Part I: Validation of Wavewatch-III Using TOPEX/Poseidon Data. *Journal of atmospheric and oceanic technology,* 21**,** 1718-1733.
DAW, C. 2012. *What Is a Moon Pool* [Online]. Wisegeek. Available: http://www.wisegeek.com/what-is-a-moon-pool.htm [Accessed].
DNV 2011. RULES FOR CLASSIFICATION OF SHIPS. *SPECIAL SERVICE AND TYPE -OFFSHORE SERVICE VESSELS,TUGS AND SPECIAL SHIPS.* Høvik, Norway: DET NORSKE VERITAS.
GUDMESTAD, O. T. 2012. Challenges Faced by the Marine Contractors Working in Western and Southern Barents Sea. *Offshore Technology Conference.* Houston, Texas, USA.
HUMPHRIES, M. 2010. *US Offshore Oil and Gas Resources: Prospects and Processes*, DIANE Publishing.
HWANG, J. K., CHUNG, D. U., HA, S. & LEE, K. Y. Year. Study on the safety investigation of the free-fall lifeboat during the skid-launching test. *In:* OCEANS, 2012-Yeosu, 2012. IEEE, 1-5.
INSTITUTE, M. 2012. *Deepwater ROV* [Online]. Available: http://www.marine.ie/home/services/researchvessels/ROV.htm [Accessed 29th, Nov 2012].
POLICE, T. R. N. M. O. J. A. T. 2008. The Loss of the "Bourbon Dolphin" on 12 April 2007. Oslo.
RAMSEUR, J. L. 2010. Deepwater Horizon oil spill: The fate of the oil.
ROLLS-ROYCE. 2013. *Platform supply vessels* [Online]. Available: http://www.rolls-royce.com/marine/ship_design_systems/ship_designs_offshore_vessels/platform_supply_vessels.jsp [Accessed 5th, Jan 2013].
ROSE, R. S. K. 2011. *Future Characteristics of Offshore Support Vessels.* Massachusetts Institute of Technology.
ROTHBLUM, A. M. Year. Human error and marine safety. *In:* Maritime Human Factors Conference, 2000. 13-14.
SANO, M., HUANG, W., PENFOLD, M., OZAKI, Y., HE, C. & LESZCZYNSKI, M. Year. Design Issues and Trends for the New Generation of Offshore Support Vessels. *In:* Offshore Technology Conference, 2012.
SUBSEA7. 2011. *ROV Fleet* [Online]. Available: http://www.subsea7.com/files/docs/Datasheets/ROV/ROV_Fleet.pdf [Accessed 2012].
ULSTEIN 2011. X-BOW Hull Line Design.
WALSH, T. 2009. *MBARI's new robot submarine completes first research dives* [Online]. Monterey Bay Aquarium Research Institute. Available: http://www.mbari.org/news/homepage/2009/rov-ricketts.html [Accessed].
WIKIPEDIA. 2012. *Det Norske Veritas* [Online]. Available: http://en.wikipedia.org/wiki/DNV [Accessed 28th, nov 2012].

WRIGHT, B., TIMCO, G., DUNDERDALE, P. & SMITH, M. Year. An overview of evacuation systems for structures in ice-covered waters. *In:* Proceedings of the 17 International Conference onthPort and Ocean Engineering under Arctic Conditions POAC'03, 2003. 765-774.
ZIJDERVELD, G., TIEBOUT, H., HENDRIKS, S. & POLDERVAART, L. Year. Subsea Well Intervention Vessel and Systems. *In:* Offshore Technology Conference, 2012.

Appendices

Appendix A – Main equipments' providers of HAIYANGSHIYOU681

Equipments	type	Provider
Main engine	WARTSILA16v32/40 8000KW*2	WARTSILA
Generator	AVK 2200KW 690V/60HZ	ABB(AVK)
Bridge control system	AUT-0	RRM
DP system	DP2	RRM
Propeller	2 X Rolls-Royce in kort nozzles, Kamewa D4800mm	RRM
Thruster	TCNS92/62-220,1500kw	RRM
Propulsion control system	Helicon X3	RRM
Gearbox	GUCK 1370	RRM
Stern roller	L6000mm(2rollersx2996mm)XD4500mm, MWL,750T	RRM

Specification of HAIYANGSHIYOU 681

HAI YANG SHI YOU 681

GENERAL DATA

Year Built	2011
Builder	Wuchang Shipbuilding Industry Company LTD
Design	Rolls-Royce
Type	AHTS
Registry Port	Zhanjiang
IMO NO.	9561849
Call Sign	BYGD
Flag	CHINA
Classification	CCS
Class Notation	*CSA Offshore Tug/Supply ship,Stand-by Ship, Anchor Boat,Oil Recovery Ship B, Fire Fighting Ship 1,Water Spraying, Ice Class B, Strengthen Deck, Max. Cargo Density in Mud Tank(2.8 t/m3), Clean Plus, Loading Computer(S,I,D) , COMF(NOISE)3, COMF(VIB)3, NAV-OSV, In-Water Survey, *CSM AUT-0, DP-2, PR-2, SCM, CMS

MAIN DIMENSIONS

L.O.A.	93.4 m
B. Mld.	22 m
D. Mld.	9.5 m
Draft Load	9.1 m
Draft Light	6.38 m
Gross Tonnage	6889
Net Tonnage	2066
Deadweight	4700t

PERFORMANCE

Maximum Speed	18.0 knots
Economic Speed	10-12.0 knots
Bollard Pull	Max. 300tons, Cont. 290 tons

DECK CAPACITIES

Deck Area	43.3 m x 18.8 m. 810 sq.m
Deck Cargo	2000t
Deck Strength	10 t/sq.m

CARGO CAPACITIES

P. Water	1100cu.m
D./B. Water	3300cu.m
Diesel Oil	1100+1710.0 cu.m.(Including combination tanks mud/brine)
Bulk	260 cu.m (4 tanks)
Liquid Mud / Brine	710.0 cu.m. (6 tanks)
Base Oil	220.0 cu.m
Oil Recovery	940.0 cu.m.(4 Mud/Brine + centre F.O. tk.)

DISCHARGING RATES

P. Water	2 x 150 cu.m. /hr. at 0.9Mpa
D./B. Water	2 x 250 cu.m. /hr. at 0.9Mpa
Diesel Oil	1 x 150 cu.m. /hr+1 x 125 cu.m. /hr.at 0.9Mpa
Bulk	2 x 60 cu.m/hr. at 0.56Mpa
Liquid Mud	2 x 100 cu.m. /hr. at 2.4Mpa
Base Oil	1 x 125 cu.m. /hr. at 0.9Mpa
Oil Recovery	1 x 75 cu.m. /hr. at 1.8Mpa

ACCOMMODATION

Crew	18
Passenger	42（可通过改装增加36人，即78人）

MACHINERY&PROPULSION

Main Engine	2 x WARTSILA16v32/40
Main Power	2 x 8000KW, Total 21768 HP
Total Power	2 x 8000kW M/E + 2 x 3000Kw PTI (Hydbri) + 1500kW (A-Z Swing-up)
Propeller	2 x Rolls-Royce in kort nozzles, D4800mm
Generator Sets	Auxiliary Generator: 4 x 2200KW 690V/60HZ Shaft Generator: 2 x 4000KW 690V/60HZ Emergency generator: 1 x 400kW690V/60HZ
Bow Thruster	2 x 1000KW(Tunnel); 1 x 1500kW(A-Z Swing-up)
Stern Thruster	1 x 1000KW(Tunnel); 1 x 1500kW(A-Z Swing-up)

TOWING & AH EQUIPMENT

Winch	Rolls-Royce SL500W/2BSL450WX
Towing Drum	Working Drum Cap: D76mm x 14800m+D90mmx3500m
Towline	D90mm x 2000m
AH Wire	D90mm x 2500m
Secondary Winch	Rolls-Royce 2SL170WX(Drum Cap: D168mm x 11000m
Stern Roller	L6000mm(2rollers) x D4500mm,MWL,750T
Towing Pins	2sets/vessel Max Working Lord: 400T
Shark Jaw	2sets/vessel Max Working Lord: 800T
SDO Crane	2sets/vessel SWL10-14,3m: 3 T(SWL3,2-10m:5 T)

SAFETY & FIFI & ANTIPOLLUTION EQUIPMENT

Life Raft	3 x 25 persons x 2(PORT&STBD)
Rescue Boat	1set x 6Persons: Max speed≥28kn, With 3persons Water jet
FiFi	FiFi 1 +water spray .Capacity: 2400m3/h at 140mlc
Antipollution	Dispersant Tank: Spraying Arm:

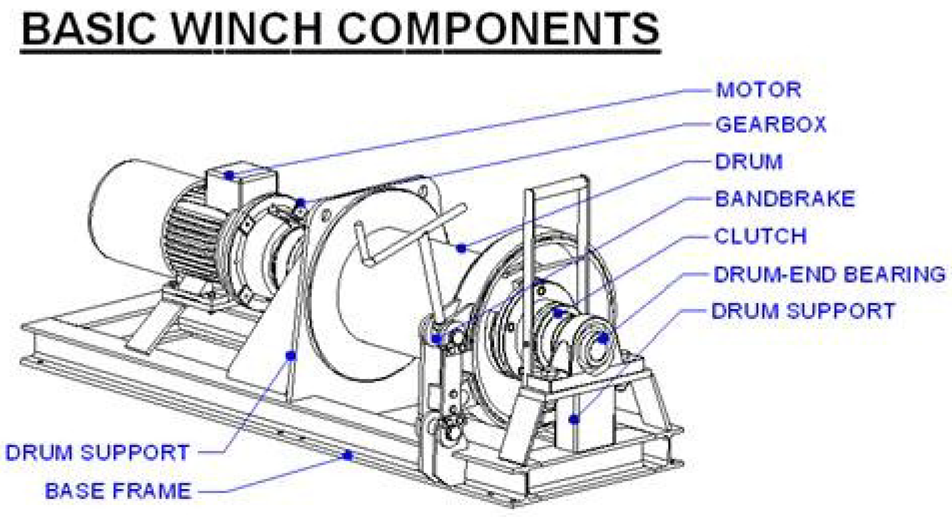
NAVIGATION & COMMUNICATION

Gyro-Compass	3 x NAVIGAT x MK 1
Magnetic Compass	1 x NAVIPOL I
Radar	1 x VisionMaster FT; 1 x VisionMaster FT
INMARSAT-C	2 x TT-3000E
INMARSAT-F	1 x SAILOR 500
SSB	SAILOR SYSTEM 5000
VHF	2 x SAILOR RT5022; 2 x SAILOR RT 2048
GPS	2 x GP150
Facsimile	1 x FAX-408
Wind Indicator	DEIF WSDI-2
Echo Sounder	1 x GDS102
Autopilot	1 x NAVIPILOT 4000
Radio	SAILOR SYSTEM 5000
EPIRB	E5
NAVTEX	NX-700A
Wave Detector	Miros Wavex
Electronic Chart System	2 x VisionMaster FT ECDIS

DYNAMIC POSITIONING SYSTEMS

DP2, Rolls-Royce

Appendix B - FMECA of an electric winch



Resource: http://www.engineerszone.net/2010/11/basic-winch-components.html#!/2010/11/basic-winch-components.html

Description of unit				Description of failure			Effect of failure		Failure rate (1-5)	Severity ranking (1-10)	Risk reducing measures	Comments
Ref.no	**components name**	**Function**	**Operational mode**	**Failure mode**	**Failure cause or mechanism**	**Detection of failure**	**On the subsystem**	**On the system function**				
1	Motor	drive the winch	normal operation	unstable running	gears are overweared	abnormal vibration	In long run, rotate gears may be damaged	None, but eventually will disrupt the gas treatment process	3	2	Regular maintenance check	
					input voltage is unstable	unstable rotate speed	No local effect		4	1	Regular maintenance check	
2	Braker	brake the winch	normal operation	low efficiency	brake oil leakage	low efficiency	No local effect	wire may be released	3	4	Regular maintenance check	
					brake pad is overweared	abnormal noise	In long run, brake pad may be damaged		4	2	Regular maintenance check	
3	Wire	pulling	normal operation	strand broke	wire is overweared	visual detection	In long run, wire may be broken	operator may be injuried	4	4	Regular maintenance check	
4	Foundation	fix the winch	normal operation	winch movement	screws are loose	abnormal vibration	No local effect	operator may be injuried	3	4	Regular maintenance check	

Note:

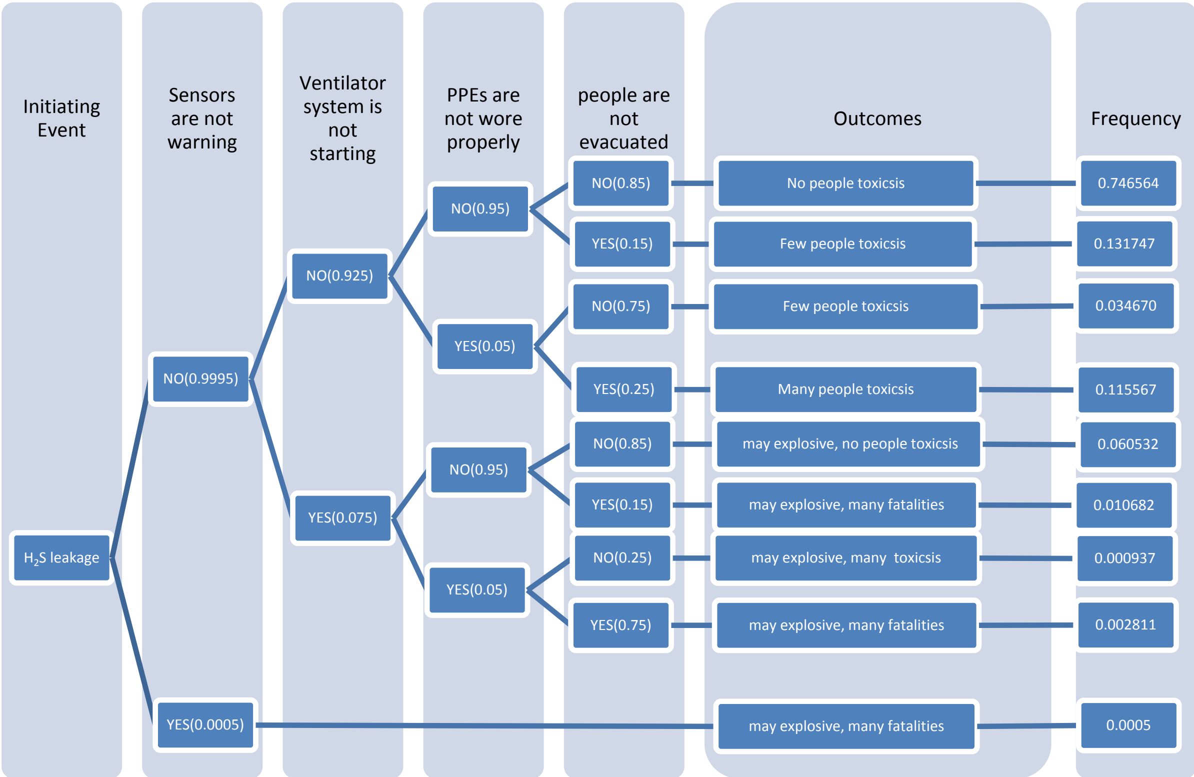
Frequency(failure rate)

Rate	Description	
1	Very unlikely	Once per 1000 years or more seldom
2	Remote	Once per 100 years
3	Occasional	Once per 10 years
4	probable	Once per year
5	Frequent	Once per month, or more often

Severity Ranking

Rank	Severity class	Consequences		
		People	**Assets**	**Environment**
10	Catastrophic	Multiple fatalities	Damage	Massive effects
7-9	Critical	Single fatality	Major damage	Major effects
4-6	Major	Major injury	Local damage	Local effects
1-3	Minor	Minor or zero injury	Slight or Zero damage	Slight or Zero damage

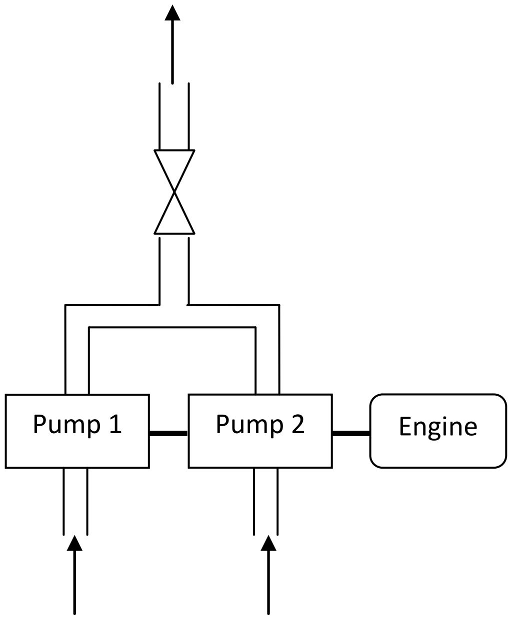
Appendix C - ETA of H_2S leakage

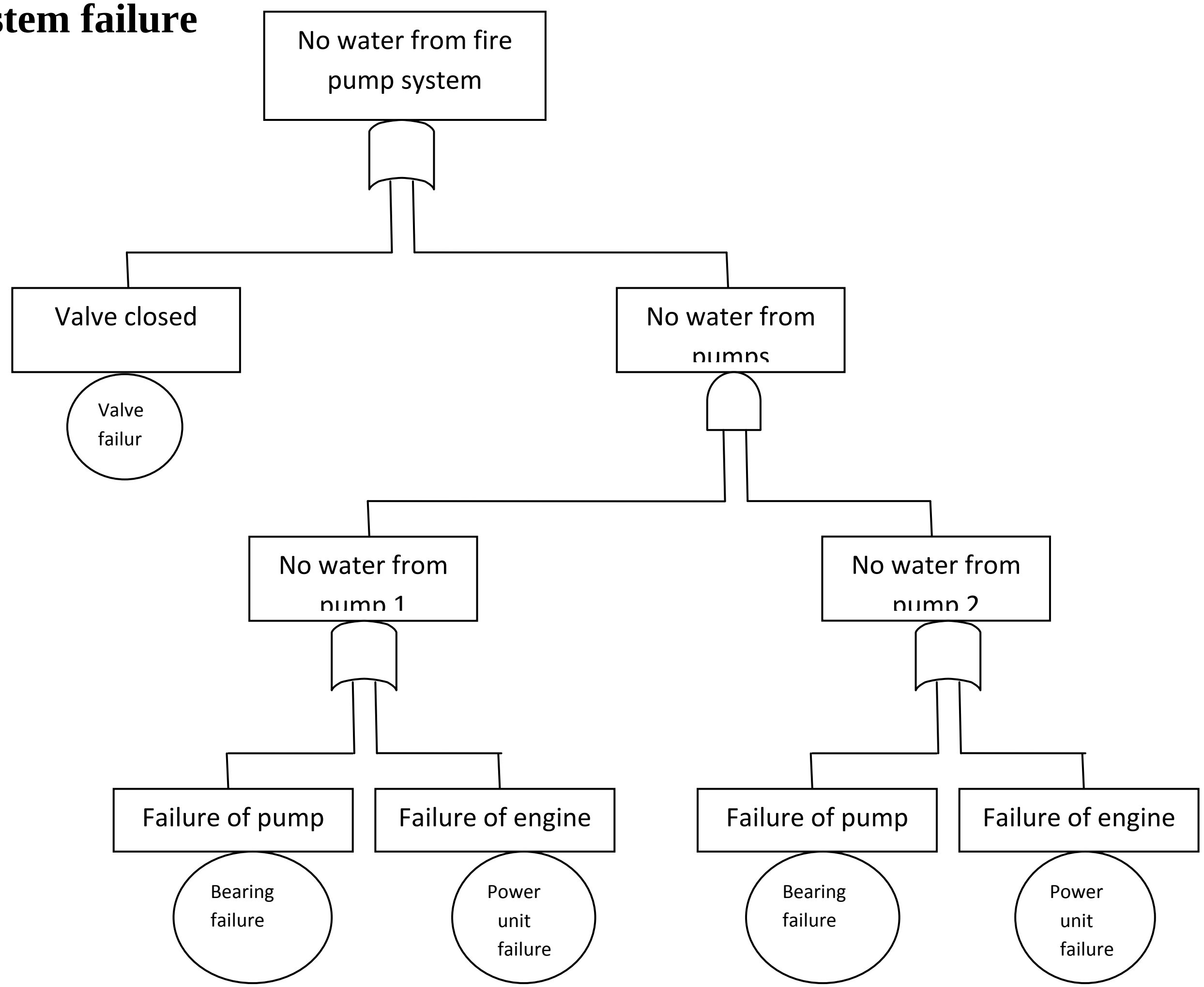


Ref: SPE-98504-MS-P,

Title	**Management of H2S Risk in Total ABK**
Authors	B. Dagtas, O. Garnier, and G. Noble, Total ABK
Source	SPE International Health, Safety & Environment Conference, 2-4 April 2006, Abu Dhabi, UAE
ISBN	978-1-55563-237-3

Appendix D - FTA of Fire-fighting system failure





Ref: Rausand and Høyland: System Reliability Theory (Second Edition), Wiley, 2004