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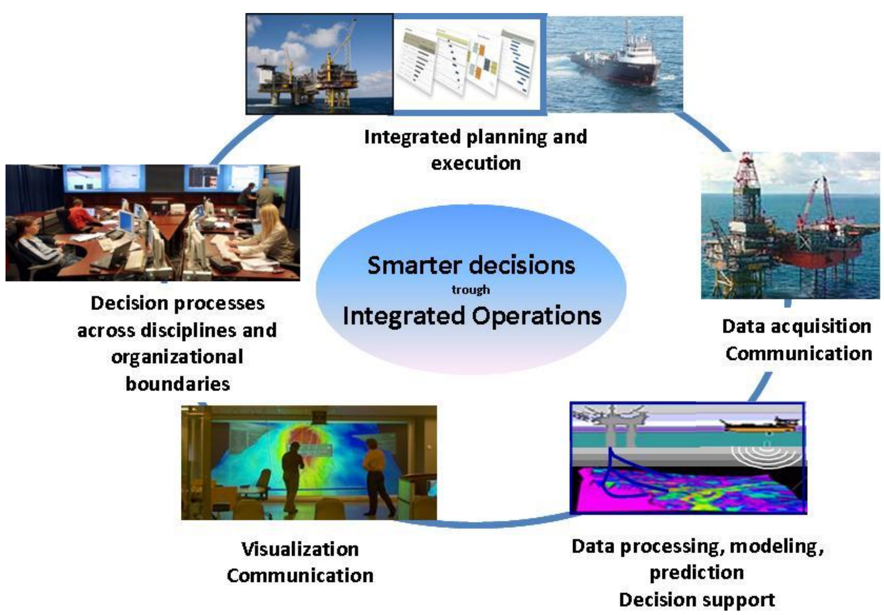
Intelligent Oilfield Work Process and Work Optimization: Turn Data into Effective Decision and Actions



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Beijing, April 2013

Hao Xiaoliang

Abstract

The oil and natural gas, due to its important role in the economic construction society development, are sought vigorously by the Governments and oil enterprises. However, as a fossil energy, oil and gas resources were formed in the harsh environments, its distribution is highly unevenly with serious heterogeneity. In the 1980s, the breakthrough in drilling and completion and upsurge of improved level of reservoir knowledge, like directional wells, horizontal wells, multi-lateral wells, the application of sequence stratigraphy, EOR technology, oil reservoir development has entered a new historical period, providing the possibility to meet the rapid growth in demand for oil and gas.

In recent years, the new proven oil and gas reserves are limited, and are mostly distributed in harsh environments, such as the desert, the deep sea and the Arctic environment, the exploration and production activities has an immeasurable impact on the environment. However, the limited resources cannot allow the unlimited mining for the increasingly demand of oil and gas. How to use the existing technology rationally to improve the oil recovery as much as possible becomes a pressing challenge for oil companies.

The concept of the digital oilfield and intelligent oilfield, making the construction of oil and gas fields in the complex conditions in the new period ushered in a ray of new dawn. The wildly application of the computer technology in oil industry makes people can conduct a comprehensive analysis of the development of oil and gas fields, and offers the possibility to optimize the production activities. The network-based information communication technology flourishing in 21st century makes the way of people's life and work has undergone enormous changes.

The intelligent oilfield is a closed-loop asset management method, can achieve real-time monitoring, real-time data acquisition, real-time interpretation, the implementation of the decision-making and optimization, oil well, oil field and related assets can be linked to each other to co-ordinate the operation and management, and thus the rate effective way and direction to improve oil recovery, especially true in the case of more expensive Injecting. At present, with the progress and mature of the reservoir dynamic monitoring

technology, horizontal wells management, and reservoir management technology established based on horizontal wells; the intelligent oilfield improves oil recovery prospects are very clearly.

As a complicated system, intelligent oilfield is an organic combination of people, process, and technology. The final objective is to increase the values of assets by managing oil and gas reserves on demand and in real time. In order to achieve this, a mass of data are collected and reported; knowledge and information could sharing in real time; and informed decision must be made timely under a collaborative decision environment. However, this is not an easy job. It needs a revolutionary evolution of oilfield management.

This thesis starts with the review and outlook of the world's and China's energy production and consumption, then try to illustrate the proposal and develop route of the Intelligent Oilfield, and how to build Intelligent Oilfield; based on this, briefly analyze some issues and challenges that exist in the process of build of the Intelligent Oilfield in China offshore oilfield, and try to find some useful and rational information to the building of China offshore Intelligent Oilfield.

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Chapter 1 Introduction

1.1 Background

Overall, the 20th century is the era of cheap oil. The low but sufficient oil supports the huge development of human industry, leads to unprecedented achievements in the process of transformation of nature. However, the cheap oil in the 20th century had a tremendous impact on the world economy; several oil crises stunned the world. The rise and flourish of world oil industry in the 20th century, is not all plain sailing, there are also low tide left us more confused, because we do not know that how much oil and gas resources the earth has until now. What we can only do is to find the means to discover and maximize oil recovery, to produce more oil and gas by virtue of existing techniques. There is still a long way that the oil industry has to go, the world oil industry in the 21st century is full of hope, but with the humanity on the increasing demand for and dwindling of oil and gas resources, the oil and gas resources – the non-renewable energy - will have a greater impact on the world economy.

Somebody predicted that the oil era is running on its way to end in the 21st century, because mankind has mined from underground through a variety of means more than a century of oil, especially after World War II, the oil and gas output dramatically increase oil and gas consumption reached unprecedented the point, and the oil and gas demand is still increasing at a faster speed, sustain development in this trend, mankind will run out of oil and gas resources of the underground in the 21st century, the age of oil will end in the 21st century. However, the impact of oil and gas on human in the 21st century will be heavier and heavier for a very long time; human beings have to rely on oil and gas resources to sustain development.

The oil industry is a long-term undertaking, due to the aforehand decisions made by the oil companies, the government in five years, 10 years or even 15 years ago, and now the world can get a new oil supply. Similarly, the forecast of the demand for oil and gas resources and the forecast of the development of the oil and gas industry that we have made today, will affect the future and development ways of oil and gas industry for many years.

There has a close relationship between energy demand and economic growth. If there is no reliable, affordable energy supply, the economy cannot grow. The number of energy consumers is very important for determining the energy demand. "IEA International energy outlook 2005(IEA, 2005)" predicts that by 2025, the world population will reach 7.844 billion, 25% higher than the total current population. Among these, 95% of the incremental from developing countries, and the rate of economic growth in developing countries are twice as fast as in industrialized countries. 85% of the world population now lives in developing countries, but the per capita gross domestic product (GDP) of developing countries is only 6% of the developed countries. With the continuous increase of the GDP in developing countries, the proportion of its GDP to the world total GDP, will up from 1/4 to more than 1/3 by 2020. The growth rate of global economy will continue to be slightly less than 3% per year, remained essentially the same as the past 20 years development pace. Average annual growth of the world energy demand is predicted about 1.7%, the daily demand is expected to increase to about 335 million barrels of oil equivalent (BOE) to the in 2030 from about 220 million BOE. Such a huge increment of energy far beyond the amount of energy consumed today, which is about 10 times the current oil production in Saudi Arabia.

1.2 Industry challenges

According to some institutes, oil companies and scholars, like World Energy Council, Hermanmiller (2005), Wamsted (2008), the oil and gas industry is facing three several pressuring challenges, namely, stable energy supply, technical challenges, financial challenges, environmental pressures, political challenges, etc..

A stable energy supply is essential and important for the society and all industry’s developments. Although we are not sure that how much oil and gas resources exactly exists on the planet, but we are convinced that, as a non-renewable energy sources, oil and gas resources will deplete at a certain period of time in the near future, and the production will gradually decline. However, the newly discovered reserves is difficult to compensate the production decline; but human demand for oil and gas resources will continue to increase, and will not reduce, so the ability to find more oil and gas resources continuously, the ability to make full use of oil and gas resources that has not mined previously, the ability to improve a variety of techniques to make full use of all kinds of oil and gas resources, will be the most important feature of the 21st century on the world oil industry. The same time, the limited resources of oil and gas will affect and restrict the development of the oil industry of the world in the 21st century.

The second serious challenge is the requirement for new techniques to discover more new reserves and produce more oil and gas from discovered reserves. We know that after more than one hundred years' extensive explorations and exploitations, the large, easy discovered reserves locate in fine terrain had been discovered mostly, and the good-quality reserves have been produced greatly. The most recent large discoveries reported by oil companies locate in hostile environments, like dessert, deepwater sea, high temperature and high pressure, deeper depth, etc.; at the same time, most old fields have stepped into the high water cut stage; they produce much more unwanted water than what we really want. Thus we need to develop new techniques to help the exploration and production, 4D exploration, Horizontal drilling, multi-target drilling, intelligent well completion, flow assurance, enhanced oil recovery (EOR), unconventional Resources exploration, real-time operations, and other new techniques are wildly applied to help oil companies to squeeze more oil and gas from reserves and better oilfield management performance to maximize their ROI, reduce operation costs, and improve assets utility.

Due to the very nature of oil resources, the environment is invariably affected. On Oct. 18, 2010, China International Energy Forum seminar on energy and climate change, Deputy General Manager of China National Petroleum Corporation, Wang Yilin noted that the current decline of onshore conventional oil resources intensifies, petroleum exploration and development activities to the sea, polar, desert and other environmental sustainability weaker geographical transfer, any failure could have disastrous consequences. Must be highly concerned about the safety of production, will reduce the possibility of accidents to a minimum. How can you forget the environmental catastrophic in Gulf of Mexico in 2010 caused by the Deepwater Horizon oil spill?

The political realm is another important issue that must have been considered by oil and gas industry. There is no doubt that oil is a key factor in the strategy of world peace. For any country, if he can master his energy supply, especially the oil supply, he can control his dynamic of economy. This is not a joke because oil and gas plays an important role on economic development. In order to get a high oil production, many international oil companies entered into the political hot area, such as Middle East, Africa and Latin American. In these areas, due to political issue, religious belief, tribal interest and so on, the situation is very complex and war of different size is very common. Some wars are still continuing until now, like wars in Iraq, Libra, Syria. This makes it is quite hard for oil corporations to gain advantage from both sides.

1.3 The scope and objectives

This paper is mainly focus on what the Intelligent Oilfield is and how to construct an IOF in CNOOC, especially the collaborative environment establishment through data management and utilization. The purpose is to contribute to make the decisions and activities more efficient and thus to help CNOOC with new ideas to increase the productivity, achieve high oil recovery, lower costs, and reduce risks to health, safety and the environment. However, this thesis is limited to the production phases of the oilfield development based on my previous work and what I have learned in UIS.

Since CNOOC is still in the initial and mobilization phase of intelligent oilfield construction, there has not have concrete data for quantitative data analysis. Thus this paper mainly focuses on the following aspects:

- The review and outlook of the World and China's oil production and consumption;
- What is the Intelligent Oilfield and its key components;
- The challenges faced by CNOOC during the next generation oilfield development;
- The collaborative working environment and work process;
- Data management and data utilization.
- Connecting data into Decisions and Activities. A demonstrative example

1.4 Methodology

This thesis is mainly an analytical thesis. A series of paper and reports about energy situation, intelligent oilfield, integrated operation, and data based decision were reviewed. These documents gave me a good idea about the next generation oilfield developments, and this will help me greatly in my future work.

When come to the construction of intelligent oilfield construction in China Offshore, I visited several production experts who work in CNOOC (Ms. Huang Zhijie, Mr. Li Yaolin, Mr. Yuan Hui, Mr. Yang Shan, etc.), to discuss the current situation and disadvantages of the oilfield developments, besides, they gave me many good ideas and suggestion about the next generation oilfield construction.

The production departments of CNOOC and COSL have built two types of database, one is the well production database and the other one is the well logging database. The data used in this thesis are mainly gathered from these two databases, besides, some information is collected through telephones and e-mails and other ways.

1.5 The limitations

However, although I try to get an in-depth analysis through this project, the limited knowledge and my position restrict my work. Due to the nature and characteristics of my job, I have less chance to deal with field works. At the same time, the organization structure of the CNOOC oilfield exploration and development is so complex and decentralized that many service companies are involved in the development. Most times they only responsible for their own works and do not need to deal with other companies. As a result, there has not have a clear and fluent communication and collaborative environment that all related parties can work organically to achieve optimized decisions and actions to maximize the value of oilfield assets. Due to this situation, it is not very easy for me to get the information that needed to have a good understanding about the construction of IOF in CNOOC. However, I try best to use my limited knowledge and understanding about my previous work and learning in UIS and information gathered from production department of CNOOC to have a better result about IOF.

1.6 The structure of the thesis

The structure of the thesis is organized as follows. Chapter 2 descripts the energy consumption and production of the world and China, offshore oil development activities in China and challenges to the China's oil industry. Chapter 3 illustrates the development route of oilfield developments, what the Intelligent Oilfield is and the contents of the IOF. Chapter 4 mainly focuses on the collaborative work environment and the work process and how to realize real-time data transmission to support the collaborative work environment and optimize the work process. Chapter 5 first defines what data quality is, classifies data problems and analyzes the reason of these problems, and discusses how to conduct data quality control. After that briefly illustrates how to construct an oilfield production data warehouse and how to use data mining to guide the production decision-making. Chapter 6 summaries the conclusions and proposes suggestions for future studies.

Chapter 2 International and China Energy Outlook

"Nobody can do without energy. The relationship between economic growth and the demand of energy is crucial, and the availability of energy sources to economies is crucial."

Maria van der Hoeven

Executive Director, International Energy Agency

In order to understand why Intelligent Oilfield is the trend of oilfield development, let's have a look of the world and China's energy consumption and production, then offshore oil development history in China and critical challenges to China's petroleum industry, after that, we can have a clear idea why Intelligent Oilfield development is the goal for China's Oil Company.

2.1 Outlook of the world energy production and consumption

When entered into the 21st century, the energy supply in most time is tight, Figure 1. Although more oil was produced with a slightly ascending tendency, but still cannot meet the increasing rate of energy consumption. The world primary energy consumption rose too fast, as shown in Figure 1.

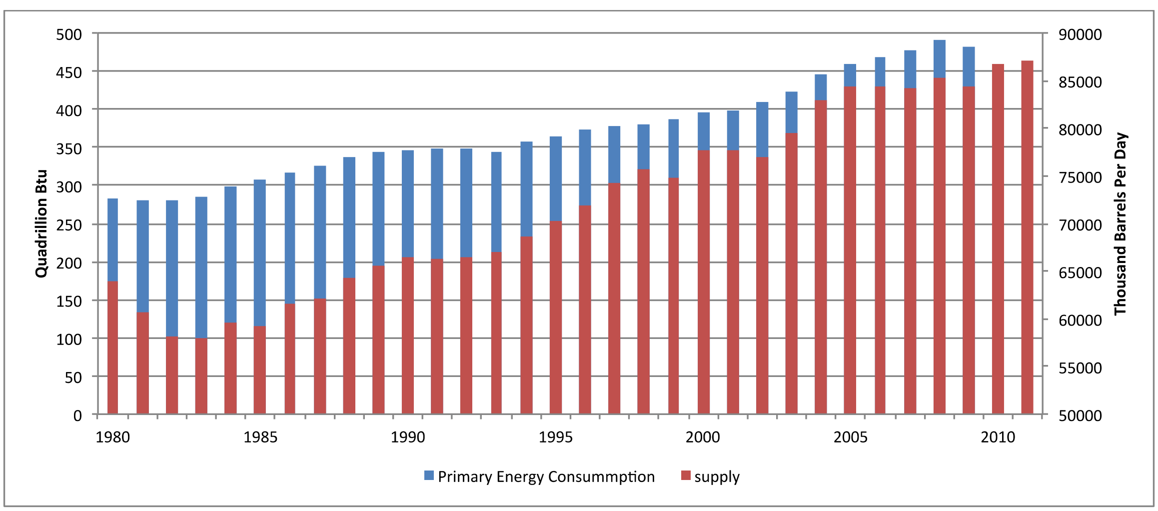

Figure 1 World's Total Oil Supply and Primary Energy Consumption, 1980-2011(EIA, 2011)

In the past decade, the worldwide oil supply and demand primarily maintains a balance with supply slightly larger than the demand, but this balance is very fragile. In some countries and regions, some of the season or a time period, oil shortage, electricity shortage, and energy supply tensions occur from time to time usually due to natural disasters, climate change, local wars, social unrest, terrorist activities and other reasons.

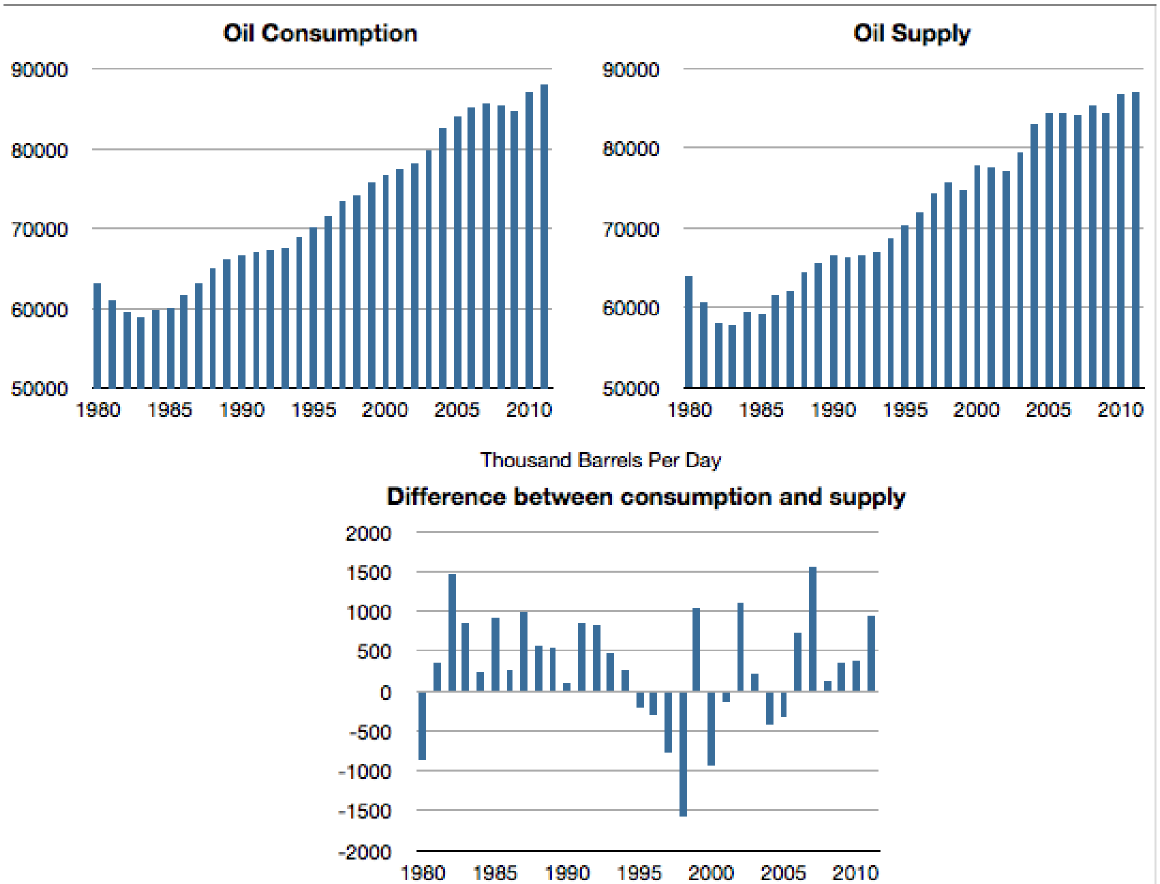

Figure 2 Oil production and Consumption, 1980-2011(EIA, 2011)

Generally, the energy production capacity increases slowly but energy consumption demand arises sharply, Figure 2. In the past 20 years, fewer and fewer new oil fields, especially large oil field, were discovered worldwide. The mature oil fields are facing series problems and the production decreases faster than expect. The world's four super oilfields, only Val oilfield maintains a high yield. In future, production of Russia's West Siberia oil field will decline. Some other countries, despite own rich resources, limit production for a variety of considerations. For example, the United States has rich oil reserves in northern Alaska, but in order to protect the ecological environment and the local oil reserves, restricts oil production for long-term. In China, most land oilfields and some offshore oilfields developed for several decades today produce more water than oil.

In the next 20 years, the world's energy needs will grow significantly, the expected increase is mainly because the economic blossom of emerging countries.

According to United States Census Bureau(NPG, 2012), the world's population estimated to will increase by about 20.5% from 2010 to 2030, reach approximately 8.2 billion, about 1.4 billion more than that of 2010, but the yearly increasing rate is decreased to 0.76% from 1.10%; however, the total income grows faster than ever and is likely to rise by 100% over the next 20 years(**BP**, 2011a), Figure 3.

ExxonMobil (2011a) estimated that the economy of OECD[1] countries will expand by about 2 percent a year on average through 2040, as the United States, European nations and others gradually recover and return to sustained growth; while Non OECD economies will grow much faster, at almost 4.5 percent a year, Figure 4.

According to the American Energy Information Administration (EIA) and to the International Energy Agency (IEA), the worldwide energy consumption will on average continue to increase by 2% per year; the report "International Energy Outlook 2011" released by EIA states that the world's energy consumption will increase 42.8 percent by 2030 compared to 2008, Figure 5. BP estimates that world primary energy consumption is likely to grow by 39% and global energy consumption growth averages 1.7% per year, from 2010 to 2030(**BP**, 2011a).

[1] OECD, the Organization for Economic Co-operation and Development, was officially born on 30 September 1961; Its 34 member countries span the globe, from North and South America to Europe and the Asia-Pacific region, include many of the world's most advanced countries but also emerging countries like Mexico, Chile and Turkey.

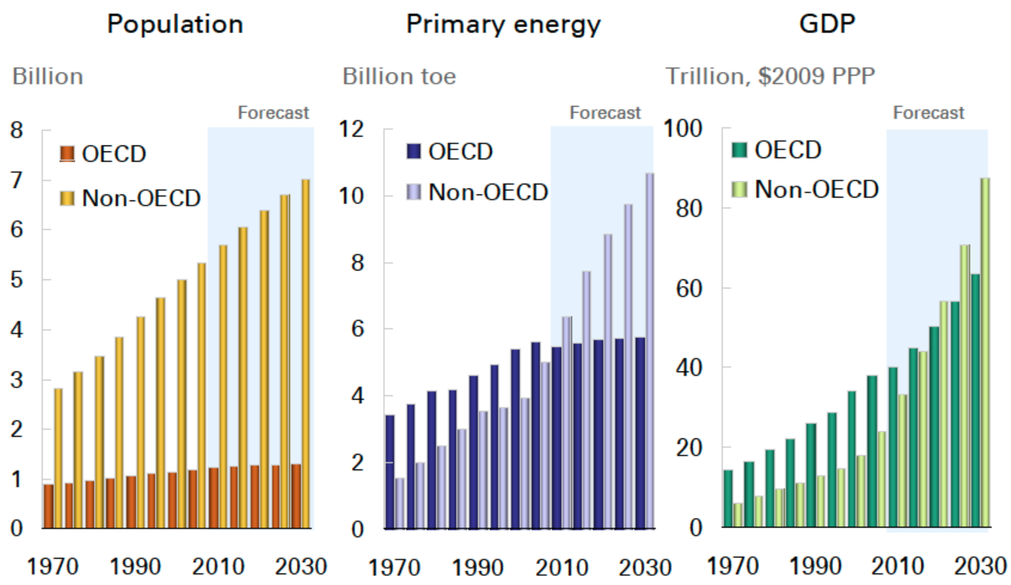

Figure 3 World Population, Primary Energy, GDP Outlook, 1970-2030 (BP, 2011a)

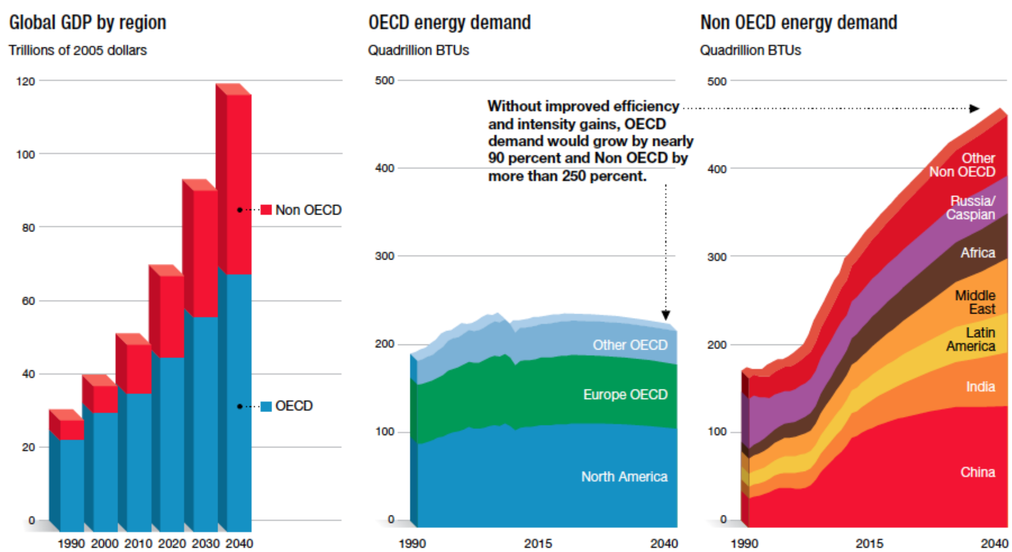

Figure 4 Regional Estimation of Global GDP and Energy Demand (ExxonMobil)

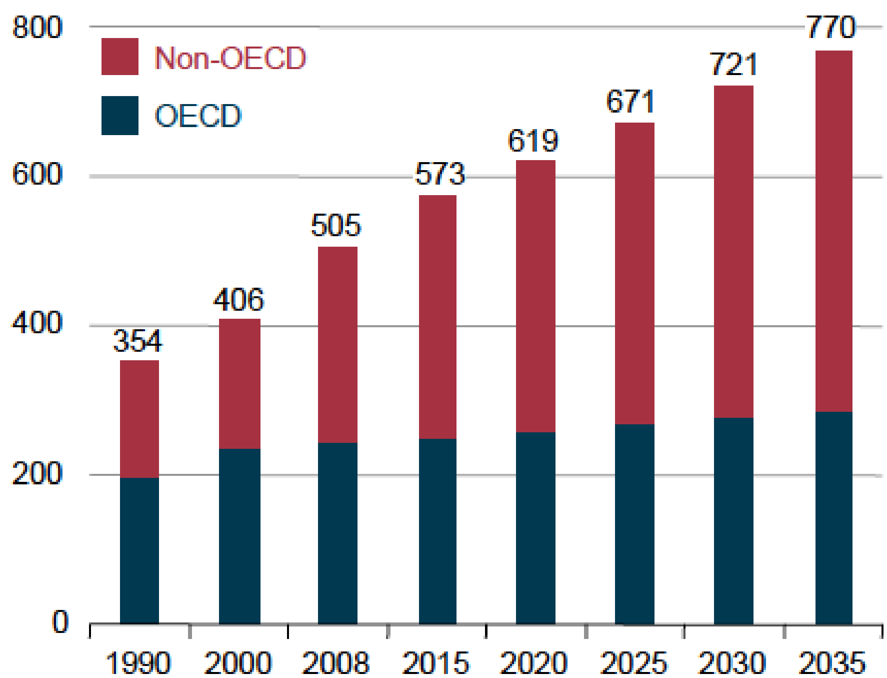

Figure 5 World Energy Consumption, 1990-2035 (Quadrillion Btu, eia.gov)

According to EIA, the world liquid fuels production must reach 108.0 million barrels per day in 2030 to meet the demanding consumption of petroleum and other liquid fuels, which is only 85.7 million barrels per day in 2008, is really a huge leap, see Figure 6.

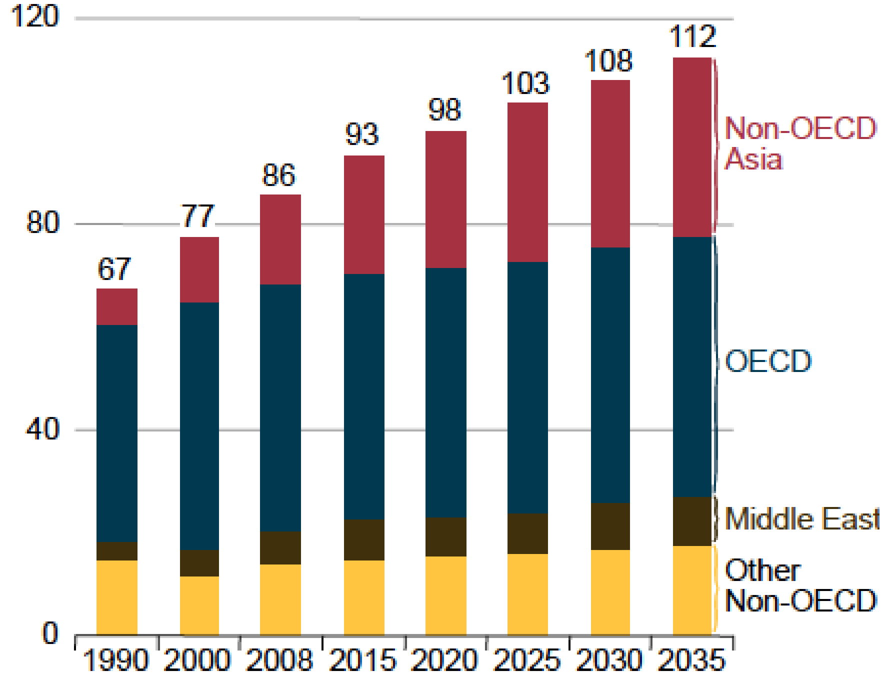

Figure 6 World liquid fuels consumption by region, 1990-2035 (Million barrels per day, eia.gov)

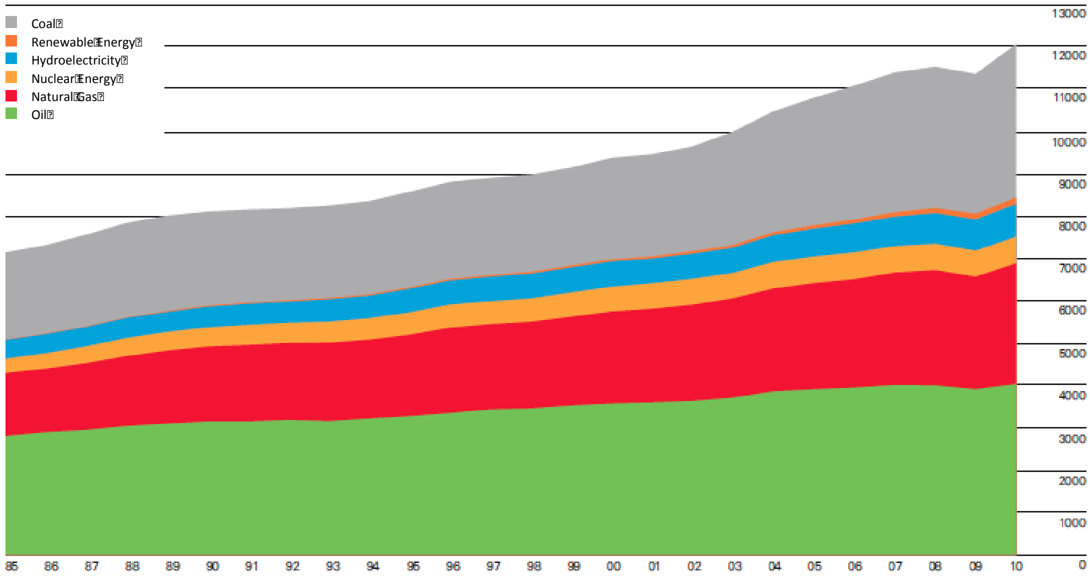

Figure 7 Global Energy Consumption, 1986-2010 (million tones oil equivalent, BP)

In 2010, global primary energy consumption increased 5.6%, achieved 12,275 million tones oil equivalent, the highest growth since 1973. Regional energy consumption growth accelerated and growth was higher than the average rate in all regional. The oil is still the world's leading fuel, accounts for 33.6 percent of global energy consumption, but its market share oil continued to shrink for the 11th consecutive year, Figure 7.

With the continued development of world economy, especially the rapid growth of emerging economies, oil demand and consumption is rising, rising by more than output growth. In the long term, loose oil supply is temporary, and tight supply will be normal.

COSL, China Oilfield Services Limited, is an oil service provider, in most times, we just deal with issues associated with oil and gas resource. Due to this reason, the following of the thesis is mainly focus on the oil industry and China offshore oil activity.

2.2 Outlook of China oil production and consumption

China, as the world's biggest developing countries, right now is on the fast lane to industrial society. In the past 30 years, china's economy experienced a strong development. To some extent, it was called as the world factory, provides powerful impetus for the development of world economy, especially for the restoring of world economy from 2008 economic crisis. However, this is based on the huge consumption of energy, especially the fossil energy. However, we cannot stop or reduce the pace of this situation, Figure 8.

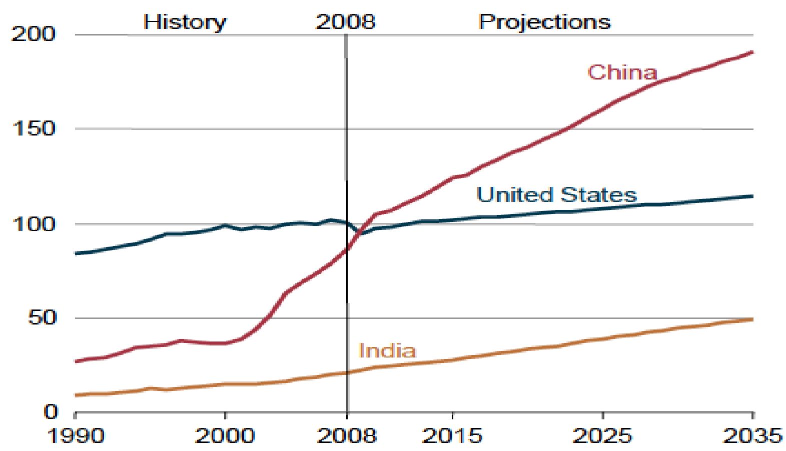

Figure 8 Energy consumption in the US, China, and India, 1990-2035 (quadrillion Btu, eia.gov)

According to BP, EIA, and other international statistics agencies, China overtook the US as the world's largest energy consumer in 2010. The energy consumption measured by oil equivalent is 2,401 million tones, accounts for 20.3% of global energy consumption. Among them, oil and natural gas accounts for 21.65%(BP, 2011b), Figure 9. The great consumption of fossil energy has a severe effect to the environment. As good news, the Chinese government has already noted it. They have already set strategies to reduce the rely on fossil energy and to increase the produce of nature gas – the so called clean energy- and renewable energy to reduce the emission of greenhouse gas to regain a beauty environment. In order to achieve this objective, Chinese oil industry needs to spend more on the exploration and exploitation of natural gas reserves.

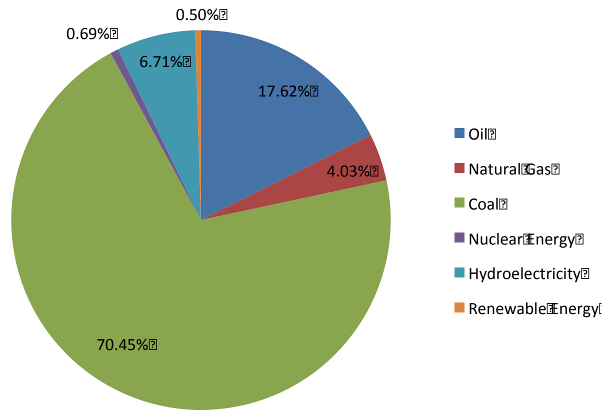

Figure 9 Chinese Energy Composition, 2010

This data is a little different with statistics released by NEA (China National Energy Administration). According to NEA, 442 million tones oil were consumed in 2010. Among them, china produced 203 million tones and 239 million tons were imported. Su Bo(2012), the vice minister of MIIT[2], states that China's dependence on foreign oil reached 54.8% in 2010, however, the UA's dependence on foreign oil in 2010 is only 53.5%. This number further increased to 55.8%(MIIT, 2011) in April 2011 and is increasing continuously.

Regardless of the statistical deviation, serious problems have been emerged since 1986(Zhou, 2004b). From then on, China's oil production growth has been slowed down significantly. The old oilfields in the east of China, which produce more than 90 percent of oil, are in the late stable production phase; remaining recoverable reserves in Northwest has a larger rise; however, the increment in Northwest only equals to 48.6% of the reduction in the eastern region. The China's overall growth of oil reserves has gradually enter into its "middle age", China's oil production and supply situation is not optimistic(Lu, 2009).

In contrast, With China's rapid economic growth during this period, China's oil demand has been growing strongly. In 1993, China became a net oil exporter. The yearly oil imports rose from 2.9 million tons in 1994 to 239 million tons in 2010, increased by more than 82 times. China's oil supply has become increasingly unable to meet domestic

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[2] MIIT, Ministry of Industry and Information Technology of People's Republic of China

consumer demand, requires a lot of imports to meet it.

In 2010, China's proved oil reserves only account for 0.91% of the world's oil-proved reserves; however, it produced 4.9% of the world's total oil production, and consumed 10.85% of the world's total oil consumption. Figure 10 is the oil proved history of China from 1980 to 2011; Figure 11 is the oil production and consumption history of China from 1965 to 2011. We can see that in recent years, China's proved oil reserves almost maintain stable with slightly decline, but China's crude oil production maintains a rapid growth rate, at the same time, China's oil imports have increased significantly to meet the huge gap between the production and consumption. The shortage of energy has become the bottleneck that restricts the economic growth in China.

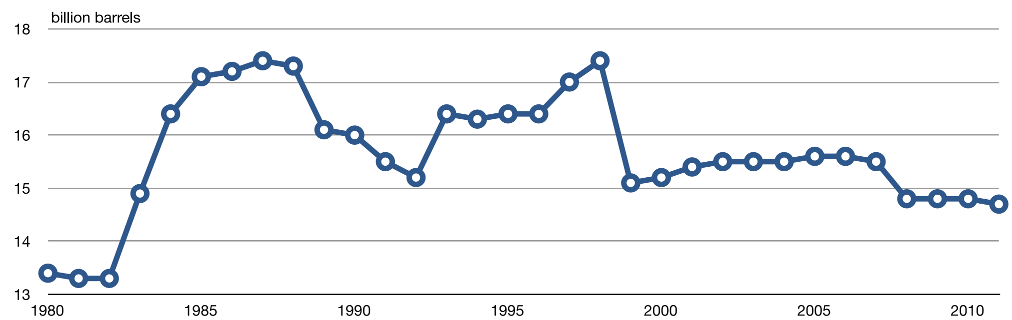

Figure 10 Oil Proved History of China, 1980-2011(BP, 2012)

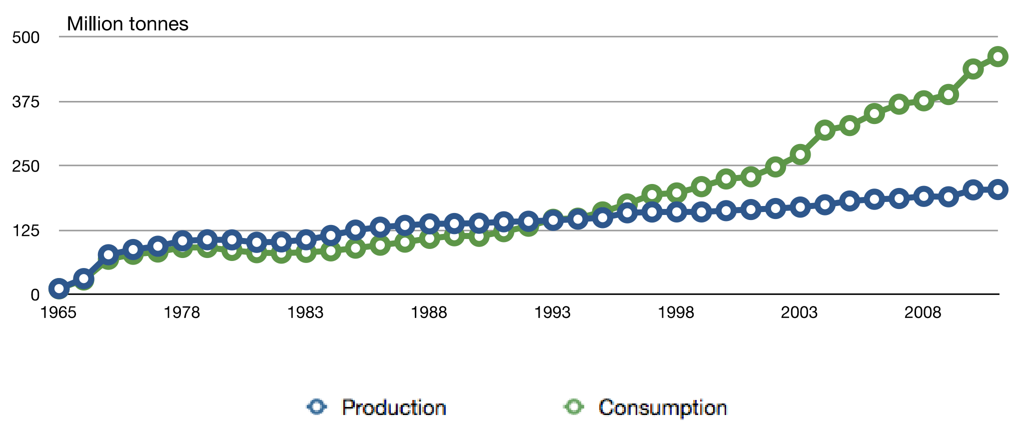

Figure 11 Production and Consumption History of China, 1965-2011(BP, 2012)

2.3 Offshore oil developments in China

The sea region of China includes Bohai Sea, Yellow Sea, East China Sea (also called: Donghai), and South China Sea. Total area is approximately 4,734,000 square kilometers(SOA, 2012, QIMG, 2005),Table 1.

Table 1 Basic Information of Offshore China

	Size	Average Water Depth	Maximum Water Depth	Remark
	km^2	m	m	
Bohai Sea	84,000	21	70	Inland Sea
Yellow Sea	380,000	44	140	
East China Sea	770,000	370	2719	About 2,000,000 km^2 is deeper than 300m
South China Sea	########	1212	5377	
Total	########			

Table 2 Estimation of Oil and Gas Resource Offshore China

	Estimation		Comments
	Oil	Natural Gas	
	Million Tonnes	Trillion Cubic Meters	proven oil reserves: 4,500 million tonnes
Bohai Sea[1]	7,670	1	
Yellow Sea	N/A	N/A	
East China Sea[2]	9,800~22,400	5.25~6.3	
South China Sea[3]	23,000~30,000	16	70% of the resources reserve in the 1,537,000 km^2 deep-sea

Remarks:

Bohai Sea[1]: (Qian, 2011), data from: Zhang Fengjiu, vice general engineer of CNOOC

East China Sea[2]: (EIA, 2008); South China Sea[3]: (news.china, 2012)

All China Sea regions are rich in natural resources such as oil and natural gas(Qian, 2008), Table 2. By far, only a small part of the estimation has been approved, especially in South China Sea, the complex geological condition, harsh environments, technological difficulties and high costs have prevented the step of China offshore oil development.

China National Offshore Oil Corporation (CNOOC) is a state-owned company incorporated on February 15, 1982. CNOOC is responsible for the overall exploitation of oil and natural gas resources offshore China in cooperation with foreign partners. Since then, CNOOC established a good relationship with foreign Oil Companies, like Statoil, Total, ConocoPhillips, Husky, Eni, BP, Anadarko, etc., in offshore oil exploration in

Bohai Sea and South China Sea.

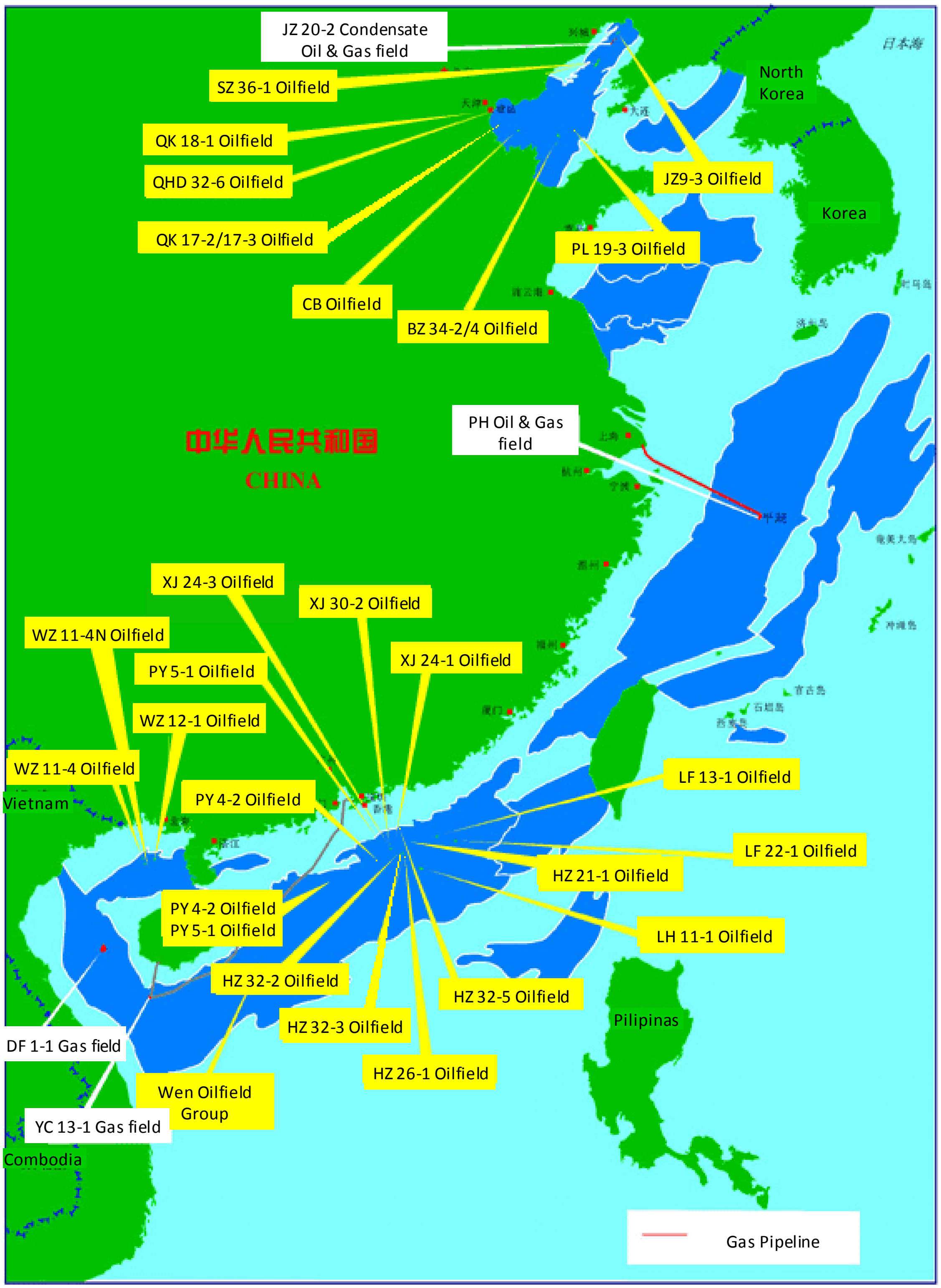

Figure 12 the Approximate Distribution of the existing China's Offshore Oil and Gas Field

CNOOC has realized fast and quality growth since its establishment. From 1982 to 2010, its annual production soared from 80,000 tons of oil equivalent to 51.78 million tones. It's really a great astride.

By the end of 2010, CNOOC has been exploiting 86 offshore oil and gas fields using 195 production platforms in China's sea region. According to the future production plan, CNOOC will construct 55 production platforms in the future 5 years, and more than 30 oil and gas fields will be put into operation, Figure 12.

Deepwater oil blocks without the help of foreign partners. In addition to building its first deepwater rig, CNOOC has been taking other steps to become independent in deepwater exploration and production(Ma, 2012).

2.4 Challenges to China offshore oil industry

The oil and gas resource is the foundation of the development of the oil industry. The lack of oil and gas resources is key factors to affect China's economic development for quite a long period of time from now to near future(Yang and She, 2007). The complexities of the international situation, the strong impact of high oil prices, and the contradictions between supply and demand have become increasingly prominent, new requirements for China oil industries are appealing.

In 2010, the equivalent oil production of CNOOC is 51.58 million tons; it is a significant milestone for CNOOC's developing. However, the oil and gas is mainly produced from shallow water fields (water depth smaller than 200 meters). In order to gain a higher production, in recent years, CNOOC pays more attention on deepwater explorations, old-field stimulation and optimized production, oversea production(Liu and Lin, 2009). In this progress, there are several urgent challenges that CNOOC must overcome.

2.4.1 Great gap with foreign advanced technology

By the end of 2004, the maximum drilling depth of China is only 505m and the word is 3 095m; the maximum developed oil and gas field depth of China is only 303m and world is 2192m. The huge gap in technology is the biggest challenge facing by deepwater oil and gas development in China, and achieving leapfrog development of deepwater technology is the key.

2.4.2 Deepwater exploration technology

Deepwater oil and gas exploration is the first challenge faced by deepwater oil and gas development(Wang, 2010), includes long distance seismic measurement and analysis techniques, multi-wave field analysis techniques, deep-water reservoir identification technology and hidden hydrocarbon reservoir recognition technology and so on.

2.4.3 Complex hydrocarbon characteristics

High viscosity, easy condensate, high wax are the main characteristics of chines offshore crude oil, also high-temperature, high-pressure, high CO2 content, these issues together brings a number of challenges for the offshore oil and gas gathering and transportation and production safety.

2.4.4 Special marine environment conditions

The special environmental conditions in South China Sea, like the strong summer tropical storm, the winter monsoon, and internal waves, submarine sand ridges, makes deepwater oil and gas development project design, construction, construction face greater challenge. The winter sea ice in Bohai Sea is another type of special condition, how to prevent the harm of sea-ice have been the problems that plague the researchers.

2.4.5 Flow assurance

The high static pressure, low-temperature (typically 4 ℃) environment proposed harsh demands for the surface and underwater structures, and more stringent requirements for subsea transmission pipeline. In the deepwater multi-phase transmission pipeline, the problems caused by multiphase flow itself, undersea terrain, and run operation, such as slug flow, the wax, hydrates, corrosion, solid particle erosion, has been a serious threat to the safe operation of the normal production and undersea gathering and transportation system.

2.4.6 The economic and efficient marginal O&G field develop technology

Large bottom water, fast pressure depletion, spreading out blocks, small reserves are the common features of China’s offshore oil and gas field especially marginal fields. Artificial lift systems are often used to get a better performance, which makes conventional development technology face more challenges, means electric submersible pumps, subsea booster pump and other innovative technologies will be applied to the development of marginal oil and gas fields in China. To reduce the development investment of marginal oil and gas fields, at the same time, to receive an economic and effective development means that more and more complex technical problems will be faced by China offshore oil industry.

2.4.7 Talent Shortage

Talent is one of the core assets of any corporation. The unique characteristics of offshore oil and gas industry, High tech, high risk, and high investment, require substantive high-quality workforces with specialized industry Knowledge. In recent years, the slowly economic recovery but the ever-increasing oil price urges Oil Companies put more oilfields into production, and a large number of unqualified workers were recruited; at the same time, large numbers of experienced workers retired or change their position(Pang and Wen, 2008). This slows the growth ability and reduces the competitiveness.

…over the next decade, attracting and retaining skilled workers will be one of the biggest risks to industry success(Orr and McVerry, 2007).

2.5 Future solutions

For China offshore oil industry, there are four primary challenges, namely, Resource issues, improper managements, low-level technological developments, and talent shortage. Each problem could become the great fetter of China offshore oil development if any of them hadn't solved perfectly.

Although there are many critical challenges confronted by China offshore oil industry, Chinese government and CNOOC has already issue some strategies to deal with these challenge.

2.5.1 Opening South China Sea for all Chinese State-owned oil companies

Before 2004, CNOOC has the exclusive right to explore in South China Sea. However, the resource CNOOC owned is not enough, like capital, technology reserve, and human resource. The work environment is hostile and the investment is so huge that the exploration pace is not as big as required just by the power of CNOOC himself. But CNPC and Sinopec are much stronger and own more resources than CNOOC. With the participation of them, the exploration rate and progress improved greatly.

2.5.2 Cooperate with foreign oil companies

Since its establishment, CNOOC have already started its external cooperation and gain great achievements (He and Ji, 1990, Lv et al., 2007).The collaboration with foreign oil companies not only reduces the exploration risk, more important, it helps China to learn advanced management experience and technology, for example, directional drilling, offshore oil and gas process, transportation design and maintenance technique, offshore positioning, FPSO, heavy oil exploitation, etc..

By July 31, 2008, CNOOC has signed 187 oil contracts with 77 companies of 21 countries and regions, introduced more than 11 billion U.S. dollars, oil and gas production reached 42.93 million tons from 90,000 tons when the company was founded in 1982. During this period, several important discoveries were revealed, like, Cheng Bei Oilfield, Qinhuangdao 32-6 Oilfield, Penglai 19-3 oilfield, Liuhua 11-1 oilfield, Liwan gas field, and so on.

2.5.3 Enhanced deepwater exploration

In deepwater zone, with the cooperation of foreign partners, CNOOC has drilled 10 wells and gain 3 achievements. In 2011, CNOOC drilled its first deepwater well in South China Sea by himself. Based on these works, CNOOC accumulated many experiences for deepwater exploration(Wang et al., 2011, Yang and Cao, 2008), such as shallow gas & shallow flow, deep water and low temperature, deep water well control technology, drilling fluid optimization, cement slurry optimization, emergency response plan, etc. however, compared to foreign offshore oil giant, CNOOC is just like an infant and still needs time and more in-depth study to build its deepwater exploration and development ability.

2.5.4 Oversea exploration and Production

Besides domestic business, the growing CNOOC also takes part in global business positively, announced a series of acquisition or participation contracts(Li and Li, 2005). The latest, also the biggest acquisition - NEXEN is waiting for the approval of Canadian government. The business of CNOOC now is expanding from domestic to overseas countries and regions such as Southeast Asia, North America, Australia and Africa, the main exploration area of 400,000 square kilometers

2.5.5 Informatization and Intelligent Oilfield Construction

In September 2012, Wang Yilin, Chairman of CNOOC, hosted a meeting to discuss the informatization construction. Wang stressed that CNOOC must improve the management structure and working mechanism, deepen the application of information systems, and promote the company to accelerate development of informatization work to promote the construction of "intelligent oilfield". It was agreed that the work of informatization is an important foundation for the work of the company, an important means to promote the management to enhance and boost "second leap". Informatization work must further strengthen the top-level design, dovetail with the head office control mode, and match with subsidiary company's management system. Adhere to the orientation to enhance the management capacity and efficiency, further definitude the contents of informatization work at different stages, concentrate existing information technology resources, and deepen the application of existing information system to promote the "digital oilfield" and "intelligent oilfield" construction.

The intelligent oilfield construction is a complex process. During this process, real-time offshore-onshore connection, integration of knowledge between business partners, real-time data exchange for effective communication of risk and efficient decision making, advanced analysis and data interpretation solutions, etc. are the important parts for the construction of intelligent oilfield. This section also is main part of this thesis.

2.5.6 Personnel training

Training is an important form of personnel training, is an important part of the personnel construction.

CNOOC establish the concept of full learning and lifelong learning in Whole Corporation to improve training network, innovative training methods to strengthen the company's internal knowledge management, to realize a learning organization thus staff grow and success quickly.

In 2010, CNOOC organized a total of about 6,300 training, a total of about 75,000 people participated; more than 100 senior management personnel took part in the centralized training, 43 senior reserved management personnel participated in the young and middle management personnel training courses; organized a total of 21 types of work, more than 4,000 people's skill evaluation; 2,300 people finished qualification test; 51.8 hours per capital training time, higher than global benchmark companies 47 hours training time.

In 2011, the company continued to intensify the training work. "CNOOC internal knowledge tutorial series" edition aims to systematically introduce the basic knowledge, development status and trends for different business segments. 27,274 training courses were organized and 502,126 staff were trained, average training time is 68.14 hours.

Training focus of CNOOC

In order to improve the quality of the employees, as the core capacity building, training work is mainly emphasis on the talent cultivation and construction of management personnel, professional and technical personnel.

Management personnel

This type of training mainly address on the ability to manage the whole system, to handle a variety of interest correctly, to improve strategic decision-making, and to execute action. Focus on the combination of theory and practice, strengthen the training and learning in the actual work, increase inter-regional and inter-professional exchange, broaden eye view and knowledge, rich experience.

Professional and technical personnel

Take the innovation enhancement as the core and focus on improving the ability to solve scientific research, key production technical issues. Strengthen learning of domestic and international state-of-art technology, provide opportunities for domestic and international academic exchanges, and selectively choose personal to learn and train in domestic and foreign universities, research institutions and foreign companies, in particular, focus on the utilization and improvement in actual work.

Highly Skilled Talent

CNOOC takes professional skills training of skilled workers as an effective way to improve the quality of workers. Make the ability to improve the practical operation and technical innovation and technical reform as the core to motivate skilled personnel constantly studying new technology.

Chapter 3 What is the Intelligent Oilfield?

3.1 History and the gradual development of the oilfield concepts

In the early phase of the oil development history, oil and gas is produced mainly rely on the natural energy. However the natural energy in a reservoir is limited and people have less means to improve oil recovery except drilling more new wells. In order to squeeze more oil and gas from underground reserves, a series simple recovery methods like water-flooding, mechanical recovery, thermal recovery, and so on, are recovery in the second phase of oil development.

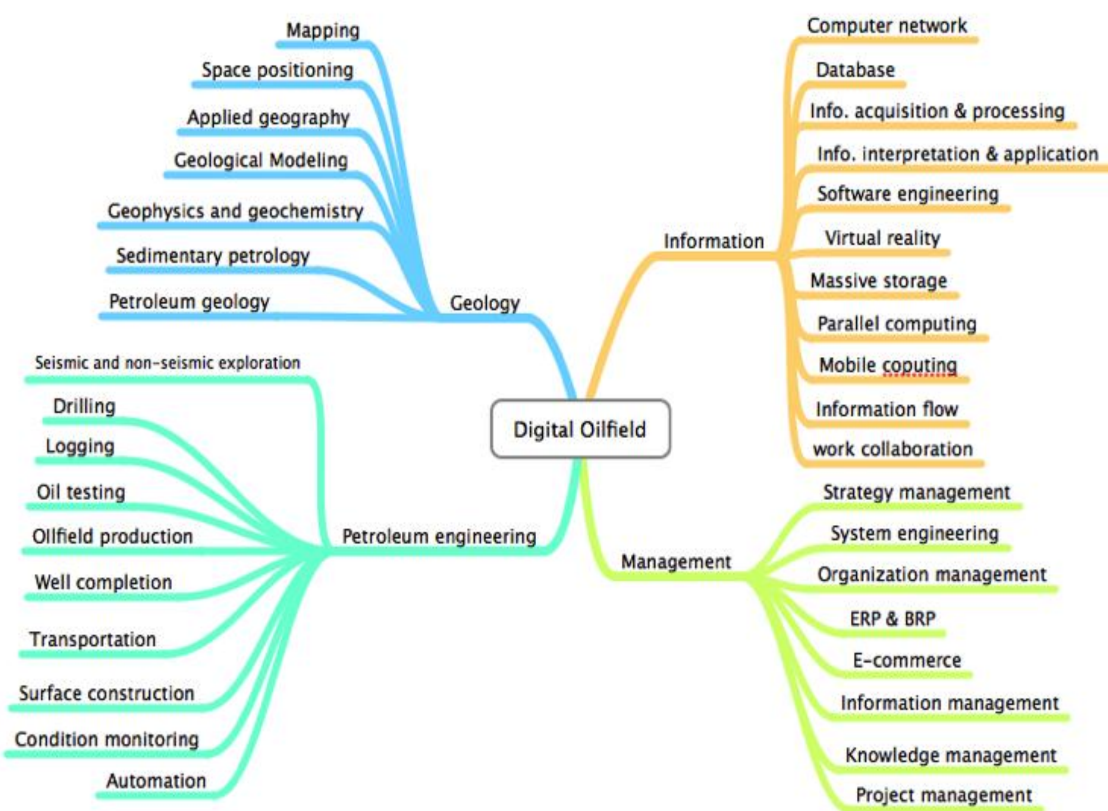

Figure 13 Theoretical Basis of the Digital Oilfield

Since 1990s, technology breakthroughs, especially breakthroughs in computer technology, have been making the society undergo tremendous changes. Similarly, the oil and gas industry has been changed dynamically and dramatically. In 1999, the concept of digital oil field (Wang, 2003) was raised based on the concept of "Digital Earth"(Gore, 1998). The Digital oilfield (DOF) is mainly about "focusing information technology on the objectives of the petroleum business"(Istore, 2011). Due to the great impact on optimizing hydrocarbon production, improving operational safety, protecting the environment, and maximizing and discovering reserves, DOF has been accepted and carried forward by BP, Shell, Schlumberger, Chevron, and other international oil service and advisory company. The DOF is a complex giant system; the construction of DOF mainly includes information technology, geology/ petroleum engineering, and management. Its research needs to learn and the support of these disciplines, Figure 13 shows some key disciplines involved in the theoretical base of the DOF.

In the past decades, the construction of the DOF runs on a fast-pace lane. Also in this period, some large international Oil companies proposed their own concept of DOF, such as Shell company's Smart Field (Bogaert et al., 2004), BP's Field Of The Future(BP), Chevron uses I-Field (a 3-D map of the surface, with oil wells, structures, vehicles, and people, all updated in real time). Generally they were known as "xField". However, the meaning of "field" is not same as the meaning of "oil field", they all focus mostly on the field operation or remote operation, Table 3 illustrates the difference and connection between Digital Oilfield and xField in the meaning and coverage range.

Table 3 Comparison between Digital Oilfield and xField

	Digital OilField	xField
Level	Involved in at all levels, from bottom to top	Focus on field operation and technical issues, less management issues
Coverage	fully informationized in various fields, from technology to management, equipment to people, overall	ralated to the field and rear support, localized
Point of view	overview of the enterprise information from IT point	solve professional application problems from application point
Complexity	multi-discipline, difficult	Relatively simple, basically equivalent to the remote real-time control

3.2 From digital oilfield to intelligent oilfield: the emerging future

In the oncoming era of "the Internet of things", how is the information management of Oil Companies look like? What is the direction and goal of oilfield information construction?

When talking about the information construction of the oil fields, people will immediately think of the concept of informationized oilfield, digital oilfield and so on.

How about the intelligent oilfield? What is the intelligent oilfield? Is it just a new concept or nice noun? What is the difference between digital oilfield and intelligent oilfield?

The goal that we advocate and pursuit is to build an “Intelligent Planet” by using advanced information technology and management concepts to build a new intelligent run. The realization of the Philosophy and goals of the intelligent earth needs the cooperation of all industries in all locations; when comes to the oil and gas industry, we have the concept of the “intelligent oilfield” and management technology solutions, whose aim is to help the oil enterprises to achieve wisdom work, smart processes, smart business and smart management.

With the continuous development of the global information technology, companies must improve the level of information management; from digital oilfield to intelligent oilfield is the inevitable trend of development of information technology management in the world oil industry.

At present, with the development of the reservoir dynamic monitoring technology, horizontal wells, the wells management, and the improvement of management technology in horizontal wells, the recovery prospects of the intelligent oilfield are very certain. The intelligent oilfield show the oil and gas field development will enter a new stage of intelligent automation, visualization, real-time closed-loop (Crogh et al., 2002). Various assets benefits for the working and development of the intelligent oilfield, such as the oil, gas reservoirs and other physical assets which includes the data assets with variety of models, plans and decision-making. Finally, the basic concept and development of intelligent field direction is related to oil and gas operations through a variety of actions (data acquisition, data interpretation and simulation propose and evaluate a variety of options, implementation, etc.), organically unified in a value chain, forming a virtual reality representations intelligent oilfield system. People can be observed in real time to the oil fields of the natural and cultural information, and interact.

IOF is developed on the basis of oil field information management of DOF, is a new stage and new forms of oilfield construction. The concept of IOF and the present DOF concept have many similarities, but at the same time on many levels IOF covers the range of the digital oilfield. DOF is built on the basis of Internet technology while IOF is built on the basis of “the Internet of things”, with perception, visualization, and intelligent features. DOF makes the oilfield digitalization and computer replace manual labor as the main purpose, as a contrast, IOF will further use a variety of business models, including the knowledge base, expert system, etc., to make intelligent auxiliary to production and decision-making, to study and management oil fields by information technology.

Compare to Digital Oilfield, Intelligent Oilfield is more than just data collection, simple digital production process, but for a higher level of integration and reorganization of the upstream industry, more digital intelligence. It includes: intelligent production, collection storage, and analysis; intelligent oilfield workflow design; a rational and efficient infrastructure; a rational and efficient institutional division of responsibilities. The concrete process of IOF is: the upper reaches of data collection - analysis of the signal acquisition - acquisition and access to information integration - data analysis and applications - upstream ERP project - business transformation and restructuring and other.

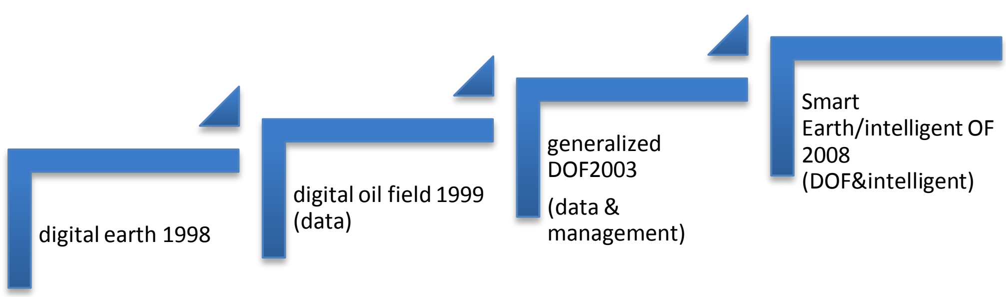

Figure 14 Theoretical Research of Digital Oilfield

3.3 The definition of Intelligent Oilfield

Intelligent oilfield is developed on the basis of interconnected information management in the digital oilfield, to achieve instrumented and intelligent information management. If the digital oilfield achieved the interconnection of information management, that is an “I”, the things that an intelligent oilfields to do is to make the oil field business management to achieve three “I”, that means imperceptible, interconnected and intelligent.

Today, many Oil Companies are still on the starting stage of Digital Oilfield, Figure 14 shows how Digital Oilfield develops(Wang, 2011). The Intelligent Oilfield to them is definitely a new concept. The study of IOF is on the way (Gupta, 2008, Ahmed, 2007). The Oil & Gas Solutions Leader, IBM Asian/South Asia, on the 7th International Conference & Exposition on Petroleum Geophysics, pointed out that Intelligent Oilfield is "a solution that integrates people, process and technology to improve oilfield performance by leveraging frequently captured data that is delivered, converted to usable knowledge and acted upon in real time." H.AL-Mutairi (2008) define intelligent oilfield as "the integration of hardware, software and work flows to optimize the operations of an oil and gas field, and to improve reservoir management."

Krome et al. (2006) state that frequently captured data, distributed, evaluated and acted upon in real time forms the basis for any IOF approach.

Dr. Grahaeme Henderson, Chief Information Officer of Shell E & P, states that intelligent Oilfield as:

The integration of time-lapse seismic, subsurface modeling, dynamic reservoir simulation, wells and production facilities will yield significant improvements in recovery and productivity, as well as a reduction in the environmental impact of oil and gas developments(Schroeder Jr and David Archer, 2003).

Intelligent Oilfield has a full range of perception that includes sensors, artificial data collection and integration. The construction of Intelligent Oilfield through the integration of the integrated operations center and collaborative environment will break the professional boundaries, and realize comprehensive data connection and data sharing. The automated processing system enables the capability of automatic processing. Efficient simulation, analysis, prediction and optimization system let the Intelligent Oilfield possess the capability to forecast and warn in advance and analyze and optimize efficiently. With virtual expert assistance systems, IOF provides a scientific and efficient decision-making manner for managers at all levels in technical and management aspects, can greatly improve the Oil Companies' decision-making efficiency and capacity.

The oilfield intelligent management is in the forefront of production of the overall information technology architecture, it mainly aims to the production of the basic unit of production wells, stations, pipelines and other process monitoring, completion of data acquisition, process monitoring, dynamic analysis, identify problems, to solve the problem to maintain normal production. The oilfield intelligent management system establishes a unified data interface; data sharing which mainly in production process management information system. And it is an extension and expansion of the company's information systems. It makes full use of the automatic control technology, computer network technology, reservoir management technology, oil and gas technology, surface technology, data integration, data sharing and exchange of technology, video and data intelligence analysis technology, electronic patrol wells, accurately determine the exact location, strengthen the control and management of the production process (Grinrod et al., 1988).

Through the study of different institutions about intelligent oilfield, intelligent oilfield can be defined as:

On the basis of the digital oilfield, assist with the business model and expert system Intelligent oilfield perceives the dynamic comprehensively, manipulates the oilfield activities automatically, predicts the oilfield developing trend to optimize field management continuously, uses virtual expert system to assist oilfield decision-making, uses computer system to manage oilfield intelligently, so as to promote new reserves, production and recovery, to achieve scientific decision-making, operational excellence and safety production, and ultimately achieving sustainable business growth. Intelligent oilfield is the new oilfield information management mode that developed on the basis of the digital oilfield, and the new stage and new forms of oilfield information construction.

3.4 The advantage of the Intelligent Oilfield

Intelligent Oilfield is not a static industry state, but a dynamic, developing, constantly optimize the industrial development and construction process. Rajan and Krome (2008) state that there could not be two completely same intelligent oilfield, just as there could not be two exactly same wells. The idea of building intelligent oilfield can be the same, but specific implementation programs and technology cannot be the same, because production and management issues facing by different oilfield are different. However, the goals of the construction of Intelligent Oilfield for different oilfields are same, they all try to increase productivity, achieve high oil recovery, lower costs, reduce risks to health, safety and the environment, increase ROI, enhance decision-making, improve NPV, reduce cycle time, and rapidly deliver enterprise intelligence(Istore, 2011).

3.4.1 The analysis data are more real-time

The location of land oilfield is generally remote and the environment is relatively poor. This is also true for offshore oilfield; more seriously, the environment is harsher than land oilfield and replenishment is more difficult. This is a huge challenge for the mining of oil (Todnem et al., 2005). When collecting the production data and other relative information, the harsh environments made it quite difficult, summarizes data for each data point also speaks very slowly, real-time data will lose. But the Intelligent Oilfield program will simplify this process; a variety of wirelesses monitoring equipment will acquire prescript data for each time interval and transfer them back to the front-line control zone server through the wireless network timely. In this process, the time is very short; staff will see the data almost in real-time. This enables the production quality has absolute protection.

The main research of Intelligent oilfield contents include digital oil field general technical framework, geographic information system (GIS) in oil field application, multidisciplinary geological model research, exploration and development of business and information integration model, information infrastructure system, enterprise information Portal (Portal), and mass data storage solutions, virtual reality technology, application of data and application system standard system, enterprise digital summary model, information flow, business flow, logistics, knowledge management, collaborative environment, decision support business model, human resources digitization, digital oilfield development strategy, etc.

When Digital management intervention, it can shorten the management level, the original between operating regions is intangible selection, it not only reduce the management personnel, and it also maintenance staff together which let the alone workers joint work now, and the operating region unified transfer can make originally regions no work, and some workers cannot find the work, so it’s not balance, with the help of the intelligent oilfield system, the phenomenon thoroughly eliminate.

3.4.2 Effective risk management and higher security

During the process of the exploitation, there will be a lot of security risks that is difficult to avoid under the harsh environment. Artificial data acquisition level is low cut backhaul slow and it is very detrimental to the security of this oil field production. However, use the artificial intelligent program, oilfield equipment used instead the manpower, and the data return is faster and more accurate which is an accurate grasp of the real-time control center wells pipelines and other places. It not only can effectively prevent the data is unknown due to security incidents; it also can effectively prevent the wrongful acts of destruction, theft of oil production facilities, which greatly improved the safety of the production process. Intelligent Oilfield construction and management is the comprehensive foundation information platform which taking for oilfield enterprise production, scientific research, management and decision-making. It plays over and the function of the guidance of oilfield informatization construction. Intelligent Oilfield construction and management has shown broad application prospects.

Intelligent exploration will change the previous field management and exploration and develop the fundamentally change. First of all is using information to manage the oil field. In each stage of oilfield exploration and development, it should have the corresponding data, model and measures, with the aid of these data explanation for reservoir analysis can be successful mining that reduce the uncertainty and risk. It is the comprehensive reservoir simulation model. The Visual reservoir can reflect the characteristics of reservoir, oil as far as possible.

Informationization that the intelligent oilfield used will change the oilfield management and the drilling orientation and model. Intelligent technology provides technical support for optimization and dynamic diagnosis in real time(Milter et al., 2006). For intelligent well data acquisition, repeated cycle analysis processing, rapid uncertain economic and effective exploration and development plan, all of these can realize the operation process of the highest value. Greatly reduces the exploration and development of the uncertain factors and risk.

3.4.3 Higher efficiency

Generally the area of the oilfield span is very large, and some even stretching over several kilometers, this is very negative on the oilfield safety monitoring, data acquisition and data processing. The process of human collection and monitoring is not only cumbersome and also in a very slow speed. The Intelligent oilfield program use the production site full wireless coverage that let all sensor data returned through the wireless network data collection terminal. And then, it returned by the data collection terminal production base server. This efficient information collection is not only greatly reducing the cost, and labor intensity, it also benefits for improve production efficiency.

The high efficiency of production is a strong guarantee for the economic benefits. Through the implementation of digital management, it obviously improves work efficiency, reduce production cost and improve the level of safety work, especially it can reduce the amount a line invalid labor. According to the forecast, the new village operating region implementation of digital management after a line labor can reduce 30% to 40%, technical personnel can reduce more than 50%. The intelligent technology will gather the ground and underground two aspects organic union to realize reservoir, oil well dynamic monitoring and constantly optimize operation plan, so as to realize the high profit. Through intelligent management of the field, this system will greatly promote the oil field and the oil well productivity.

3.4.4 Lower cost

During the intelligent oilfields, the system uses wireless LAN technology, installation is simple and easy to maintain. Without wires avoid the harm brought about by aging, fault. Low cost is undoubtedly a direct manifestation of the high efficiency. According to the character of the intelligent oilfield, Dynamic digital reservoir model technology can bring various disciplines expert experience quickly copy to every staff, thus it can avoid the professional and technical personnel shorthanded which brings problems. The dynamic digital reservoir model technology can dynamic adjustment oil development production plan according to the market demand changes and make it more reasonable which let the enterprise gain more benefit. Using advanced dynamic digital reservoir technology can save millions of dollars for the many harbor in oilfield developed every year. At the same time, the field works with dynamic digital reservoir model to improve the success rate of horizontal well.

In the practice, when meets any problems in any one specific problems, the intelligent oilfield system can use computer science and network communication technology, cross region barrier, the breakthrough time and space limit, gathered the experts who in different places in the Internet remote online for decision. Dynamic digital reservoir model is adapted to the advanced work flow needs which includes multidisciplinary, such as shock, mass, drilling, engineering, logging, oil capital management and so on which provide a timely sharing dynamic changing model together. And the team type work means, so that the produce efficiency, scientific nature and the basis of decision-making provided high quality are traditional relay mode which cannot reach. This kind of revolutionary change is the world exploration and development trend of the development of the industry.

3.4.5 Broader prospects for development

Compared to the traditional reservoir mode, the Dynamic digital reservoir model has a huge progress(Tollefsen et al., 1992). The past reservoir model is fixed and static. Traditional exploration and development operations and the geophysical exploration department, quality department, development department specialized technical personnel to set up digital model which like the railway police each tube and each does things in his own way. This relay workflow type often can appear problems, if appeared, it will need to step by step from the beginning again come, and it waste time. The more important is the barriers between department and working environment appeared which let they cannot unified pace effective quality control and uncertainty evaluation, so it will cause the overall efficiency is low.

Based on the low efficiency condition, the important function of the intelligent oilfield appeared. With the mature and growing popularity of the sensors, RFID, wireless communication networks, cloud computing and other new technologies, the Internet of things technology more widely, in a word, intelligent oilfield is the inevitable trend of development in the future. It is technologically advanced, innovative and easy expansion which benefits for the future development of the enterprise.

3.5 Status of the Intelligent Oilfield Development Efforts

IBM (International Business Machine Corp.), as the world's information technology company, became the leader of research of the Intelligent Oilfield. IBM runs an innovative seminar with many Oil Companies. Every year hundreds of million U.S dollars were spent on the study of IOF. By far, a great number of researches have been carried out and IBM developed advanced industrial solutions of IOF.

Since 2005, IBM has started joint innovative business cooperation with the Norwegian national oil company to help Statoil develop solutions to extend the lifespan existing and new oil and gas fields in areas of adverse conditions including the North Atlantic Ocean and the Barents Sea(IBM, 2006) by the construction of Intelligent Oilfield.

The objectives established by Statoil and IBM are to increase the North Sea oil recovery (OR) of subsea platform to 55% and fixed platform to 65% through the application of advanced technology and business process optimization. To this end, Statoil together with IBM and other partners create a bran-new business process framework, connect the advanced real-time sensing system deployed and the powerful collaborative analysis accessed to the entire system together, make exploration, development, production as a complete system to realize integrated operation, through the application of various advanced technology, processes, methods, OR was improved and the revenue receive an increase of tens of billions. The project was regarded as the best practice of Intelligent Oilfield.

In May 2010, Karamay oilfield signed IBM as the key contractor to construct China's first Intelligent Oilfield. They plan to use 5 years, on the basis of digital oilfield has been built, through the establishment of knowledge and decision making analysis model that covers various oil business, to provide intelligent auxiliary means for the oilfield production management and decision analysis, realize data and knowledge sharing, scientific research cooperation, production process automation, system integration, production command visualization, analysis and scientific decision-making, true implementation with computer research field.

3.6 Principal contents of an Intelligent Oilfield

Through the theoretical studies and practical applications in real oilfield, the main components of IOF were gradually determined. Krome et al. (2006) points that "IOF is composed of five key components, encompassing people, process and technologies, which need to be addressed for any IOF vision to be truly realized", Figure 15.

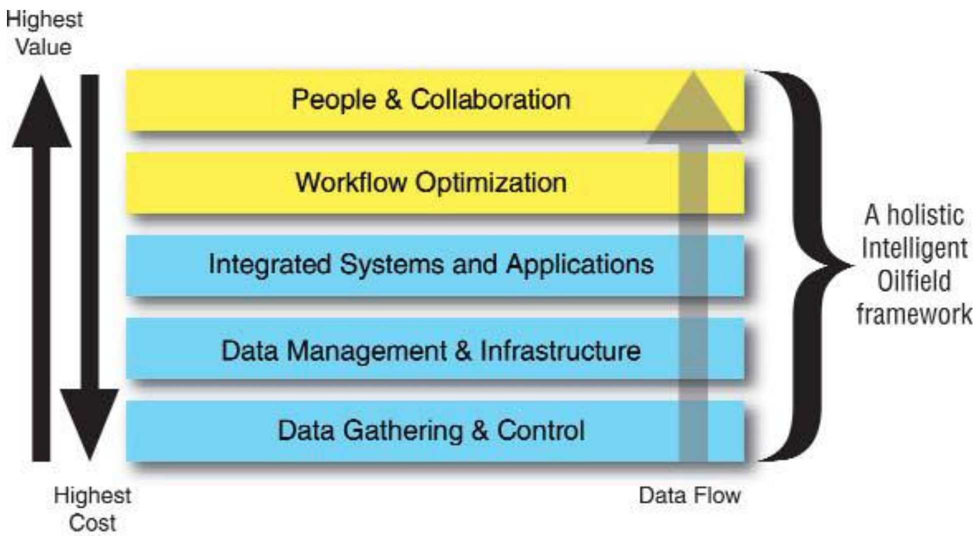

Figure 15 Composition of the Intelligent Oilfield ((Krome et al., 2006))

Di J.R. Matson (2007), Associate Partner IBM Global Business Services Upstream Oil and Gas, describes that a successful Intelligent Oilfield is consisted by the following aspects:

3.6.1 Creating a Collaborative Environment for Decision-Making

A collaborative environment for communication, data collection, reporting and monitoring, knowledge and information sharing is a necessary part of the Intelligent Oilfield (Farrelly and Records, 2007). Under this collaborative decision-making environment, people can make informed and timely decisions and take proper actions. Besides, it enables alignment, focus and common understanding to help prioritize operations.

Innovations in various technologies are helping people make the intelligent oilfield a reality (Krome et al., 2007). Dispersed array sensor systems gather massive amounts of production data and deliver it to remote research terminal office (RRTO) by satellite or fiber information transmission; in RRTO, advanced visualization technology reprints the data to skilled engineers to convert to usable knowledge. Through visualization, modeling and analytics, people can detect complex production problems easily and initiate a response before a problem occurs, this can improve the oil and gas reservoir management greatly.

3.6.2 Successfully Integrating People, Process and Technology

Through their intensive and diligent research, IBM points that an intelligent oilfield solution has five key performance-oriented implementation components, Figure 15. These interdependent components are essential to achieving significant ROI from an intelligent oilfield.

With a right IOF program, more informed and predictive business decisions can be made effectively from the massive information that generated from oilfield assets. Wells and fields can be managed remotely and collaboratively. Time and money cost can reduce significantly and skilled resources can also be reached wildly, meanwhile this increases the oil recovery and reduces risks. From the illustration of IOF of IBM, we can get that "the intelligent oilfield is designed to help people (the highest-valued component) work together more effectively, in order to reap the greatest value from the highest-cost component (data gathering and control) and its midlevel by-products. Raw data (bottom right) migrates up through each component until it is converted into knowledge (upper right), which people use for improved decision making. Ultimately, all the technology components support the workflow of skilled personnel. Depending on circumstances, a company may focus (or start the program) via any of the five components first. But a successful initiative depends on fully integrating all five."

3.6.3 Limitations of Traditional Information Analysis

In the past, the technology that we used in the exploration and development of oilfield is limited and only a small size of production data that can be gathered to decide what actions will be took to improve productions. However, today's society is the age of information, people deals with massive information every time. The advance of technology, especially the advance of information technology,, convenient us greatly. We can perform real-time condition monitoring by many state-of-arts technologies and gather massive status and related data. But on the other hand, the data volume is so vast that it is quite hard to screen useful information from the database and turning raw data into useful, relevant information - and, in turn, knowledge. This knowledge is critical to assist people make business-critical decisions. Furthermore, the reservoirs and wells locates in different regions has no similarities, thus the appropriate action that will take is difficult to initiate and depends largely on the raw data generated by an individual well, especially in diverse and unforgiving environments.

Due to the technique restrictions, much potentially useful raw data is not stored and rarely analyzed in past. Of course, it is not distributed to the people who need it most. Common and complex production problems – such as sanding, gas and water production that limits productivity, corrosion and scaling – adversely affect production and/or equipment.

To prevent and solve these problems, skilled personnel need to understand the issues and processes and be able to critically analyze information and take appropriate action(Matson, 2007). In IOF, the facilities and equipment is different with the traditional oilfield, more and more advanced techniques are used by IOF method and generate a much bigger data volume. Thus the data collection, interpretation and analysis methods need to be upgraded to achieve better and effective decisions and actions.

Another different is that more global collaborations are required for upstream oil and gas companies, because now fewer skilled staff members are responsible for the expandable global activities to reduce operation cost. But this method of work can leverage available skills, facilitate work in appropriate physical environments and support the use of common applications and IT infrastructures.

3.6.4 People and Collaboration: the Human Factor Matters

Although the advance of technology makes people’s life and word easy and convenient, and makes the intelligent oilfield be reality, however, people still the most critical success factor in any intelligent oilfield program. The techniques and equipment that used in the oilfield development upgrades so quickly that it is hard to leverage the latest tools and technologies for improving analysis, alarm capabilities and process management to help them make better-informed, more proactive decisions. Besides this, the extensive requirements of multi-skills and different ways of working make it impossible that one person himself cannot suit the job best and timely.

Since the construction of intelligent oilfield is a very complex work and the vast use of new techniques changes the management and new organizational models become the heart of realizing the intelligent oilfield. In an intelligent oilfield environment, people must collaborate in innovative ways to enhance their productivity and improve the performance of the organization's oilfield assets. The cooperation makes it simple and efficient to share knowledge and resources regardless the department, distance and time. Moreover, they could learn skills from each other to improve their own profession quality.

3.6.5 Workflow Optimization: Process as a Catalyst for Chance

Workflow management system helps the employee to organize the process of passing information and task effectively. Through the appropriate use of this system, each of these employees or machines will pass the work on according to a predetermined procedure to improve the production efficiency. As technology advances, much workflow management has become automated and takes advantage of special software to make the process much smoother (WiseGEEK).

The raw data collection and delivery frequency is the basis of many of today's oilfield-related workflows and processes. However, in traditional oilfield developments, due to technical limitations, as well as data collection is not timely, much of the data is not rational utilized; as a result, many workflow are not properly designed and many work are not necessary and has no meaning. In the intelligent oilfield, this is not a problem. IOF takes full advantage of all data that can be collected almost in real time by streamlining numerous oilfield-related processes and their sequence, and unnecessary steps are eliminated. This in turn helps people increase their productivity and efficiency. The way people process and use information is changed dramatically by the real-time data collection and delivery. Operator can respond more quickly to change with the integrated business processes. This optimization then increases the efficiency of making decision and carrying out to improve the productivity and reduce time and operational cost. By increasing the flexibility of information analysis, oilfield operators can extract more value from information through an increased ability to manage volatility and unpredictability.

3.6.6 Integrated Systems and Applications: Connecting the Dots

Oilfield development is not a simple project, but a very complex combined project. It incorporates many activities and generates a vast volume of data (more than a terabyte of raw data per day). The technique advances make it reality that many monitoring technologies can be used to inspect the production situation of each well. If these massive amounts of data cannot move across department effectively and fluently, the interdepartmental communication could be slow down and thus a low productivity. In an intelligent oilfield environment, applications need to interact with each other more effectively and efficiently and use the same data.

Besides these, a standard set of tools is also required to convert data into actionable information. With such tools, the confusion could be eliminated in different groups to positively impact decisions and timing.

3.6.7 Data Management and Infrastructure: Managing Data Better

In previous sector, we say that the data everyday people deal with is huge and data management is a big struggle for most of today’s upstream oil and gas companies. For offshore oil and gas companies, operation centers are usually established onshore and the demands of quality information, timely decisions and response is more impending, this situation increases the struggle acutely. In order to decrease the cycle time from an adverse occurrence in the field to a decision and its proper execution, effective data management and infrastructure is more important for the intelligent oilfield construction. Only in this way, oil and gas companies can realize accurate, real-time, remote access to all data and information related to wells, reservoirs and the associated equipment.

3.6.8 Data Gathering and Control: Collecting the Right Stuff

In intelligent oilfield, data is not just collected and stored. It is scrubbed, normalized and calibrated. Data is the core asset and the basis of any other activities. Data and the information derived from it sustain the entire oilfield effort. But many companies today did not realize this; they collect data with uncertain frequency and deliver it for conversion into actionable knowledge with similar uncertainty. With the proper real-time information fuse and analysis, operators can foresee and prevent the occurrences of many negative activities, such as pump failures, sand production, degassing, and predict future performance more accurately and proactively solve problems.

The intelligent oilfield construction is still in its infancy, but intelligent oil field is a booming concept, is the advanced stage of development of oil and gas fields. Common intelligent oilfield service solutions are focused on people, process and technology areas. Although these three core components have been recognized for some time, innovation, integration, R&D and industry expertise are what differentiate average performance from a truly successful intelligent oilfield initiative that delivers optimum results.

3.7 The development of an Intelligent Oilfield solution for China

The construction of Intelligent Oilfield is a systematic project, and the establishment of a data bank and information platform is the basis of the Intelligent Oilfield. The core of the Intelligent Oilfield is to change the work process of exploration and developments from the orderly process of historical segment information into a real-time parallel processing of the data, and the use of real-time data streams combined with applications of innovative software and high-speed computer systems, to establish fast feedback dynamic reservoir models. Using these models and telemetry sensors, smart wells and automatic control functions, the operators can directly observe the underground production dynamics and to more accurately predict the dynamic changes in the near future, to improve the yield and effective management of the oil field, to achieve closed-loop optimization management in various levels, and ultimately realize the field-wide real-time closed-loop operation and management of assets.

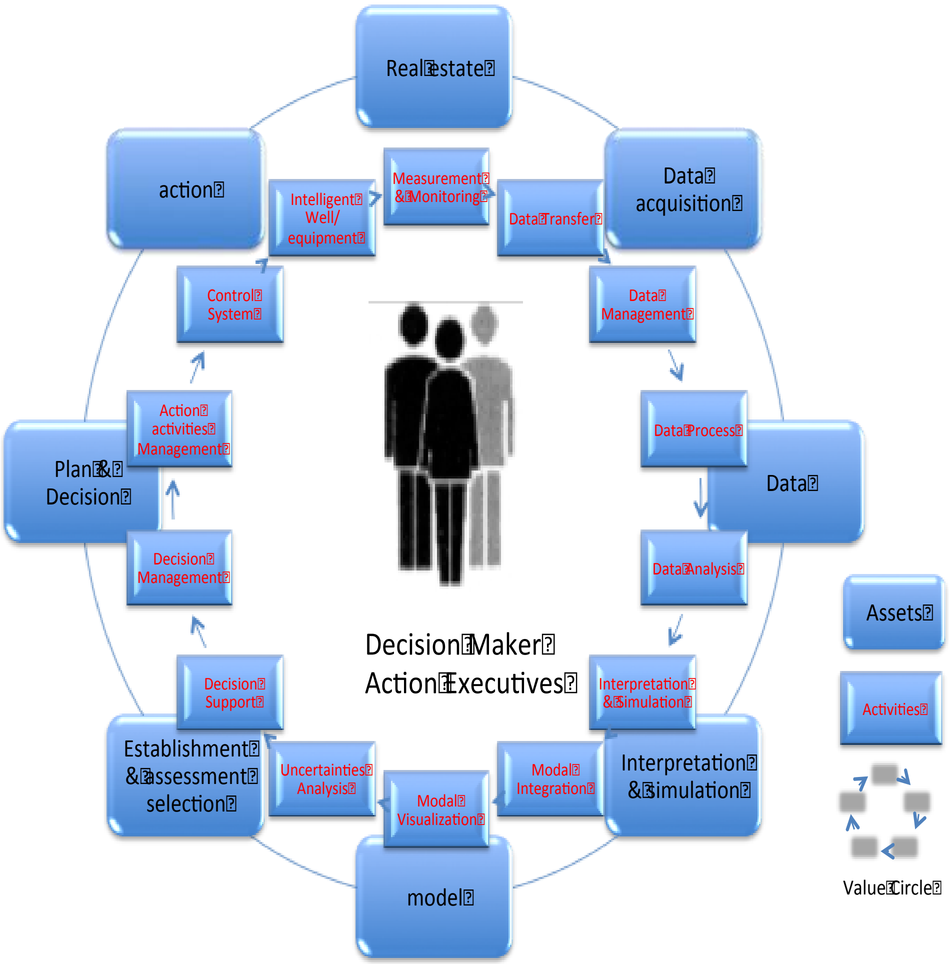

Figure 16 Concepts and Tendency of Intelligent Oilfield (www.chinacir.com.cn)

Actually, intelligent oilfield is not out of reach, but also a step-by-step development and improvement. Now, the foreign Intelligent oilfield developed alone in the third level and they all aim to the gradual development of the fourth, fifth grade.

Intelligent oilfield is a set of processing application system that includes the connection ground and down closed loop information collection, bidirectional transmission. It can accompany operation process real-time guiding exploration development program execution and related technology application that is covering all major value cycle process of a closed loop system. Therefore, when involving exploration, assessment, development and mining areas of the emerging technology for oil and gas resources, all of the whole life cycle have a great impact on the telemetry, virtual reality, and intelligent well completion. Automatic control and data integration is a key technology of digital oilfield.

The Intelligent Oilfield shows that the oil and gas field development will enter into a new stage, which is an intelligent, automation, visualization, and real-time closed-loop. Figure 15 shows the basic concepts and developing direction of Intelligent Oilfields (Chinacir). It illustrates that IOF integrity Various assets that related to oil and gas operations (oil and gas reservoirs and other physical assets, data assets, models, plans and decision-making, etc.) through a variety of actions (data acquisition, data interpretation and simulation, propose and evaluate various options, implementation, etc.) to form a digital oilfield system represents the virtual reality in an organic value chain. By IOF, the natural and cultural information of the oil fields can be observed in real time and interact with people.

Through the innovation of technology and management concept, Oilfield digitization management improve process monitoring level, improve the production process management and intelligent level which setting up the whole oilfield unified production management, comprehensive research of digital management platform. It aims to strengthen security, process monitoring, saving (human) resources and improve the benefit goal. Oilfield intelligent used the wireless LAN technology which let the production process is simple, safe, and efficient. Greatly reduce the cost of oil field production and significantly improve the economic benefits of the oil field. Compared to conventional oilfield, intelligent oilfield has many advantages, such as the lower cost, high efficient and so on. And the following analyses are mainly explained from the aspects of the economic cost, efficiency, and environmental impact.

The intelligent oilfield system project aims to the wireless local area network coverage which constructed in view of the oilfield and satisfies oilfield daily production operation, production management, production control, equipment management and show demands. It is a set of oil exploration, development and production of information collection, transmission, storage, processing, analysis, issue, management and application at an organic whole, standard, unified, safe, efficient new modern production management integrated data in the integration of management application platform.

3.7.1 Various application

The 21st century is information ages that take the computer as the core. The digital, networked, intelligent has become a characteristic of the era of the 21st century, with the rapid development of information technology, computer technology, wireless network technology, the Internet of information technology has been applied to each row and industrial sectors (Aasheim, 2000). In the past year, the Internet of things has been a high degree of attention and concern of the country as well as government departments at all levels, as a focus on the development of information technology to the beginning of this year, "Twelve Five" is bound to the Internet of information. The continuous development of the Internet technology, as well as the convenience it brings to all walks of life, the intelligent oilfield systems technical support construction is very necessary but also feasible. With the development of the society and the Internet, people know form the virtual information space to the perception of the reality of the physical world. So the intelligent field will be more timely reaction current Oilfield situation with the help of the Internet.

3.7.2 Extensive contents

Intelligent field contains the geological, seismic, logging, analysis of testing, drilling, production, oil test trial mining ground pipe network, geographic information, extensive coverage, so they are both independent and dependent. In the production information system, the intelligent oilfield develop the oil and gas exploration information integrated management system, develop the oil and gas management information system owns two production management information system, it not only covers the oilfield exploration and development the main business management, but also provides the comprehensive query, data entry, business processing and so on. All of these provide many features for scientific research and providing powerful tool production management.

In the enterprise management system, the Oilfield Company has developed a financial management system, labor management system, science and technology information management system, office management system (OA) and other information system, and it obtained a good application. Especially the financial management system, it is the most successful application promotion(Njaerheim and Tjoetta, 1992). The oilfield company has achieved basically financial computerization, thoroughly get rid of the manual account and greatly improving the work efficiency.

3.7.3 Safety protection enhancement

Digital oilfield is the comprehensive information oilfield, which based on the information technology as the means to achieve oilfield entity visualization technology and virtual reality technology. It will not be able to realize video browsing occasion's intuitionist simulation out and enterprise the digitization, network, intelligence and visualization. Digital oilfield construction is a complex system engineering that involved a number of disciplines. It includes a series of process from oil detecting to oil refining transportation. According to the collection, simulation, analysis and decision, the whole process needs mutual cooperation and work together, such as information technology, petroleum geology, geophysics and reservoir engineering, business management, project management and other professional and technical personnel.

Intelligent oilfield can do real-time monitoring in oilfield safety. With the offshore fields developed, the oil field security issues connected to the elbow and the network, the newspaper is not difficult to see the "oilfield oil spill" wording. It brought to people is no longer a pure oilfield safety, but also a wide range of ecological pollution problems. Many technology which used in the Intelligent oilfield system benefits for the safety protection, such as wireless temperature monitoring, wireless vibration monitoring, wireless corrosion monitoring, wireless pressure monitoring, wireless sensing valve position, wireless video technology. It can concern about the undersea oilfield dynamic at any time, reduce the oil fields hidden, and also coupled to the ecological environment insurance.

3.7.4 Automatic stabilization equipment

The intelligent oilfield acquisition equipment installation and maintenance convenient, reliable work, long equipment life, rather like a wired device installed as cumbersome, not the aging, the emergence of poor contact and other issues. It will not be caused the host job insecurity due to lightning, etc. Oilfield Company has gradually realized that data is the precious wealth of the oil field. In the exploration, the link direct product of geophysical prospecting, drilling, testing for oil, logging and other production is data. In

The development system, it is necessary to collect all kinds of production data, analyze the change of reservoir and optimization scheme. So the data is the "raw material" of exploration and development research. Oilfield Company spends a lot of money for these "raw material"(Petter and Knut, 1995).

Therefore, in order to protect these data and make full use of it, Oil Field Company vigorously promotes the data construction and ensures the data reliability and usability. There are three main task of data construction. The first is establishing data standard and database structure. The second is put the current various production data timely acquisition warehousing. The third is the history data warehousing sorting and file. At present the companies has built many oilfield exploration systems and develop owns two production database; all kinds of production data have timely collect warehousing. And most of the historical data also put in storage. The database construction for scientific research, management provides decision basis. when exploration and development of scientific research, the introduction of advanced software and hardware, the establishment of a interpretation workstation, seismic processing center, parallel numerical simulation system, improve the research level, reduce the exploration investment and development cost.

3.7.5 Managing availability

The intelligent oilfield system is not only a great progress in science and technology, as well as it take facilitate form the management of the oil field(Zachariassen et al., 2006). It can help the oilfield enterprises to reduce the waste of time, such as oil work, at first, oil production worker with the data field patrol wells and collected data analysis slowly. The intelligent oilfield system through the video surveillance system to data transmission by the network that will be able to control and observe the production of the individual wells, and the work efficiency is greatly improved. Implementation of intelligent oilfield enterprises can reduce more employees' salaried pay that will facilitate the management of oilfield employees.

Digital oilfield construction and management can promote the further deepening of reform of oil field and further improve the management level of oil field. The powerful strength of the digital management prepares the platform for the labor organization optimization. And the labor organization optimization let digital management strength infinite release. Because the new labor organization optimization on human resources and work efficiency is doubled than the original. From the oilfield construction initial, the oil workers battles with the sandstorm, bucket cold artificial long wellhead samplings, multiple round record analysis data, to the every well real-time data sharing now, the video or network feedback analysis results. So the digital management greatly releases the human resources that invest to a more urgent post.

In conclusion the intelligent oilfield is a huge systems engineering which must explore new cooperation pattern. So we should not only joint industry, but also closely related the high technology and new technology industry to develop oil and gas fields intelligence technology which benefits for realize the real-time monitoring and management of oil and gas fields. Beyond that, building the intelligent field must have a whole design which from the exploration drilling stage start to every phase of oil production in succession, orderly construction completed, and constantly optimize the operation process that aims to get high profits for the enterprise. In the long run, intelligent oilfield application and development is an upgrade process that will be constant innovation, development, so the domestic should make the overall planning and started as early as possible.

Chapter 4 Collaborative and Efficient Work Process

1.7 4.1 An industrial case from CNOOC

From June 4 to July 12, a series of oil spills happened at Bohai Sea(Wikipedia, 2011), so called the 2011 Bohai bay oil spill.

The first and second oil spills that occurred at the platform B of Penglai 19-3 oilfield were caused from a sea floor leak. The first one began on June 4 lasted until June 7, and the second one occurred at the platform C on June 17 but was contained within 48 hours. These two oil spills cause a total of 840 square kilometers Bohai Bay was polluted(Schmidt and Bannon, 1992).

The third oil spill took place on July 12 at the Suizhong 36-1 oilfield(Chen and Lv, 2007).

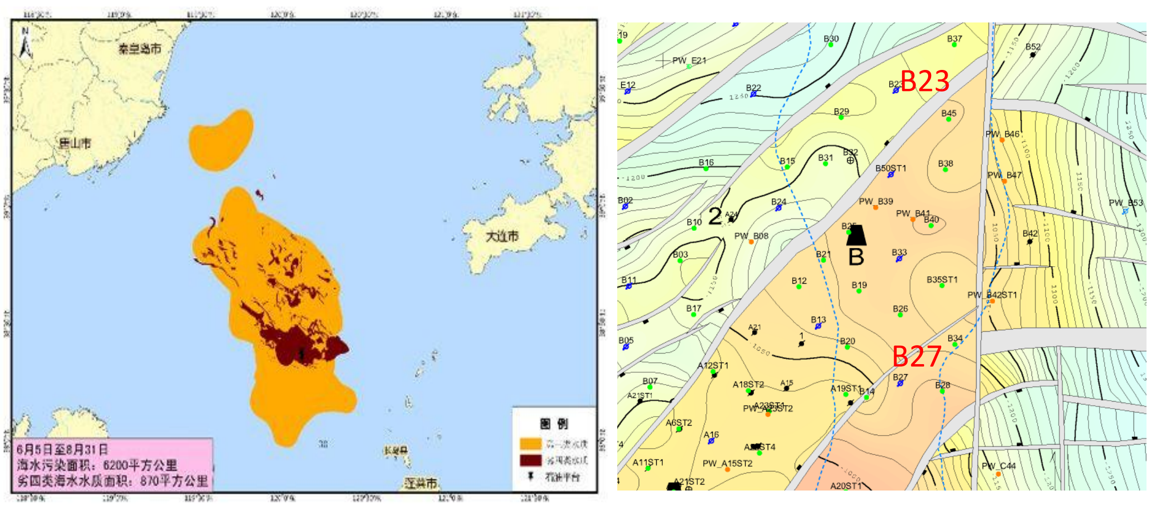

Figure 17 Schematic of Penglai 19-3 oilfield polluted area and L70 structure surface map

Penglai 19-3 oilfield locates in 11/05-contract area in south-central Bohai Sea (Figure 17), longitude 120 °01 'to 120 °08', north latitude 38 °17 '~ 38 °27 ', average water depth is of 27 to 33 meters. The oilfield developed in two phases, platform A was put into operation in December 2002, platform B, C, D, E, F, M were put into operation in July 2007 to April 2011, among them platform B was in May 2008 into operation and platform was in July 2007. By far there are total 193 production wells, 53 water injection wells, 6 drilling debris reinjection wells; the daily oil production is 23,000 tons in May 2011. The oil field is 51% owned by China National Offshore Oil Corporation, and 49%

owned by the United States Company ConocoPhillips.

The oil spills were received highly attention from Chinese Government. Platform B and C were closed immediately after the accidents and the whole oil field was closed on September 2, 2011. The B and C closure led a production reduce about 20,000 barrels oil per day, and the total production reduce was about 62,000 barrels oil per day. On August 18, 2011, a Joint investigation team led by SOA was set up mainly responsible for the thorough investigation of the oil spill accident, the nature of responsibility, as well as pollution damage.

On June 21, 2012, the inspection report was released by the joint investigation team(Liu and Dong, 2010). According to the in-depth investigation, the reasons of the oil spills are:

1. The overall development plan approved is selected water injection, however, it was not executed by ConocoPhillips China during the operation;
2. Parameters for selected injection program has been developed by commingle water injection during test-mining stage, but did not put in practice by ConocoPhillips China.
3. Before the oil spill occurred, the risk of high-pressure at shallow L30 reservoir due to B23 well commingle injection had been found, but did not block this layer in a timely manner.
4. ConocoPhillips China ignored the accident signs seriously and did not take proper emergency measures.
5. ConocoPhillips China did not follow the overall develop program for debris reinjection layers. It adjusted the debris rejection layers to shallow formation that close the reservoir for several times without permission, and there had no precautions for these man made potential risks.
6. The loose management for debris reinjection of ConocoPhillips China. The well C25 had already upped the reinjection layer, but the operation department did not did not inform the drilling design departments and personnel about UHP caused by debris reinjection, resulting severe mistakes in the C20 well drilling design.

7. ConocoPhillips China violated the requirements of the approved environmental impact report; the surface casing of C20 well runs shallower than required that has lost emergency disposal capacity when kick appeared during the drilling process.

However, this tragedy could be avoided if there is a collaborative working environment and effective work process. In December 2010, ConocoPhillips carried out an injection profile logging at well B23, Figure 18. The zone L30&L40 was blocked when logging. However the shut-in temperature logging (track 5) shows that water not only entered zone L50, but also entered into zone L30&L40. Since there has no production in L30&L40 in this area, the zone has an abnormal pressure and this was confirmed in February 2012, but nobody took this serious, and four month later, the leakage occurred.

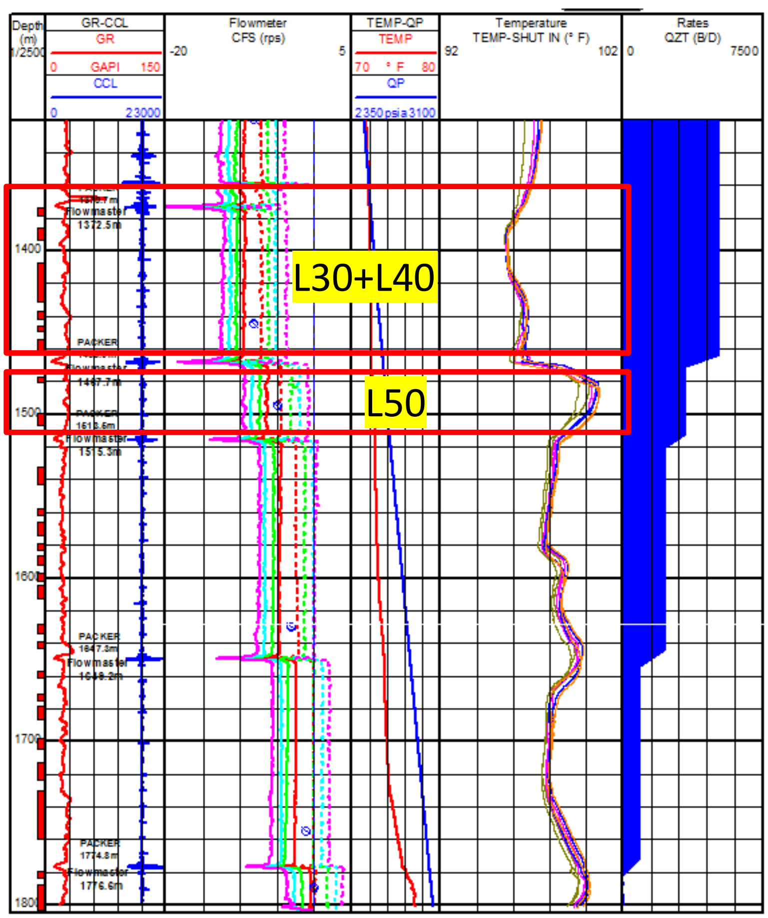

Figure 18 Penglai 19-3 Oilfield Well B23 Injection Profile Logging (2010.12)

1.8 4.2 Collaborative work environment

We are undergoing the network and communication revolution promoted by the Internet technology(Xie et al., 2006). Before the 1990s, the information communication is mainly by mail, telephone or facsimile, etc. however, today, along with the popularization of wireless network, intelligent mobile terminal and social network, the Internet has more profound influence on people's life and work mode.

With the wildly use of Internet and information communication technology, distance and time difference are no longer a problem. The rapid development of information, communication and computer technology is pushing the organization to change. The application of different aided computer technologies and remote information network connects the people and enterprises with different functions that locate in different places to work for one thing at the same time. However, a free information transmission, exchange, and management system has not been realized in the related departments; in actual, many units' information system is not open enough, information data format are disunity and incompatibility, no integrated computer application system for business, and lack of electronic information exchange management system, so even in a unit itself, sometimes data of one computer information system is hard to be fully used by other information systems, thus a lot of "information island" are formed; this phenomenon is more common between units. Oil industry is a very complicated industry; usually there could be more than several dozens of departments involved in one job. If there has not have an effective information exchange and utilization system, "Information island" will make the information data transmission and exchange untimely and collaborative work between partners is hard to realize; as a result, the management and coordination efficiency of the large cross-enterprise and cross-region project will be very low and the cost will be very high.

Along with the wildly application of the information technology in petroleum industry, the real-time collaborative decision-making based on the computer and network environment is an important future developing direction of the oil assets management.

The modern reservoir management is trying to construct a multidisciplinary professional reservoir management team, to break department and subject boundary Limit, to achieve cooperative advantage of multiple discipline and professional.

For modern reservoir management, the Multidisciplinary Collaboration is the core. The complex underground situation means that in order to achieve an efficient development of the reservoir, a collaborative multidisciplinary professional team of geological, geophysical, reservoir engineering, production engineering, ground engineering, economic evaluation, etc. must be established in the early exploration and development stage (Liu and Dong, 2010), Figure 19, to achieve professional complementary and to participate in the management in different stages based on the full use of various technical expertise's professional knowledge. Through the Multidisciplinary Collaboration, the professional team can consider the issue more comprehensive, more coincident with the underground conditions, and realize the synergies that "1 +1> 2". The operation of the multi-disciplinary team needs the integration of geological sciences, engineering personnel, technology, tools, and data. The multi-disciplinary professional of team is more like a coordinated "basketball team" instead of a "relay team".

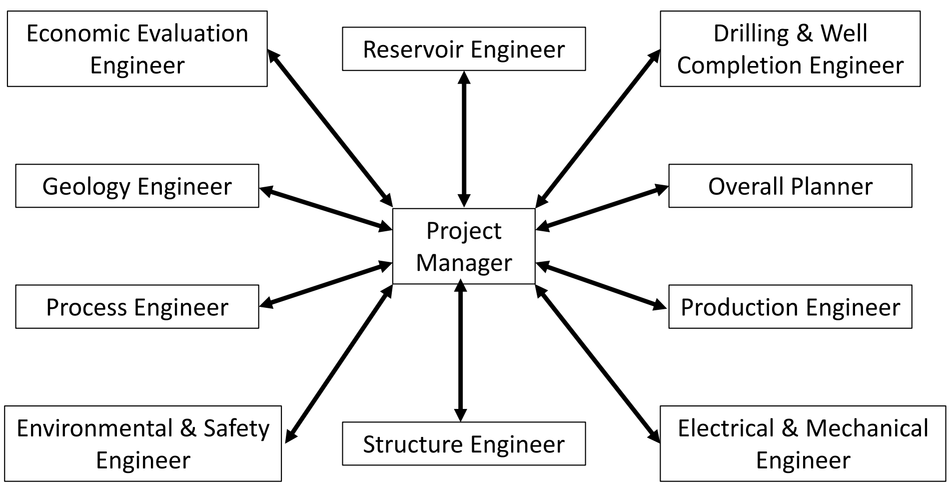

Figure 19 A Typical Multidisciplinary Professional Collaborative Team for Oilfield Development

CSCW is a new integrated cross disciplinary that composed by computer science, psychology, ergonomics, cognitive science and social science, and other disciplines. CSCW provides a "face to face" collaborative working environment for scattered person in time and space domain. Through the establishment of collaborative work environment, the operator can: improve the way of information communication, eliminate or reduce the barrier formed by time and space separation, save time and energy of onsite working staff, and improve the overall work quality and work efficiency.

The process of oilfield geological modeling, development planning, drilling engineering and technical program design, scientific decision has its own characteristics: covering a couple of research subject, involving many experts in different fields, multiple departments take part in the decision-making, and regional dispersion of information source, Figure 20. With the development of communication technology and the progress of distributed processing technology, as well as the development of computer local area network, remote network, and online database, the dispersed decision-making includes a wide range of experts becomes possible. According to the characteristics of oil and gas exploration and development, the concept of remote group cooperative decision-making support (RGCDS(Zhang and Guo, 2005)) based on CSCW(Computer Supported Cooperative Work(Schmidt and Bannon, 1992)) environment is proposed.

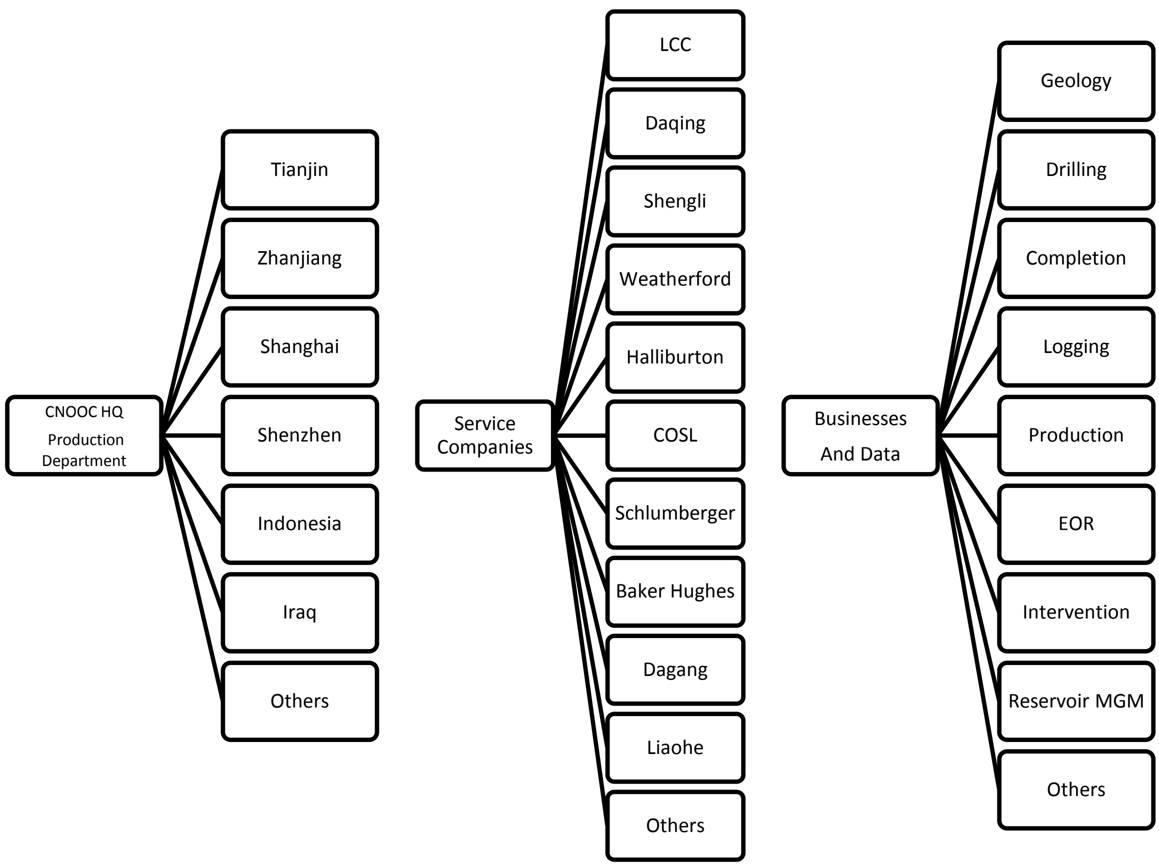

Figure 20 the Structure of CNOOC Production and Involved Service Companies and Businesses

Since the involved parties usually are far apart so that the staff need to shuttle among different places, the cost is high, but the efficiency is low and the results generated could not be well shared between different parties, this phenomenon is more common in offshore oilfields. Such as a well-logging or a well-test task involves the production management and technical departments of the oilfield, test service companies, logging companies, and many process like planning, geological design and transmission, operation design and transmission, production management, field work and quality supervision, progress tracking management, data interpretation and material certification, cost settlement and others will be involved in the task.

in the process of oil and gas field development, RGCDS concept is based on computer network, human-computer interaction system of communication technology making full use of modern Information technology, to integrate dispersed decision makers in different departments, experts of related fields, and the on-site technical service personnel an organic whole, to make full use of remote real-time well-site information to provide decision support for oil and gas exploration and development.

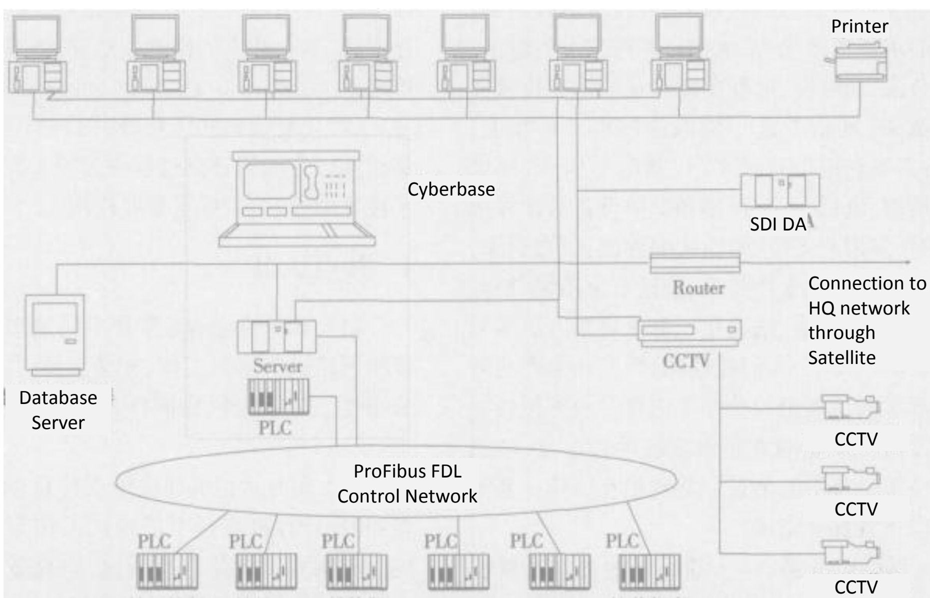

Figure 21 Schematic of Well-site Distributed Database Management System(Zhang and Guo, 2005)

A typical oilfield computer system can be divided into two parts: one is the well-site computer system and the other is the remote office computer system. Figure 21 is the schematic of well-site distributed database management system. Through the computer network system, the platform management personal can share and exchange information with HQ technical support experts and manager. Once there is a complicated situation, field engineer can request technical support from the base experts, and the base experts can offer specific suggestions to field engineer through the theoretical analysis and the experience of knowledge base to improve the feasibility, pertinence and maneuverability of the decision.

Figure 22 CNOOC Well-site Real-time Exploration Data Monitoring System

By far, CNOOC has already established the collaborative work environment and remote support center for the offshore exploration and drilling works. Figure 22 and Figure 23 are the real-time well-site exploration data monitoring system and real-time exploration decision-making system of CCLZ (CNOOC Zhanjiang ltd.). The system established is mainly used to solve the problems appeared in the drilling process and to make adjustments to hit the target section accurately. But the collaborative work environment for offshore production is still under the construction due to the large number of offshore oilfields and limited professional staffs.

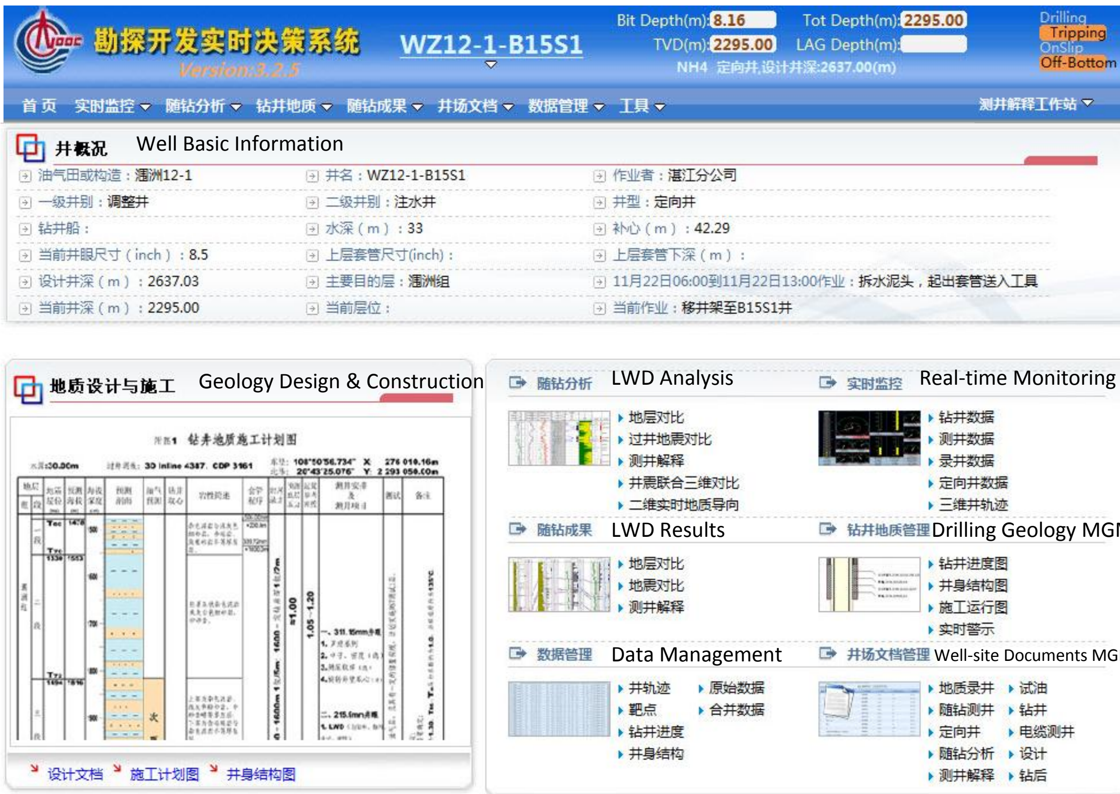

Figure 23 CNOOC Real-time Exploration Decision-making System

In 2009, CNOOC research institute has developed a specific system for tracking the main economic evaluation, the system programs and standardizes the economic evaluation calculation model and calculation flow; realize the intelligent application of economic evaluation calculation. The system has altered the approach of evaluation calculation and analysis that is performed manually by using EXCEL. It can automatic select model, match data, batch calculation and produce standardized statements, which greatly improves the work efficiency, shorten the work take over time by personnel replacement, and realizes a transparent and intelligent calculation and evaluation analysis. The wildly application of this system in CNOOC led the tracking economic evaluation work into the network collaborative era based on database system from single based on a single application of Office, greatly improving the informatization and intelligent level.

1.9 4.3 Real-time data transmission

Although the collaborative work environment and work process is very important for the effective oilfield management, it could not be realized unless the management is able to access the real-time well-site and production data. Without the real-time and other necessary data, everything likes talking in air.

From this point, remote monitoring and controlling system is becoming a necessary process in the construction of intelligent oilfield. As a key process, real time data publishing based on remote monitoring and controlling system is playing a more and more important role in the system.

Remote monitoring and controlling system connects the data acquisition system through computer networks in production site to access to real-time data analysis, statistic, and publishing through on-site information processing systems, so a team of experts in remote place can obtain real-time field data to schedule field job and make decision.

However, the offshore oil exploration and production has its specific characteristics.

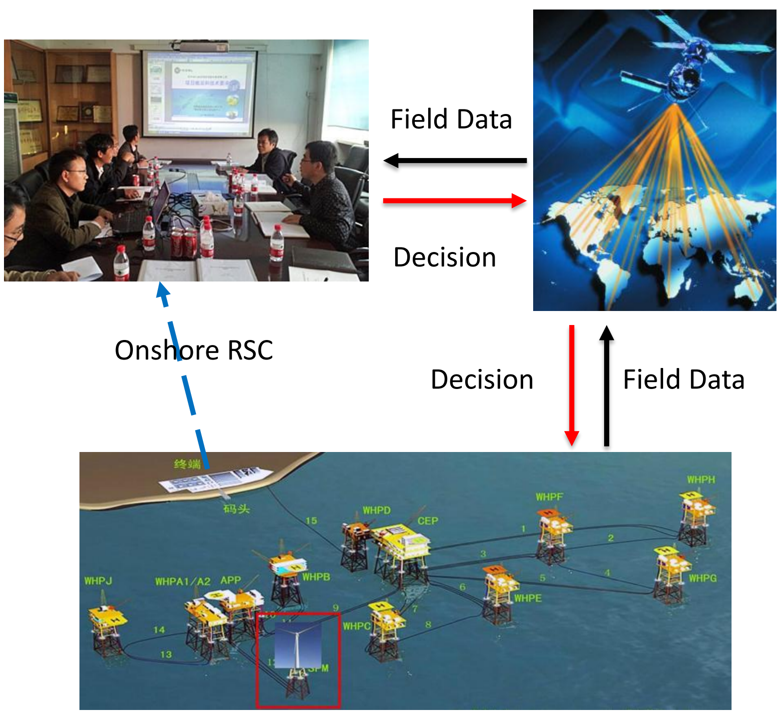

Figure 24 the Schematic of Data Transmission in CNOOC

First is the distance. In general, the platform especial the deepwater platform is very far from the mainland, sometimes more than 1000 kilometers. It is hard to use wire or fiber to transfer data as the land field does, especially in the harsh offshore environment, the waves, storm, marine activities all will affect the safety of wire or fiber. Besides the technical difficulties, the cost is also an important factor need to be considered. Thus, the non-regional restriction communication, satellite communication, is wildly accepted by oil operators in early stages. Figure 24 shows the current data transfer method applied by CNOOC in Suizhong 36-1 oilfield. This method can give the onshore expert a basic idea about the offshore operation and production status.

Although the satellite communication neglects the regional difference, the limited bandwidth is a serious defect of data transmission. Due to the high cost of satellite band rental, CNOOC has only rent a limited bandwidth that just meets the basic needs for all offshore works. As we know, there is a number of inter-related companies are working offshore at the same time. They can only share a very limited bandwidth for onshore and offshore communication. This leads the very slowly data transmission, sometimes the transmission rate is only several kilobytes per second. This is acceptable for a limited communication demanding, such as there are only a small number of offshore platforms and less information exchange; when there is a large quantity of working platforms and large amount of system visit, this method of information transmission and exchange cannot satisfy the ever increasing demand for data transmission today.

Second is the volume of information. Along with the increasing of China's offshore oil production, the number of production platform is increasing as well. By far, there are more than 25 drilling rigs and more than 150 production platforms and more than 2000 wells are in operation every day. The data generated each day is a mass amount, usually larger than 1 Gigabytes, even a small number is need to be transferred to onshore offices, the bandwidth needed is still a huge number.

The construction of intelligent oilfield and the collaborative work environment and real-time decision-making are all based on the access of information, if the data exchange and transmission is not smooth and straightway, everything is an empty talk. Thus, find a way that information can be exchanged timely is the key to the construction of intelligent oilfield and the collaborative work.

At present, the external communication (offshore-onshore) of all CNOOC's offshore production platform relies on satellite communications. With the constant expansion of the business, the dependence of the oil field production on communication also increased. But the satellite communication has several problems, such as low transmission rate, heavy interference; these problems to a certain extent can affect the efficiency of oilfield development. Thus establishing a high-speed offshore-onshore wireless communication system is the key to break bottleneck of the intelligent oilfield construction. Ultra-distance microwave communication is an effective way to realize high-speed offshore-onshore communication; besides, the 3G/4G mobile communication, Remote wireless relay communication and other new communication technology are also effective to break the bandwidth limitation of long even ultra-long distance communication.

But the realization of ultra-distance microwave communication is not easy; it must solve the difficulties like signal attenuation and time-delay of signal transmission that brought by ultra-distance.

In 2012, an ultra-distance microwave communication is tested in South China Sea(Li and Yang, 2012). The ends of test are Huizhou oilfield and Beijian Island, Zhuhai, the distance between is 117 kilometers. The test is performed by point-to-point ways. After repeated trails, the 117 km microwave communication routes is successfully connected, the maximum bandwidth is 30 M and the data transmission rate can achieve 3.2 MB/s, which is hundreds of times of the current satellite communication.

Take Suizhong 36-1 oilfield mentioned in previous sector as an example of ultra-distance microwave communication. The real-time data transmission system based on microwave communication can be realized through the automatic measurement and controlling system. The overall design of the automatic measurement and controlling system is triple level’s management and double level’s control, Figure 25. The first level is onshore central station, mainly responsible for the supervision and control of the production and operation status of the whole oilfield to process the production information; the second level is the central platform station, mainly responsible for the observation and control of the production and operation status of the center platform and the satellite platforms; the third level is satellite platform station, in charge of the process and judgment of the production information acquired by remote terminal units (RTU) and send to the center platform station, meanwhile receive the control order released by the center platform station. The parameters are wellhead parameters of each production platform, measurement parameters and safety parameters. For each well the parameters gathered are pressure, temperature, flow rate, water cut, and so on. In order to guarantee the accuracy, reliability and timely transmission of gathered information, the three central stations each creates a local network individually and together form a LAN. Given the distance between the satellite platform and the central platform and the onshore central station as well as saving investment, Information transmission between the stations can use spread spectrum microwave combining the radio communication.

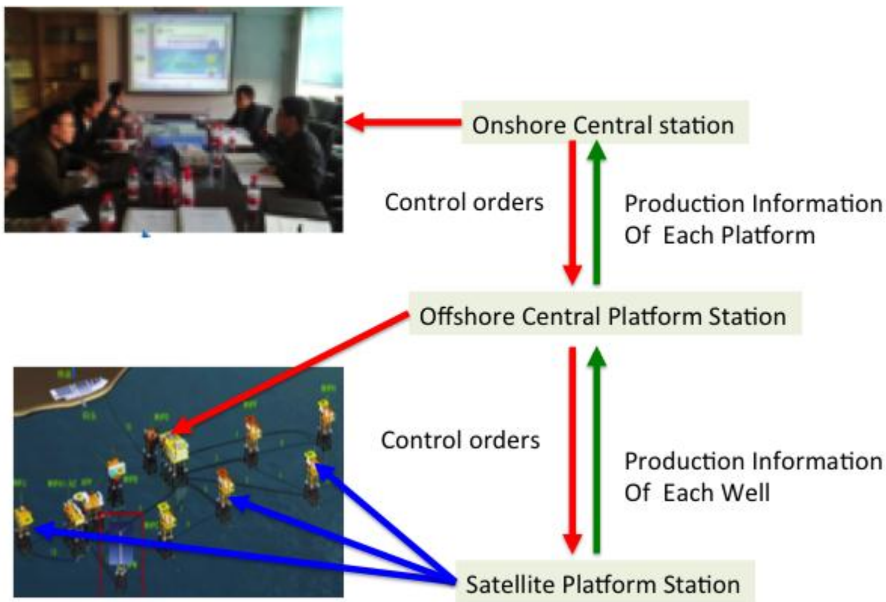

Figure 25 the Schematic of the Oilfield Microwave Communication

1.10 4.4 An Effective workflow

Workflow or Business process is the sequence structure of a series of interrelated behavior of the enterprise production activities management. It reflects the objective laws of the target-guided activities' order, connections, restrict propulsion, input and output. The enterprise executive power refers to the ability to carry out the operator's strategies, policy, rules, plans and the ability to achieve the corporate's strategic objectives for each management level, business unit and staff. It bridges the enterprise strategy decision and the achievement of the strategic, its strength will directly restrains the enterprise to realize its management goal smoothly, also depends on implementing will, maturity of implement system and other factors. Figure 26 shows the relationship of executive power, executive system and work process. Workflow is the explicit core of the executive system and the main difficulty of the organizational foundation management.

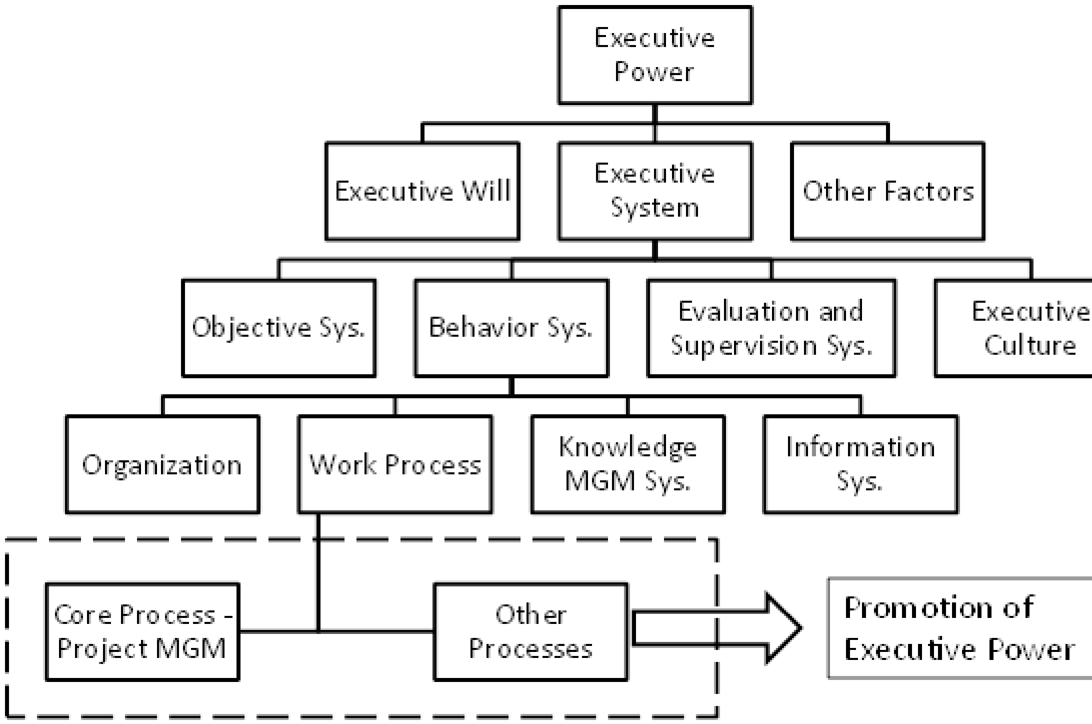

Figure 26 Influent Factors Analysis for Executive Power (Chen and Lv, 2007)

Workflow refers to the complete process of an internal corporation business that achieved from its beginning to end together by multi-departments, multi-jobs, multi-coordination and sequence work. Simply speaking, workflow is the process that a group of input into the output.

Workflow is the source of work efficiency. Process determines efficiency, process influences efficiency. A good workflow enables enterprise has a well carrying out of the business management, thus to ensure the efficient operation of the enterprise; on the contrary, a poor workflow issues frequent problems like unclear responsibility and buck-passing between departments and personnel, etc., thus resulting in a waste of resources and low efficiency. Therefore, designing and establishing a scientific, rigorous workflow and maintain effective implementation, control and management of these processes is essential for a business, a unit or department.

In order to establish an effective workflow, we need to perform five aspects analysis.

A) Objective Analysis: eliminate the unnecessary works

Actually do what?

Why to do?

Is this work really necessary?

What should be done?

B) Place Analysis: merge the related activities as much as possible

Where to do this activity?

Why do it in other place?

Could it be done in other place?

Why should do it in other place?

C) Sequence Analysis: ensure the order of activities more rational and effective

When to do?

Why do it at this time?

Can do it at other times?

When should do it?

D) Personal Analysis: analyze the reasonability of the personal match

Who?

Why is this person?

Can other person do?

Who should do?

E) Method Analysis: simplify operation

How to do it now?

Why do it in this way?

Do other methods available?

Which way should be accepted?

Through these five aspects' analysis, we can eliminate redundant work, merge similar activities, and make the work process more economical, reasonable and easy, therefore improves the work efficiency.

Figure 27 is a simple demonstration of a workflow.

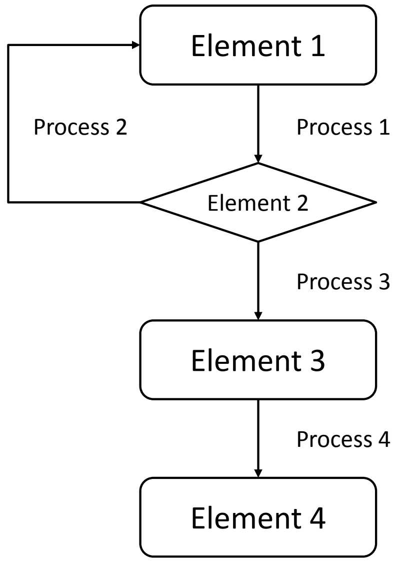

Figure 27 the Demonstration of a Workflow

Based on the study of work process, CNOOC has developed different workflow for different types of works; Figure 28 shows the main work process of exploration and development work, and Figure 31 demonstrates the main work process of well test job.

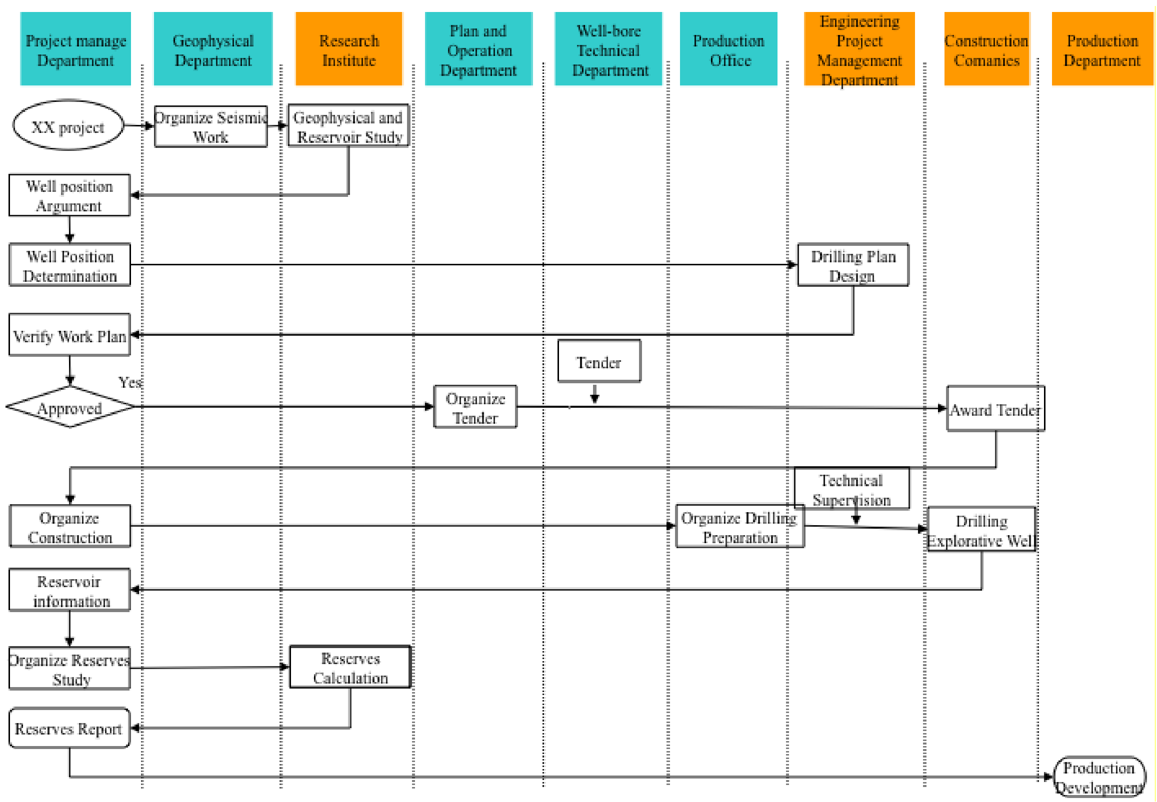

Figure 28 the Main Work Process of Exploration and Development

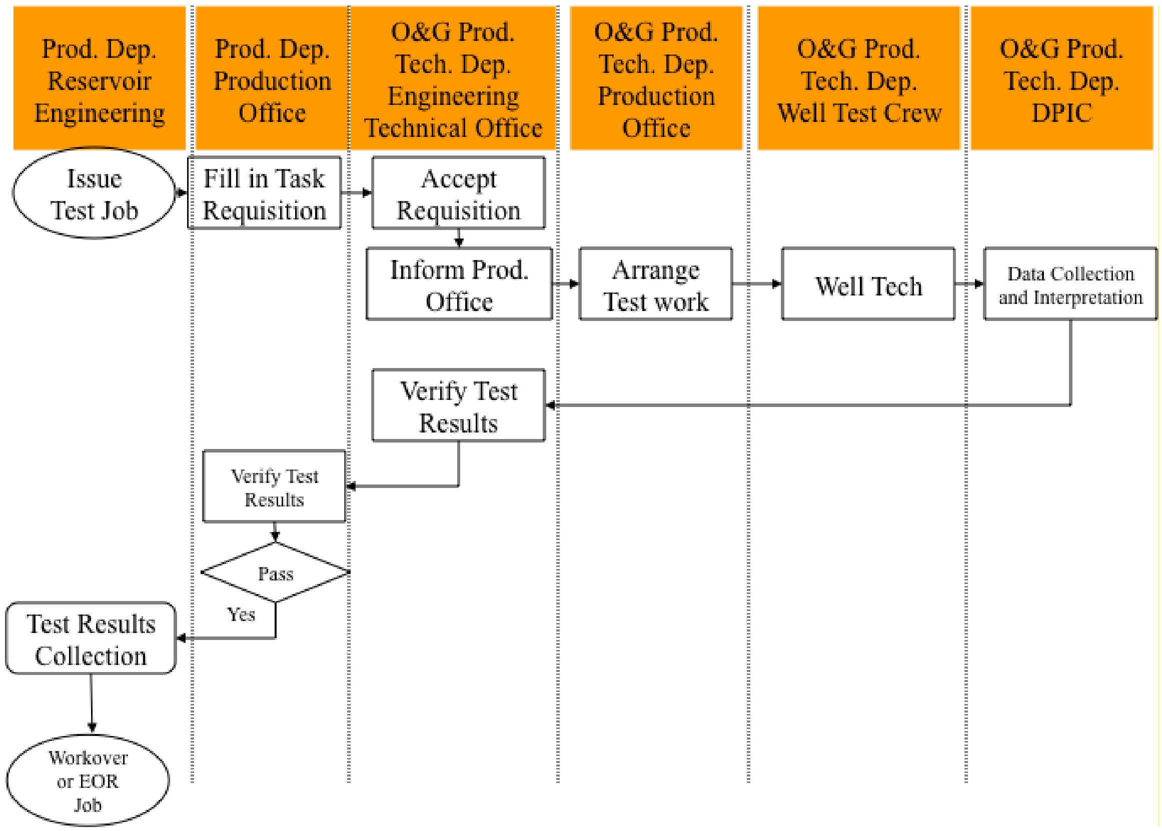

Figure 29 the Main Work Process of Well Test Job

Although CNOOC has established a serious of workflow for oilfield development, many rules have not well performed due to the specific situation of CNOOC oilfield development and have not realized a successful cooperation between departments and units.

China has been starting its offshore oilfield exploration since 1950s and built CNOOC in 1982. During the development of China's offshore oil industry, in order to gain much production to meet the increasing demand of oil and gas, more resources were spent on the preliminary exploration work and large scale drilling activities, but less were put on the later stage's production monitoring and production adjustment. This wrong attitude was partly inherited by today's reservoir management team because today's demand for oil and gas is more vigorous. In 2011, 808.2 million U.S. dollar was spent on exploration works, among it, 307.5 million U.S. dollar was spend on drilling 82 exploration wells; at the same time, only about 5 million U.S. dollar was spent on the production monitoring of production wells(CNOOC, 2012). Due to this developing perspective, only limited information was acquired to adjust production means. This is not consistent with the construction of intelligent oilfield, but this is the true reflection of CNOOC develop situation. If there are enough information were gathered and analyzed, the tragedy of Penglai 19-3 Oil Spill could be forecast and avoided with proper treatments in advance.

Another serious problem is the incompatibility between preliminary cost saving and later production adjustment jobs. A typical phenomenon is the improper well completion design which only considers the easiness to construction instead of the intelligent well production.

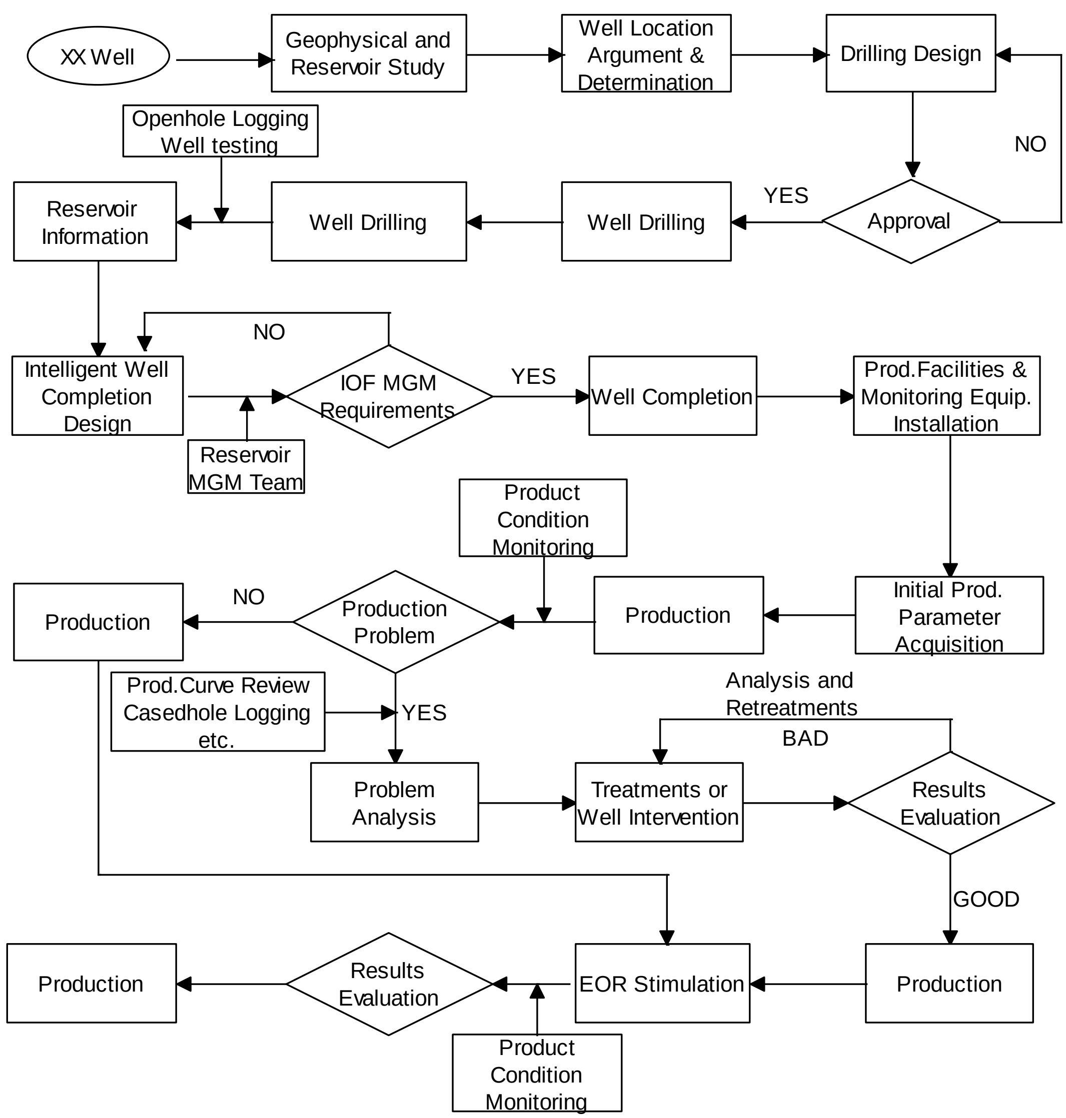

Figure 30 an Optimized Work Process of Well Production Management

In order to achieve an effective work process, CNOOC reservoir management team need to have a thorough consideration of how to manage scientifically an oilfield from beginning to end and acquire which production parameters for effective actions. As the start point, establishing an intelligent downhole system is the basis.

An intelligent downhole system needs to consider the interrelationship between reservoirs, downhole tools, completion methods, production methods, production condition monitoring system, well intervention jobs, EOR activities, and so on. Thus, the current workflow of well production and test must be reconstructed, Figure 30.

Although CNOOC has already recognized the importance and the function a collaborative and effective workflow for the construction of intelligent oilfield, it just on the starting line of intelligent oilfield construction. But we know, reservoir management is a broad and complex business, the achievement of intelligent oil still needs a very long time to realize. The new advanced and high efficiency technologies used will change the way of the modern reservoir management, in order to establish a collaborative and effective workflow that needed for the modern oilfield management and to maximize the value of the oilfield assets, the relationship between CNOOC, the numerous service companies, the government departments, the various operating departments, manager and work staffs, etc., needs to be better organized.

Chapter 5 Transforming Data into Effective Actions

Since 2000, the application of information technology in oil industries has been developing with a rapid speed. No matter how big or how small the size of the oil company or the service company, have popularized the information management system, and gradually formed a consensus that the information system as the center of business operations. Some outstanding enterprises, has accumulated years' experience of the application of information technology and raw data. However, we can see that, for the vast majority of oil companies, the continuing accumulated massive amounts of data has not produce the best possible results; these growing vast amounts of data just become cumbersome that affect their operating efficiency. In order not to influence the efficiency of operation system, a considerable number of enterprises regularly, constantly manually truncate the data and package them into dusty shelf. Because of poor management some companies even lost these valuable historical data.

With the further developing of the oil and gas exploration and development, the demanding of the oilfield information construction is increasing sharply. Digging out the useful information for decision-making from the complex and vast amounts of data environment to make correct and timely analysis and decision-making has been becoming the vital link of the long-term oilfield development. During the oilfield production process, a large number of historical production management data and results data have been accumulated, but among them the really valuable information is very limited. Traditional database technology regards a single data resource as the center, only retains the current management information, lacks a lot of historical information that needed by decision analysis, and unable to meet the requirements of the management decision-making and analysis. The data warehouse(Inmon and Hackathorn, 1994, Poe et al., 1997), established on the base of database, meets the data environment that needed by decision analysis.

Data warehouse and data mining(Inmon, 1996, English, 1999) has gradually become an important technology to support analysis and decision making. By building interest model, people can extract and dig out a lot of useful information hidden behind the data to study the oilfield developing trend and to explore the production regularity, thus to predict reservoir production index and to forecast future production, thereby adjust and optimize the actual production more effectively to make important decisions for participating in the market competition.

5.1 Data and Data Quality Control

5.1.1 Why we need qualified data?

With the in-depth application of the information, the level of the oil enterprise's informatization is raising, and a variety of data were pooled into the corporate's database continuously; however, the data quality has become the top priority issue in application of information technology.

As a type of resource, data is the main body to support the informatization construction and informatization application. According to the rule that garbage in and garbage out(Bininda-Emonds et al., 2004), reliable data that can accurately reflect the actual production situation is highly required if we try to make right decisions. The CNOOC plant data center stores tens of millions of data, at the same time, is increasing with the speed of tens of thousands a day, how to make huge amounts of data to play its due role in the production and management, scientific research, corporate decision-making, thus the user can, dare to use it and would like to use data to serve the corporate, has become an urgent problem for almost all informationized companies. The poor quality of data is becoming an important factor to affect the right decisions. How to protect the quality of the data has become a common concern of management, technics, and researchers.

Due to the historical reasons and the current division of labor, the different subsidiaries and departments of CNOOC are focus on different concerns. They together formed the CNOOC database group and manage the multi-disciplinary data which includes exploration, development, production, operations collaboratively. Whether the data is timely and accurate became a critical factor for the success of the CNOOC's informatization development. Along with the gradual increase in the amount of data, data inconsistencies and data incorrect has become increasingly obvious. Although CNOOC and its subsidiaries have invested a lot of resources in the information construction, a lot of information system has been up and running, but the utilization rate is lower. There are many causes of the effect of system applications failed to achieve the design goal, the main reason is the quality of the data and this problem is gradually grasping the senior management attention. Currently, the CNOOC is conducting in-depth study in improving the data quality management and carrying out the construction and implementation of information systems. Practice has proved that through the establishment of information technology and data quality management system, you can simplify the procedures to ensure data quality, to better serve the oilfield production and lay a solid foundation for the ultimate realization of the intelligent oilfield. All in all, through the continuing in-depth research, can realize automated data services, standardized and programmed service processes, networked service environment, and scientific service management, to achieve software tools as supports, quality control norms as guidelines, and management as the basis to establish data quality management system for data collection to achieve the full data quality monitoring of data applications, thereby improving the overall quality of the data.

5.1.2 Data quality problems

With the continuous development of IT technology and business needs, during the whole oilfield development, CNOOC hopes to add some new data into the existing multiple development and production database to establish a new central database to meet the requirements of the new system. In the process of combing multiple data sources and the upload of new data, data quality issues are generated inevitably. There are many factors to affect the quality of the data, including management and technical aspects; however, no matter which factors, the result is the same that the data did not meet the data quality expectations.

Thus what is data quality? Which kind of data is qualified and which kind of data is unqualified? There has not had a clear definition! J.M.Juran summarized that data are of high quality "if they are fit for their intended uses in operations, decision making and planning".

Based on the analysis and study of actual cases, several cases here listed below are prone to produce data quality problems. If the conditions that can produce these problems were not taken seriously, even small issues will also be turned into a serious quality problem.

Conversely, if you pay enough attention to them, the experience received through the analysis can help us better control the data quality.

a) Multiple data sources

   The problem of inconsistent that the same information stored in different data source may exist, while the representation of different information may be the same, thereby generating a conflict.

b) Subjective judgment of data generation

   The access of some data can only be obtained by a subjective judgment. These data may be deviated with the actual data. The data we used should be the true portrayal of reality. Also we should try our best to maintain the data authenticity during the data collection process. However some information can only be generated by subjective judgment, we can only enhance the knowledge level of the field data acquisition personnel to improve the data quality.

c) Limited data resource

   Although the computer and micro-sensors are widely used in today's oil industry, the lack of data resources still constrains the access of data.

d) Balance between security and Availability of data

   The high-quality data requires that data is easy to access, while has better security and confidentiality; but when the availability of data is high, the security, privacy and confidentiality are bad, so it is necessary and important to achieve the balance between them.

e) Constantly changing of data requirements

   With the change of information users and working environment, the data also changes. Only when the information meets the requirements of data users, it is of high quality. It is not an easy thing to provide data users the information they need, different user has different concerns and these concerns are in constantly changing.

5.1.3 Data quality evaluation: Sampling method

In practice, the data amount we used is so huge that to evaluate the quality of whole data source is cumbersome. In fact, the majority of the data used are in good data quality. It is unnecessary to conduct all data quality checks within the acceptable error range.

Therefore, according to actual needs, we can only extract part of the data from the data source to evaluate its data quality and achieve an overall impression of the whole data source. Meanwhile, it is evident that the greater the amount of samples taken, the smaller the error generated.

The sampling method is to extract a small amount of sample, then conduct data quality assessment to inspection the quality level of the whole data source. Before the sampling, we must first assign the sampling objects, second specify the basic sampling unit and the whole object from which we obtain information, and finally select appropriate sampling method. For example, water output, oil output, and water cut are only parts of a well's total production information.

There are basically four sampling methods:

(1) Simple random sampling: randomly sampling a given number of stochastic samples.

(2) Systematic sampling: improvement of the simple random sampling. Samples are extracted periodically with a certain interval. Systematic random sampling is easier to carry out than simple random sampling.

(3) Stratified random sampling: if the data quality of different types is varying and uneven, that is the data error rate of one type of data is higher than another one, we will try to describe the properties of each part of the data to reach a right understanding of the whole dataset. By stratify method we can keep the quality of the data on each layer is relatively consistent, and then conduct simple sampling on each layer.

(4) Group sampling: divided the whole dataset into several groups according to specific criteria, and then randomly select a subset from these groups to conduct data quality assessment. We can either check all elements of the group, or just check some of the group. This method is very useful when we need to merge the different data source into the data warehouse.

The sampling methods play an important role in the data quality problem-solving, such as the presence of missing records, data out of range, wrong data types, inconsistent data quality, and sampling evaluation is a kind of better solution.

5.1.4 Data quality check and assessment system

Data quality evaluation model is established based on the definition model of data quality and implemented by data quality management model to realize quantitative diagnosis and evaluation of data quality and presents the evaluation to the end user. There are many types of data quality problems, so if we want to establish a complete, all-around data quality inspection and evaluation system, we must first set up data quality constraint rules. The core function of the data quality evaluation model is to generate quantitative indicators of the data quality through the processing of the data quality constraint rules, data quality inspection, and results analysis, evaluation and summary.

1) Sampling inspection and evaluation

The sampling check ensures that the user can get an understanding of the overall quality of the data sets, thus consumes system resources as little as possible and improve the quality check speed. The sampling quality inspection is used to investigate the data based on quality constraint rules. The sampling inspection and evaluation has following key issues:

a) Objects: the object of inspection can be the entire data set or part of the data set. For each type of data quality problems, we can call the appropriate rules to do data quality inspection and quality evaluation.
b) Sample size: the sample size is determined by the user according to the actual needs. If the sampling proportion is 100%, which means performing data quality inspection and evaluation for all data, we can get the most accurate evaluation results, but at the same the maximum time-consuming and system resources.
c) Evaluation index: by sampling inspection and valuation, we can calculate the amount of the record that does not meet the rules and the proportion to the entire database. In addition to the direct use of constraint rules defined in the rule base for quality inspection and evaluation, we can also add custom rules to the rule base.
d) Evaluation purpose: clarify the evaluation purpose so that the user can get a clear understanding of the various data quality problems exist and the severity of the problems.

2) weighted evaluation

Through the sampling inspection and evaluation, the evaluation results of each type of quality problems is obtained; however, these results only reflect the indicators of a certain kind of the quality problems, but cannot reflect the data quality of the entire data set comprehensively. Therefore, weighted evaluation method is introduced to solve this problem. The following aspects of the weighted evaluation method should be notified:

a) Objects: the object of the weighted evaluation is the evaluation results obtained by the random sampling evaluation.
b) Weight factor: The weight factor is given based on the experience of the professional or according to the analysis of historical data and quality requirements for each type of data quality problems. These weight factors indicate the importance of a certain type of data problem to the whole index.
c) Evaluation purpose: The main evaluation purpose of the weighted evaluation is to calculate quality indicators: a data set to determine the level of the quality of its data, the importance of the quality characteristics are not the same for different sets of data, starting quality problems from different angles. Take into account the weight of each characteristic requirements, the indicators weighted arithmetic from multiple perspectives, the overall data set identified quality problems.

5.1.5 Rule-based quality inspection & evaluation model

Data is the most valuable asset for oilfield management. In order to make a right decision and turn it into effective action according to the real production status, we should ensure the data used is accurate and in good quality. Data inspection and evaluation system can help us to guarantee whether the data quality is ok. However, we must establish a quality rules base to better use the data inspection and evaluation system. Thus the rule-based quality inspection and evaluation model is introduced, Figure 31. It includes three main aspects:

1) Data

   Entity base/library: during the oilfield information construction, according to the classification of data, various types of database were established, such as the ground engineering database, production database, operation and management database etc.

These databases are collectively referred to as the entity library. In each base, data quality problems could exist, so all of them are objects for data quality checks.

Data quality rule base: it is unrealistic to perform data quality checks without the support of the rule base. Data quality is the process to evaluate the data quality check according to the corresponding constraint rules extracted from the rule base. The rule base can be said as the core of the inspection system.

Evaluation result: The evaluation results are divided according to the classification fo data quality problems.

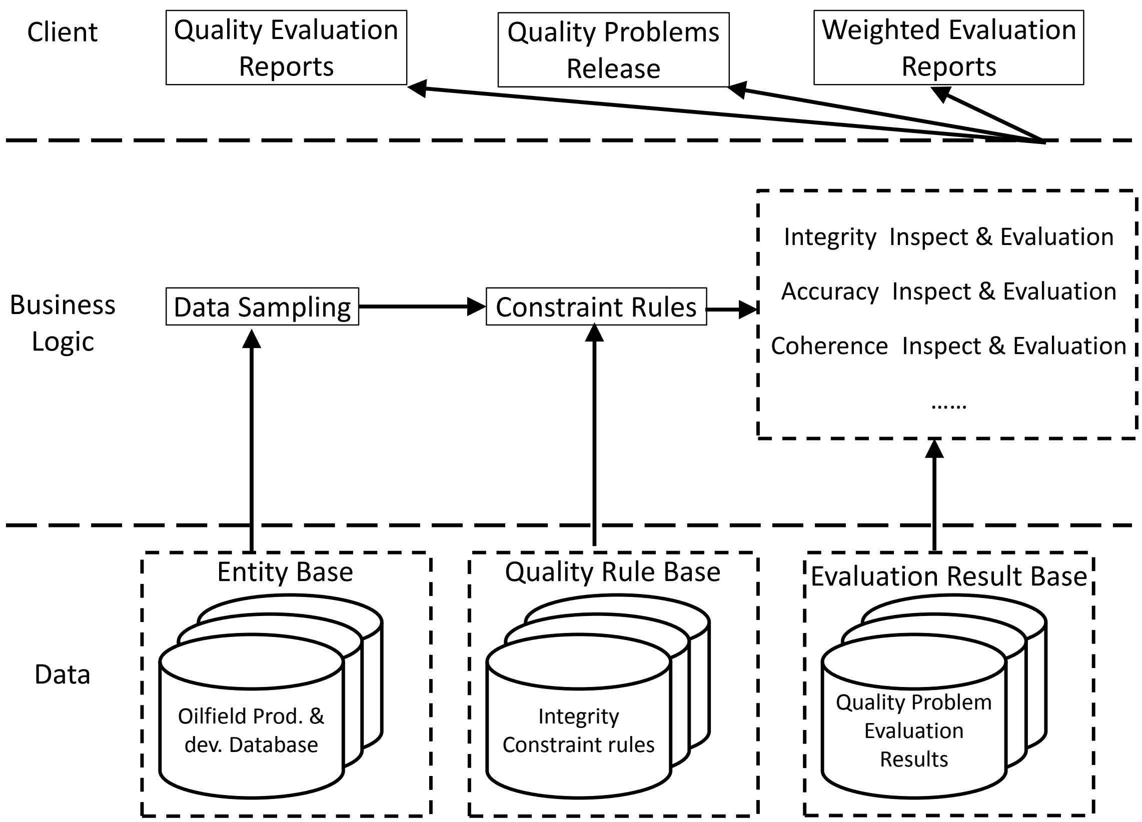

Figure 31 Rule-based Quality Inspection & Evaluation Model

2) Business logic

The business logic is mainly responsible for the data logic processing of the oilfield data quality inspection and evaluation. In practice, business logic is critical, it is the core of the whole system, is the most concerned part of the user. The business logic mentioned here includes data sampling, constraint rules selection, and the inspection and evaluation of the quality problems.

3) Client

The end user can use the visualization method to view the evaluation results, and use weighted method to statistic and analyze the quality check results.

5.2 Data Mining and its Application in Oilfield Decision Making

In oilfield production, many factors can affect the production in different mechanism. Among these influencing factors, many of them are uncertain. In order to improve the oil production usually a variety of measures will be adopt, but these measures taken often are based on empirical description. Therefore, how to integrate and use the oil field production data to enhance oil production efficiency is becoming one of the main issues concerned by the decision makers of oil field production. To solve the problem of data availability and data utilization, we can make use of the data mining technology.

5.2.1 Data mining

By far, the construction of enterprise information is toward to data centralized, integrated business, flatten management, and scientific decision. In order to improve and enhance their market competitiveness and international competitiveness, Enterprises have proposed data mining system based on the years of historical data accumulated and the core business. China's oil companies also have some development in data mining. But compared with international oil companies, there is still a huge gap. Take Shell as an example: Shell uses ERP as its core system, the daily production data, and operating data will be uploaded into the system before 0:00, on the second day the analytical results will be presented to the company's headquarters and each level’s network, and shared across the company. The company's monthly business analysis reports will be generated in the first two days of the following month, the company’s production and management is able to maintain close contact with the market, and achieved good economic benefits.

Data mining is a new technique that has been widely used in various fields of the oil industry. Today, with the promotion of intelligent oilfield, efficient oilfield, data mining technology plays an important role in promoting the efficiency of oilfield production.

Data mining is to dig out the knowledge that conceal under the amounts of data, generally it can be divided into descriptive data mining and predictive data mining (Han and

Kamber, 2006). The descriptive mode is to express the general characteristic of data by normatively describe the truth of data stored in the database; the predictive mode is to predictive the future value based on the historical data, it is time-order. There are two key issues that affect the data mining quality: one is the quality and the amounts of the data that used in data mining; the other is the validity of data mining techniques. The data mining process is a dynamic process, and needs to be modified according to the expectation of the users.

The well-used data mining methods are: statistical methods, association rules, clustering analysis, decision trees, neural networks, genetic algorithms, support vector methods, cloud theory, and gray theory and so on. The main function of data mining can be divided into: estimates and projections, association and sequence discovery, clustering, description, deviation detection.

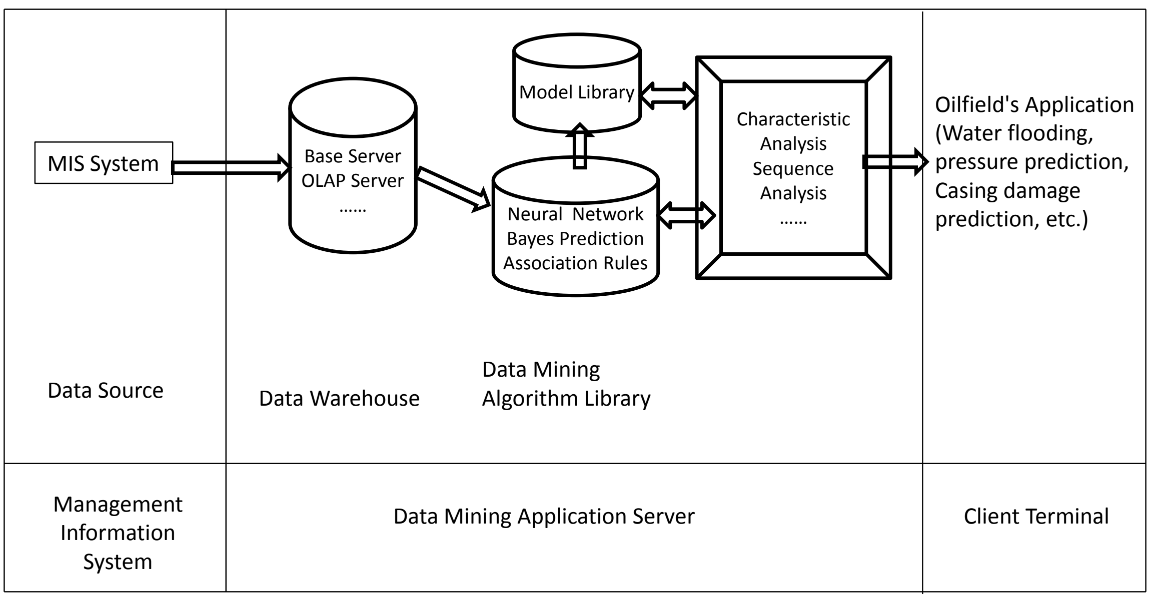

Figure 32 Data Mining Application System

From the technical perspective, data mining can be used in the following areas:

1) Association rules detection: to find the association rules in a given data collection that meets certain conditions. In simple, data mining is to provide guidance for business activities by reveal the relationships hidden in the data.

2) Sequence mode analysis: is similar with association rules detection, but the focus is on the analysis of the contextual relationships of the data. Mode is ordered by time. The sequence mode is to find all orderly sequence in the database that satisfy the given minimum support threshold.
3) Classification analysis and cluster analysis: actually, the classified rule mining is to find the common characteristics from the data objects based on classification model, and divide them into different classes.
4) Automatic trend forecasting: data mining finds potential predictive information automatically inside a large database.

5.2.2 Application of data mining to the decision support of oilfield production

With the deepening of the oil and gas exploration and development, technician often need to process and use a lot of information and data to deal with oilfield problems. But in this process lot of problems are appeared and need to be solved, like the growing complexity of the operation of the management personnel, dispersed users, low degree of interconnectedness, the low level of information sharing, and poor means of information processing. These issues made it is hard to collect data and make comprehensive utilization of the data directly from the different business information systems, the large amount of data generated by the business system is unable to timely provide to the decision-making department. The oilfield management personnel still need to query multiple business systems and external systems based on a variety of heterogeneous data sources, and conduct abundant heavy data analyses to make decisions. The heavy workload is prone to generate human error, thus affecting the quality of decision-making.

Data mining is an important technology for intelligent oilfield decision-making and modern reservoir management. Therefore, on the basis of reasonable data warehouse platform, carrying out the decision support system study through online analytical processing and data mining is meaningful and provides reliable technical support for the oilfield production and development trend study to decision makers.

1) Analysis and design of the oilfield production data warehouse

The various data sources of data warehouse, varied use requirements, and complex query requirements predestine the structure of traditional database systems cannot provide enough flexibility to meet this complex and volatile requirements. Therefore, from the user perspective to analyze and design the data warehouse architecture, first we should determine the subject of analysis and the various analytical indicators according to the requirements of the use of the data warehouse. Before loading the data into the data warehouse, pretreatment process such as data extraction, data cleaning and data conversion must be performed. After that, we can select the appropriate storage model to effectively organize and store the data into data warehouse, and then to analyze and dig out the potential hidden useful knowledge to provide reliable information for decision-making.

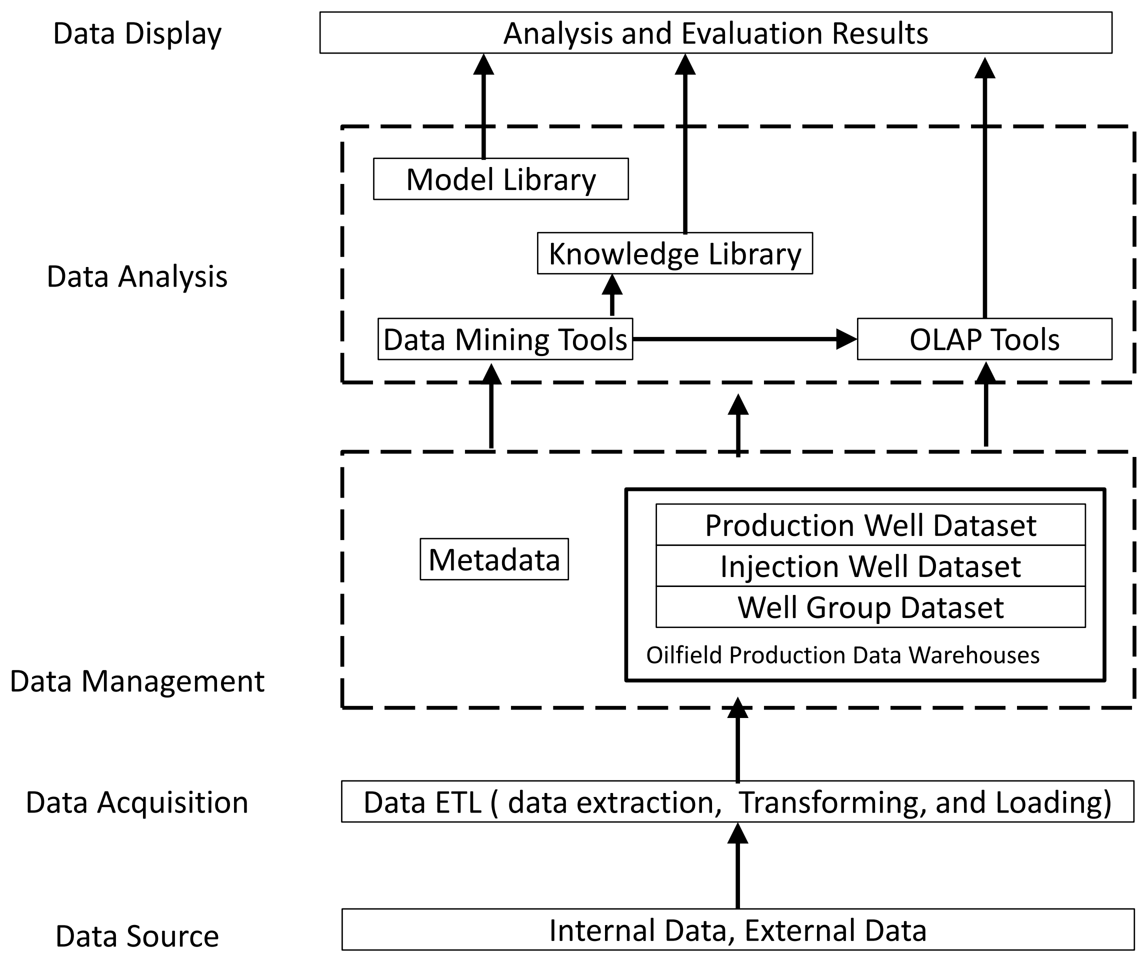

Figure 33 the Architecture of Data Warehouse of Oilfield Production Decision Support System

Generally, a typical data warehouse can be designed in three separate data layers: information acquisition layer, data management layer, and data application layer. Taking the characteristics of oil field production data into account, the oilfield production decision support system mentioned in this paper is consist of the data source layer, the data extraction layer, data management, data analysis layer and data display layer, as shown in Figure 33.

The data source layer mainly deposits a large number of historical oilfield production data and external data used for production analysis and decision-making. Data acquisition layer extracts the data required for data analysis and decision from the source data layer, and then integrates the purified and converted data into the oilfield production data warehouse. Data management layer stores and manages the data and data sources in the data warehouse, creates datasets to reduce the amount of data processing based on different subjects. For different topics' datasets, by online analyzing and processing and data mining, data analysis layer achieves multi-level's data analysis and data mining. Data mining tools pool the knowledge excavated from the data warehouse into the knowledge base of the expert system to achieve qualitative analysis and support decision-making. The model library achieves multiple model integrated decision-making. Finally data display layer presents the analytical results to decision-makers for decision-making.

2) Construction of the oilfield production data warehouse

In order to construct a successful oilfield production data warehouse, we first need to perform data modeling to determine the system subject domain(Inmon, 2002). Take the well group production as example, the determined system subject is the influence on the well production for the different water injection rates and production and injection measures in different layers.

Once the subject domain is established, the contents of each subject can be described more specifically. The data used includes production time, oil well attributes, oil well production data, injection well attributes, injection well production data, layer attribute data, and then can determine the facts and dimensions of each topic, and establish the conceptual model of the data warehouse using the multi-dimensional data modeling. For the well group production subject, the actual data concerned by decision-makers are daily liquid production, daily gas production, gas-oil ratio, water cut, and the allocated injection rates and so on. Traditional conceptual model focus on the structure of the data, this is inappropriate for analytical applications; but the multidimensional data model is focused more on the meaning of the data, and able to express clearly the data model of the analysis area, therefore, the conceptual model of the data warehouse can be modeled by multidimensional data model. As shown in Figure 34.

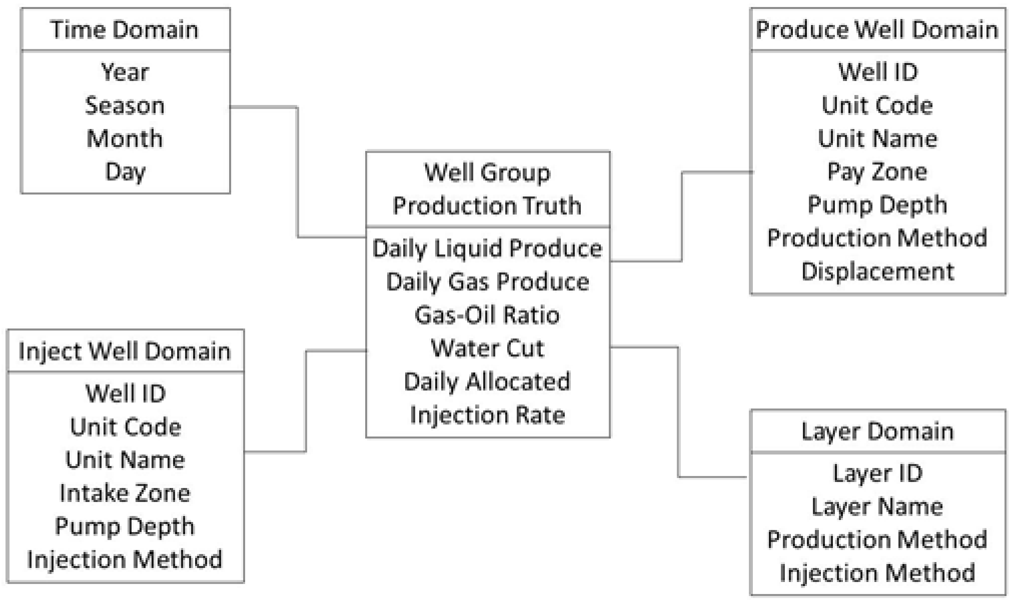

Figure 34 Multiple Domain Data Model of Well Group Production

However, only establish the conceptual model is not enough for us to create a physical model of the data warehouse directly. We must first create a logical model to guide the physical implementation of the data warehouse. The logical model design of the data warehouse mainly includes the division of the granularity level, the definition of relationship schema, data sources, and the determination of data extraction model. The determination of relationship model depends on the division of the granularity level. The granularity size must consider adequately the analysis capabilities of the data warehouse, and take into account the amount of the data size and efficiency of query analysis.

The data in the data source are very different with the requirements for data of the data warehouse in many aspects, such as the data organization means, data formats; therefore data extraction and data clean-up must be carried out before pulling them into the data warehouse(Zhou, 2004a).

Data extraction, including the description of the data sources, data extraction rules, the relationship between the column of data source and the corresponding column of the data warehouse, not all data in the data sources are need to be extracted to the preparation area , the data to be extracted must meet certain conditions. In many cases, the data need to be extracted may scatter in different tables, thus the table connect rules must be specified. Before loading the extracted data into the data warehouse, a variety of clean-up work, including format conversion, type conversion, unit unify, or data etc. must be conducted in advance. Only the data after data extraction and data clean-up can be loaded from data preparation to data warehouse.

By the end of 2012, CNOOC Zhanjiang had digitalized more than 12 million old paper documents and structured 120 million data records generated later than 2000 into its data warehouse. By far, CNOOC Zhanjiang had established 6 sub-databases for intelligent production decision-making, which are exploration dynamics library, drilling geology library, development and production library, core library, and etc., these libraries include the data such as drilling geology, well logging, mud logging, well test, downhole works, inventory and so on that related to the production, every day more than 600 staff visits this system to making production decisions. The more important is that these libraries are all inter-connected, you can find the data whatever you wanted just through one platform, said Caijun, the General geology supervisor of CNOOC Zhanjiang, this structure eliminates the information islands as much as possible and improves the efficiency and quality of the decision-making, promotes the data integration of exploration and development greatly.

3) Decision Analysis and Its Application

a) Online Data Analysis and Processing

The purpose of establishing a data warehouse is to query and analysis flexibly the data in the data warehouse. The data organization ways of the data warehouse provides this possibility for query and analysis, but the data warehouse itself cannot complete this complex data query and analysis. In order to realize this multi-angle, multi-view query od the data in the data warehouse, to easily access the recapitulative or detailed information, we need adopt online data analysis and processing technology to assist decision-making.

During the process of online data analysis and processing, using the multidimensional data model based on the dimension and fact model, through the analytical processing like section, block, rotation, drilling and so on of the well group multi-dimensional data, we can inspect the various types of oilfield production data from different aspects and different sides, such as gas-oil ratio, water cut, daily allocation, etc., to have a more in-depth understanding of the information contained in the data.

Using the methods mentioned above synthetically, production engineers can observe and analyze production data from different aspects and different levels to obtain valuable information to support production decision-making.

b) Data Mining and Its Application

Data mining is the technique that based on the artificial intelligence to analyze data, to discover the latent patterns and data relationships through the analysis of the data stored in the data warehouse. The effective established efficient data mining models is the key matter to successfully implement data mining works(Han and Kamber, 2006).

In previous sector, we noted that the modeling methods used frequently includes association rules, decision trees, rough sets, statistical analysis, neural networks, support vector machines, clustering, and Bayesian prediction. But in the process of actual modeling, we need to compare and analyze the various modeling methods aimed at the specific issues. Therefore, combined with the actual oil production situation, hereby we just try cluster analysis algorithm based on the production data warehouse to set up the data mining model.

When using cluster analysis algorithm in a N-dimensional space, we can use Minkowski distance(Groenen and Jajuga, 2001):

$$\mathrm{d(i,j)} = \left(\left|x_{i1} - x_{j1}\right|^{q} + \left|x_{i2} - x_{j2}\right|^{q} + \cdots + \left|x_{ip} - x_{jp}\right|^{q}\right)^{1/q}$$

Where

$$\mathrm{i} = \left(x_{i1}, x_{i2}, \cdots, x_{ip}\right)$$

$$\mathrm{j} = \left(x_{j1}, x_{j2}, \cdots, x_{jp}\right)$$

i, j are two data object of P-dimensional, that is the i[th] record and j[th] record of a p fields in the database. In cluster analysis, some production parameters need to be given greater weights based on the cluster requirements. The weighted Minkowski distance formula now changed as follows:

$$\mathrm{d(i,j)} = (w_1|x_{i1} - x_{j1}|^q + w_2|x_{i2} - x_{j2}|^q + \cdots + w_p|x_{ip} - x_{jp}|^q)^{1/q}$$

Here, w_p is the corresponding weight of $|x_{ip} - x_{jp}|$, its value range is between 0 and 1, but the sum of all the weights should be 1.

Since traditional clustering technique is a learning process without supervision, thus two extreme cases are easy to produce: one extreme is regarding each record in the database as a class, although in this way the purposes for record classification were reached, but against with the ultimate purpose that the clustering technique is used to achieve a clearer understanding of the records in the database; Another extreme is all records were classified as one class, but does not provide any useful information even it summarized contents of the database. Therefore, hierarchical clustering method(Inmon, 2002) is adopted to solve these two extremes. The hierarchical clustering method allows the end user to specify the number of the final generated classes. Establishing the index structure that generated by hierarchical clustering technique like a tree structure can determine the appropriate number of classes, which summarizes the contents of the database, while providing useful information for subsequent decision-making. The tree can be generated either from top to bottom or from the bottom to up.

Thus we can access the data mining model for oilfield well group production decision-making system. As shown in Figure 35.

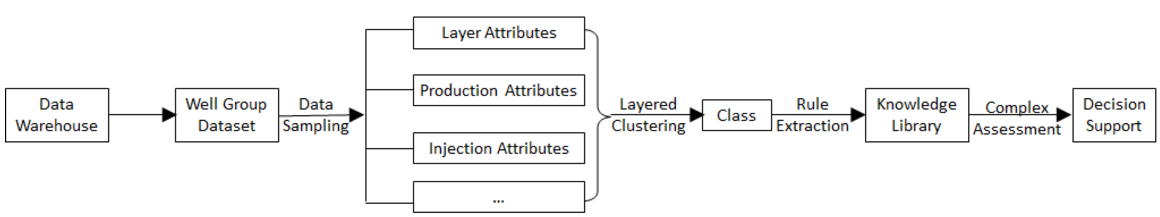

Figure 35 Data Mining Model for Oilfield Well Group Production Decision-making System

Systematic solutions using Analysis Services to build oil field production data warehouse using DTS (Data Transformation Services) to import the required data (production information, injection information, layer information, etc.) from the oilfield enterprise data sources (such as ERP, etc.) into oil field production data warehouse, and then carrying out the on-line analysis and data mining aimed at the multidimensional oilfield production data model, to identify the characteristics of the various types of well group, and to provide powerful decision support for the subsequent production treatment

Data mining analysis help us to find the quantitative understanding of the impact on the key indicator parameters (such as daily production, water cut, daily inject allocation, etc.) of the different parameters like layers, production and injection means, also help us to conduct mono-parameter and multi-parameter analysis and evaluation, this is of important guiding significance for oilfield production adjustment and optimization to provide reliable technical support for intelligent oilfield decision-making.

5.3 Production Logging in Well Drilling: A Real Case of Connecting data into Decisions and Activities-

Well drilling is a widely distributed underground engineering with very extensive and continuous operations, many unexpected problems occurred during drilling process, there is a lot of complexity and uncertainty factors (Zhang and Guo, 2005). In additional, the work processes and work aspects involved in the drilling operations are so many that making a great risk of potential drilling with the restriction of the staff technical level, the operating capacity of the equipment and management standards and other factors(Li and Yang, 2012). If it is possible to timely and effectively identify risks in the beginning of the accident even before the accident, and issued a warning to field operations personnel, so as to take effective measures to avoid accidents, will be one of the possible ways to fundamentally solve the complex problem of the drilling accident. However, timely and effective risk identification requires a large number of reliable historical data and real-time measurement data based on fully data sharing considered in many fields of geology, drilling, well logging and mud logging, and decision is made together by different experts from the drilling sites and oilfield bases based on professional software models and data analysis results. How to comprehensively utilize the various types of data resources coming from the drilling site and the bases in a unified data platform, timely and accurate access to the data during drilling process and decision information from bases, is essential for drilling technical staff to accurately identify the operating process risk.

Because the author is mainly engaged in the well logging performed in the oilfield production phase, here I just want to use a real example occurred in the east china sea to illustrate the importance of logging data in the treatment of well drilling accidents and to guide the further work.

5.3.1 General Information About Well PH-Xs

PH oil and gas field has already entered into the late production phase with high water production low gas production. The oil and gas production declines sharply and the production situation is grim.

Well PH-X is a gas production well and now produces nothing under the current production situation. By far Layer P3 in well PH-X only produced 56 million cubic meters gas with a very low recovery rate of 12.6%. In order to make full use of the potential gas reservoirs of P3 Formation, well PH-X is designed to be sidetracked to improve the recovery rate of P3 and put P8 into production.

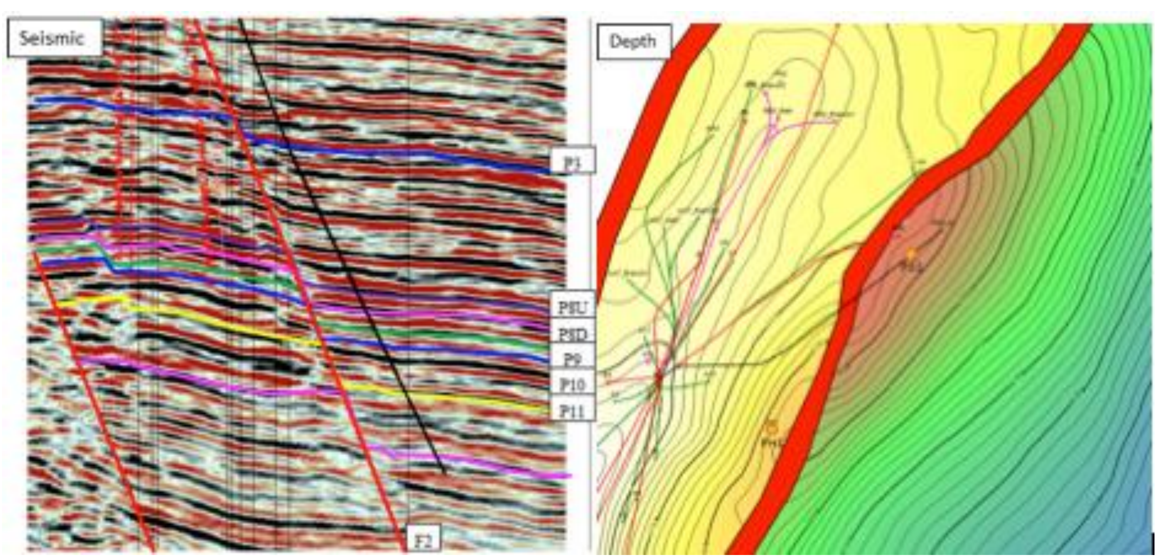

Figure 36 Seismic-Profile over Well PH-X and 2D Well Track Projection

5.3.2 Potential Risks During Drilling Process

a) Ultra-deep

PH-X and PH-Y are near to PH-Xs, the possible reservoir and depth were predicted based on these two wells, Table 4. We can see that the target formation depth is much deeper than others.

Table 4 Possible Reservoir and Depth Forecast Sheet

Formation		PH-Xs			PH-Y	PH-X	PH-Z
		MD, m	TVD, m	Reservoir	TVD, m	TVD, m	TVD, m
		KB=46.62m		TVE, m-layers	KB=28.70m	KB=46.62m	KB=22.92m
HG	H23	2398.85	2323.62	3-1	2313.8	2323.0	2309.20
	H62	2780.69	2686.01	3-1	2715.5	2728.0	2677.00
ph	P3	3346.57	3144.62	9-2	3133.0	3147.5	3026.50
	P8	3982.00	3608.62	26-2	3470.0	3621.7	3397.10
	P9	4162.9	3741.62	7-2	3538.3		3502.30
	P10	4236.37	3795.62	18-2	3610.0		3535.50
	P11	4490.78	3982.62	28-1	3789.8		3689.20

b) High Temperature and High Pressure

The formation pressure measured at formation P11 (3663.94m) in well PH-XY is 47.45 MPa with pressure coefficient is 1.328 and temperature is 144.4 ℃, while the formation pressure measured at formation P11 (3682.53m) in well PH-Y is 45.99 MPa with pressure coefficient is 1.281 while temperature is 133.39 ℃. So the temperature gradient of well PH-Xs is about 3.3 ℃/100m and the downhole temperature is 152℃, the pressure coefficient is about 1.33 (Table 5) and the downhole formation pressure is about 51.30 MPa, these really are HPHT environment for well drilling and very susceptible to accidents.

Table 5 Pressure Forecasts in Reservoir Zones

层位	MD (m)	TVD (m)	压力系数
P3	3347	3145	1.03
P8U	3982	3609	1.08
P8D	4045	3655	1.08
P9	4163	3742	1.12
P10	4236	3796	1.15
P11	4491	3983	1.33
END	4718	4150	

c) Upper Water Sensitive Shale

The shale shallower than 1000 meters is in poor diagenesis and water sensitive, so wall collapse and drilling pipe stuck should be avoided.

d) Unconformity

At the top of the HG formation a huge unconformity exists and blowout or leakage is easy to happen.

e) Pressure deficit

Some production layer’s pressure in PH formation have already deficit due to long-term’s production and absorbed jamming is easy to occur.

5.3.3 Brief description of the Leakage and Blowout Accident

On January 31st 2012, when drilled to 5,108m (Figure 37), about 600 meters deeper than the estimated depth, beware of the number, which is the fetal issue for the following accident. A high-pressure strata, P11, the estimated gas layer was exposed. By far, the drilling job was almost come to its end. At this depth, the pressure is almost 60 MPa, the mud used is too lighter than it’s really need. In order to avoid well blowout snubbing was performed. Since the platform hasn’t has adequate barite storage (during the drilling the mud density is 1.57g/cc, then increased to 1.67g/cc with the existing platform barite), the snubbing failed and unexpected gas blowout was happen. The initial gas blowout is approximately 100,000 cubic meters. When barite transported to the platform, mud adjust to 1.80g/cc to kill the well, but manifold and drill stem washout were appeared (approximately 500 meters away from the wellhead, estimated by the drilling experts). Then displacement killing method was adopted and adjusts the mud weight to 1.9g/cc to continue kill the well by drip irrigation method, at the same time, gas circulation through vertical pressure loop and choke adjusting were also adopted to mitigate the consequence.

5.3.4 Emergency handling

The emergent risk handling system was started at the first time of the gas blowout and mud leakage. According the quantity of the mud leakage and the annulus pressure test, the expert team from onshore support center estimates that the leakage point in the drilling pipe string is about 500 meter and the size is about 5*5 centimeters. During the previous POOH works, some drilling pipes were damaged and presented as holes or thin seams, showing in Figure 38. Since the estimated hole is so large that it is impossible to pull out the drilling pipe string safely and successfully. In additional, the concrete depth of pipe damage and how many damage depths are not determined, if POOH the drilling pipe string blindly, the DP string is very likely to be cracked and formed another serious accident.

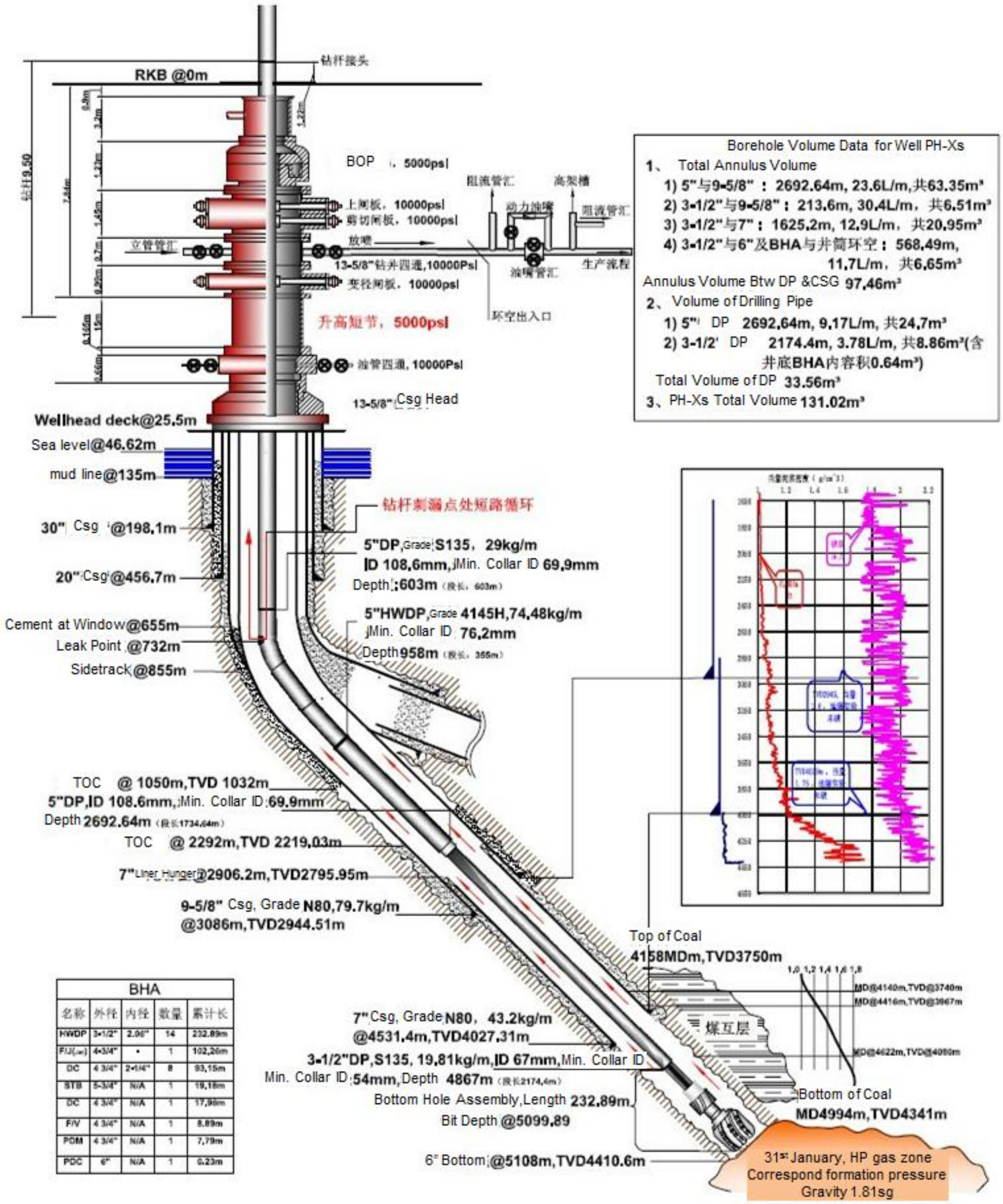

Figure 37 Well Schematic of Well PH-Xs

Figure 38 DP Deformation Photos (Photo by CNOOC, 22nd December, 2012)

In order to protect the environment maximally and to close the emergency process, many countermeasures were tried. During this progress, the application of production logging had played an important role in the accident handling and provides a strong basis for further treatments.

After almost one month’s useless handling, the possibility of using Production logging to detect the specific damage depth had been considered. When looking back, this is really a wise decision.

Totally three cased hole logging items were performed to try to solve the DP string damages, there were multi-finger imaging logging (MIT), radial bond logging (RBT, Figure 39), and Injection profile logging (PLT, Figure 40). The results were perfect. The original purpose of RBT logging is to detect the sedimentary depth to determine whether it is safe to POOH directly. However, due to the mud was invaded by the gas, this goal was failed, but what a surprise that RBT logging showing a clear interface around the leak point, and the following PLT logging confirmed the leak depth.

Using the results of the RBT and PLT logging, the emergency expert team calculated the possibility to safely POOH the DP string, and the DP string were safely POOH on 6th March, the second day after the logging (Figure 41). Also, the downhole mud density were reduced by downhole pressure measured by PLT logging, this is a key parameter for the calculation to POOH the DP string and other snubbing works.

5.3.5 Conclusions

a) The concrete and reliable data is the fundamental for the construction of oilfield exploration and developments;

b) Timely data sharing is essential for technical experts to make timely decisions;

c) Collaborative working environment is necessary for the construction of intelligent oilfield.

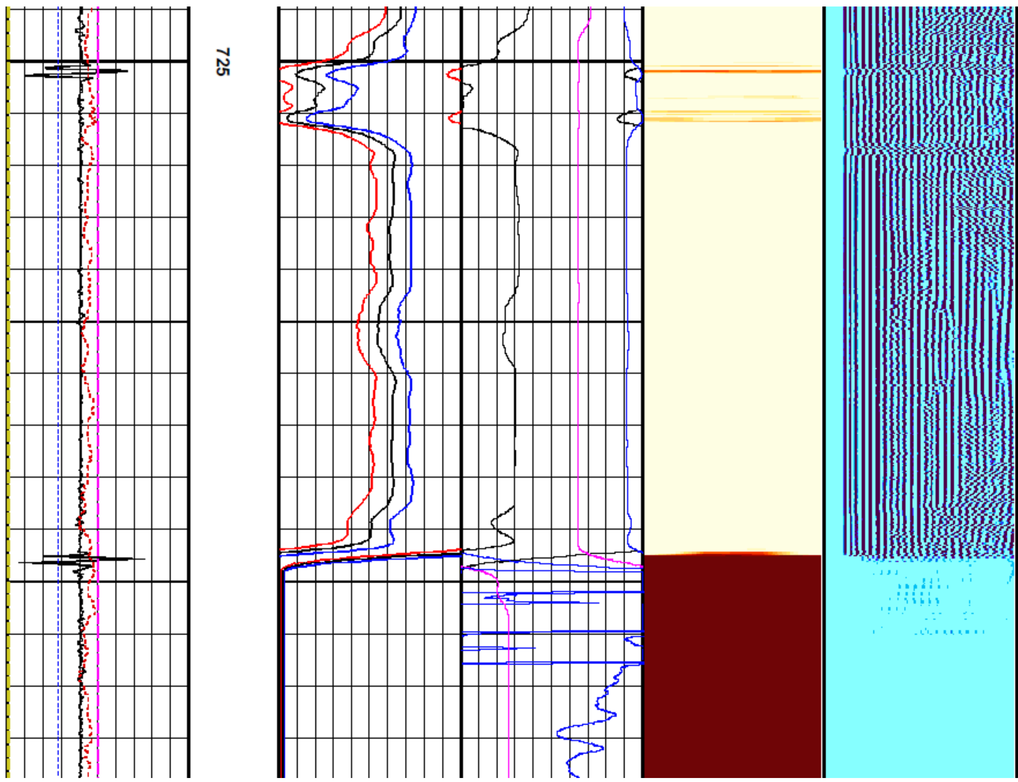

Figure 39 RBT Logging Result of Well PH-Xs

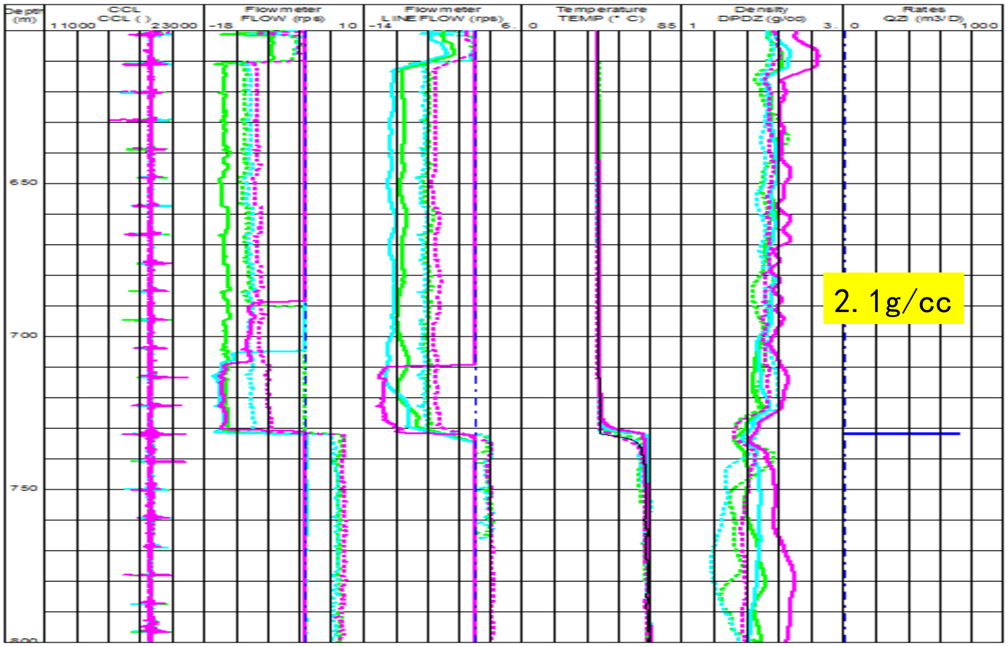

Figure 40 PLT Logging Result of Well PH-Xs

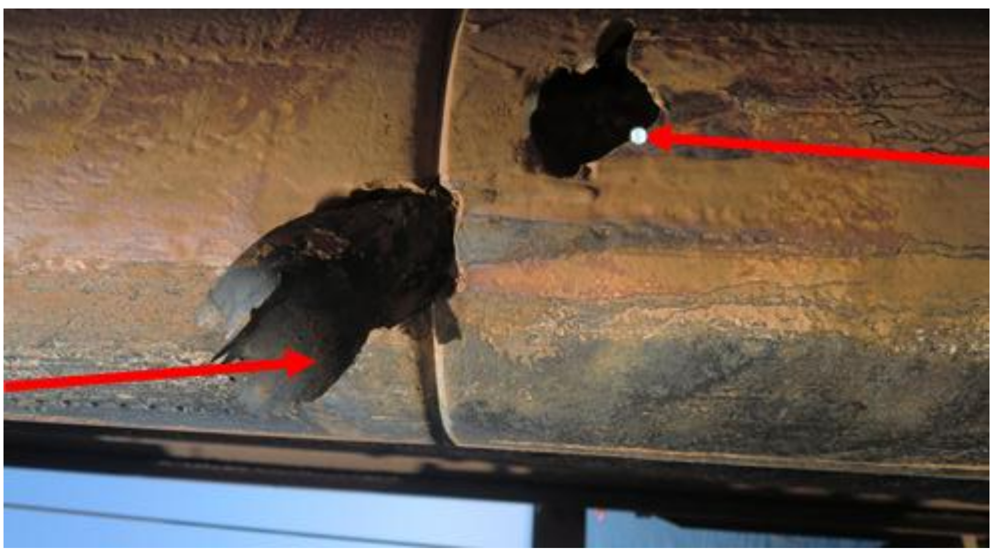

Figure 41 Photo of DP String Damage in Well PH-Xs

Chapter 6 Discussion and Conclusion

6.1 Discussion

Intelligent Oilfield construction is still a state-of-art subject and on its surging period. This could be a long-term business for all oil corporates and many important issues must be considered to establish a successful Intelligent Oilfield.

1) How to balance the initial investments and the later stage's income?
   In order to maximize the value of the oilfield assets, operators mush start the Intelligent Oilfield construction from the birth of the oilfield, this will increase the initial invests much more, but the later income is unpredictable, how to balance this?
2) How to allocate the professionals and experts more rational?
   An important characteristic of Intelligent Oilfield is the knowledge sharing and collaborative working environment. But accompanying with the growing of the corporation, an effective collaborative working environment is hard to achieve. Thus how to arrange the professionals and experts more rational to solve the production problems more effectively is an important issue for oil companies.
3) How to optimize the whole work process more fluent?
   Right now many oil corporations have oversea assets, these assets generate vast amounts of data together with their homeland assets, how to integrate these data organically and how to eliminate the information island to improve the inter connectivity as much as possible?
4) How to design an efficient data warehouse structure to welcome the ever-growing amounts of the information?
   By far, data warehouse and data mining techniques are still in the study stage, and has limited application especially in the oilfield development and production stage. There still needs a great number of studies to digging out the potential benefits of the data warehouse and data mining for production decision-making.

6.2 Conclusion

This paper mainly reviews the World and China's oil and gas production and consumption trends. Based on these retrospective studies, the necessary of Intelligent

Oilfield construction was prompted, summarized the main contents of the Intelligent Oilfield, briefly demonstrates the collaborative and efficient work process, and discusses how to extract useful information from the data warehouse using data mining methods to make effective decisions. Through the study of the thesis, some common ideas were achieved:

1) With the constant increasing demanding for energy, especially oil and gas, the construction of Intelligent Oilfield is inevitable and is an effective way to maximize the value of oilfield assets.
2) Data warehouse and data mining techniques are very useful for the production decision-making during the whole life of an oilfield.
3) Data quality is the foundation for each decision relates to the oilfield development and production, setting up rule-based quality inspection and evaluation system is the key to access good qualified data to make high effective decision.
4) Through the study of the data quality problems, classified the quality problems exist in the data sources, and analyzed the reason how these problems generated. Based on these, weighted evaluation method was discussed and adopted to solve these data quality problems.

This thesis has just done some exploratory work on these aspects, but there are still inadequacies, especially in the business process, data mining methods and others. However, through this work, I have accumulated a lot of valuable experience and have laid a good foundation for my future work.

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