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MASTER'S THESIS

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Writer: LIU, HONG GANG (Stud. No: 214765)	………………………………………… (Writer's signature)
Faculty supervisor: **Jayantha Prasanna Liyanage, UiS**	
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This thesis is submitted as a partial fulfillment of the requirements for the Master degree of Industrial Asset Management at the University of Stavanger (UIS), Norway. The thesis is carried out on the COSL's first ultra-deep water drilling platform HYSY981 in the period from September, 2009 to March, 2013.

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Abstract

The offshore deep water drilling has attracted global attention since the Macando blowout. It raised worldwide concern on the safety level of oil & gas industry and resulted in directly influence on offshore drilling activity. The thesis start from the introduction of offshore drilling, and the development of global oil & gas market, then come back to China, and generally described the history of offshore petroleum exploration and production in South China Sea and the deep water activity. Then this thesis centered on the offshore deep water drilling process, cooperated with the general work flow of drilling operation on COSL's 1st deep water drilling unit HYSY981 to build up a general work flow map. Identify the critical activities from risk prospective, clarify the risk level of different activity and find out the related issues that contribute to the risk and efficiency by using different kind of risk analysis tools.

The thesis starts from the background of the offshore drilling industry, and introduces current situation and developing trends of offshore deep water drilling. Then the author turns his sight into China and introduces the development process of China offshore petroleum industry.

In the following chapter is the theoretical basis of further study. This part discusses drilling risk, maintenance activities, human factors and work optimization, and develops the relationship of them.

Use the risk analysis tool, bow-tie diagram and risk matrix, related to the practical operation on the rig, the work flow map is used and choose running/pulling BOP as a specific activity to do further study. Using of the concept of integration of risk analysis, equipment maintenance activities, and human factors to improve the safety level and operation performance.

I will conclude from the discussion, and come back to the very basic point: safety and performance issue. By describing the implementation of risk analysis, maintenance activities, and human factors in BOP operation, we could explore their contribution to work optimization and how do they impact on the operation. The author still introduces the success factors and stimulus for work optimization, and then briefly concludes the work optimization points on running/pulling BOP operation.

At last, we will provide two simple cases that have been implemented on the rig. Basic risk analysis tools and minor modification has significant contribution on safety and work performance.

Key words: risk-based analysis; maintenance; human factors; work optimization; running BOP; deep water drilling operation.

Table of Content

1. Introduction

1.1 Background

The modern offshore drilling industry started in 1947, when the first offshore well was drilled out-of-sight of land in the water depth about 20 feet from a fixed platform. (Odland 2011) This symbolized the beginning of offshore drilling. In 2011, Transocean Ltd. announced the world water-depth record in offshore drilling by the ultra-deep water drillship Dhirubhai Deep water KG2 in 10,194 feet of water. (Transocean 2011) The water depth of offshore drilling is getting deeper and deeper, and the output of the deep water oilfield share an increasing part of the total production. For example, in Gulf of Mexico, the active drilling units operating in deep water account 60% of total drilling fleet and the deep water production contributes 18% of the US gross production. (figure 1.1.)

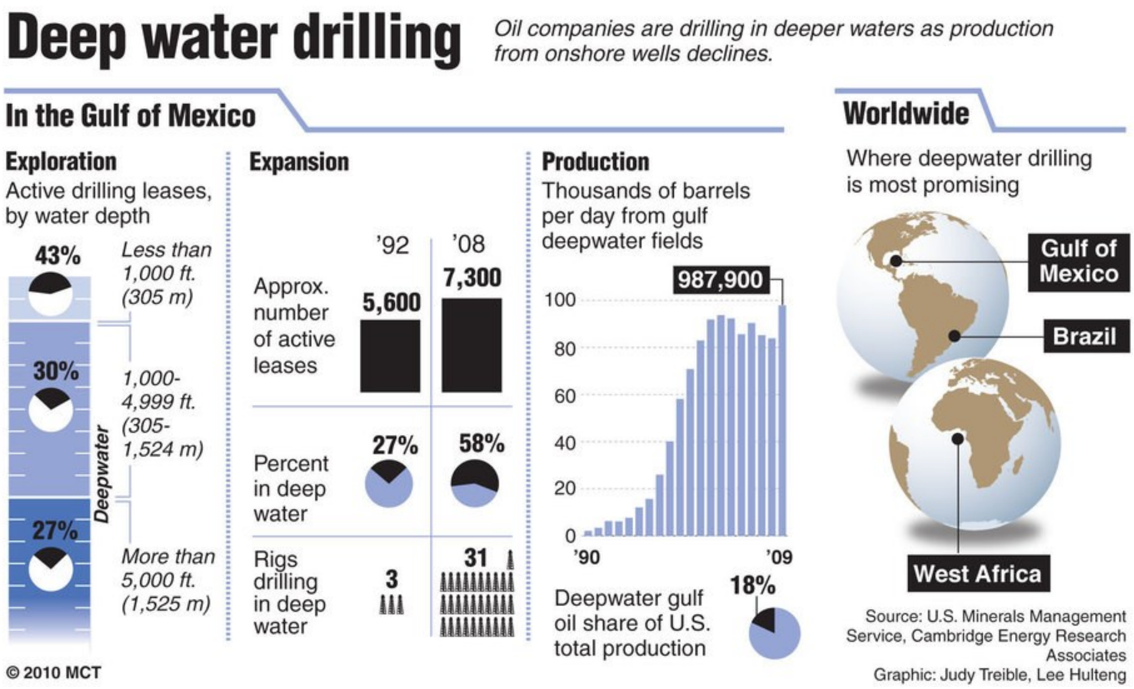

Figure 1.1 The developing trend of deep water drilling activities (Mcclatchy 2010)

Benefit from the technology development in offshore exploration and drilling, offshore oil production has played an important role in the petroleum industry, and contributes about one third of total world production. Offshore production has grown consistently and steadily for more than 5 decades and it has been the main source of global oil supply. (Sandrea and Sandrea 2007) This can be found from the figure 1.1 and 1.2. From the Figure 1.3, we can find that the most productive regions of offshore oil in the world. There are: Persian Gulf, North Sea, West Africa, Gulf of Mexico and Asia/Australia. They play a crucial role in the energy supply market in the world and will become more critical in the future. Especially in the new emerged production regions, such as Brazil and China, etc. Brazil started offshore operation in 1973, and the giant discoveries came from offshore boosted the country to be a fast growing country in petroleum production. The offshore production contributes about 80% of the total output which makes Brazil the third largest oil producer in the west hemisphere.

China is the world's most dynamic country with largest population in the world and vast geographic area. This made her the largest energy consumer in the world, and the second in petroleum consumption. (CIA 2012)

China started its offshore petroleum drilling in 1960s, and completed the first exploration well in Yinggehai area of South China Sea in 1965. Since then the exploration and production activities in the coastal area kept developing, at the end of 2010 the annual production of oil equivalent from offshore already surpassed 50 million cubic meters, which made a significant contribution to the country's energy supply. The offshore oil production has become one of the critical succeeding areas of petroleum resources. But after about 40 years of development in shallow water around the coastal area of China, the potential for further increment of production is limited. At the same time, the discovery has been made in deep water area, especially in South China Sea. Only 160,000 square kilometers has been explored in South China Sea, over 5.2 billion tons of crude oil has been discovered. (Qian 2006) The further prospect is even more exhilarated that there would be more than 20 billion tons of oil resources in this area where is regarded as "The 2nd Persian Gulf".

From figure 1.2, we can find that the offshore production of oil and gas only take a tiny proportion of total output between 1950s' and 1970s'. Since 1970s' the offshore oil production has grown consistently over 40 years and never experienced drastic downward fluctuations. In 2005, about 25 million barrels of oil per day (Figure 1.3) has been produced from offshore, representing 30% of global oil production. While onshore crude oil production is struggling to maintain the output level since sharp drop in early 1980s', the offshore production is playing a noticeable role in worldwide energy supply. Oil/energy demand is increasing, after over several decades of exploration and production, most of the onshore and offshore shallow water existing oilfields are getting to the tail-end of production. As we discussed previously, the deep water activities has a significant contribution to the total offshore production.

The Chinese company has realized the rapid growing in the deep water region and the challenges that would exist in activities. COSL (China Oilfield Service Limited) as the leader of China offshore drilling industry has been focusing on this area and set deep water drilling as its strategy in the following years. Once the strategy is set, the issue will come to how to operate the activity in deep water zone safely and efficiently. And the practice has started, symbolized by the first deep water unit HYSY981 starting its first well in South China Sea.

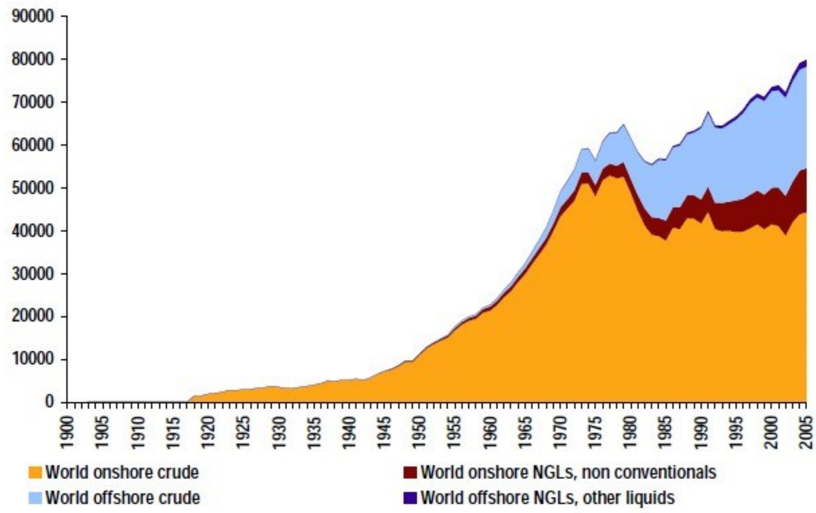

Figure 1.2 Historical global oil production split by offshore and onshore (kb/d)

(Sandrea and Sandrea 2007)

	Production Start-up	Daily Production (mb/d)	Cumulative Production (Bb)
Crude oil			
Persian Gulf/ME	1957	5.3	51
North Sea	1975	4.7	45
West Africa	1969	3.5	25
Mexico GoM	1960	2.6	20
Asia/Australasia	1960	2.1	21
U.S. GoM	1947	1.6	24
Brazil	1973	1.5	6
China	1980	0.6	2
Caspian	1950	0.4	1
Russia/Artic	1999	0.05	0
Others		0.8	2
Total NGls		1.6	7
World Offshore		**25**	**204**

Persian Gulf/ME: Egypt, Iran, Iraq, Neutral Zone, Kuwait, Qatar, Saudi, UAE.

North Sea: Denmark, Norway, UK.

West Africa: Angola, Cameroon, Congo, Equatorial Guinea, Gabon, Ivory Coast, Nigeria.

Asia/Australasia: Australia, Brunei, Indonesia, Myanmar, Malaysia, New Zeland, Thailand, Vietnam.

Caspian: Azerbaijjan, Kazhakastan, and bordering countries.

Others: mainly Argentina, Canada, Germany, India, Netherlands, Trinidad, Tunisia, Lybia.

NGLs: mainly Australia, Egypt, EQ, Iran, Nigeria, Norway, Trinidad, UAE, UK, US.

Source: IHSE, OPEC

Figure 1.3 **Largest offshore oil producing regions in 2005**

(Sandrea and Sandrea 2007)

1.2 Industrial Challenges In Deep Water Drilling

But there is a significant challenge standing in front of the development of offshore exploration and production: the water depth. To conquer the water depth, giant drilling facilities have been constructed to operate in deep water area, these facilities are equipped with most advanced equipment aim to perform operations safely and effectively. The sea environment also need to be considered, for instance, hurricane in Gulf of Mexico, typhoon in South China Sea, both have direct influence on offshore activities.

Except water depth, other characteristics of deep water drilling are the temperature gradient and narrow pressure window and young depositional formations. The temperature gradient of deep water is negative from surface to seafloor, but turns positive below sea bottom. This affects the drill fluid properties and same with the cement, which could cause gas hydrate and upgrade design in cement slurry composition. Beside this, the great water depth also causes narrow pressure windows of formations, which requires specific design on well casing schemes and close tolerance.

Riser manipulation is a noticeable challenge found in deep water drilling. One of the characteristics is the weight of riser string. Although further study is under going to develop innovative lighter risers, the handling of riser string and its related BOP stack is critical and challenging for deep water operation.

The petroleum drilling activities are management of people, equipment, and environment under specific regulations and laws from industry and government. For deep water drilling, the specific items listed above increase the cost and complexity in the work process, would require specific research work to manage the operation.(Rasheed 2002)

In this thesis, we will focus on the running BOP operation based on the basic operations process, identify the risk in each step and find out how we could conquer them and complete the drilling work flow safely and successfully, and satisfied by our client.

Firstly, for deep water drilling activity, as aforementioned, platforms are mainly constructed in recent 10 years. These units are equipped with advanced technological equipment and system, they are designed with high reliability, availability, maintainability and supportability, but it is still a big challenge for operation team working on the rig. In order to maintain the whole system functioning at their designed status, experienced and strong technician team is crucial and critical for the operation. Maintain high function level of the equipment and system on board is the basis for drilling operation. Then practical maintenance and routine inspection program is extremely important and efficient on site. BOP operation is a heavy duty operation involved various handling equipment. All equipment are closely related, one of them failed will cause the whole operation suspended.

Secondly, optimize the operation procedure. Procedure is the achievement of experience accumulation and data collection process of practical operation. The operation is carried out by following the existing procedures, and the iterative operation provides opportunities for optimizing procedures. Make effort on procedure optimization by after action review and search for improvement opportunities.

Thirdly, human factor is a significant performance influencing factor. People working on board are in an operational environment. The operation skill and capability of employee will directly impact the operation performance. Various human factors will be discussed and solutions will be provided in this thesis.

In order to demonstrate work optimization on BOP operation and the three challenges listed above, it is necessary to analysis the whole operation flow and identifies the risk level of each operation. By using the risk matrix, we can grade the risk level of critical operation. Then analysis it from maintenance, human factor and procedure optimization prospective to optimize the work and reduce the risk associated with the activity.

1.3 Scope and Objectives of the Thesis

This thesis is mainly focus on the analysis of operational process on a drilling platform. Start from introducing the background of offshore drilling industry, we describe the challenges and current status of deep water drilling activities.
The main part of the work will focus on BOP operation, analyzing drilling risk, maintenance activities, and human factors, and their function and contribution to operation safety and performance efficiency. We will demonstrate the influences of different factors from practical prospect and associate with onsite operation management to explore organic approach for work optimization.
We will still find out the success factors that could be helpful to implement work optimization and the work optimization points that we could be on BOP operation. At last, two simple cases will be introduced to show the way improve safety and work performance.

With respect to the scope this thesis covers the following aspects:

- Elaborate on the developing trend of deep water drilling industry;
- Identify and describe the issues and challenges associated with drilling risk, maintenance activities, operational procedures and human factors;
- Work out the general operation flow on a deep water drilling rig, and identify critical operation with high risk level;
- Elaborate on an approach to optimize procedure from risk, maintenance activities and human factor's prospective;
- Possible success factors that would promote the practice;

1.4 Methodology

The initial idea of work optimization for deep water drilling is from the author's personal working experience, and the significant downtime caused by the operational reason when the deep water drilling units started operation. Due to the high running cost and day rate of platform, both drilling contractor and operator are desire to improve safety and operation efficiency for operation activities.

The material is mainly from company reports, research papers, and the operation regulations and procedures that the author working with. Associate with the literature on risk analysis, maintenance and human factors, try to combine these factors into the process of operation. The author still goes through websites of world top contractors and search for development history and trend of drilling industry.

Based on the general drilling process, we set up the general work flow of offshore drilling process. Safety is the first priority for the offshore drilling, so we start analyzing the risk level of each activity individually. Then we choose the BOP operation as the object of study. Identify the influencing factor from a practical view, and find out the contribution factors that would improve safety level and performance efficiency: risk control, maintenance activities, and human factors. The author still expresses the relationship among different influencing factors and work optimization, find out success factors for implementation of work optimization concept. Then conclude the work optimization points on BOP operation by apply the recommended methods.

The author still provide with some simple cases that has been done on rig HYSY981, during the thesis writing period, and it shows positive feedback and get satisfied by rig management and operator. It increases safety level and work efficiency, thus create value for rig operation.

1.5 Limitations

Work optimization on deep water drilling is a very general description and it is too vast to write on a thesis. So here the author only focus on the drilling activities and select one of the critical activity, running/pulling BOP as a target to analysis work optimization, and the remarkable influences of maintenance, human factor, and procedure optimization on safety and efficiency.

2. Current Status of Deep Water Drilling

2.1 Definitions of deep water

The definition of deep water varied along with technological conditions. Colonel Edwin Drake drilled the first well inland in 1859 symbolized the beginning of modern oil drilling industry. In 1940s, about 9 decades after the first modern drilled well, human commenced offshore drilling and since then the water depth of drilling record has been getting deeper and deeper. In 1940s, drillers could only drilled in water up to 5 meters deep; 3 decades after that people commenced work in 100 meters of water, and it took another 2 decades and 1 decade to go to 2000 meters and 3000 meters, respectively. (su, Feng et al. 2006) Nowadays, the most advanced drilling units already drilled in more than 3000 meters, which has change the concept of human about the definition about deep water. Commonly, there are two set of definitions: they set 300 meters or 500 meters as the cutting point of deep and shallow water.

Based on the current status of offshore drilling and production, the operating unit such as compliant towers, gravity based platforms and 3rd generation of semi-submersible platforms all can perform operation at the water depth of 300 meters; the production and technical solutions have become mature and widely applied in the industry.

Here the author adopts 500 meters as the limit of shallow water, we set the following definitions:

Shallow water: 0—500m

Deep water: 500m—1500m

Ultra deep water: >1500m

2.2 The current development of deep water drilling platforms

The developing status and trends of deep water drilling platforms actually represent the current technological level and exploration and production (E&P) status of offshore petroleum industry. After looking into the top five offshore drilling contractors: Transocean, Ensco, Noble Corporation, Seadrill and Diamond drilling, the author found that almost all of them clarify their deep water units and capability of deep water drilling in their company's file. The deep water drilling units have become a crucial role in their development strategies.

From the statistical data on the world fleet of drilling units at the end of 2011, there are 291 semi-submersibles and drillships in service in global industry with 93 additional units under construction. See the table below.

Table 1.1 Global fleet of semi-submersibles and drillships (291 units in service)			
Built before 1998	Built after 1998	Under construction 93 units	
154 units	137 units	23 semis	71 drillships

For units were built after 1998, there is a substantial characteristic that more than 90 percent of them may be capable of drilling in ultra-deep water. This is a significant contrast with units were built before 1998, which indicate the development trends of offshore drilling and strong demand from petroleum industry.

Another point is the floaters' contribution to the total revenue of drilling contractors. From the Seadrill's financial report of year 2011, it shows that its contracted revenue at the end of 2011 is $12.6 billion, with which 67.46 percent of this amount is contributed by his semi-submersible units and drillships. Thus we believe that deep water and ultra-deep water drilling units will be emphasized consistently, and will take a lion share in offshore drilling activities.

2.3 General introduction of deep water drilling operation

Deep water drilling operation has its own characteristics, capital intensive, labor intensive, work intensive with high risk, high investment, high returns for oil companies and drilling contractors. The average cost for each deep water drilling unit is more than $500 million, it is a limited space and far away from shore base, has more than 100 people aboard working day and night when in operation.

The diagram below shows the general work flow of drilling operation.

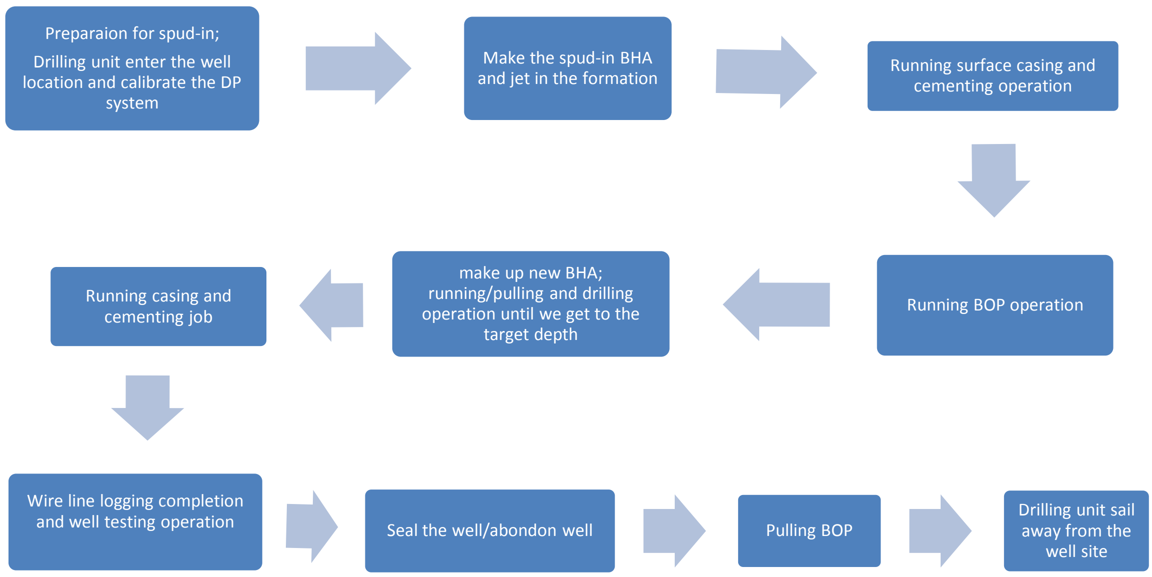

Figure 2.1 General work flow of drilling operation

From this general work flow, we find that the drilling work process consists of serial sequence activities.

Start from the preparation phase, the oil & gas company, need to mobilize drilling unit, material, and people, get all the required conditions ready onboard for spud-in. When the rig is on well location, beacons for positioning reference are deployed for dynamic positioning (DP) system. Before starting operation, we need to complete the calibration for DP system. During this period, the biggest challenge is logistics and coordination between shore and offshore. When we ready to start drilling operation, we follow the general work flow sequence and manage the people, technology and environment under the local law and regulations. As discussed in chapter 1, during the drilling process, there still some special challenges both on engineering and geological aspects. For offshore operation team, we are in charge of implementing these solutions for engineering and geological challenges safely and successfully. The emphasis of this thesis is to study the work optimization methods that the operation team can use to improve the safety level and work performance.

For the operational process of drilling, as we discussed in previous chapter, the deep water riser manipulation is a distinguish aspect compare to shallow water in engineering and operational process. It involves risk management, multi-professional personnel, equipment, and procedures. Based on the general work flow of drilling process on semi-submersible platform, we choose BOP operation, running/pulling BOP, as a typical activity and do further study on it.

Drilling activity is one of the crucial frontier operations in the whole life span of oilfield development plan. Its operation situation influences the whole program of field development. Oil companies usually are extremely prudent when they choose drilling contractors. Professional auditing company is designated and performs thoroughly inspection according to the requirement and standard provided by Oil Company.

For example, the semi-submersible rig HYSY981 has been audited by Chevron would use specific requirement. Such as Rig Selection Scoring Matrix, semi-submersible rig check list, health safety & environment (HSE) system management check list, dynamic positioning and power management system check list, etc. the auditing items would include almost all relevant aspects that could occur during operation period. From the operation perspective, the integrated safety management system, procedure optimization, preventive maintenance system, training and risk identification, etc. These will be main challenges for the drilling contractor to conduct the drilling operation. Aim to complete drilling operation in a safe and efficient way, the operation team working onshore and offshore should be able to reduce the risk involved in the operation, and find the way to optimize the work and deal with challenges might be meet in operation.

3. Drilling risk, Maintenance activities, Human factor and Work optimization

3.1 Drilling risk

3.1.1 The definition of risk

- Risk equals expected loss.(Willis 2007)
- Risk is equal to the two-dimensional combination of events/consequences and associated uncertainties (will the events occur, what will be the consequences). (Aven 2008)
- Risk is an uncertain consequence of an event or an activity with respect to something that human value.(IRGC 2005)

When we talk about risk during drilling operation, it is something that we do not want to happen. It is normally refer to the probability of an incident happen, and the associated consequences that could occur to people, equipment, well and environment. For minor incident, it may only cause damage to equipment or cause operation down time, but for serious accident, such as Deep water Horizon event would be a disaster for people and the ocean environment, has significant influence for the whole petroleum industry.

Risk-based analysis includes two aspects: risk analysis and risk management.

Risk analysis-systematic use of information to identify initiating events, causes and consequences of these initiating events, and express risk.(Aven 2008) Relating to the risk analysis process, there are basic key elements:
1. Risk identification
2. Risk decomposition and risk assessment
3. Risk treatment, etc.

Risk management is defined as all measures and activities carried out to manage risk. Risk management deals with the balancing conflicts inherent in exploring opportunities on the one hand, and avoiding losses, accidents and disasters on the other hand. (Aven, Vinnem et al. 2007)

Here in this thesis, we discuss the operational risk exists in drilling operation. The operational risk is normally related to human error, equipment failure and their related working environment.

3.1.2 Methods and tools for risk analysis

1) The bow-tie diagram

The bow-tie diagram is a common tool used in risk analysis. At the center of a bow-tie is an initiating event, possible causes and possible consequences are listed on its left and right side, respectively. The process to create the bow-tie diagram is a risk analysis work to find out the possible causes and barriers. Barrier that could be set and developed can be put in between causes and event to prevent undesirable event happened. And for the right side of bow-tie, barriers still can mitigate relevant consequences that caused by initiating event. Generally, the bow-tie diagram is a visual risk picture generated after risk analysis. Figure 3.1 is an example of bow-tie diagram.

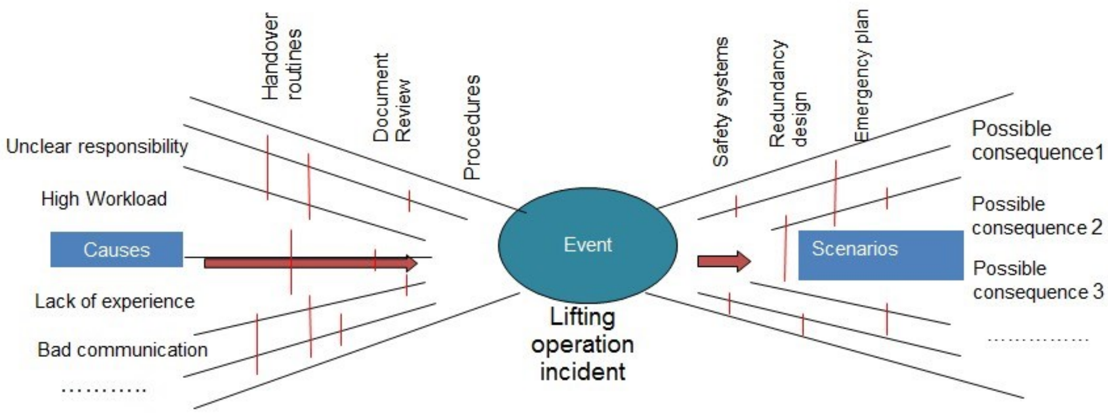

Figure 3.1 An example of Bow-tie diagram

(Modified from Risk analysis Aven, 2008)

2) Risk matrix

Risk matrix is a graphical table used in risk analysis which can indicate the risk level by the combination of the probability and its related consequence of the activity. Risk matrix is generated from the two dimension risk definition. This table displays the risk in a visible sense, and provides decision maker with direct guidance of risk level. The probability and consequence of each activity is estimated by risk analyst based on their knowledge and experience.

Table 3.1 Risk matrix of COSL drilling (COSL_Drilling 2011)

Risk Matrix	Probability				
	A	B	C	D	E

		Rare	Unlikely	Possible	Likely	Frequent
Consequence	1 Negligible	A1	B1	C1	D1	E1
	2 Slight	A2	B2	C2	D2	E2
	3 Moderate	A3	B3	C3	D3	E3
	4 Serious	A4	B4	C4	D4	E4
	5 Very serious	A5	B5	C5	D5	E5

For the whole process of BOP operation, it is hardly to locate which risk level of the operation is. As part of the drilling program on the rig, it has been performed many times, even for the same operation on a designated platform, the risk level varies as the working environment changes. So for the risk level of each step of the BOP operation, as show in table3.1, we have to evaluate each time and find out the risk mitigation plan to reduce the risk as much as possible.

There is a general rule for using risk matrix.

- Risk level in red, C5, D4, D5, E3, E4, and E5 is unacceptable, actions must be taken to reduce risk.
- Risk level in yellow, A5, B4, B5, C3, C4, D2, D3, and E2 is moderate risk level, as low as reasonable practical principle is applied, actions would be required to continually reduce risk.
- Risk level in green, acceptable risk level, work will be done by following safety requirement and operation procedure.

3.2 maintenance activities

Maintenance, in Merriam-Webster it is defined as "*the act of maintaining; the state being maintained*" and "*the upkeep of property or equipment*". (Merriam-Webster)

In oil and gas industry, European standard has given the following definition: (EN13306:2001 2001)

"Maintenance is the combination of all technical, administrative and managerial decisions and actions during the life cycle of an item intended to retain an item in, or restore it to a state of specified capability. Capability is the ability to perform a specification within a range of performance levels."

Regardless of the definition of maintenance, it has been widely accepted that maintenance can be planned and controlled, and it creates additional value for business process.

Maintenance activities normally include the repairing and maintaining work on company's asset and equipment, and make sure them would function at the designed level, mitigate and prevent the operational risk of failure. To ensure the asset and equipment is safe and friendly for people and environment around them.

Maintenance activities can be divided into two types: proactive maintenance and reactive maintenance.

For proactive maintenance it is normally refers to preventive maintenance and predictive maintenance. Preventive maintenance is kind of planned maintenance activities and it is normally time based. The foothold for PM is that all machines would degrade or fail as time elapses. The maintenance schedule and time interval is normally provided by original equipment manufacturer based on historical statistical data and experience accumulated. On platform this is one of the mainly used methods on most of the drilling operation related equipment.

Predictive maintenance is condition-based maintenance activity. It relies on condition monitoring techniques, such as Vibration monitoring, Thermodynamic, Thermography, Tribology (wear and lubrication), Non-destructive testing (NDT), Process parameter monitoring and visual inspection, etc. By using condition monitoring methods, failures would be predicted in advance and maintenance action can be planned at a convenient time without interrupting the normal production.

Run-to-failure maintenance is a reactive maintenance. It is particularly practical for those cheap equipment and their shutdown will not have direct effect on operation. We do not need to spend any money before the equipment failed. But there is another situation that for equipment is managed in the proactive maintenance activities, it is still has chance that they may fail during operation and cause down time for the rig. In this situation, the author still consider it as a reactive maintenance activity and the time spend to restore equipment back online is kind of additional cost compare to offline repairing work. This is inevitable and will be an urgent event when it does occur.

3.3 Human factors

The definition of human factors has been adopted by International Ergonomics Association since August 2000: (HFES 2013)

Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and other methods to design in order to optimize human well-being and overall system performance.

Ergonomics is the synonymous of human factors. Human factors focus on the interactions between human beings and their interactions with equipment, facilities, procedures and the working environment. For drilling platform, human factors can be considered in two phases: design and construction phase; operation phase.

In the first phase, ergonomics aims to build up a safe, efficient and friendly working environment for personnel, and to enhance the facility and equipment with highest operability and maintainability. But for field operation on a drilling platform, human factor most focus on its interactions and influences with equipment operation and work process, such as personnel competence, training and skill and management support.

According to the analysis was done by Petroleum Safety Authority, Norway (PSA), the main operational challenges were: "management; planning and cooperation; work load; design/lay out; competence; procedures and work routines; and communication". (Heber, Wiig et al. 2008) All these challenges can be clarified into following categories:

- Physical limitations;
- Psychological limitations;
- Employee's competence;
- Concept of responsibility & Outstanding safety awareness;
- Procedures: Optimize procedure work program and implementation of improvements;
- Management: Get people motivated;

In this thesis, the author will describe human factors and its influences and challenges in an operational environment and find out critical factors that we will focus to optimize the operation.

3.4 Work optimization:

Work optimization on a drilling platform, generally it is to increase operation efficiency, reduce equipment failure and human error, avoid nonproduction time at a safer environment.

The optimization work have been done on drilling process is drilling optimization, and it is normally analyze the job from a technical prospect. Here in this thesis the author will study work optimization from a different view. After using the risk-based method to identify the critical and high risk activity, we will decompose the activity from 2 aspects: maintenance and human factors. After analyze from this two aspects, we will compare the solutions among each other and find out practical methods to improve the operation flow. Then further compilation work will be required to improve relevant operation procedures. The figure below shows the basic structure of this thesis and the whole thesis will be developed based on this.

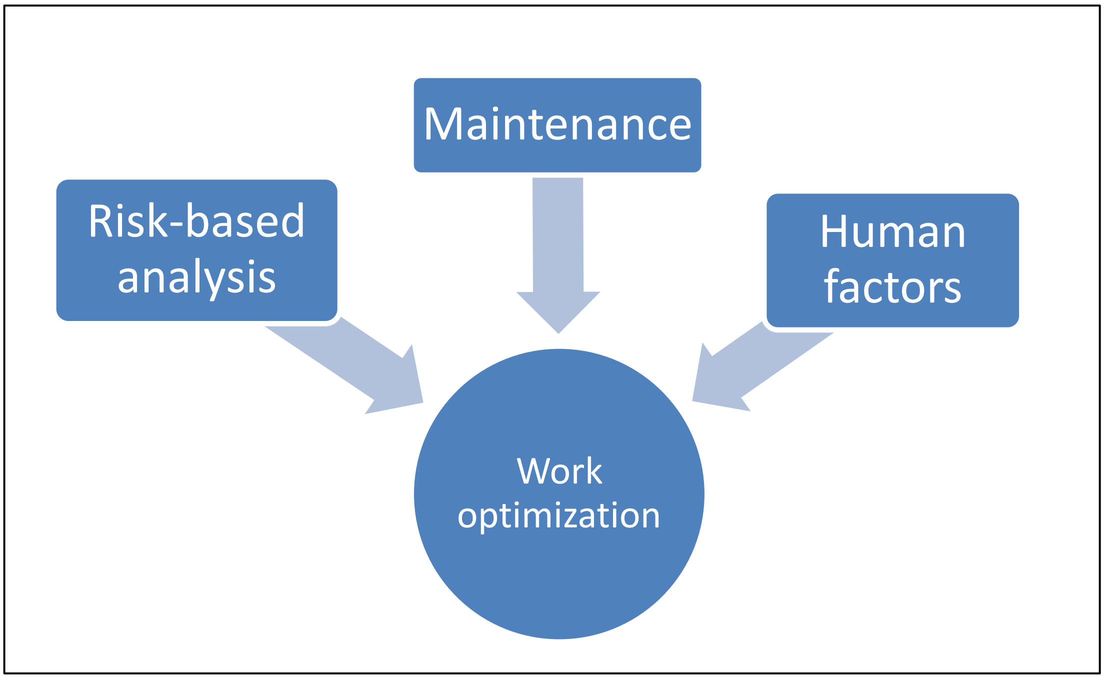

Figure 3.2 The basic structure of methods for work optimization

4. Analysis and Work optimization on BOP operation

4.1 Operational risk analysis on BOP operation

4.1.1 Description of BOP operation work process and critical activities

Compare to traditional drilling operation, the process of deep water drilling operation is almost same. But when the water depth is 1500 meters or deeper, riser manipulation becomes a significant challenge for the drilling operation. This is what we called running/pulling BOP operation on the platform. On traditional shallow water semi-submersible platform, the running BOP operation may be finish in 24 hours, say water depth 300 meters. Once shift into deep water area, on the rig HYSY981, things has been changed, not just because the water is getting deeper, but also the related upgrade and change in relevant areas, such as operation environment, equipment, procedures, and technical challenges, etc. When worked on the rig during the period of writing thesis, there were several mistakes and incidents happened during the process which generated lot of unnecessary downtime and damage to the equipment. These incidents are:

1. Malfunction of riser chute; equipment failure and worker's operating skill need to be trained and improved;
2. Lifting sling broke when lifting divert, heavy weight and critical lifting operation;

This reminded the author that we need to make effort on running/pulling BOP operation, analyze and optimize the work process from different view.

Table 4.1 The process and duration of running BOP to 1500 meters water

Test the braking system of Drawworks;	2.0	Hrs
Clear drill floor of excess tools, remove pipe handler and change bails;	2.0	Hrs
Install riser gripper head; install the pull up cylinder for the R/tool;	0.5	Hrs
Remove power slips/all the bushings; Install Spider and Gimbal;	3.0	Hrs
Install BX5 elevator and pick up diverter running tool;	0.5	Hrs
Drill floor pick up two slick joints and make a double and ready to connect with BOP stack;	1.0	Hrs
Main deck unsecure BOP and skid from port side deck park position to well center ;	2.0	Hrs
Connect double slick riser joints to BOP stack;	0.5	Hrs

Moon pool place guide sheaves of MUX cable and hot line, set up the storm loop for running risers;	2.0 Hrs
Run BOP through splash zone and BOP submerge in water	0.5 Hrs
Pick up and run 62 joints of flotation riser at 2 joints per hour +3 times of high pressure test.	39 Hrs
Pick up pup joint and slip joints	1.5 Hrs
Pick up space joint and landing joint	1.0 Hrs
Install goosenecks and pressure test	4.0 Hrs
Install Mux clamps and brackets	2.0 Hrs
Skid riser tensioners to well center and latch to the riser string	1.0 Hrs
Lower down and transfer weight to tensioners and engage the compensator;	0.5 Hrs
Perform a dummy run	0.5 Hrs
Move rig over the well head and land BOP, pressure test against well connector	1.0 Hrs
Stoke out the telescope joint and lay down the landing joint	1.0 Hrs
Pick up and connect the flex joint	1.0 Hrs
Pick up and install the diverter, set the diverter into divert housing	2.0 Hrs
Remove the riser running devices, spider, gimbal, etc. and clear drill floor with excess tools;	4.0 Hrs
Total time required	71.5 Hrs

Based on the above practical operation process and equipment status, the following factors have been selected:

- Weather conditions;
- Lifting operation of heavy weight;
- Crew/department involved in the operation;
- Time duration of the activity;

a) Weather conditions have directly impact on BOP operation

The deep water drilling operation is significantly affected by weather and sea condition of the platform operating area. Such as storm, wind, wave, tide, water depth, surface current, deep current, and soliton, etc. These parameters have directly impact on the rig motions, such as heave, roll and pitch. In some specific area, such as typhoon in west Pacific Ocean and South China Sea, hurricanes in Gulf of Mexico, which have severely impact on offshore operations and my cause catastrophic damage to structures. Thus for each drilling unit, the classification society will limit specify the operation limit for them. The American Bureau of Shipping (ABS) has certificated the rig HYSY981 with the following operation limits for various operations.

Table 4.2 The operation limits under different status

Operation limits under different status	Heave limit (m)	Pitch & roll limit (degree)	Significant wave height limit (m)	Wind speed limit (knots)
Handling BOPs	2.3m	2°	4m	30 kts
Running BOP/Riser	3.4m	1.5°	6m	45 kts
Disconnect BOP (LMRP) By DAT	N/A	N/A	6m	45 kts
Reconnect BOP (LMRP) By DAT	1.5m			
Hang Off by DAT(Standby)	N/A	N/A	6m	50 kts
Landing BOP(LMRP) By DAT or AHC	1.5m	2°	6m	45 kts
Handling piping, Casing and Vertical Riser	N/A	2°	6m	45 kts
Running Casing	N/A	3.39°	6m	45kts
Normal Drilling and Tripping	4m	3.39°	6m	45 kts
Jetting in Conductor	4m	3.39°	6m	45 kts
Logging/ Cementing	4m	3.39°	6m	45 kts
Running Completions	4m	3.39°	6m	45 kts

It is obviously that operations related to riser and BOP have much lower limits than other operations. Like the items have been highlighted in orange color, the pitch & roll limit for running BOP/riser is only 1.5° , which is the lowest limit for all the operation listed above. This table shows that the weather and sea state has noticeable influences on BOP operations. When we prior to this work, the weather condition and the rig motion need to be considered and evaluated.

Besides this, the weather and sea conditions still has remarkable influence on the working environment that people working in. Such as the wind, temperature, rain, and the noise generated due to rig movement, etc. This will be a significant factor when we analyze human factors.

b) Lifting operation of heavy weight equipment

It is obvious that running/pulling BOP operation is the section with heaviest equipment on the rig HYSY981, and without a doubt, the lifting operation is the inevitable task to complete this process.

Table4.3 The list for main components would be lifted during BOP operation

Equipment items	Weight (tons)	Equipment items	Weight (tons)
BOP stack	420T	Fill up valve	6T
Single riser joint	24T	Telescopic joint	38T
Spider	15T	Space joint	10T
Gimbal	12T	Landing joint	15T
Diverter	19T		

See from the list we know that some of the components and their weight, we can imagine that these are kind of risky job on the platform. But for running BOP, these are must-do lifting work, and should be performed following the operation steps.

Lifting procedures have been developed for the lifting operation, whereby careful risk analysis will be made for each lifting operation. Before crew start any of these lifting operations, a toolbox talk is held and Job Safety Analysis (JSA) is followed to identify the hazards and classify the actions required to secure the operation.

Specifically, we use BOP crane to lift the BOP stack, and use riser gantry crane to lift the riser from vertical storage area to the riser chute, from where it could be picked up by travelling block. The BOP crane and riser gantry crane are special designed lifting device for their work, the related operations and procedures are mature and can be easily followed.

For the rest of the components of running BOP operation, we use the deck crane to lift them. Deck crew and drill crew will be involved in this job, and the cooperation and good communication is necessary. For the component heavier than 10 T is normally consider as critical lifting operation, special process and lifting gear would be required to complete this operation. Prior to this operation, a permit to work and job safety analysis (JSA) is required with involved personnel.

c) Crew/department involved in the operation

Running/pulling BOP, is one of the labor intensive, time consuming, and highly required for cooperation work on the platform. Most of the departments on the rig will be directly involved into the operation.

1) Subsea Department: Be responsible for planning and organizing maintenance and function test of BOP related equipment. Be in charge of technical preparation and operation. Such as BOP and control system, replacement of consumable part, operation procedure, and work organization. Ensure riser tally is correct and riser analysis has been performed.
2) Drilling department: Be responsible for carrying out the task safely and efficiently in driller's chair and on drill floor. Assist subsea engineer work in the moon pool. In charge of the operation of the relevant equipment during running BOP operation. Drill crew take primary responsible for safety and efficient in the operation.
3) Mechanical department & Electrical department: Assist subsea engineer and drill crew to do maintenance and function test on related equipment; operate yellow & blue mux cable reel in moon when running/pulling BOP. They are still part of the technician team and responsible for any fault and failure on the equipment.
4) Marine department & deck crew: Responsible for organization and implementation of the lifting operation. Communicate with subsea engineer and drill floor about any heavy load movement on deck, in order to maintain the rig at a suitable stability status.

Besides this, possible 3rd parties will be involved into the operation, such as ROV (Remotely Operated Vehicle) and cementer. ROV will be placed on the seabed to watch the alignment of the BOP funnel and the high pressure well head. Without the visual view of ROV, it is impossible to position the rig and land BOP on the well head. Cementer's work during running BOP is to operate the cement pump and pressure test the riser string and well head connector after BOP is landed.

d) Time duration of running/pulling BOP

The process of running/pulling BOP is critical operation on the platform. As the water depth is getting deeper, the time required is becoming longer. For water depth up to 1500 meters, it normally takes about 3 days to complete the whole operation. The table above shows the running BOP process and time consumed for each step, so we can have a general picture about the BOP operation on the rig HYSY981.

The process is based on the time duration at a serial operation without considering any other influencing factors. But under real conditions, the production time is highly affected by working environment and variable factors under different situations. Weather is one of the noticeable force majeure factors that have direct impact on the operation which causes unnecessary non-production time. Maintenance program on equipment and human factors are also unexpected aspects that interact with the operation through equipment.

When different activities have the same risk level, the time duration of activities will influence the probability dimension, thus risk level will be changed. Normally, the longer the exposure time of activity, the higher the risk level will be.

4.1.2 Risk level of running BOP

In the previous part, we analyze and compare BOP operation in four different aspects: Weather conditions, lifting operation of heavy weight, crew/department involved in the operation and time duration of the activity. From the analysis, we conclude that the BOP operation is considered to be one of the risky operations of the rig. It is sensitive to weather condition, involving lifting operation of heavy weight equipment; it involves working crew from different departments, and work together as a team to carry on the operation. This operation goes through long time duration, involves various equipment and people, and has a high possibility to cause equipment failure or human error, and thus generate non-production time and increase risk level of the operation.

In the following part, we will discuss the approaches that will help us to optimize the work process, from maintenance work prospect and human factors prospect.

4.2 Maintenance work required for BOP operation

In the oil & gas industry, it has been widely accepted that maintenance work on equipment creates value. A well-developed maintenance system and programed maintenance activity will maintain equipment at their intended availability and reliability. The following aspects need to be considered when develop and plan the maintenance program.

1. Develop a maintenance program according to manufacturer's recommendation. This is the primary information for the maintenance program and should be referred when developing any maintenance plan for the equipment. Technician team on board need to abstract the necessary points from equipment manuals and put into the maintenance system.
2. Identify the operational environment of the equipment, and recognize force and combination factors that would impose on equipment. These could be temperature, humidity, work load, using frequency, interface status, power system, and so on.
3. Asses and evaluate any foreseeable failure that would be likely to happen during service. This is the deduction or prediction based on the experience accumulated.

Lessons learned and statistical data collected during operation and maintenance would be valuable for this work.

4. Asses the interface parts of the equipment that would withstand force and identify vulnerable parts that need regular maintained or replaced. Parts that wear quickly and damage frequently should be organized to ensure safe and efficient operation.

A combination maintenance system will be defined, aims to maintain availability and reliability of equipment at their intended use. The maintenance system should have the ability to keep log of operation and maintenance, which will be important reference and analysis basis for future maintenance activities.

On rig HYSY981, we use first line maintenance and AMOS (Asset Management Operating System) to perform preventive maintenance. By using these two programs, work equipment and assets would be adequately maintained at recommended intervals by manufactures; and all the maintenance work logs are kept into these system, for future reference and optimization work.

The first line maintenance program is conducted by equipment operator on site. Its main task is consisted by daily, weekly or monthly maintenance and inspection work. The maintenance interval is estimated according to the recommendation of manufacturers and equipment failure history. First line maintenance work for equipment is normally a maintenance list, according to which operator can perform the routine inspection and maintenance work, then just write down the equipment status of each item, then put them into AMOS system.

AMOS system is an integrated management program of maintenance work, stock control, purchasing and cost control.

Figure 4.1 The login window of AMOS system

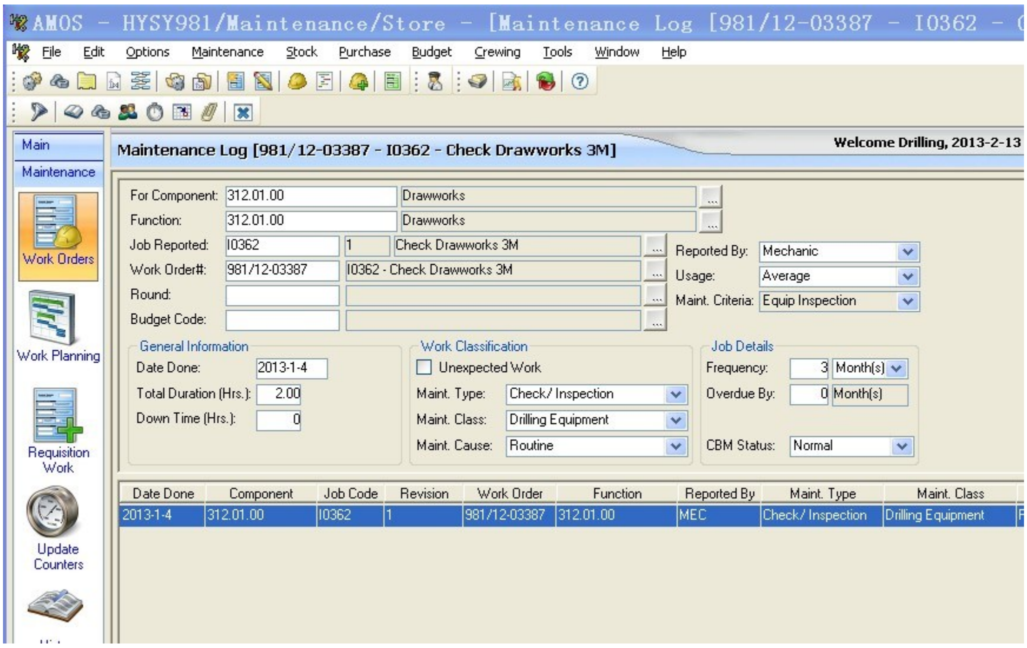

Figure 4.2The main screen of AMOS system

The maintenance function of AMOS helps operation team on board to perform regularly inspection and maintaining activities. It reminds technicians with planned maintenance work with various equipment, at same time it is still a data base to keep all the maintenance and service record in the system. This will be valuable information for future work on the equipment, such as spare parts order, operation efficiency analysis, optimization opportunities, etc.

Except for preventive maintenance, predictive maintenance (PdM) system is another important method has been applied on the platform. Like we discussed in chapter 2, predictive maintenance is based on condition monitoring techniques. By using these techniques, the data about operating condition of the system and its parts is collected and evaluated in real time. The real time evaluation can monitor and identify operating changes, thus eliminate unnecessary downtime and excessive maintenance service. For critical equipment, this has significantly effect in reducing production downtime, and condition monitoring methods are implemented to get real time status of critical items. For example, the temperature monitoring on electrical motors of derrick drilling machine (DDM), oil level monitoring of lubricant, regularly oil analysis, etc.

Mobley (Mobley 2002) stated that “ A relatively slow deterioration before failure is detectable by condition monitoring. Whereas rapid, catastrophic modes of failure may not be detected. Great advances in electronics and sensor technology are being made”. For these modes of failure, continuous online monitoring, real time detection and quick raction based on real status is much more important expecialy in some critical processes.Various benefits have been derived from conditon based mentanance:

- It improves safety of operation due to unexpected breakdown is avoided under the condition based predictive maintenance strategy;
- It maintains a high production performance by planning citical componets work properly during production period;
- Optimize maintenance interval and avoid excessive maintenance and lack of maintenance. Thus can extend components life and reduce the cost of spare parts cost.

But there is a characteristic that on drilling platform periodic preventive maintenance is the principal method of routine maintenance program; predictive maintenance is playing as an assistant role to improve the system reliability and availability for critical equipment. It is not possibleto set up contition monitoring method for some of the critical parts. It is need to go through a specific methodology for selecting suitable equipment for applying predictive maintenance.

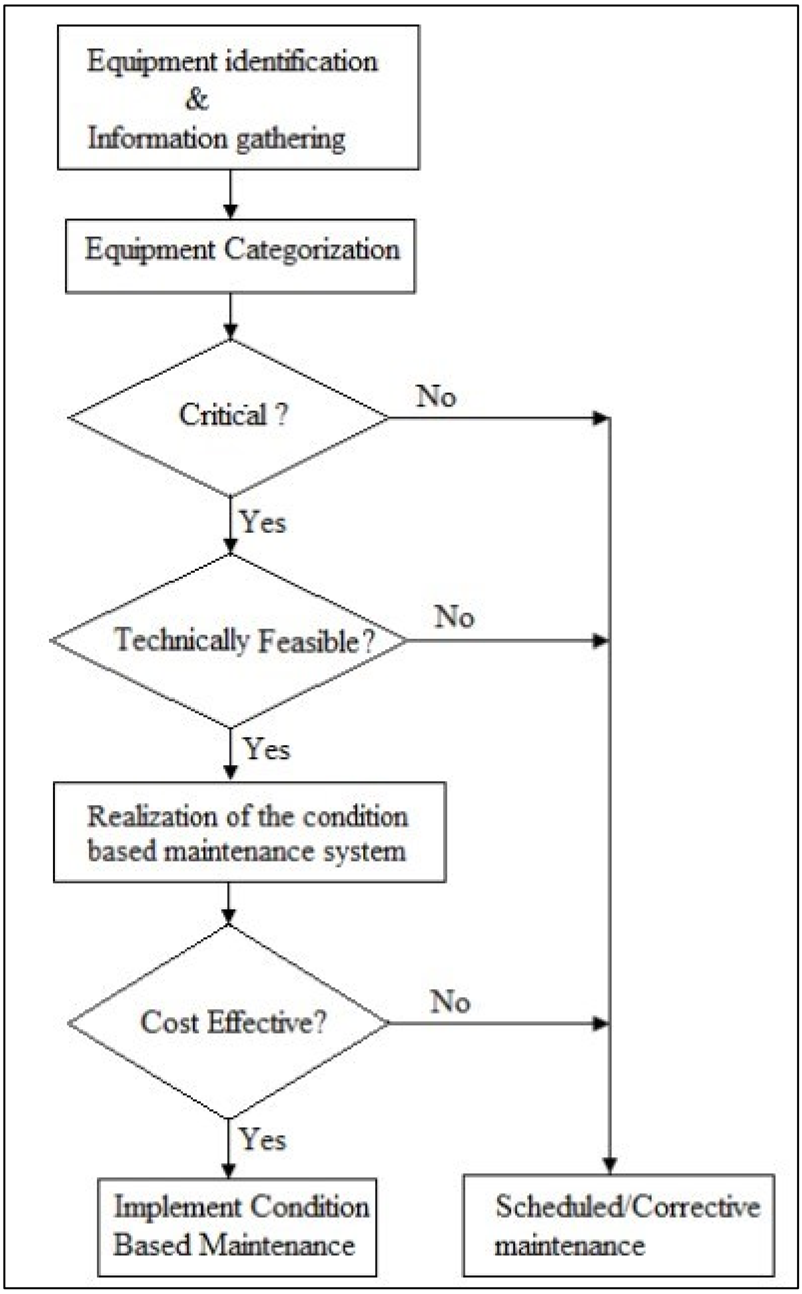

Figure 4.3 Equipment selecting methodology for condition based maintenance. Modified from Milje (Dagnew 2012)(Dagnew 2012)(Dagnew 2012)(Dagnew 2012)(Dagnew 2012)(Dagnew 2012)(Dagnew 2012)

Although we make systematic effort on maintaining equipment function at their designed status, failure occurs inevitable. As operator and drilling contractor, either of them wants failure appears. But as a contingency plan, we have to plan for equipment failure and train staff skills to handle it. Run-to-failure maintenance program is carried on to restore equipment back to service. During production, failures on critical equipment normally cause non-production time and the restore work is in an urgent situation, sometimes a backup plan is must do requirement and further suspending work has to be done for safety requirement. For a new built platform, it seems that the run-to-failure maintenance has played a significant contribution in experience accumulation and maintenance procedures optimization. Failure on equipment directly reflect weak points of maintenance program, would be considered as improvement opportunities for following work on optimization. From this point, we will not just focus on the maintenance program of equipment, but also can be analyzed from human factors and optimization perspective.

4.3 How human factors impact on BOP operation

In operational process, human factors affect operation's safety and performance through procedures, equipment facilities and environment. The challenges of this period are much different from the design and construct phase of the facilities. Human factors have now developed into a dynamic and complex stage involving human, technology and organization issues. In operational situation, several indicators have direct influences on operation safety and performance.

Back to running BOP operation, refer to the general description of work flow, we can analysis this process through some typical indicators of human issues.

- Physical limitations;

The physical limitations are human body, vision, muscle and action, etc.. The ambient environment situation, such as wind, temperature, humidity, air pressure, lighting and noise level, all have influences to human physical condition. For BOP operation, workers will work on drill floor, main deck, and moon pool area. These areas have different working space, lighting condition, and noise level, on drill floor we still need to consider wind and rain that will have direct affection on work. During bad weather and rough sea situation, we still need to consider the rig motion which will affect the whole process on different aspects. People will be not safe to handle the work if weather condition exceeds the operation limitations. It is the foundation to evaluate the working condition and make sure it is comfortable and suitable for people to handle equipment and perform work safely and friendly for both human and environment.

- Psychological limitations;

Psychological sense is perceptions of human on various activities and working conditions. These perceptions are human sense and reflected through people's attitude. Lots of influencing factors impact on psychology of human, but under the same physical condition and working content, the working period and work organization will have noticeable effect on worker psychological status. Fatigue and tiredness appears along with time, and negligence and discontented generate potential risk for operation. Running BOP operation in deep water, normally cost about 3 days and involve multiple parties, organized cooperation and communication of people is prerequisite for expected operation.

- Employee's competence

Employee's personal competence directly impacts on operation performance. Qualified people are needed for each of the designed position. For each position, a job description is required to define their responsibility, work content, qualification and capability requirement, managerial requirements, supervisory level and places in organization. As the daily management of human resources, it is an essential part of safety defenses at offshore operation. This requires organizational process to assure people have adequate knowledge, skills and resources through training and experience accumulation.

- Personnel Organization chart: role of responsibility & execution of safety procedure

  Consider from managerial aspect, an organization chart for all positions on the rig is required, and a systematic safety procedures need to be followed. An organization chart clarifies the structural composition of different positions, describes places of each job and their relationship in vertical and horizontal direction. Through the organization chart, responsibility of each position shall be defined and same for the role of each position in performing the safety program and operation procedures. Reversely, work content for each of position, will be specifically described in relative working procedures. For running BOP operation, it is mainly conducted by drilling and subsea department, and assisted by marine department and maintenance department. The main working areas are drill floor and moonpool, drill crew and subsea engineers work with each other in this two areas. Due to cooperation and communication problems, and lesson learned from experience, area responsible persons should be designated in operation procedures. They are in charge of their area and take responsibilities of safety operation and work performance. Safety operation refers to safe on human, equipment, well and environment. Work performance refers to completion status of work content, work quality and time consumed. On rig HYSY981, we use the following personnel organization structure. Toolpusher (expatriate) takes primary responsibilities of operations performed by drilling and subsea department. This position is set because the language barrier exists between operator and rig personnel. This a special structure for rig HYSY981, and in order to bridge the gap due language problems.

On rig HYSY981, over 90% of operation team are Chinese, but when we drill for an international oil & gas company, the working language of client is English. Because of culture difference and average language level of operation team, thoroughly communication and deep understanding of client team becomes a daily issue during operation, so for the core activities on drilling platform, drilling and subsea operations, an English speaking toolpusher (Toolpusher expat as shown in figure 3.4) will help national team to conquer this barrier. Under foreign toolpusher, there is senior toolpuher who directly organize and supervise on the operation of drilling and subsea department. Toolpusher and subsea supervisor direct their own department separately on daily work under supervision. During running BOP operation, toolpusher (expatriate) and senior toolpusher will organize and coordinate with deck crew and maintenance crew to work together. For different working area, we designate driller is the area responsible person on drill floor and subsea engineer is in charge of moon pool area.

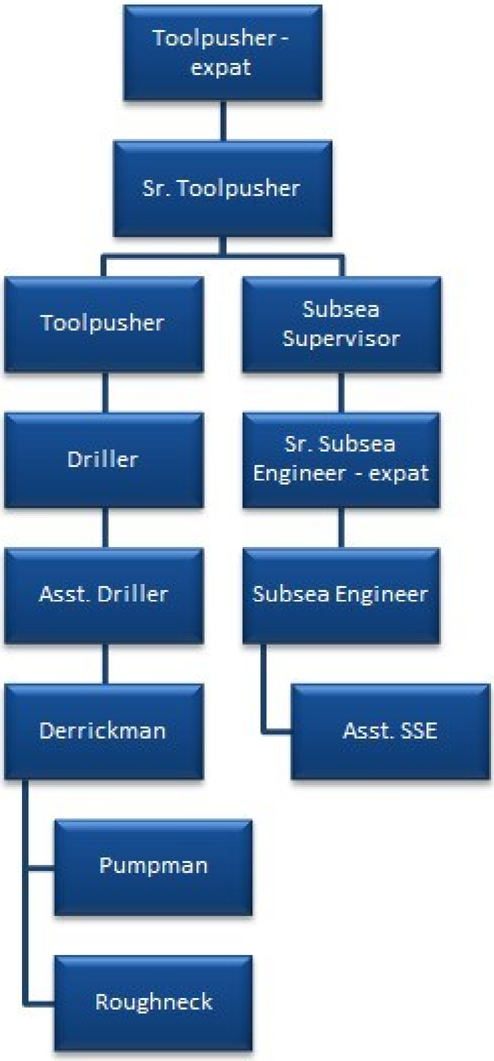

Figure 4.4 Organizational structure for drilling and subsea department on rig HYSY981

The organization structure has the same function to supervise the implementation of safety program. Outstanding safety awareness is necessary for every employee on board. “Everyone can say stop” policy is conducted by all personnel and mutual supervision has been followed, but effective organization structure is still necessary to executive the integrated management system of company efficiently.

- Procedure execution and optimization

Procedure is the operation process executed by human to perform required work and task. Procedure optimization can be considered as a process of after action review and opportunities for improvement. The human factor has directly influence on execution. The optimizing process will be studied from the following aspects that have been discussed. These aspects are practical for operational person to use and implement into operation. In both of those two items, human’s competence, attitude, safety awareness, and experience accumulation sense are all stimulations. This is the reason that I list the procedure execution and optimization item into this part.

- Management of human: Get people motivated

Motivation is the desire and need that drive a person to act and take actions. People get motivated will do their work and act proactively; and their talent and potential may be inspired and do their job at a highest professional level. The motivational strategy can be divided into two types: extrinsic and intrinsic. On a drilling platform, the extrinsic motivations are working and living condition, welfare, salaries, awards, work pressure, performance measurement, and company’s mission, value and culture, etc.. The intrinsic motivations are self-gratification, sense of accomplishment. And recognition of company’s mission, value and culture still can be regarded as the intrinsic motivation factors.

Get people motivated is a soft power of management, and will have great impact to the work and operation.

4.4 Various factors contribute to work optimization

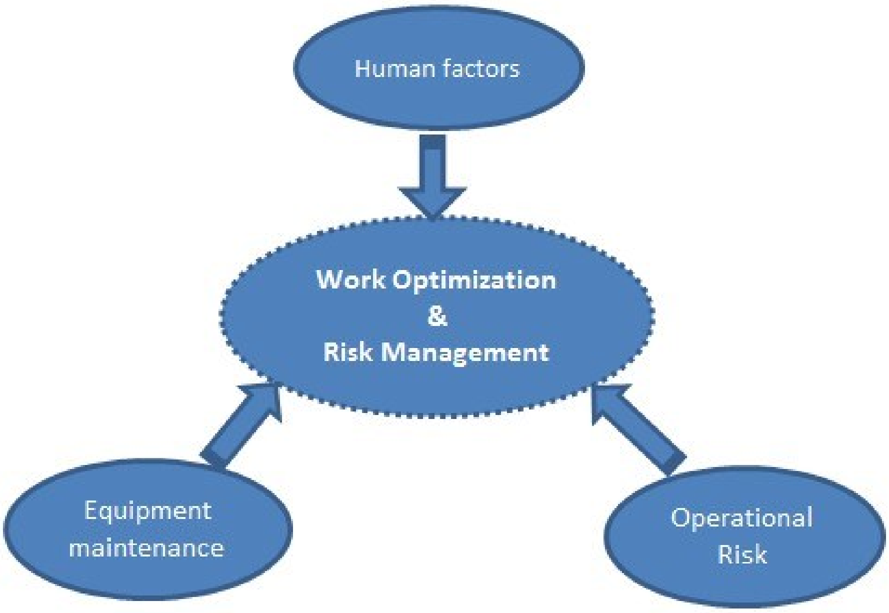

Figure 4.5Various factors contribute to work optimization

1. Risk analysis and management

   This could be done by simple risk analysis tools, such as bow-tie diagram and risk matrix, have been discussed. For operation, safety is the first priority. Risk analysis is necessary and is the foundation for optimization. In company's safety management system, various safety tools have been clarified and required to be used in daily operation. The procedure optimization has to consider safety factors and risk mitigation actions and barriers.

2. Equipment & Maintenance activity

   Equipment realizes its function through people's operation. Human activities have impacts on equipment status. Professor Markeset (2012) states in his lecture that maintenance and operating procedures has about 30%-40% influences to equipment system failure in operational phase. (Figure 4.6)

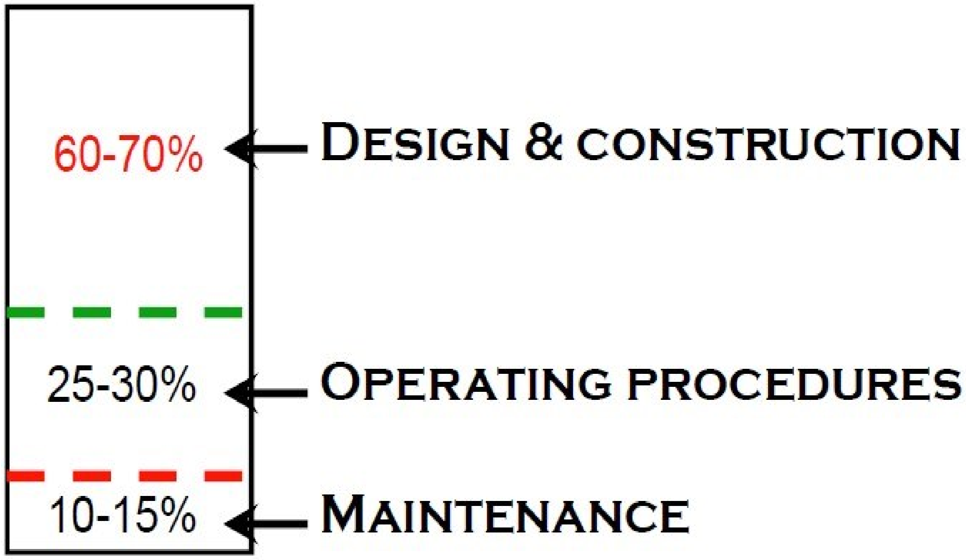

Figure 4.6 Contribution factors to equipment system failures(Markeset 2012)

On a drilling platform in operation, the equipment and related operation and maintenance system has been set up in place. There are no much we can work and design and construction phase, so our effort should focus on procedures and maintenance phases.

The figure shows the importance of maintenance and operating procedures, and the reason why do we need to optimize work procedure and implementation of maintenance. Equipment risk is the main contribution to operation risk, and the maintenance strategy is a key factor in the seriousness equipment risk.

If some of the failure mode cannot be optimized through maintenance and operating behavior, then modification and re-design need to be implemented.

3. Human factors

The human factors here discussed is about human, technology, and organization. After introducing the physical and psychological limitation, we go further to discuss the organization issue that related to each position. With competent employee, we need to enhance the responsibility awareness and safety consciousness through organization. Get people motivated, and improve the implementation and execution of work procedure and safety program. Thus reduce potential risk and improve operation performance.

5 Success Factors for Implementation of the Proposed Solutions

5.1 Success factors and stimulus for work optimization

In the previous chapter, we have discussed the methods and aspects that would help us to optimize work process by reducing risk level and improving operation performance. Risk-based analysis approach, maintenance strategy, and human factors interacts each other and impact on work optimization.(Figure 3.5)On rig HYSY981, the first deep water drilling unit started operation in May, 2012. The rig has only been in operation about half year, and workers, equipment and management system are still in a run-in period, the work optimization is highly demanding, systematic and practical work optimization methods are easy to implement. Success factors and stimulus have promoted the application of these approaches in COSL.

Industrial requirement on safety and risk management has been emphasized especially after the Deepwater Horizon accident. Much more strict regulations and industrial requirements have been published. Companies of oil & gas industry have to set up and execute safety management system and risk analysis approaches in higher level as well. COSL has implemented the Integrated Management System since august 2011, and it includes HSE (Health, Safety, and Environment) Management System and Safety Management System. In those systems, they have defined safety and risk management from a managerial view. Except for these, some practical safety and risk analysis tools also have been introduced, such as permit to work, risk matrix, job safety analysis, STOP card system, ETA (Event Tree Analysis), and FTA (Fault Tree Analysis), etc. These practical tools have been required to use on any single activity and effective supervision also has been built. Strictly requirement from top management and systematic risk management methods are main success factors to implement the risk-based methodology.

Operator's requirement for systematic and optimized maintenance work. Maintenance work creates value. This concept has been widely accepted by oil & gas industry, and risk-based maintenance methods are commonly used on operation process, such as Reliability Centered Maintenance (RCM), Risk Based Inspection (RBI), and Reliability, Availability, and Maintainability (RAM). These approaches are keys for optimization of preventive maintenance program.

Drilling contractors' desire to improve safety management and operation performance. These two aspects are main factor to win operator's satisfaction and would gain good reputation in the industry. It is a necessary way to improve drilling contractor's competitive power in market by improving risk management level and operation efficiency.

Advanced equipment and technological support have been applied. Some of the condition monitoring techniques has been implanted into system, and status information of different components can be displayed on screen through its analysis center. This will be helpful for service work in planning and choosing maintenance strategy.

Employee's awareness and knowledge on work optimization has been improving. Through work optimization, the operation risk has been reduced and work performance has been improved. Employee realizes that work optimization has benefit for their own safety and working status. They are proactive and motivated to find improvement opportunities. So the performance assessment system is also necessary for work optimization, which helps us to quantify the performance of optimization and gets work optimization more visualized.

The existing procedures on different operations are the basis for work optimization. Optimizing work is based on the existing work and operation, go through the proposed methods and process to analysis weak points and high risk level activities, solutions would be made and action would be taken.

5.2 Work optimization points on running/pulling BOP operations

Based on the running BOP process that has been described in chapter 3, there are numbers of steps to complete BOP running operation, and for each step it consists of several individual but interrelated activities. These steps and activities are essential for the whole operation, and have been arranged in a particular sequence. Systematic and detailed operation procedures are necessary and crucial for safety and work performance. Procedures define what, when, and how to do the work, but risk exists in operation process, equipment malfunction, environment changing, human errors are all affect the performance of procedures. How can do work in a safety and efficient way? We need a specified process to optimize the operation procedures and an efficient team and organization structure to execute those procedures. In oil & gas industry, the risk-based methodology has been widely accepted and implemented for daily operation management, such as work optimization.

In this part, we use the following structure to demonstrate the methodology of work optimization. Please see the figure 4.1, it shows clearly that the risk-based work process analysis and management is the foundation to work on assets and equipment management, and human and organization management. These two aspects are methods or barriers to reduce the risk and increase the safety barriers. Their target is to optimize the work flow in safe and efficient prospect.

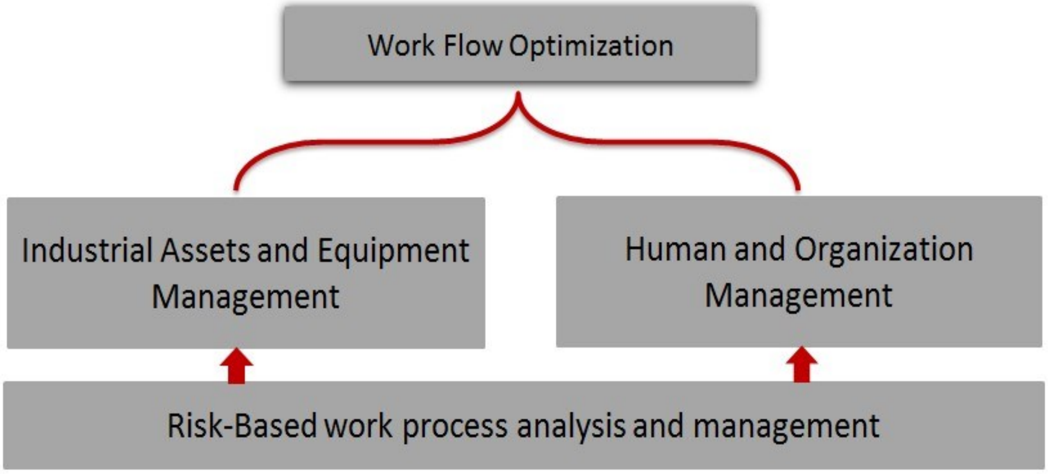

Figure 5.1 Management structure for work flow optimization

This management structure can be analyzed in detail from the following aspects:

1) Specific risk analysis needs to be done for each step or any single activity, especially for those critical and high risky operations; various safety management tools and risk analysis method aforementioned may be used for risk analysis. By using suitable risk analysis methods, various causes of can be identified and classified. Equipment failure and human error are two aspects that we should focus and pay more attention on, actually engineers and scientists have been studying consistently on these two areas and systematic theory and practical experience have been introduced to the industry. Except for those, force majeure is a considerable factor for offshore drilling operation, such as hurricane in Gulf of Mexico, typhoon in South China Sea and tsunami, for a platform is in operation, the best way to avoid any loss is evacuation based on proofed emergency plan.
2) Pre-inspection and function test on equipment and re-evaluate the operation procedure according to the current situation, such as the equipment status, weather condition, members' competence of operation team, etc.. This method is different from the previous discussed maintenance strategies, PMS and PdM. It is neither time based nor condition based. It is task-based in order to mitigate the risk of equipment failure. This method is actually not a maintenance process, but a test for the routine maintenance to check if relevant equipment and tools are working properly for following operation. By seriously conducting this process, it is still an excellent opportunity for operation personnel familiar with operation procedures prior to operation. Remind them and get practiced.

3) Lifting operation, special procedures and safety measures are required. The standard of lifting operation and slings are getting stricter. Lifting of critical and heavy equipment and joints are considered high risk activities. For example, picking up diverter, lifting telescopic joint, and so on. A toolbox talk is held and JSA is required to explain the work process and identify potential risk that would occur and prevention action that should take. We still need to classify roles and responsibilities of each position. Designate work responsible person who is in charge of operation, and have the duty to organize and coordinate with people that may involve in the operation. For a competitive drilling contractor, an internationally certificated lifting procedure should be set and followed.
4) Organization of operational personnel, human factors, and human errors are influencing factors when we thinking about people. But as the basis, qualification of workers, such as operation skill, capability, sense of cooperation and responsibility, safety awareness, etc. are all significantly impact on human management. In running BOP operation, responsibility, cooperation and communication are three critical elements that ensure each individual perform its own profession and ensure the organization working as it should be.

6 Practical Case: Work Optimization Practice on HYSY981

HYSY981, the 1st deep water drilling platform of COSL, it started operation in 1500m water depth in South China Sea on 9th May, 2012.For a new built platform, there are lots of challenges when we use the operation procedures we have to perform the work on the new rig. These provide us with numerous opportunities of work optimization. During the half year of operation, HYSY981 rig has been doing a great work in optimizing the work both in risk management and equipment maintenance management, and noticeable improvement in human factors management.

In this chapter, some practical examples will be presented to show the practical use of integration of risk analysis, maintenance, and human factors to optimize the operational process.

6.1 Simple risk analysis tool is practical to mitigate potential of risk

One simple tool is named Step 10 Engagement. It is a simple tool that consists of 10 concise steps. It is summarized by both contractor and operator teams based on the practical issue and the special communication problem when the rig operated in an international environment, the language barrier. So in this 10 steps, (Figure 5.1) the very first step is to identify the language issue, and the corresponding solution, get translator involved. Very simple? But very practical, and it shows the sense of attitude and problem we have.

In this simple program, we have use the several analysis tools, such as permit to work, Job Safety Analysis, and 4-point check (PC), etc. and the using of human factors, for instance, the 6th step, the human perception about risk level and still the communication and cooperation issues. It still focus on the motivation of operation personnel (step 7 & 10), the purpose for work optimization (step 8 & 9), which is still discussed in above chapter.

It still indicates the sense of work optimization and the method, this method is based on workers' sense, capability, and competence.

STEP 10

Date:

Task Reviewed:

1. Do they understand English? if no, invite the interpreter

2. Has a work permit been issued? if no why?

3. Has a JSA been discussed? if no why?

4. Has a 4 PC been done? If no why?

5. Do they understand the job being performed and how to do it safely?

6. Do they feel the job was being done safely? Did this job affect any other task / personnel & if so were other parties informed correctly?

7. Tell the group / person; the good behavior / work practice being observed:

8. Observations for improvement:

9. Ask the men what they can do to make the job safer:

10. Thank them for being safe.

Figure 6.1 The Step 10 Engagement (Seadrill, 2011)

In this small card, it comprises some basic methods I have discussed in this thesis; it is a best example to demonstrate the practical value of risk analysis, human factors, and work optimization.

6.2 Work optimization in operation creates value

The drilling operation consists of different tasks; each task can be performed through some of individual activities, just like the running BOP operation that I have described in chapter 3. Here I will use some basic methods that related to risk analysis, equipment maintenance and human factors to optimize the process of changing hydraulic power slips (Figure 5.2) during tripping operation.

The power slips is corresponding to manual slips which makes the tripping operation efficient and safe without manually to pull and set manual slips. For PS750 power slips (Blohm + Voss) the HYSY981 has on board, it had the old changing program showed in figure 5.3.

Figure 6.2 PS750Blohm + Voss Power Slips

After several times of operation, there are some of the processes are not necessary and can be optimized after further study. Please refer to figure 5.3, there are three rectangle boxes in orange and two diamond boxes. For orange boxes, there are optimization points that have been identified as experience has been accumulated and extracted from practical operation.

In one box, it shows we need to disconnect hydraulic hoses of guide gate, and one more step later we need to reconnect the same hydraulic hoses back, which takes about 10 minutes to perform each action. One more issue is risk that people is exposure around rotary table for a longer time with hand tools which has a potential that tools have the probability to drop into well; another issue is the disconnection and connection hoses of hoses increase the malfunction chances of power slips system.

After checked the drawings and discussed with technicians, redesign and modifications could be took to conquer this unnecessary step. Then the process will be changed into a process as described in figure 5.4. Please compare the figure 5.3 and 5.4, especially the activity colored in orange. In figure 5.3, we found that there two orange boxes have opposite activities. One is to disconnect and the other one is to reconnect, but in figure 5.4, there no need to spend time on those activities any more. This will save a lot of time and man work, at the same time risk is mitigated due to reduced intervention of human activities with power slips.

One more improvement is to get technicians up to drill floor prior to installing the power slips. Visual inspection and function test would be performed before we stop tripping operation on manual slips. (Refer to figure 5.4) This brings the diamond box, the decision point two steps ahead before installation without interrupting tripping. If it is not test good, technician can directly involves in the repairing work without any delay. If it is test ok, we can start the installation.

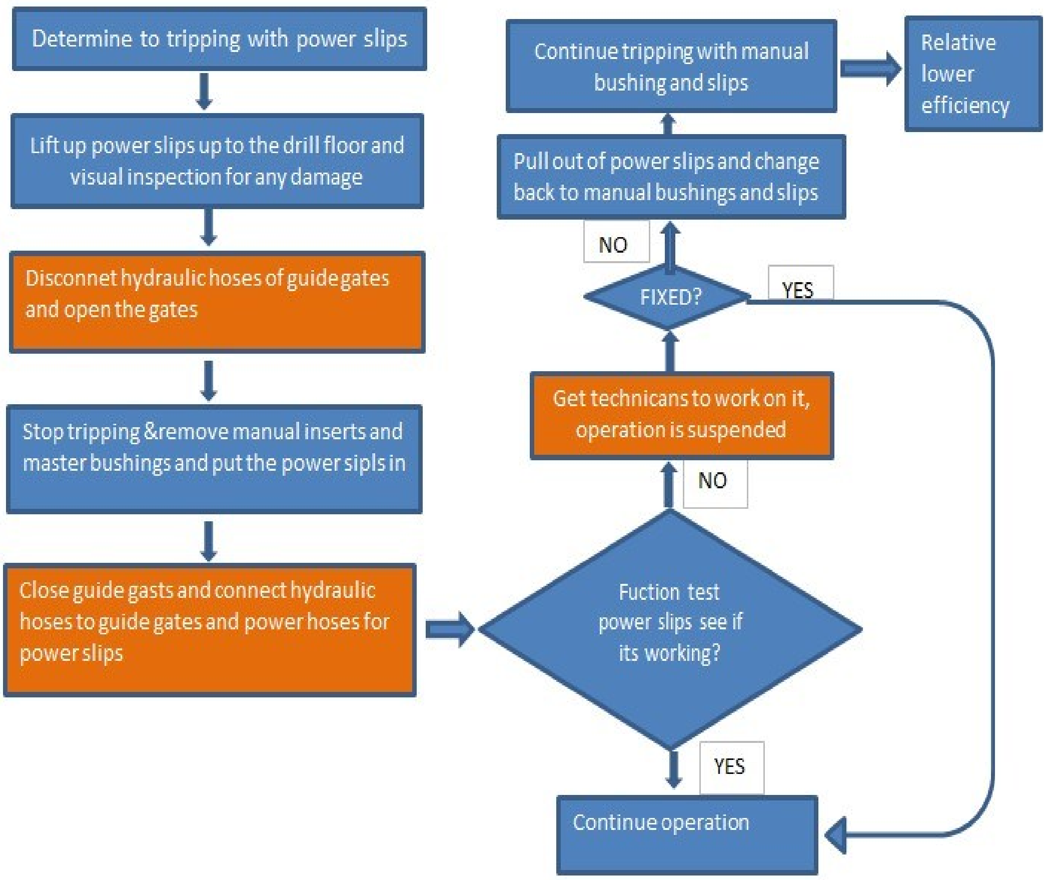

Figure 6.3 The changing process before work optimization

After the power slips is installed, both processed are enter to a decision point. It seems we go into a same point, but if we go through this two programs, it can be easily identify that the chance of failure of double confirm in figure 5.4 is remote compare to the function test in figure 5.3. Because the optimized process has done the function test once before power slips is set. So for the activities labeled in red solid line are considered as a contingency plan which has a remote probability.

Before installation and after using, periodic maintenance needs to be conducted according to relative procedures, this is kind of task-based maintenance. The function test conducted before installation is very useful for a new build platform, equipment are still in run-in period and additional insurance on equipment will noticeably increase the operation performance. It is a good sense of work optimization for rig crew to be proactive in the process, for instance, technician come to work site prior to operation when perform critical process instead of when failure comes.

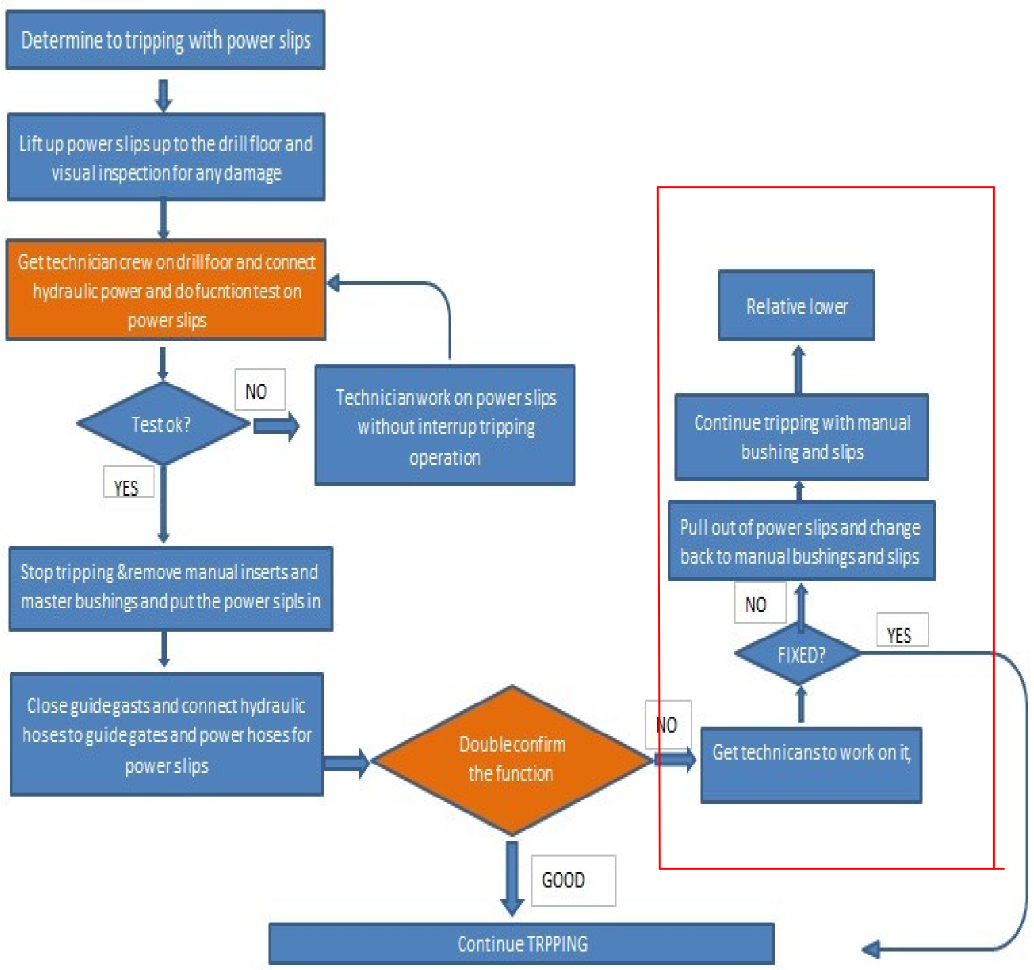

Figure 6.4 The changing process after work optimization

By complete the above process, the whole operation is cut short at least 10 minutes. For a ultra-deep water drilling platform, the general day rate is, let's say, $500,000 US. Simple mathematics can work out how much money we will save:

500,000/(24*60)=347*10= $3472 US.

It is 3472 US dollars has been saved for one single job for one time, we can imagine that how many job will perform on a drilling platform and how many times will we do to complete drilling operation. So if we consistently working on work optimization, after we finish one well for one month, half or one million of US dollars might be saved. The money saved is the value that created by work optimization.

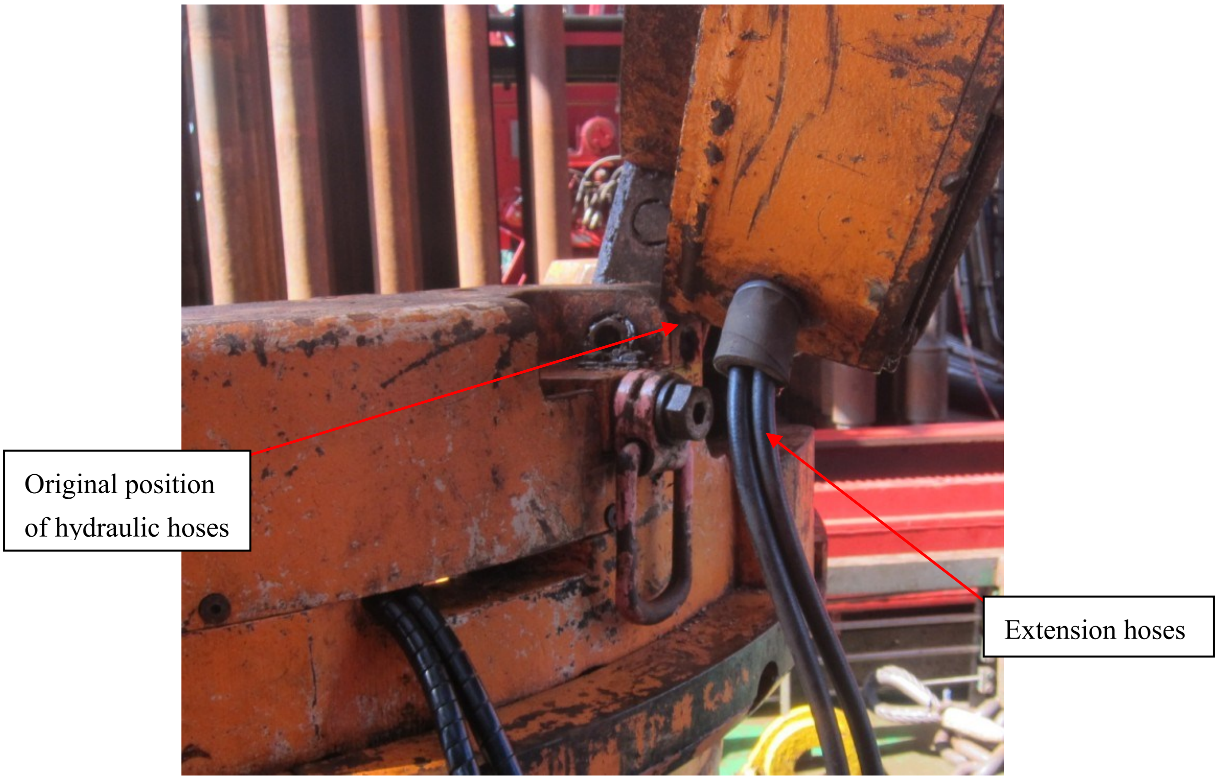

Figure 6.5 The modification point

Note: A hole is drilled and extension hose is connected to avoid collision between lifting pad eye and hydraulic hoses based on original design.

In this simple work optimization action, different factors contribute to it, for example: Human factors, cooperation and team work of people from technical and drill crew; Maintenance actions, periodic service on power slips; Risk analysis, long time exposure of worker to work with tools around rotary table has a high potential to drop objects into well; Optimization on procedures, etc.

Except for power slips, the same method can still be applied on any other equipment or system, such as the vertical pipe handling system, torque master which used to make up and break out different types of tubular, riser running tool, and so on. For extreme critical equipment, this method can still be implemented, such as BOP stack. Prior to running into water, systematic, complicated and time-consumed test and maintenance must be completed and proofed under supervision.

For offshore drilling operation, especially in deepwater, the rig management needs to make more effort on risk analysis, equipment maintenance, and human factors, integrate all these factors into procedures.

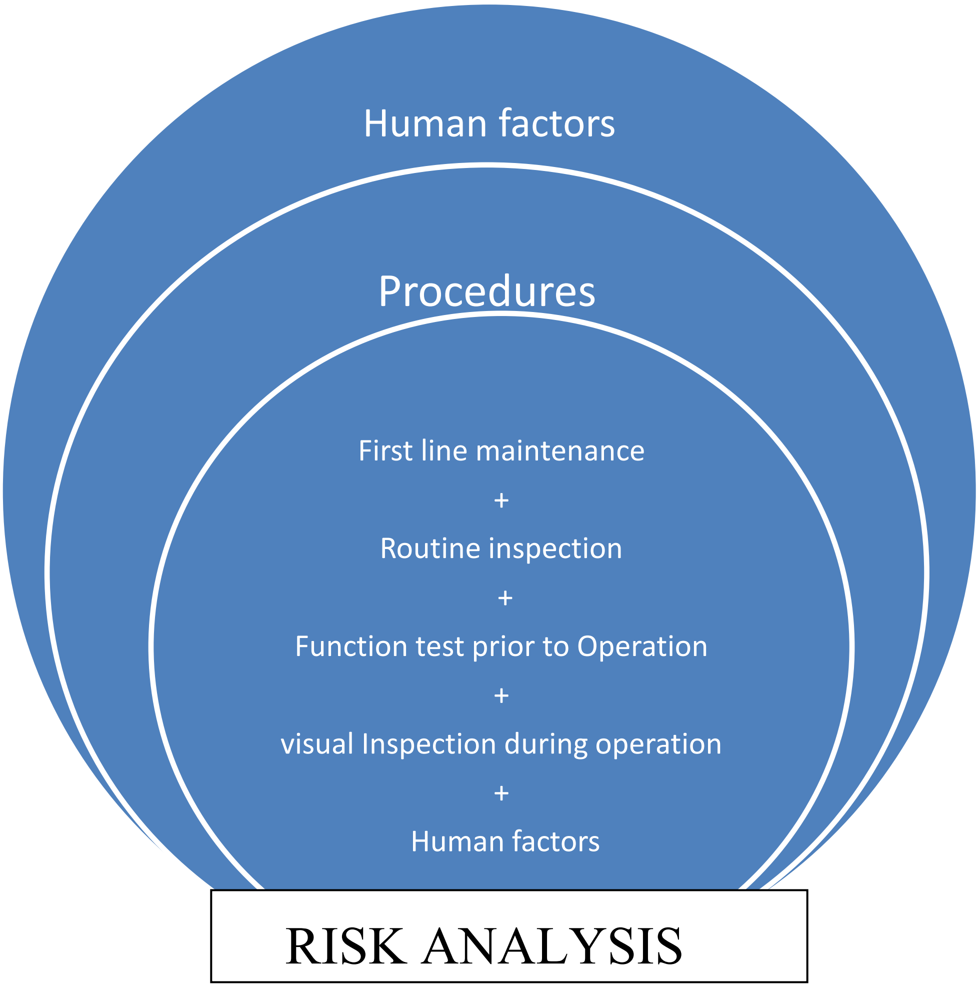

Figure 6.6 The general relationship of related contribution factors

7 Discussion and Conclusion

This thesis risk-based work optimization of deep water drilling operation has generally described the development status of offshore drilling and deep water drilling and the practice ongoing in global area. The world has a strong demand for oil which excites the nerve of giant oil & gas industry. The general drilling work process is drawn out to describe the critical path of deep water drilling. And based on the process and the experience of author, several aspects are brought out: risk-based work analysis, maintenance, human factors, and work optimization. Then all come to work procedures, it is paper summary of work effort has been made through the aforementioned aspects and experience accumulation. The optimized procedures are also excellent way for experience learning and transferring. This is the process of standardization, combine practical experience with professional knowledge, summarize and update into relevant procedures and document.

The analysis goes deeper into the BOP running process of rig HYSY981, describe its process into individual steps, and use the simple risk analysis tool: bow-tie diagram, risk matrix, FTA, and ETA and so on, to analyze each step. It still combines different maintenance strategies into the operation steps, consider the human factors that would contribute the work performance and significant impact on risk management.

Here the author brings up a new maintenance strategy, especially for critical equipment that has directly affected rig operation time, pre-function test strategy. It is different from preventive maintenance or predictive strategy, pre-function test is to do a simulation running prior to operation to make that all the relevant equipment that may involve the work are working properly. Just like a pre-operation or test run of the future operation. This method has been widely used in the oil & gas industry, and beneficial to operation safety and efficiency.

The thesis also describes human factors which has a noticeable influence in safety and work performance. The human error is one of the most important causes for operational incidents and equipment failure. And on the other side it is also critical when we find way to optimize the work and safety. The responsibility of people is the first aspect we need to consider for work optimization. It depends on different conditions, but get people motivated is critical and fundamental to inspire them. A responsible employee will devote his effort, knowledge, experience and wisdom into career, creates positive and direct effect to safety and work performance.

After go through different of aspects that could exert on work optimization, the author combines them together and try to explain the relationship, please refer to figure 2.1, figure 3.5 and figure 4.1, it seems a little of confusion among them and reflects how intensive the interactions are among these contributors. To simply the expression and get directly idea for onsite operator, we can use a formula to show this which is just a simple list.

Responsibility + Procedures + Risk analysis + First line maintenance + routine inspection + function test prior to operation + visual inspection during operation+ human factors

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Additional Value Created

8 Reference

Aven, T. (2008). Risk analysis: assessing uncertainties beyond expected values and probabilites. Chichester, John Wiley.

Aven, T., J. E. Vinnem, et al. (2007). "A decision framework for risk management, with application to the offshore oil and gas industry." Reliability Engineering & System Safety **92: 433-448**.

CIA (2012). "Country analysis: China." Retrieved 22, NOV, 2012, from http://www.eia.gov/countries/cab.cfm?fips=CH.

COSL_Drilling (2011). HSE Manual Integrated Management Manual. Beijing.

Dagnew, A. (2012). Optimization of Periodic Maintenance Using Condition Monitoring Techniques and Operational Data. Stavanger.

EN13306:2001 (2001). Maintenance Terminology. Brussels, European Standard, CEN (European Committee for Standardization).

GU, M. (2010). Early project phases and uncertainties in cost and schedule. Faculty of Science and Technology. Stavanger, University of Stavanger. **Master:** 111.

Heber, H., S. Wiig, et al. (2008). "Human Factors in Drill and Well Operations—The Drillers' Work Situation." SPE.

HFES (2013). "What Is Human Factors/Ergonomics? ." Retrieved 16, January, 2013, from What Is Human Factors/Ergonomics? .

IRGC (2005). International Risk Governance Council. Risk governance: Towards an integrative approach. White Paper No. 1,O. Renn with an Annex by P. Graham. Geneva.

Markeset, T. (2012). Lecture of Operations and Maintenance management. Stavanger, Norway, Universtiy of Stavanger.

Mcclatchy (2010). "Gulf spill reminds America: The era of 'easy oil' is over." Retrieved 28, NOV, 2012, from http://www.mcclatchydc.com/2010/05/07/93754/gulf-spill-reminds-america-the.html.

Merriam-Webster. Retrieved December, 21, 2012, from http://www.merriam-webster.com/dictionary/maintenance.

Milje, R. (2011). Engineering Methodology for Condition Based Maintenance, University of Stavanger.

Mobley, R. K., Ed. (2002). An introduction to predictive maintenance. Amsterdam, Butterworth-Heinemann.

Odland, J. (2011). Lecture Note_Historic overview and some cases. Stavanger.

Qian, S. (2006). "海洋石油——石油生产增长的潜力所在." 中国石油和化工经济分析(02): 43-49.

Rasheed, W. (2002). "Deepwater drilling faces challenges." Retrieved 14, January, 2013, from http://www.epmag.com/EP-Magazine/archive/Deepwater-drilling-faces-challenges_3050.

Sandrea, I. and R. Sandrea (2007). "Global offshore oil: geological setting of producing provinces, E&P trends, URR, and medium term supply outlook." Oil and Gas.

SKOGDALEN, J. E. (2011). RISK MANAGEMENT IN THE OIL AND GAS INDUSTRY INTEGRATION OF HUMAN, ORGANISATIONAL AND TECHNICAL FACTORS. Faculty of Science and Technology. Stavanger, University of Stavanger. **Philosophiae Doctor:** 62.

su, B., L. Feng, et al. (2006). "世界海洋石油工业现状和发展趋势." China petroleum enterprise(Z1).

Transocean (2011). "Transocean Ltd. Announces World Water-Depth Drilling Record in 10,194 Feet of Water." Retrieved 22 NOV, 2012, from http://phx.corporate-ir.net/phoenix.zhtml?c=113031&p=irol-newsArticle&ID=1549073&highlight=.

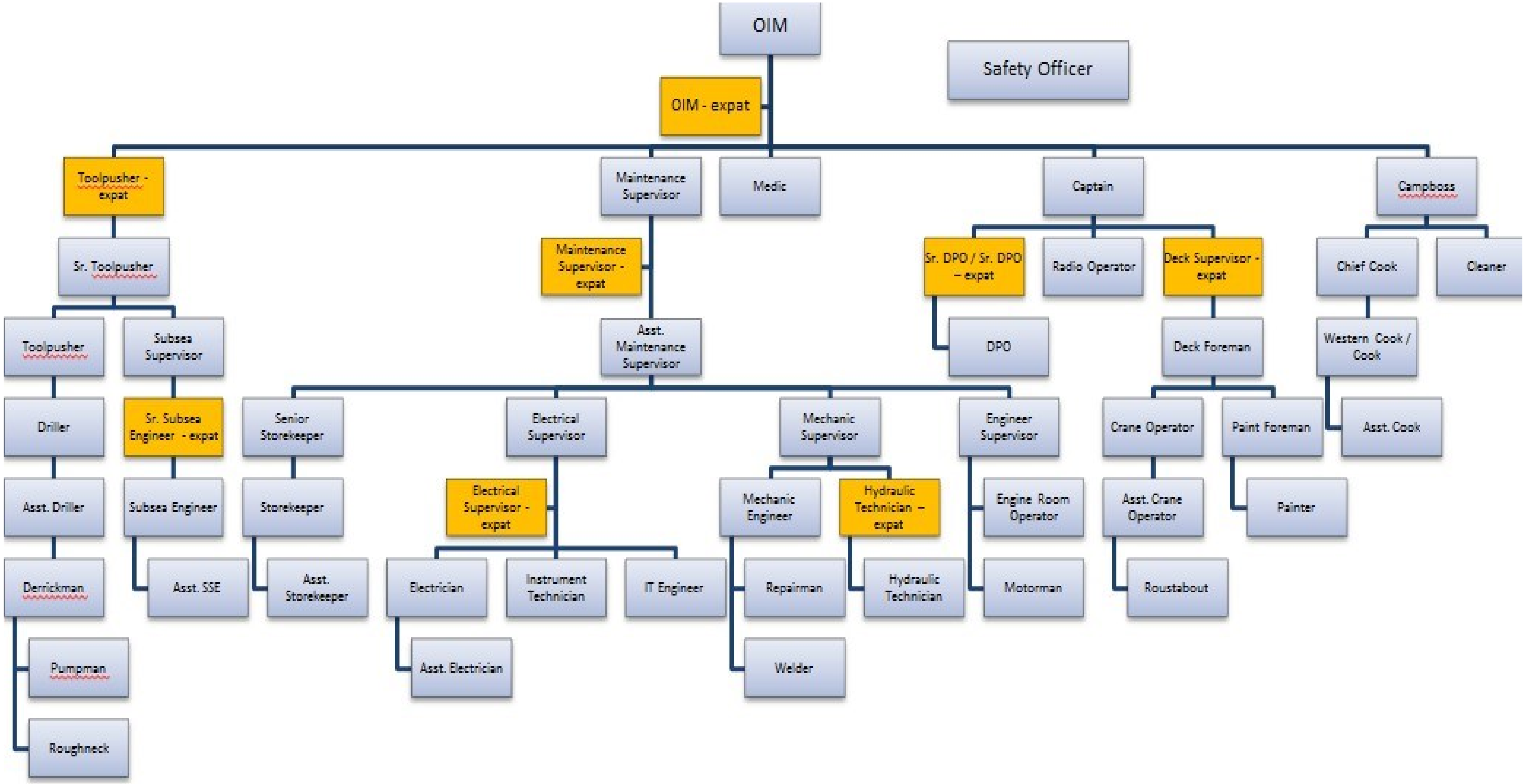
Vignes, B. (2011). Contribution to well integrity and increased focus on well barriers from a life cycle aspect. Faculty of Science and Technology. Stavanger, University of Stavanger. **PHILOSOPHIAE DOCTOR:** 364.

Vignes, B. and J. P. Liyanage (2012). "On the human performance model for complex and safety critical operations - A Case study on Drilling and Wireline operations from North Sea." International Journal of Strategic Engineering Asset Management.

Vulchi, K. R. (2011). Human factors, Technical and Organizational Issues in Onshore Operation Center: Challenges, Best practices and Recommendations. Faculty of Science and Technology. Stavanger, University of Stavanger. **Master:** 85.

Willis, H. H. (2007). "Guiding resource allocations based on terrorism risk." Risk Analysis: 27.

Appendix 1: Personnel Organization onboard HYSY981



Appendix 2: General work flow of drilling operation