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TianJin, June 2014

Yin Qingkui

Abstract

With the development of offshore oil and gas industry, the offshore constructions and subsea operations are increasing rapidly, at the same time, the demanding of the offshore inspection, maintenance and repair work are becoming more and more accompanying the existing infrastructures aging. COSL as one of the leading offshore engineering service providers in Asia-Pacific regions covers the entire process of offshore oil production, who has invested a huge resource to keep the leading position and occupy the large market share. Especially in nowadays, it is very important, however, not easy to manage the enormous assets in safe and sustained profitability.

The purpose of this master thesis is to make some proposal to improve and optimize the safety management in the process of design, construction, and operation, basing on the diving operations on DSV 709, and what we have learnt from the Industrial Economics program.

This thesis mainly focuses on the design and operational issues of a saturation diving support vessel (DSV). First, make the right investment decisions from the market survey of the saturation diving operation and the market needs, referring to the worldwide saturation diving support vessels design and specification. In DSV design stage, design a more reasonable human, machine and organizational interface by fully considering the human factors, organizational factors and the actual operation demands of saturation diving teams, especially the safety of saturation divers in a hyperbaric environment. During construction, how to execute the project management, monitor safety, cost and schedule the more effective. In the operational phase, choose the suitable maintenance strategies for the vessels and saturation diving equipment. Monitor the running status in order to ensure the sustainability, availability, high performance, and safety for potential improvement in economic performance and safety.

KEY WORDS: saturation diving, underwater operations, FMEA, DSV, project management,

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1 Introduction

This master thesis is inspired by an offshore riser installation project, which I have participated with saturation diving operations on DSV HYSY708 last winter, when I returned to my work. This chapter is mainly to introduce the background and objective of this thesis.

1.1 Background

DSV is new since last 70s, but technology and management are the sophisticated for the offshore practice. There are over thirty purpose DSVs and multipurpose offshore support vessels. The diving support vessels, especially the purpose DSV in the global offshore market, are now full of contracts for years. The DSVs as the offshore construction support vessels have a lot of advantages and competitiveness integrated with ROV. The divers working underwater are more flexible and reliable than ROV. Divers could feedback and reaction more quickly to underwater operations. For example in a seabed installation project in XiJiang oilfield development, the first choice was ROV operation, however, different kinds of difficulties, weather, current, waves and equipment, occurred in the process and one month passed, the installation get nowhere. Then the owner changed the sat diving operation, only 12 days all the installation and tie in was completed.

As sat diving on DSV has a broad application in offshore oilfield development, the main challenges ahead are how to get deep in technical and theoretical research, breakthrough 500msw. The second challenge is develop the new generation DSV, which has the high performance, adaptive, affordable and good man-machine interface. The third challenge is the risk management of DSV, diving operation and procedure control.

2 Scope

This thesis is based on the real sat operation with DSV and after the practice, I tried to summarize the manage methods and technical features. As a good hope and conclusion, the company, COSL, had better to have its own purpose DSV for a diversified offshore services. So in this thesis, I try to research the feasibility and operability to construct a purpose built DSVs, after learning and thinking of the saturation diving equipment, diving operating procedures, safety management and facilities management, combined with the development situation of the company and offshore O&G service market. Then, I analysis and study how to achieve such a DSV design, construction, and operations management the based on the industrial economy

knowledge I have learned, hoping to make a beneficial attempt and exploration in managing large equipment and assets.

Why I set the goal to build a purpose DSV? As we know, there may be alternative methods to fulfill the underwater operations. Many projects have been completed by the modular sat system with a DSV, ROV or other manned facilities. However, from my knowledge and awareness, I believe the purpose build DSV have 3 fundamental advantage over the alternatives. There are three reasons that should be considered when making the decisions:

- Flexibility. Now, the diving contractors are tending to adopt the modular saturation diving equipment when facing such an investment and construction. Because the investment would be smaller than build a specialized vessel, and when there is an offshore operation, the company should mobilize two or three weeks in advance to spread the system and installation, and after finishing the operation, if not continuous operation, the system can be demobilized from the ship. The DSV equipped with system is easily accessible renting from a shipping company; and the support vessel can go for other jobs when no saturation diving task.
- The second point is the alternative. ROV is one of the major alternatives, and particularly, has been used widely in the underwater operation. ROV could complete the same underwater tasks like saturation divers which equipped with the right tools. If the water depth is less than 70msw, some simple diving operations could be instead by open bell diving.
- The third limitation is management. Sat diving is a high risk of underwater operations, and any improper operation will lead to decompression sickness, or even fatalities. So the first important task is risk management and complies with the regulations, the guidelines and standard procedures constituted by IMCA or ADCI. The sat diving operators are freelancers, and there is not much experienced workers, especially for China. Related training, certification are not mature enough for the saturation diving in the Chinese market is relatively new. The saturation diving equipment need professional staff to maintenance and operate, which needs to innovate and adjust the existing managerial method and organizational structure for the DSV operation

2.1 Methodology

I try to get more information about the present DSV operation in the market form different ways and to make a decision whether it is possible to construct or operation a DSV. Such information or data could be found for the internet and websites of the main DSV contractors. Then, I want to analysis a sat diving system on the DSV, using knowledge of project management, risk management. For this issue, the international diving societies, DNV, IMCA, OGP, have set up standards, recommended practice and regulations which should be complied with to carry out the operations.

Here I suppose that the company would build and manage such DSV, and I want to

discuss the possibility of a complete design for layout, system selection, maintenance strategy and life cycle cost control. The construction process should be controlled as a project practice. For the whole project, the risk management should be paid enough attention so that it could be continuity and retrospective for the well recording.

3 Structure of the thesis

In this paper, I first investigate the background knowledge for diving operation and diving support vessel in chapter 1 and 2. Then in chapter 3, I introduced a project I have experienced and share my thoughts from the practice in section 4. I try to apply the industrial knowledge in constructing a new purpose diving support vessel. So in section 5, I try to analyze the feasibility and economics, in order to make the right decision. Then, I try to discuss some project management issues in the next section, how to organize the project team and how to improve the design. In section 7, the main content is risk and safety management of the diving operations, and some PSA data are cited to reveal the risk level of the sat diving.

4 Background and status review

From a historical perspective, the DSV have three generations: using the offshore installations like drilling platform in the early 70s~80S; converting the offshore support vessels to DSV; and newly the purpose build DSV.

JENS CHR LINDAAS, and KJARTAN VARTDAL (1991) had summarized the development of offshore support vessel in the paper **SUBSEA SUPPORT VESSEL FOR THE NINETIES**. They have shown the trends of the DSV development. They have identified more than ten features or requirements for the new DSVs which now are the general design principles. In the thesis of IKENYIRI (2010), he proposed three different concepts for the DSV layout. He discussed and compared the pros and cons for these concepts and gave suggestions to the operational efficiency and LCC.

4.1 Diving Support Vessel

In last 90s, JENS CHR LINDAAS, and KJARTAN VARTDAL (1991) had summarized the development of offshore support vessel in the paper **SUBSEA SUPPORT VESSEL FOR THE NINETIES**. They have shown the trends of the DSV development. They have identified more than ten features or requirements for the new DSVs which now are the general design principles. In the thesis of IKENYIRI, UDO OKWUCHUKWU's, he proposed three different concepts for the DSV layout. He discussed and compared the pros and cons for these concepts and gave suggestions to the operational efficiency and LCC.

Because surface-supplied diving is generally a simple system and less relevant personnel, it can be arranged flexibly on a work boat or other facilities. However, the saturation diving systems are more complex and more personnel are required, normally specialized diving support vessels are required, who have a sufficiently large deck area to satisfy the engineering tools and diving system spread. A saturation diving system typically includes deck decompression chambers (DDC), Personnel transfer capsule (bell), launch and recover system (LARS), life support systems, communications, mixed gas storage, gas reclaim systems, hyperbaric rescue and escape systems etc.

Currently, there are two types working mode of saturation diving vessel; one is a purpose built DSVs, the saturation system is built-in saturation diving support vessel, which has the moon pool-launched system and a clear deck space for other equipment, for example, SHENQIANHAO (China ShangHai), SOV Windermere and SOV Ullswater (Hallin Marine), Skandi Singapore, Skandi Arctic (DOF Subsea) Seven Atlantic, Seven Kestrel (Subsea seven) MERMAID ASIANA, MERMAID ENDURER (Mermaid Offshore Services)

The other is the modular saturation diving system deployed on the deck of an offshore support vessel, and the bell runs usually need a crane on the shipboard. The diving

support vessels are like HYSY 701, HYSY708 (COSL), and the Modular saturation systems are like CNS: 'AF-05', Hallin Marine 'HMS-SAT-06', Cal Dive International 'S-8' system.

4.2 Diving Operations

Diving is the most primary means to executive the underwater operations and engineering. The offshore commercial diving industry, has been accompanying the development of offshore O&G exploration in last century, especially in last 4 decades. It also has made great progress in diving theory, diving medicine; the diving system. Usually depending on the diving depth and diving environment, it is decided the type of diving methods and diving system, for example, Scuba, known as free diving, (0~10msw), Surface-supplied diving (0~60 msw), Wet bell saturation diving (50 msw ~ 120 msw) and Closed saturation diving (60 msw ~ 500 msw). The main job for diving is like IRM, cutting, welding, salvage, survey and installations, or other missions.

B. J. WARREN, THOMAS M. ANGEL, ROY GRAY (1971) has begun to research the sat diving technology and try to use this methods to finish the seabed operations. In saturation diving techniques, divers are exposed to a specific pressure, which approximates the water pressure at the depth of water in which they are working. This pressure is maintained for about two weeks, or until shorter tasks are completed.

Saturation diving is mainly used in the depth range from 50 msw to 300 msw, for the maximum depth of the majority of saturation diving systems are at 300m. Compared with conventional air diving, the saturation diving has a higher efficiency, because it does not decompress frequently and has a longer underwater working hours. However, the sat system must be very complicated and the working procedures should be followed carefully, because of the hyperbaric condition and high risk operations. The sat divers live in the artificial high-pressure environment; they could not breathe the normal air, for the normal air is toxic in the hyperbaric for the human body. Their respiration oxygen is the same partial pressure, approximately 0.5 Bar, and the balance gas is helium, which is no harm to the diver's body even it is reach the saturation limit in the blood and tissues. When the divers are going to decompress to the normal atmospheric environment, they should take a longer time and strict procedures to avoid the decompression sickness. For example, the divers only need 6 hours to compress to level 90 msw but the decompression duration could be nearly 100 hours.

Now, all the commercial offshore diving should comply with the International commercial diving co-ordination and regulatory associations, IMCA (The International Marine Contractors Association) and IDCI (The Association of Diving Contractors International). These two organizations have published and constituted a lot of standards, practice guides and recommendations for diving safety and QHSE managements. These organizations qualify divers, sat divers, diver supervisors, life

support supervisors and other related occupants. They also certificate and audit the diving contractors.

4.3 Diving market in China

Saturation diving operation mainly aimed to the underwater jobs in the depth range from 60 msw to 300 msw. These operations include underwater cleaning, inspection, replacement, maintenance, repair, installation, survey, salvage, and other engineering support. With the development of China offshore O&G field, the number of offshore facilities constructed and under construction is increasing year by year, so the demands of saturation diving operations are particularly large, referring to the North Sea oil and gas development conditions, where are over fifteen saturation diving vessels, the China offshore market could hold at least five sets saturation diving systems.

Based on the CNOOC market, the offshore O&G fields, Le Dong, YaCheng, WenChang, PanYu, HuiZhou, XiJiang, LuFeng, ChunXiao, are in the depth range of 50 msw-500 msw. There are over fifty production platforms and over thousands of kilometers subsea pipeline, at the same time there are a lot of new facilities under planning to be installed, and more new subsea productions will be deployed. Other clients like Husky also have a great demand to saturation diving. The saturation diving system in China currently only three sets. Shanghai Salvage Bureau has two set, including one purpose build DSV; and Shenzhen DeRun subsea has a second-hand system purchased from Cal Diving International. There are saturation diving operations subcontracted to international saturation diving company.



Figure 2.3: Oilfield development depth diagram

Douglas Westwood has forecasted that \$77bn will be spent globally on subsea vessel operations, servicing field development, well intervention and inspection, repair and maintenance (IRM) in next five years. This is a staggering 63 percent increase on the preceding period. At the same time, looking at the subsea IRM market specifically, predictions in 2013 showed that this sector of the vessel market was set to be worth over 10bn \$ annually by 2016. This sector was seeing huge growth thanks to the sheer magnitude and age of this global subsea infrastructure. Unlike the CAPEX-led field development sector, IRM is largely unaffected by the oil price.

Nicolas Mouté (2013) has foresaw that the coming IMR market, the aging or new offshore facilities required the specialized subsea fleets and resource. The Harkand are lead the new standards and practice of the IMR and diving /ROV support.

From the perspective of international market and trends, there are about 150 DSV in the world market, and the day rate for saturation diving vessel is about 200 000\$ (120W RMB). The large international offshore O&G service companies, such as subsea 7, Bibby offshore, Harkand and Marin Teknisk AS, are investing and building more advanced, high-performance saturation diving support vessels, expanding their DSV fleet to meet the business development demands.

5 Sat diving operations

Last year, I had participated in an new platform installation project, WENCHANG 13-6. The sat diving operations involved installation of clamps, riser, cable casing below 50 msw at WenChang 14-3 platform, including: cleaning the marine growth, surveying, cutting, inspection and tying in. the seven clamps were installed to hold the riser and cabal casing in different designed positions. The whole riser was installed in four separate sections, two from top side by air diving and two by SAT diving (sections 3 and 4). The cabal casing was similar to the riser, however it did not require sealing with the steel gaskets for and not withstand high pressure. That connecting the riser of WenChang 14-3 platform to seabed flexible flow line and riser of WenChang 13-6 platform to subsea flexible flow line by flange connections was part of the job. ; I obtained three aspects of knowledge form this project: project managements, Sat diving systems, diving procedures and risk management.

Table 3: the project progress plan for sat diving

编号	工作名称	持续时间	开始时间	结束时间	1	2	3	4	5	6	7
1	Tendering&Bidding	28.00	2013-07-26	2013-08-22	Tendering&Bidding						
2	contracting	34.00	2013-08-23	2013-09-25	contracting						
3	Sea transportation	33.00	2013-09-03	2013-10-07	Sea transportation						
4	customs clearance	8.00	2013-10-07	2013-10-14	customs clearance						
5	diving system spread	14.00	2013-10-15	2013-10-28	diving system spread						
6	offshore field operations	61.00	2013-10-29	2013-12-28	offshore field operations						
6.1	weather waiting	30.00	2013-10-29	2013-11-27	weather waiting						
6.2	diving operations	20.00	2013-11-28	2013-12-17	diving operations						
6.3	sailing	6.00	2013-12-18	2013-12-23	sailing						
6.4	decompression	6.00	2013-12-23	2013-12-28	decompression						
7	dembilization	10.00	2013-12-28	2014-01-06	dembilization						
8	exporttransport	21.00	2014-01-07	2014-01-27	exporttransport						
					2013.1	2013.8	2013.9	2013.10	2013.11	2013.12	2014.1
					1	2	3	4	5	6	7

5.1 Project management

The diving subcontractor was CNS international SRL from Italy, who was very experienced and fully qualified. They offered a set of new sat modular diving system-AF-05, and this is the first put into use. So many difficulties and challenges need to overcome. This project was a very typical application of the project knowledge, controlling the cost, managing time, detail documentation and balancing different expectation. The project team was the central role to obtain the project information to company, owners, regulatory organization. Our team prepared relevant documents and notification; the project team also

5.1.1 CUSTOMS

The system was imported to China from Italy, so transport time and cost should be well controlled. The customs clearance was other big problem. If we could not offer the required materials to the customs, the diving equipment would be locked in the customs supervision. So it was very important to handle the relationship with the customs, and we consign a lot of clearance work to a agency who was familiar with the import procedures and regulations,

5.1.2 Mobilization and demobilization

It took two weeks to finish the system spread on the deck of our DSV. As this was the first spread, we have discussed the mobilization schedule in great detail. Especially for the units prefabricated or purchased in China, we have confirmed all the specification with the field engineer avoiding errors. In the mobilization process, the system deployment required a lot of high risky operations, such as welding, lifting. All staff needed be well organized and comply with the port and vessel regulation, procedures. The lifting tasks was vey onerous for this two process, all the equipment should be lift to the port twice in the limited space

5.1.3 Process Management

When our vessel arrived at the job site, the sea conditions were other big problem. In the whole November, the weather conditions did not meet the job restrictions which were set in the HSE document, current 1.5nk/h, and wind speed over 30. Though the vessel has excellent DP performance, the rolling and pitching was too heavy. But we seized every opportunity for the good condition to carry out the diving operation. We cooperation with staff on platform, crew, DPO, client owner's Representative. We followed the designed procedure, quality control, and HSE plan. All the underwater work

5.2 Sat diving systems

We could get the fundamental knowledge of sat diving from the U.S. Navy diving manual, and IMCA guidance. The sat diving systems are the only operation means for divers to expose to the high pressure in the deep water. Since the diver cannot easily and quickly transfer from the high pressure environment to the normal ambient, or the divers would suffer a severe decompression sickness, joint pain. So the most important design principle is that to design an emergency evacuate chamber and adequate redundancy for the divers' safety.

From a systematic perspective, the sat diving systems are constituted by a number of

modular functional units. These subsystems undertake correspondent functions, such as life support, underwater support, environment control, communication, and emergency, and all the units should certificate and comply with the DNV or IMCA requirements.

- The deck decompression chambers usually accommodate 3 or 6 divers. The chambers are connected to the main chamber which couples with the bell by trunks. Divers could live in the chambers in the duration of the pressured day and night. So the chambers should be able to offer the divers with food, beds, shower, lavatory, lighting and even internet. The chambers usually are locked by the autoclave type door, which could avoid opening if the external pressure is imbalance with the internal pressure. The chambers' specification and layout could be different design however the functions are the same more or less.
- The core underwater part are normally called bell. The bell can carry three divers to the operation depth and one diver is in the bell, we call him bellman or tender, while the other two could move out and accomplish the tasks. The bell equips a batch of cylinders around the main body for the underwater emergency and there is a bell clump weight under the bell which could stop the bell rotating when lowering or lifting.



Figure 3.3: 3-man bell

- The bell is launched and recovered by the LARS system, which includes a big one- drum winch, a twisted pair cable, and a wire rope for the clump weight. The LARS system should have some active compensation for the heave to keep the bell in the position. The umbilical which are essential to the divers is synchronous with the LARS. If the umbilical is fault, the divers in the bell could lose oxygen supply, hot water, and communication with the surface, the divers can only rely on the bell itself.

- The control, monitor, and communication systems are very critical for life support in a sat diving operation. There are many types of valves and control panels in the main control rooms, the different types mix gas are supplied to the chambers and the concentration of the oxygen and carbon dioxide should monitor all the time. The audio and video communication should always keep it propped open, so that the life support supervisor and technician could acquaint the chambers inter condition and the divers need. The environment control unit (ECU) should also monitor the internal temperature, humidity, pressure, water supply.
- The gas supply should be adequate for the whole operation duration. The primary breathing gas are 2%, 6.5% and 9% oxygen, and the balance gas are helium. The total amount of the gas is more than 4600m³, including the therapeutic oxygen, high pressure air, and emergency backup mix gas charging for the cylinders on bell and hyperbaric rescue chambers. All these gas are produced by the Air production company in Shenzhen, and delivered 2 weeks before the sat diving system spread. All the gas should be certificated and calibrated for the delivery and the life support technician should retest all quads before supplying to the divers.
- For safety reasons, the sat system has been design enough redundancy for communication failure, hot water supply, gas contamination, firefighting, and sanitation. For example, the diver suddenly loses the hot water supply at working position, he would close the discharge valve to preserve the hot water and at the same time return to the bell. If the umbilical leaks out somewhere, the tender should close the supply valve and use the mix gas on the bell.

5.3 Diving procedure

The IMCA has issued a series of recommendations and guidance to direct the diving contractors to draw up the diving procedure. The diving procedures are aimed to carry out the diving operation in a safe and controllable manner. The procedures have been reported to the owner and related regulation organization. Though the procedures have been designed as the standard procedure, other considerations like real site condition, workers' culture background, human factors and performance, should be reassessed in the project. We could learn something from the investigation report of Skandi Arctic accident in 2013.

The standard procedure for a sat diving operation should contain at last these steps:

- Before the diver enter the chambers, the related project documents and procedures have been handed out to the personnel, making sure that they are aware of the work scope, requirements, hazards and risk.
- The superintendent and supervisor would access the weather and sea condition to determine whether to deploy the bell, then the master and DPOs would sign the permit to work(PTW) and the crew are ready to support the diving team
- The diving supervisor and life support supervisor will follow the approved

procedure to lower the bell to the work depth, the two divers equipped their underwater kit, and swim to the work position. They follow the supervisor's guidance to finish their underwater.

- The time control is very important. It is usually 8 hours from the bell lock off to lock on, and the divers in the water are nearly five work hours. Some experiments show that the initial four hours are most efficiency, and the dressing time should be shortened by improving the individual diving equipment.

In this project, we used the new modular AF-05 saturation diving system, which could fully transportable by land and sea, and the modulus has the size of a standard ISO container with twist locks. It has a max working depth 300 msw and No. of divers in bell is 3 (2 divers + 1 bell man). The No. of divers in the chambers is 12 basic (3 optional), however, it has ability to connect additional chamber for more divers. The system could work within the temperature range from -10 °C to +50 °C.

Table3.4: Main modulus of the system AF-05

NO. of the Module	main functions or components
Chamber ALPHA	Life support for 3 divers; top trunk, toilet and leaving compartment. ECU, trunk to the bell.
Chamber BRAVO	Life support for 6 divers, connection with chamber A and HRC
Chamber CHARLIE	Life support for 6 divers; connection with chamber A
Bell handling system	Handling the bell and umbilical; hydraulic power, ram and anchor weight wire.
Diving Bell	Life support for 3 man underwater operations.ECU
Saturation and Diving control van	Two compartments for saturation control panels and diving control panels. The main electric distribution cabinet
Hyperbaric Rescue Chamber (HRC)	For emergency rescue and life support.
HRC receiver	HRC control panel, ECU, gas storage and hot water supply
Gas reclaim unit and booster pumps	Diver gas reprocessing unit, gas transfer compressor, Sanitary hot and cold water system
hot water	Hot water boiler supply hot water to divers
emergency generator	supply power to the diving system in case the vessel power is lost

5.4 Risk management

It is quite vital to be safe for the project success, so the safety management should always be put in the first consideration. The risk management is also primary importance to the asset management and class certification. So the project risk management needs a detailed risk assessment and hazards identification for the equipment, diving procedures, personnel, and working environment.

The diving system are designed and manufactured by the specialized Italian

companies. As this is the first run, the diving subcontractor has arranged technician and mechanic to respond for the deployment, commissioning, maintenance, and emergency repairs. The diving systems are operated by the certificated personnel, who have the competence and experience in the career. The divers are also competent personnel, who are familiar with the diving system and have trained by the IMCA. Before the job carry on, all the personnel should show up in the risk analysis and understand the risk and hazards.

Before every operation, the operators should follow strictly detail checklists, to make sure that all the valves are in right position; the communications with the bridge and divers are good. The DPO or master could stop all the operations for the vessel reasons, and the diving team member could stop operations at any time if he found any possible risks, not only the supervisors or superintendent.

All the quads, gas line, valve, and other components are clearly marked and the labels punish the critical information in a conspicuous location. They are only operated by the authorized personnel.

The data logger is a very important role in the project management, who has been a member of the design and manufacturing team. He keeps all the detail design and manufacturing files of the whole system. For the everyday job, he makes the maintenance plan and assigns the tasks to the competent personnel. He also manages the daily progress report and business affairs.

6 Deductions from the project practice

From this project practice, we could get such deductions:

We have the capability and resource to successful complete the saturation diving project. For the riser and cabal casing installation, we manage to control the diving procedure and installation procedure, which need lifting and locating the riser and cable casing to the exact depth. The riser and cable casing are manufactured under ours monitoring.

The diving procedures and safety control procedures are very essential for the offshore diving operation. The safety for sat diving are more strict than the surface air diving and the procedure are more complicated. The life support is also very important for the divers in the chambers have their special requirements and the life support needs a full day monitoring and recording to the chamber inner condition. The life support personnel should reply all the demands from the chambers in all time.

The diving team should familiar with the diving system, related operations procedures and emergency response measures. Before the sat system spread on the DSV, we have asked the contractors CNS to present the system and brief the deployment plan in detail to our side and related vessel partner.

The hazards identification and risk assessment should be thoroughly execute step by step in according with the work procedures, and all related personnel should aware the risk. For the project management, one of the main points is the safety, so the owner and the classification society have strict requirements, while the diving contractors and the diving system should be classification and authentication. Saturation diving

system together with the diving support vessel requires a good safety and asset management.

Here I present another idea that the COSL, we had better investing to build a purpose DSV for the offshore SAT diving operations. Along with the increasing competition in the offshore diving, there is a trend that the doorsill of the diving industrial and the industrial societies would be stricter in auditing, supervising, and admittance. The large equipment would set invisible barriers to monopoly the market. As an example, before China private company purchase the second set of diving system, the salvage bureau has occupied all sat diving operations and all sat divers in China. If the offshore companies want to select another subcontractor, they only turn to foreign companies at higher prices.

According to the company's strategy, we would be integrated offshore services providers. The company has developed a large fleet in the western pacific resign. We could make an investment to build a sat diving support vessel for the offshore operations and engineering, which may be profitable judging from the current market, even though, we just provide the vessel, for the diving supervisors and divers could obtain from the professional human resource company.

Our company is experienced in managing offshore support vessel, and now the subsea Engineering & Technology Center has get the competence and qualifications in the diving subcontractors market. Our center has engaged in the diving operations and management for years. If we could get such a sat diving support vessel, the rapid development would bring adequate return from the Chinese offshore engineering market.

7 Investment Analysis and Decision-Making

Such large-scale construction projects should carry out a detailed argument before deciding to invest resources, in order to ensure the rationality and feasibility of investment and obtain recognition and support from shareholders. Therefore, a successful investment analysis and decision-making will convenient the development of sequent operation behind the construction project management and asset management, to ensure the project success.

7.1 Feasibility Analysis

Here, I tried to carry out the analyses from three aspects: Technical feasibility, vessel specification's selection, DSV prototype selection, and investment analysis.

7.1.1 Technical feasibility

In 1957, the U.S naval diving physiologist George F. Bond proposed the "saturation diving" concept and started the experiment that humans withstand prolonged exposure

to different breathing gases and increased environmental pressures. Fifty years have passed and it has made a continuous progress in saturation diving equipment manufacturing technology, life support technology, diving medicine, especially the study of in the theory of decompression sickness, which has ensured that the saturation diver to go deeper. In 1992, the French has created the record for 701 msw. In recent years, the saturation diving techniques has developed quickly, we have had the technical capability to reach the depth of 480 msw, and we have just finished the first commercial diving to 300 msw with the ‘ShenQianHao’, which was built by Chinese company. At the same time, the development of supporting technology such as communications technology, control technology, gas production testing, materials, new umbilical, has contributed to the divers’ healthy and underwater safety.

The worldwide mature manufactures, such as Drass, SMP LTD, BPM OFFSHORE, Hallin Marine, have a wealth of experience in designing and manufacturing the saturation diving system, for they have produced so many sets of saturation diving system, which have served for offshore O&G development in the world.

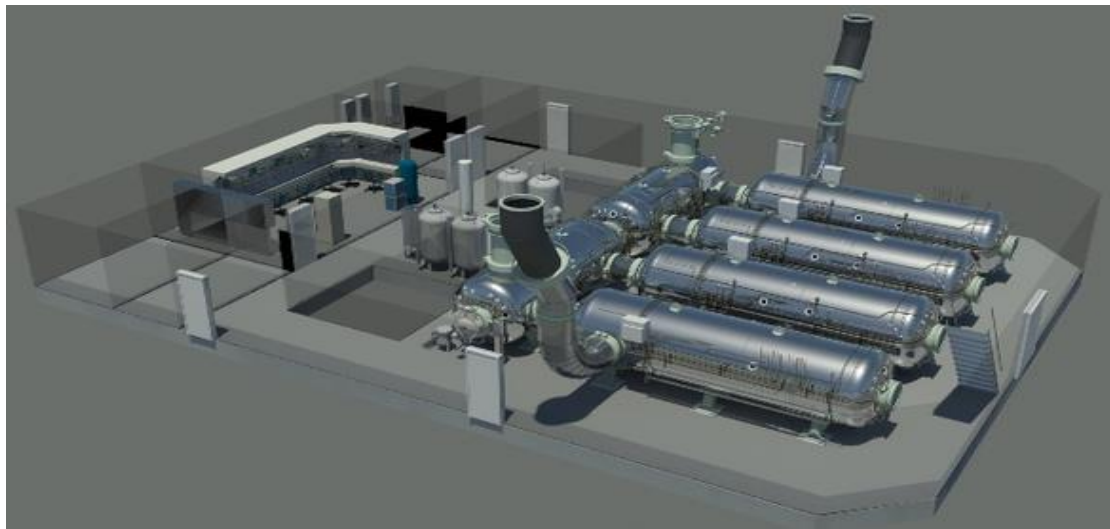


Figure 5.11: Build-in Sat system form Drass technology

A complex SAT diving system is usually integrated of several modular: deck decompression chambers (DDC), diving bell, launching and recovery system (LARS), gas transfer compressors, gas reclaim unit, diver gas reclaim, hot water system, underwater diver suits and tools, hyperbaric external regeneration system (HERS), hyperbaric lifeboat and gas storage quads. The entire system also has the control system, communication system, monitoring system, hydraulic power supply and related software.

7.1.2 Vessel specification’s selection

Now saturation diving system and vessel are usually designed and manufactured by different specialized manufacturers, then the modular saturation diving system would be built in after the vessel specification was chosen. Therefore, the main consideration is to satisfy our projects’ needs, and here we could refer to the world's mature saturation dive vessel specifications.

Following table are main parameters of the DSV'S specification.

The new DSVs which have been built recently are listed in table 1.

From table 1, we could get some information of the DSV: build in diving system, ROV system, Cranes, DP System and Main Deck.

We could draw some conclusions:

- The depth rating of the saturation diving system is generally 300msw. But there are some new ones reaching 350 msw, 370 msw, 450 msw. At present, China has a DSV with 300m SHENQIANHAO.
- Saturation diving systems usually accommodate 18-men, and the 12-men, 15-men and 24-men are few. Single bell and twin bells are both common way.
- The DSV generally equips with one or two sets of ROV, There is a control room and LARS system for ROV operations.
- For the DSV/supply mission, the ROV chooses mainly observation class. But for construction or ROV supply DSV, the ROV usually equips with work class.
- The DSV equips with AHC cranes over 100 tons, and other one or two smaller auxiliary deck cranes.
- DP Class II has been able to meet the current operation requirements. However DP III is the future development trends.
- A large deck area can equip with other operating equipment or tools for other purpose.

From the parameters and analysis, we could build such a DSV to meet the operation requirements:

300m depth rating;

18-men; 2 twin bells;

150 tons of AHC crane,

A LARS for air diving and another LARS for ROV systems,

DP2 class

Optional ROV – mobilization if required;

Free deck area about 1000m², 10 t/m².



Figure 5.12: DSV DA VINCI

Table 5.1.2: DSV'S specification in the world

VESSEL	LOA*Beam (m*m)	Dive System			Main Crane	Deck Area (m ²)	DP System	ROVs
		Depth Rating (msw)	Bells	Man				
SHENQIANHAO	125.7x25	300	1	12	140+350TA-FRAME	1500	DP II	1*3000m work class
SKANDI ARCTIC	156.9*27	350	2*	24	400T AHC crane	1700	DP III	1*1500m observation class 2*3000m work class
SKANDI SINGAPORE	107.1x21	350	1	18	140T AHC crane	900	DP II	2 *3000m work class
HALLIN Ullswater	78x20.4	200	1	15	50T AHC crane		DP II	optional, installed as required
HALLIN Windermere	80x20.4		1	15	50T AHC crane	700	DP II	optional, installed as required
Harkand DA VINCi	115.4x22	300	2	18	140T AHC crane	1120	DPII	2000m Mohawk ROV
Harkand Atlantis	115.4x22	300	2	18	140T AHC crane	1120	DPII	2000m Mohawk ROV
Acergy Havila	120m x 23m		2	24	250T AHC crane		DP III	
Mermaid ENDURER	95Mx20	300	1	18	100T AHC crane	700	DPII	optional, installed as required
MERMAID ASIANA	90mx20	300	1	12	100T AHC crane	700	DPII	optional, installed as required
Seven Atlantic	145mx 26m	350	2	24	120t AHC crane	1,200	DP III	1200mWork class & observation class
Seven Falcon	120x23.45	400	2	24	250t AHC crane	1050	DP III	1*500m observation class
Seven Osprey	102x20	450m	2	18	150t AHC crane	1080	DP III	1*1600m observation class
Seven Pelican	94x18	370	2	18	120t AHC crane	670	DP III	1*1600m observation class
Rockwater 2	119x22	300	1	16	200T AHC crane	1150		1 work class
Seven Kestrel	125.4x24	300	2	18	120t AHC crane	1038	DP III	1 observation class
BIBBY TOPAZ	106.6x22	300	2	18	150t AHC crane	900	DP2	1 work class

7.1.3 DSV prototype selection

According to the analysis mentioned above, we could select 4 new-generation DSVs as our prototype, Harkand DA VINCI, BIBBY TOPAZ, SKANDI SINGAPORE, and Mermaid ENDURER, which have the capabilities satisfy our demand. In table 2, the vessel's specifications are listed and we could see the details.

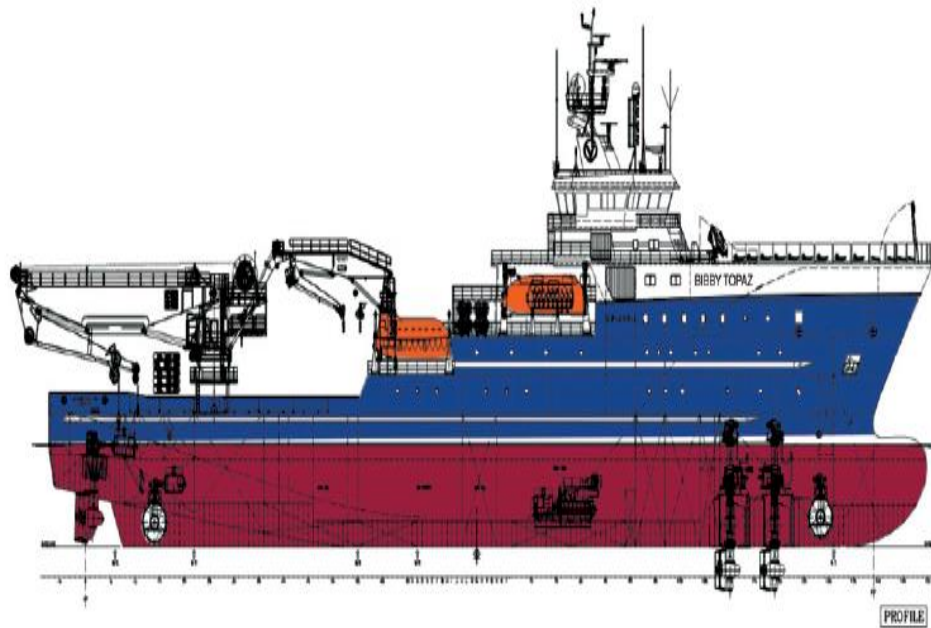


Figure 5.13.1: The ideal DSV model (BIBBY TOPAZ)

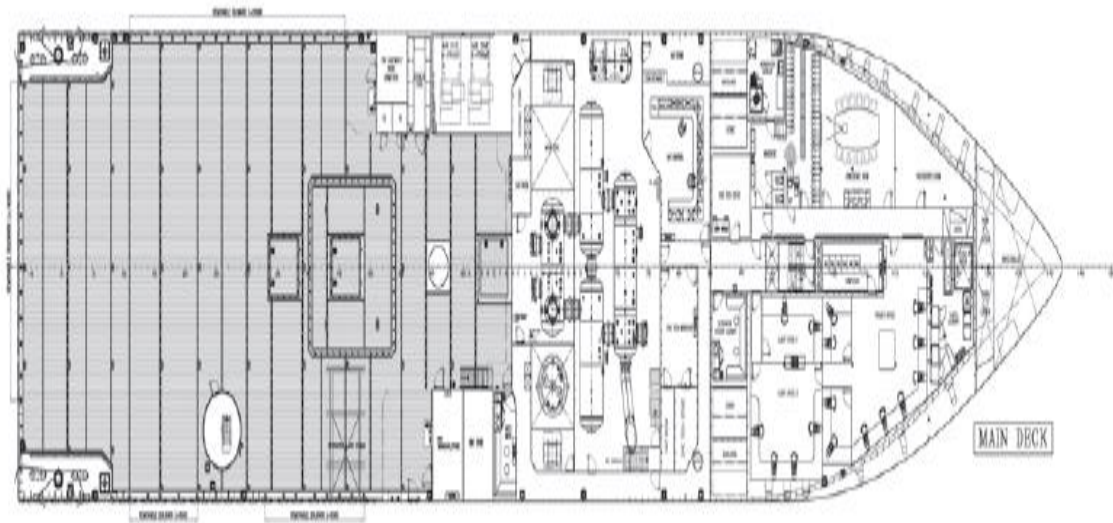


Figure 5.13.2 The layout of BIBBY TOPAZ

From table 4, we can know that these new generation DSVs are special design for the IMR and supply operation. They all have a long duration and good stability in the bad weather and severe sea conditions, which enable the DSVs having a long time window to finish the tasks.

Table 5.1.3: Details of DSV properties

DSV	Harkand DA VINCI	Mermaid ENDURER	SKANDI SINGAPORE	BIBBY TOPAZ
Build	2011	2010	2011	2007
DWT(t)	5662	4500	4,000	5337
GT (t)	8691	6365		8009
LOA*Beam(m*m)	115.4X22	95X20	107.1X21	106.6x22
Depth/draught(m)	11.8/7.035	9.8/7.7	8.5/6.6	9.6/7.3
Cruising Speed (knots)	11	11	12	11
Total Power:	11290 Kw	10080KW	12000KW	115KW20
Accommodation	120	86	100	107
Helideck	Sikorsky S92	Sikorsky S-92,	Sikorsky S92	Sikorsky S92
Classification	DNV 1A1, CLEAN ,DSV-SAT ,DYNPOS-AUTR	DNV+1A1 DSVSAT, ice-C CLEAN	DNV 1A1, DSV-SAT, DYNPOS-AUT	DNV + 1A1 CLEAN, DSV-SAT,

Crane	Main crane	TTS AHC 140t Crane 140t@7m 500MSW;	McGregor 100 t AHC @ 9m 50T@15M; 25t at 25m	NOV AHC 120T @12M 10T@42M	AHC 150t @10m
	Auxiliary crane	40T@13M 10T@27M	AUX 1 10T@26M AUX 2 5T@15M		10T@1S8M 1.5T@14/7
DP system		DP 2	DP2	DP2	AUTR DP II
Sat system	equipment	2*3 man bell 18 man- 300msw	1*3 man bell 18 man- 300msw	1*3 man bell 18 man- 350msw	2*3 man bell 18 man- 300msw
	Gas Storage	18,000 m3@200bar	21,600m3 of 200BAR	18,400 m3@200bar	20240m3 @ 200bar
Moon pool		2 x (3.9m x 3.9m) for bell	1 x Aerated moonpool	1 for bell1 for ROV 4.2mx4.2m	Main 7.2m x 7.2m, 2 for bell
Deck area/ Strength		1120m2 10t/m2	700m ² 10t/m ²	900 m2 10 t / m2	900 m2 5.0-10.0t/m2
Other mission equipment		2000m Mohawk ROV	optional, installed as required	Air Diving System ROV 2 x TRITON XLX Work Class Power 150	Comanche 10 Electric Work Class ROV

7.2 Investment analysis

First, I want to present some newly cases of DSV offshore contracts. The news is from the special marine website.

1. Seamec India and Technip has signed the charter contract, and the DSV 'Alliance' will work near Dubai for 75 days from mid of this June. The contract value is nearly 35 billion \$.
2. Alam Maritim Resources Malaysia offshore company has just purchased a second hand DSV to expand his fleets for deep water market. The purchase price is over 80 millions.
3. Mermaid Maritime AS Singapore has just order one new build DSV to satisfy the offshore market. The new DSV cost is expected to 138 million \$ and the new DSV will be delivered in fall of 2016. The Mermaid Maritime's new DSV will equip with an 18-men diving system, two work class ROV, and a 140T AHC crane.
4. The COOEC has rented the 'Mermaid Endurer' from Mermaid offshore

services for a seabed construction project. The contract was from last March and lasting for 6 month with sixty days optional. The total price was about 40 million \$.

5. Bibby offshore UK has just rent the DSV ‘Mermaid Edurer’ for 6 months at a price of 30 million \$.

We could base on market information from above cases to executive the investment analysis. According to the market information, we could make the basic estimations for the investment analysis. The investments are 150 million\$ in two years, while the income is 50 million \$ for the first 3years, with a 5% increasing rate in every 3 years. The period of depreciation is 10 years

Table 5.1.4: worksheet for the cash flow of the DSV

cash flow	unit: million \$											
year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
investments	-50	-100										
depreciation			-15	-15	-15	-15	-15	-15	-15	-15	-15	-15
operational costs			-10	-10	-10	-12	-12	-12	-14	-14	-14	-16
incomes			50	50	50	55	55	55	60	60	60	65
tax (40%)			-10	-10	-10	-11	-11	-11	-12	-12	-12	-14
net income	-50	-100	15	15	15	16.8	16.8	16.8	18.6	18.6	18.6	20.4
operational CF	-50	-100	30	30	30	31.8	31.8	31.8	33.6	33.6	33.6	35.4
discount rate (10%)												
NPV	\$32.92											
IRR	15.098%											
Payback period	8.3											

From the invest analysis above, it is profitable to invest for the NPV is 32.9 million \$ >0, the IRR is 15>11. At the end of 8 years the project has broken even. Actually, under an effective asset management system, the DSV would still run after the first ion0 years and continue to profit, thought the asset depreciation has been finished. So our estimation is conservative and lower than the actual situation.

7.3 Decision-Making

In addition to the reasons already discussed above, when we are facing such an expansion and long-term decision, some non-economic factors, like policy, industry development, enterprises' operating capacity should also be considered carefully. We also need to manage the operational uncertainty and risk in the construction and operation, and compare the various alternatives carefully.

7.3.1 Non-economic factors

In the 12th Five-Year Development Plan, the government has established series of policies to support the offshore O&G industry and encourage marine engineering equipment manufacturing, providing technological guidance and support and giving tax incentives. Specifically after the first saturation diving operation at 300msw in the early 2014's, is successful dive number, the state is aiming to develop diving system

and other equipment fitting to diving to 500msw, and optimized for diving to 350 msw. So this will be a good opportunity to build such a new DSV with the country's investment and support.

With oil prices rising, more capital will be invested to the offshore O&G industry. As mentioned previously, saturation diving operations has just begun in China, so the new construction offshore facilities need to support diving, and the IMR will be increasing in the facilities in operation. It may be hard and expensive to obtain the overseas resources. The strong market demand would surely guarantee our assets investment in upstream.

Looking around in CNOOC; there is still lack of such a purpose built DSVs among various offshore support vessels. But if we COSL can take our advantages as a service company, we could get huge profits from such a DSV for we have managed a big vessel fleet, and sufficient resource to ensure operation.

7.3.2 Uncertainty and risk

Knight (1921) has been elaborated that to the distinction between uncertainty and risk in classical decision theory. Aven (2009) also discussed how to make decisions with uncertainties in a risk perspective. Here, the uncertainty mainly refers to O&G prices, vessel building cost, and Ship prices.

It is obvious that the fluctuations in O&G prices will have a big influence on the oil industry. When the prices falls, the oil company' profits decrease, then they will reduce investment and slow the development pace, accordingly, the daily life, chemical and other industries will be affected. Since the current O&G demand is so huge, it may fall down because of enormous onshore exploration discovery, success of shale gas or popularization new energy sources.

In the current economic situation, shipbuilding costs will not to have a substantial growth in Chinese shipyards and shipbuilding market. With the labor costs and production overcapacity in China, the cost may be savings and reduce. So if we could manage and control project effectively, the uncertainties in the construction stage will be controlled within a reasonable range.

The day rate will affect the income during the operational stage. According to the current trend, the day rate is going up year by year, but there may be greater uncertainty. Especially if there are other competitors, so measures are necessary to ensure the engineering quantity and rates. A long-term agreement is an effective way to avoid revenue fluctuations.

7.3.3 Alternatives

This alternative does not refer to ROV, but it means modular saturation diving system equipped on offshore support vessel. Compared to the purpose built DSV, there are more and greater uncertainties with a modular diving system.

First, the modular system usually need an mobilization and demobilization process as

part of the operation process , in which have a lot of welding, cutting, lifting and other jobs. These high-risk jobs would be deployed on the deck, increasing the safety management difficulty and risk. It also needs to have a lot of commissioning and inspection, so it is relatively low efficiency. It is not suitable for fast response and emergency repair, while the build in saturation system vessel is more efficient and faster.

Second, the mix gas consumption of saturated job requires quite huge, but if the deck area is limited, the vessel would carry less mix gas amount and return to port for recharge in many cases, which may miss the good weather and lower the operating efficiency. The purpose built DSV could carry more than 10 000m³ mix gas (200 Bar) to endurance two months.

The modular saturation system would mount on the deck area, so the deck would not have enough space for other operating equipment. So it may require additional support vessel, which will increases the cost.

Operators would be more safety and comfortable to work in the moompool than in the side of the vessel. The system would be easy to maintenance so they would have a longer life cycle.

To buy a second hand DSV is another option for building the new DSV. This choice is seems not too bad, however, just as the Brandt and S.Mohd.Safif. (2013) said, the aged equipment may have significant deterioration and damage mechanisms which will potentially effect on the functionality, availability or safety. Because our company does not have such a DSV, if decision-makers want to make a relatively smaller investment compared to the new generation DSV, first to gain experience and to explore the market. While we have other offshore support vessels and ROVs which can occupy the deeper and heavier missions. The smaller DSV only focuses on supporting the saturation diving operation IMR. But now the safety and environmental management is highlight under the public focus and have a big influence on the reputation of the company and the capital market; as well as the class regulations have further qualified the design of the purpose built DSVs. So a new generation of DSV may be easy for these concerns.



Figure5.2.3: the Bibby Polaris (build in 1999)

8 Project management

Shipbuilding is usually a systematic, large-scale project involving a wide range of engineering, machinery, navigation and so on. The project management has played an important role in shipbuilding projects after the PM has been founded. This chapter is trying to explore some improvements in modern project management in ship building project.

8.1 General features of the ship PM

Ship building is a typical application of project management discipline. A successful shipbuilding program covers all areas that involves in project management, like technology, monitor, control, and other skills.

- 1) Before making such a decision, the managers should thoroughly investigate the market, demand, and company's capability, to form the basic goals. General speaking, a feasibility study would fully assess and estimate the possible uncertainties, risks, gains and losses, to ensure making the right decisions.
- 2) A special project manage team will be set up after the decision-making. A project manager is usually be designated to responsible for the overall work for his experience and ability, while various professional staff would be drawn from different positions to execute the project management.
- 3) In the initial stage of construction, the project team should design the time schedule, cost plan, quality control plan, resource planning and integration plans. At the same time, the project team should cooperate with a professional design company to perfect the vessel design according to our

specific requirements. It is very important to identify the main uncertainties and difficulties in the various stage of the design and construction of the ship. It is also necessary to put forward the comprehensive requirements and regulations, including technology, quality and economic requirements, develop appropriate design drawings, technical documents and planning documents in the beginning.

- 4) The project team should control and monitor the detail jobs during the project' implementation. All the team members should cooperate and organize well. The project control mainly covers the schedule control, cost control, quality control, safety control and other types of control. In the implementation process, the project team should continuously formulate different construction progress reports, cost & payment reports, accounting reports, quality inspection reports, etc. These reports should be documented as part of the final documents to deliver.
- 5) For the time schedule, a lot of manage tool can be used, like Gantt chart, planner. Depending on the index, we can speed up or keep pace to the time schedule. If the time management does well, the project would carry out the activities in an order and reasonable manner; then we can ensure completion of the entire project in time. Conversely, if poor time management, the project may exceed the schedule, increase costs; even worse the ship-owners may fine or even abandon the project.
- 6) Procurement and contract management are the core part of cost management. According to the project budget, we could determine the target cost for the project specific activities and procurement expenses. Then the project team should try to control the actual cost of the project within the budget and keep the pace of the project progress, then adjust the target cost according to the actual project situation and cost trends.
- 7) Communications management is share and transmission of information among the project manager, project team and the project relative stakeholders when the overall management activities are carrying out. It is one fundamental factor to the success of the project. There are various of ways and forms to communicate among the different stakeholders, such as contracts, specifications, notices, memoranda, all kinds of working schedules, process plans, drawings, confirmations, meeting minutes, various reports, etc.. The communicating ways are not limited to the written documents; but also have a variety of verbal communication, meeting required by the management system.
- 8) Any project has to carry out the project accompanying with uncertainties and risks, so does the vessel construction project. Project Risk Management's task is to identify these risks as much as possible and take different measurements to control and reduce the exposures risks or risk consequences. Therefore, the risk management is essential in ship construction projects. There are a lot of risks, such as security risks (accidents, fires, etc.), the risk of weather-related (such as typhoon, painting delay, etc.), the risk of transportation, lifting, etc.

8.2 Improvement in PM

If such conventional project management points we have mentioned above could be implemented well, the project will progress smoothly. However, I still want to propose some ideas, and wish these ideas that could be adopted and applied in project management.

Project management and operational management usually have different objectives and principles. Delivery of the ship is a dividing point of the two stages. Though the shipbuilding stage has come to an end, it does not mean the project team members have no relationship with the vessel operation. Normally, some key personnel would continue work on the vessel for the maintenance or administer. So our project team should have some adjustments in the structure.

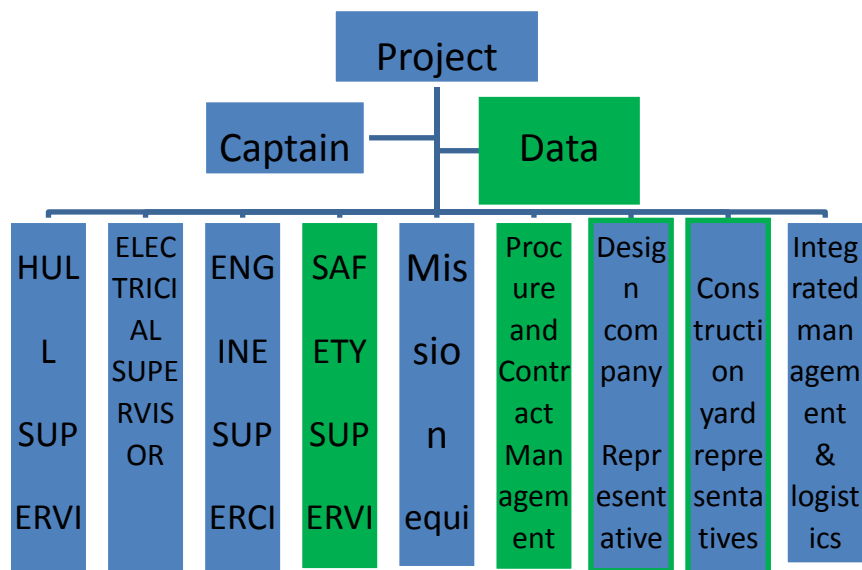


Figure 6.2.1: the structure of the project team.

I would like to discuss the duties and responsibilities of the green ones, who should join the subsequent operational management.

- **Data logger:** He is in charge of the documents and materials of the relevant professional, which are related to the equipment or components, such as principles, material, manufacturer, failure mode and other data from the shipbuilding process. He should also to set up a database with the information to create maintenance software for the vessel equipment, including inspection, certifications, FMEA, manufacture and maintenance planning, spare parts inventory and so on.
- **Safety supervisor:** He is mainly responsible for the oversight safety assessments in the constructions; risk identifying and completion of the design of safety-related paper work, implementing the FMEA analysis form the design stage. He also need to master qualification requirements of different class societies and international associations, as our vessel would have classification such as DNV +1A1 Diving Support Vessel, COMF-V(3)C(3), HELDK-SH, , E0, DYNPOS AUTRO, DSVSAT, CLEAN

and so on. So we should comply with relevant safety requirements for standards, safety management, and regulations. In the construction process, his jobs are mainly to implement the standards, procedures and standardized operating processes, and have a strict process control.

- Procure and Contract Management: It is necessary to carry out a successful procurement and cost management so that the project could be completed within the limits of time and cost. The procure management has a big influence on the time and cost, for the big-scale equipment always need a long period to be delivered. The contract terms should be detailed for reducing the risk, especially when the contractors speak different languages.
- The cost control may face some dilemma, using a high performance equipment or a low price but medium quality equipment. So we must adopt the whole life costing method and apply the whole life costing principles to provide a powerful analytical capability: coupled with logistic support and economic analysis techniques, J. Crabb, Arnerada Hess (1995) said.

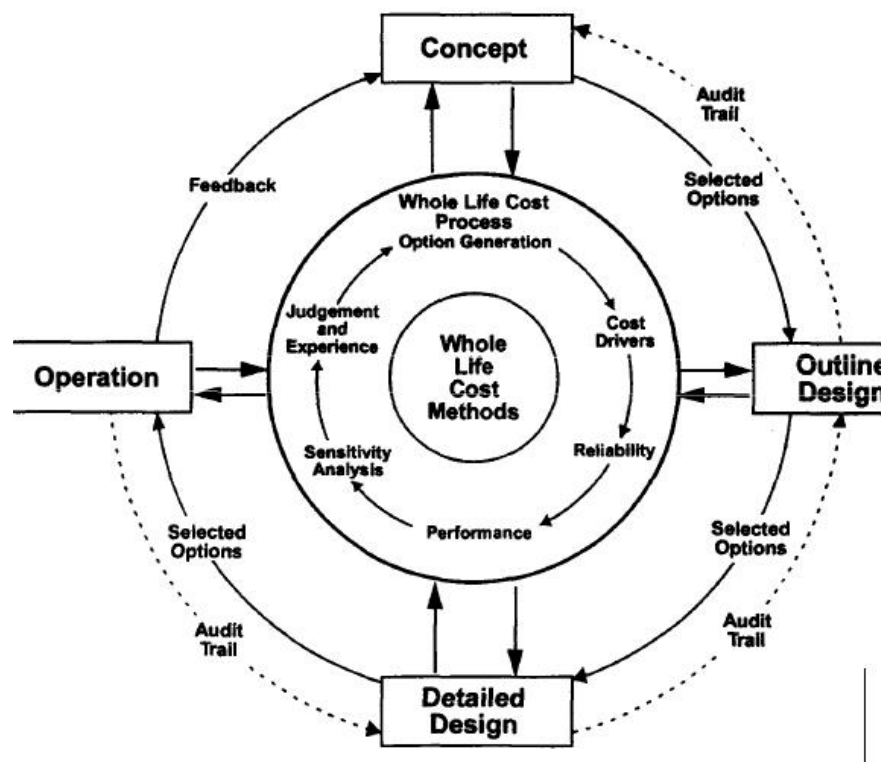


Figure 6.2.2: Whole Life Cost process flowchart of the project phases

8.3 DSV design optimization

Before we contact with the ship design company, we had already identified the main functions and selected prototyping target vessel. Then if we have a chance to work with the design company, the rest work is to optimize the main mission equipment layout and ergonomics. And we should combine the maneuverability,

and stability within the design constraints, cost, time, as well as its class.

First, this DSV is positioned to do the IMR, surveys, construction and installation with a saturation diving system in China South Sea. So we should investigate the harsh environmental condition and set up some basic line of the vessel stability for the DP system, the vessel endurance and some other vessel's function. Then the layout of the diving system could be optimized. For this mission, we should refer the NORSK standard U-100 (2008) 'Manned Underwater Operation', and IMCA standard M 103 (1999) section 2, 'Guidelines for The Design and Operation of Dynamically Positioned Vessels. It is very importance to optimize the ergonomics of the saturation diving system, which means we should design and arrange the system to convenient the divers' operation or living. The redundancy for the system should not only for the DP system, but also very important for the diving components, such as the bells, ECU, LARS, gas reclaim units, gas supply units and communication system. For example, the new DSV, Skandi Arctic, which have used the 'State of The Art' technology, has improved the diving process by the monitoring and controlling with software, and the he also has used a higher level standards and safety redundancy for the equipment failure. Another novel concept like the SWATH DSV, first raised by S.D. Harris, and C. Mowry in 1995. The acronym stands for small water plane area twin gull, diving support vessel.

Custom tailored to meet the functional requirements set forth by Global Industries, Ltd. for service in the offshore oil industry. The internal hull design is principally governed by the operational arrangements, damage control, global strength, and fatigue while still providing a payload which meets the functional requirements. Model test comparisons have proven that this vessel performs well beyond equivalent mono hull capabilities, Modular fabrication is used to reduce schedule and costs, while aiding the procurement of major equipment. These chambers have given the divers a perfect hyperbaric habitat and allow a silence team shift without affecting the other's rest.

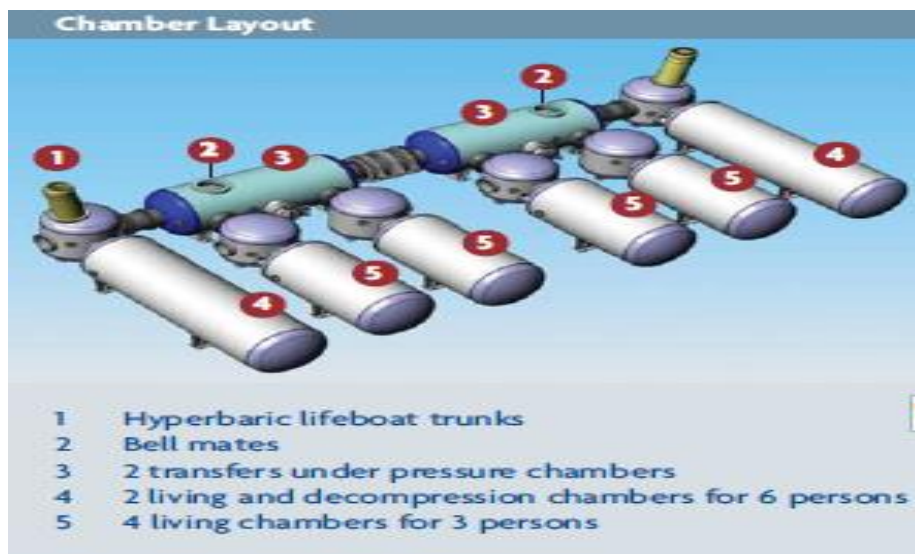


Figure 6.3: layout of the chambers on Skandi arctic

9 Risk Analysis and management

Because our company has built many vessels to expand our service fleet, COSL has accumulated a wealth of experience of risk management in building new vessel. Here, we do not discuss the vessel risk encountered in the construction process; but we mainly discuss the risks regarding with the saturation diving operations.

9.1 Risk review

Here, we use the PSA report for saturation diving operations to carry the risk analysis. From the PSA report, 'REPORT FROM diving database 2012', we can get the risk conditions of the saturation diving on NCS. In 2012, totally over 40 000 underwater operating man-hour was recorded, however, it was a little bit lower than the average level of activity per year (68,000 hours in saturation, corresponding to approximately 180 vessel days) in the last 20 years. There was no death; only two injuries and a nearly missing were reported. In the period of 1985 to 2012, there are totally 200 near miss and 200 personal injuries in the saturation diving, while only one death was recording in the database in 1987. The activities level was high up to about 150,000~200,000man-hours in the begin 7 years. After 1992, the activities level drop to a half level, and the minimum year was 2002 with a 10, 000 man-hours. The PSA forecasted that in the following years, the saturation diving would increase for the IMR operations in NCS.

According the underwater expose time in NCS, we could roughly calculate the FAR which usually show the risk level. So far, there are only 1 death in the all diving operation, and the activities level is about 68 000 man-hours in the past 27 years. Use these data, we can get:

$$FAR = \frac{PLL \times 10^8}{POB \times 8760} = \frac{1 \times 10^8}{27 \times 68\,000} = 54$$

We can get a message that the sat diver working underwater are subject to high risk, and all underwater operations should be treated seriously and follow the safety procedures. Though the FAR cannot fully expose all uncertainties, it will decline with the safe operations in the future.

UNDESIRED EVENTS IN SATURATION DIVING

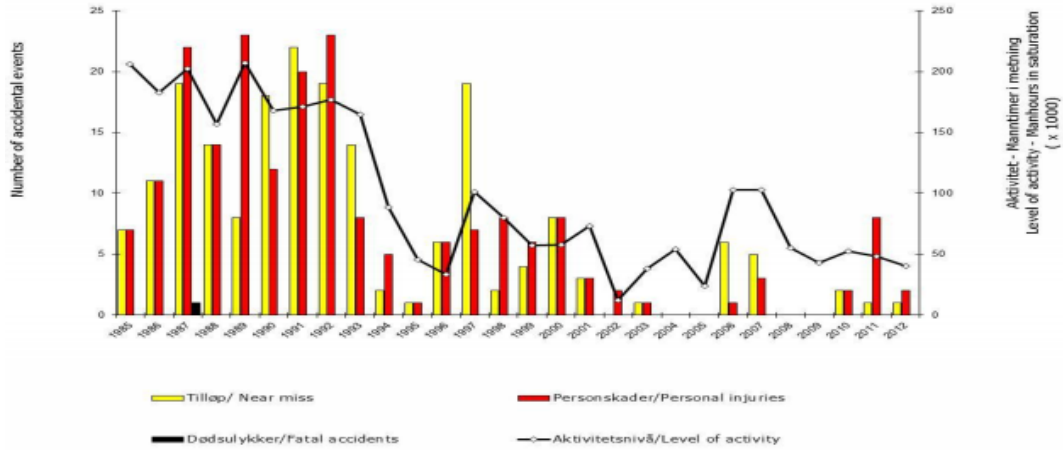


Figure 7.1.1 : the saturation diving activities level and hazards statistics in 1985-2012. We can also get the types of personal injuries related to saturation diving. See fig 10. In the total 121 accidents, the number of mescal/joint pain is 25; decompression sickness is 4, and barotrauma is 5. All the 34 injuries are caused by the hyperbaric environment.

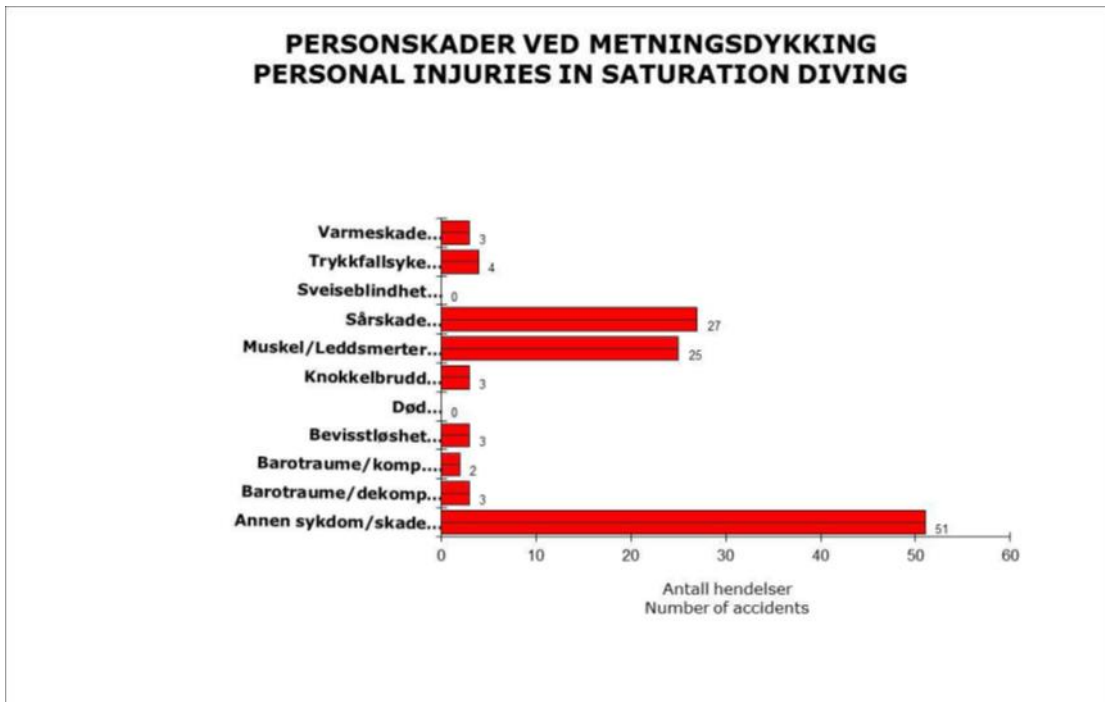


Figure 7.1.2: types of personal injuries related to saturation diving

9.2 Risk management

Through studying the courses of, risk analysis, I learnt that how to describe risk with

assumptions and uncertainties, and how to carry out risk analysis by qualitative analysis and quantitative methods, such as Checklist, HAZOP, risk matrix, FMEA. On the other hand, risk management utilizes the information or result of the risk analysis. It is more important to deal with, take measures, or respond to the risks. Project risk management process can involve, but not limited:

- Identifying the preventive measures
- Establish the emergency and contingency plans
- Execute further investigations or study
- Transfer the risk by insurance or other contractors
- Accept the risk to ALARP level.

Different international organizations and societies have given the guidance or direction of the risk management. For example, risk management progress from the ISO 31000, see below.

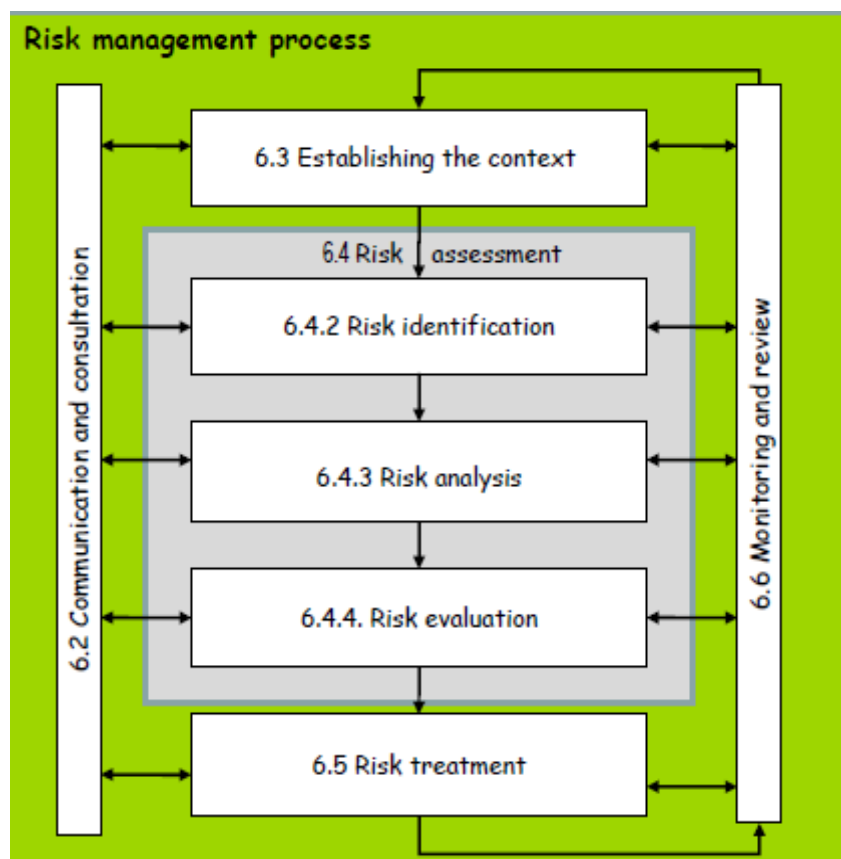


Figure7.2: risk management progress

However, a successful risk management is not only to reduce safety risks by design, modification or maintenance aspects, but also can reduce operating costs by improving the availability reliability, operability of the system, reducing the down-time, increasing operational efficiency and optimizing spare inventory

9.3 FMEA for diving system

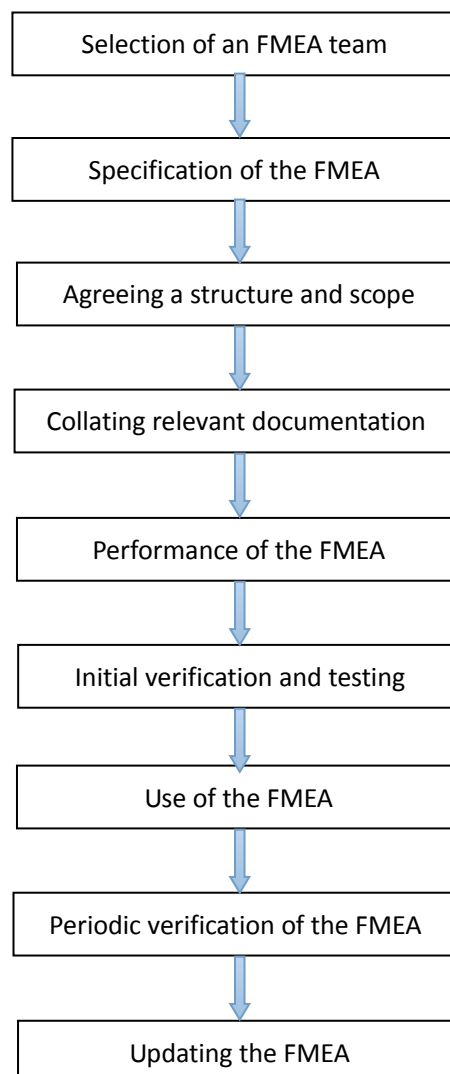
For the new build diving support vessel, the FMEA analysis is very complicated. It covers a very broad range from vessel equipment, DP system, and diving system. The

vessel equipment is more or less the same as support vessels. This would determine by the vessel's performance, and the FMEA should be done before and following the vessel design stage. The master would focus on these issues for the vessel safety.

The DP system is very important to ensure the diving operation safety. If the DP system failures and lost its position when divers in water, the divers would suffer a decompression illness, even death. So the DP system should have at least two independent signal systems available for the operation periods. The system should have enough redundancy and backup for the failures. However we want to discuss the FMEA of the diving system following the IMCA guideline D-039, to carry out the whole FMEA in the detailed steps.

The standard FMEA procedure has been discussed in the risk course, and the IMCA D039 also gives a practical application of the method to analyze the diving system.

FMEA procedures:



From the flowchart of the FMEA procedure, we could get the basic requirements and main points of executing a FMEA. AS there are nine sequential steps in the procedures and each step has different stress and task, so we can analyze them one by one.

- **Step 1: Selection of an FMEA Team**

The team should cover all aspects of the diving system and the team should recruit the competence persons who have been working in this field for years. They should be the machinist, technician, electrician, diving supervisor, life support supervisor, engineering safety experts and so on. Each of the team members would be responsible for his profession, and he is in duty to give advice and recommendations. The competent personnel have been defined as certificated and trained by the special societies. The FMEA team members should have adequate knowledge about the diving discipline and practical engineering experience. They could use their specialties to give advice and recommendations of the diving design and application. The whole team should have a lead to organize the FMEA tasks and manage all the documents.

- **Step 2: Specification of the FMEA**

The mission of this step is to clarify the targets of the FMEA. The main functions of the FMEA are to identify the potential failure mode and effect of the system, equipment, or single point. The team should give alternatives to the failures and design one or more effective redundancy. They also need to analyze the possible sequent effect causing by the failure, which should be reduced or mitigate to the minimum level. As concerning of time and cost, the team needs to make a time schedule to finish the FMEA and define the lowest level of the analysis.

- **Step 3: Agreeing a structure and scope**

This step is the continuation of last step, and this step is focus on the refine of the FMEA's structure and scope. Then, they should communicate with the stakeholders to final determine the boundaries, internal, external, ranking the criticality, and documents format.

- **Step 4: Collating the Relevant Documentation**

The team would carry out the FMEA analysis based on the relevant documents from the system design companies, manufactures, operating manuals, emergency response plan, maintenance plan, and relevant legal requirements. These documentations are latest and they should be available for all members and all the time. The new test reports or modifications should be updated timely.

- **Step 5: Performing the FMEA Study**

A diving system has many small system components, and the FMEA should carry out one by one. And the team should use some teamwork to accomplish the job in the time and cost restraints. All reports and advice should be easy to update and the final report need a comprehensive summary the main subsystem, main profession, and discipline. We need not only the failure causes and effect, but also need the right maintenance strategies, feasible and reasonable alternatives, and practical improvements. The team should also try to fulfill the requirements of the international standards and regulations. After the final report deliver to the owner, the team should guide the owner to set up related procedures, maintenance plan and spare parts strategy.

- **Step 6: Initial Verification and Testing**

This step aims to confirm whether the system FMEA is available and verifies the

procedures they design are practicable and economical. The system should be tested in this period and related personnel are training to familiar the system and the working procedures. The results of the testing and trial should feedback and update in the files.

- **Step 7: Using the FMEA**

The outputs of the FMEA should be used and reflected into the operations procedures, emergency plan, and maintenance manuals. These also can be used as the fundamental material to execute the risk assessment for each diving operation. It is basic requirements to the relevant personnel, especially the diving supervisor and life support staff.

- **Step 8: Periodic Verification of the FMEA**

When the system has been in use, the system should have enough maintenance and inspection records. If there are some unforeseen failures or repairs, new FMEA should be carried out and the whole system should be checked before a project operation beginning. An FMEA can be reanalyzed by the suitably competent employees of the company or by authorized FMEA specialists. Usually the verification trial may require executing in every six months or twelve months.

- **Step 9: Updating of the FMEA**

If the system or procedure has any changes, the FMEA should update following the change and the systematic FMEA review through the operational life cycle must be an ongoing process. Another reason is the annual audit by the class organization. We should maintain a detail and complete records and keep them updating in the latest status.

10 Discussion

From my practice experience, when I take part in the project, I have shaped this thought in the process. However as the first corporation with the western saturation team, who have showed us good practice of management and engineering experience. We should accumulate the project experience and also learn from the partner. The diving teams should be carefully organized. For the divers underwater need good communication with the supervisors and life support supervisors, they could give the divers right directions and orders to finish the underwater jobs. They should be competent and experience to handle the problems of equipment or other emergency situation.

From the economic perspective, I believe this project should be more profitable if the contracts were more detail and skillful. This project just had an exceeding standby time, regardless of the offshore weather factors. The long standby period, like transport period, customs clearance and spread on DSV, make the project lower time efficiency. And other problem, the DSV were not purpose build DSV, during the sat systems' spreading and demobilization, a high risk level is imposed to the vessel, and the vessel has some limitations which needs Transform or add new facilities.

The aim of the thesis was to study and conclude the sat diving operation. Also I presented my thought to build and operate a purpose DSV, which would be a good investment and benefit for the company's development. With this equipment

investment, better sat diving system, sat diving service integrated maintenance and safety management, our COSL would have a more comprehensive fleet and provide a more excellent service for the offshore oil development. The DSV could have different operational models, the traditional charter to the owner as a subcontractor or undertaking projects as a contractor, which could exert our technical advantages. The DSV would be a strategic asset in many different tasks.

However, building such an DSV needs special prudent to make the decision and a construction period, so we should first do well the convention diving operation and maintain a safety operation recording to ensure the existence in the diving industry. Then we should reserve the profession staff and familiar the relevant class regulations and guidelines. As we have known, the investment would be nearly one billion and a long period for 2~3 years, so a good project management is essential for cost and time control. The project team should play the central role in the process. They should be charge for information communication among the stakeholders, and they should take care of the documentation, recordings, drawings, and certificates for the further class requirements. The DSV should aim at world first-rate vessel and the world offshore engineering market, actively competing in international market. One problem is that most of the Chinese sat divers are working for the Salvage Bureau in the past a few years, however, the diving training school has trained more sat divers for other companies. So there would be more divers who can work for us in the future, moreover, the sat divers are usually free lances; and we could hire them from the manpower companies when a project is started. We only need to offer full time job for the technical engineers and maintenance personnel.

If we have the opportunity to construct the purpose diving support vessel, it is of importance to integrate the project management and the operational management, and the highlight is safety management, including the FMEA of the diving system and the risk analysis in the diving procedures. The industrial societies have set a series of different guidance for carrying out the operations, just like how to use the lifting bag, how to diving with a DP vessel. Following the risk control procedure, we can identify the potential hazards and risk; then we should take correspondent measures to reduce the risk level to an acceptable level. As an important content of the safety management, the emergency procedures should be formulated to every work site. All the personnel should familiar to his responsibility in case of emergency. Effective exercise could help to promote the awareness of the risk and to enhance the emergency cope capability.

11

12 Conclusion

13 According to analysis the practice and study on related materials, I believe that it is feasible and profitable to invest a purpose build DSV. The company could manage the DSV to win more contracts in the diving projects. We could take our advantages of project management in the construction period. We also can share the general assets, human resources and other common spare parts for

intergraded management. The new DSV should be detail designed which we could learn from the selected prototype and cooperate with the professional design house to optimize the integrated design. All the design and materials should strictly comply with the class requirements.

- 14 If we could work with the DSV, we should focus on the HSE management, which will be the most performance index to appraise the safety management. The HSE recordings are very important to maintain the class and the owners also value the control level as well as the technological capability. However, if we follow the FMEA procedures and get the maintenance plan, we could find that the assets management would be more cost effective and less down time which could bring good reputation in the diving market.

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