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MASTER'S THESIS

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ABSTRACT

The main scope of this master thesis is to analyse subsea asset maintenance on Norwegian Continental Shelf (NCS) and to evaluate the fitness of the Life of Field (LoF) concept to the future subsea asset maintenance on NCS. Subsea asset maintenance is part of subsea asset operation and maintenance which is a subsequent phase of subsea asset installation. Subsea asset management is a stable segment since oil and gas (O&G) companies always need to continuously maintain their existing subsea assets regardless of the volatility of the activities in offshore production system development.

This study is started by describing the role of subsea asset maintenance in O&G field development. The critical enablers which enable subsea asset maintenance to successfully perform the role are also described. Additionally, the offshore operation and the object of subsea asset maintenance are also parts of the description.

Existing subsea asset maintenance projects on NCS will then be presented to identify the current practices of subsea asset maintenance on NCS. Afterwards, since subsea asset operation and maintenance is a subsequent phase of subsea asset installation, a number of subsea asset installation projects awarded on NCS in the last 10 years will be presented to predict the upcoming trend of subsea asset maintenance on NCS. The findings regarding the current practices and upcoming trend will help to identify the requirements of the future subsea asset maintenance on NCS.

This study will be continued by describing the LoF concept used by Subsea 7 in providing subsea asset maintenance services to O&G companies. Analysis will subsequently be performed to evaluate the LoF's fitness to the future subsea asset maintenance on NCS.

Keywords: offshore production system, NCS, subsea asset installation, subsea asset maintenance, Life of Field (LoF)

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Finally I would like to express my gratitude to all my lecturers and my friends in the Offshore Technology master program at the University of Stavanger.

Hopefully this small work could have positive contribution for the O&G industry on NCS.

Stavanger, 15 June 2014

Agus Darmawan

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LIST OF ABBREVIATIONS

AHC	: Active Heave Compensation
AIV	: Autonomous Inspection Vehicle
CALM	: Catenary Anchor Leg Mooring
Capex	: Capital expenditure
CDU	: Control Distribution Unit
DEH	: Direct Electrical Heating
DSV	: Diving Support Vessel
EPIC	: Engineering, Procurement, Installation and Commissioning
ETHP	: Electrical Heated System Pipe-in-Pipe
FEED	: Front End Engineering Design
FLAGS	: Far north Liquids and Associated Gas System
FPSO	: Floating Production, Storage and Offloading
FSO	: Floating Storage and Offloading
HSEQ	: Health, Safety, Environment and Quality
IMR	: Inspection, Maintenance and Repair
IMS	: Integrity Management System
IOR	: Improved Oil Recovery
IPSU	: Infield Power Service Umbilical
IT	: Information Technology
ITS	: Integrated Template Structure
LNG	: Liquefied Natural Gas
LoF	: Life of Field
LPG	: Liquefied Petroleum Gas
MBE	: Multi Beam Echo
MEG	: Mono-Ethylene Glycol
MHS	: Module Handling System
NCS	: Norwegian Continental Shelf
NDT	: Non-Destructive Testing
NPD	: Norwegian Petroleum Directorate
O&G	: Oil & Gas
Opex	: Operational expenditure
OROV	: Observation class Remotely Operated Vehicle
PFS	: Power-from-Shore

PiP	: Pipe-in-Pipe
PLEM	: Pipeline End Manifold
PLIM	: Pipeline Inline Manifold
RFO	: Ready For Operation
ROV	: Remotely Operated Vehicle
SAGE	: Scottish Area Gas Evacuation
SCR	: Steel Catenary Riser
SSBI	: Subsea Separation, Boosting and Injection
SURF	: Subsea, Umbilical, Riser and Flowline
TCM	: Tordis Central Manifold
UTA	: Umbilical Termination Assembly
VLS	: Vertical Lay System
WGC	: Wet Gas Compression
WROV	: Work class Remotely Operated Vehicle
ÅSCP	: Åsgard Subsea Compression Project
ÅTS	: Åsgard Transport System

1. INTRODUCTION

1.1 Background

During the last decade, a number of big subsea asset installation projects on NCS have been awarded to a number of subsea contractors (e.g. Subsea 7, Technip and Saipem). The scope of work of the projects is mainly to install Subsea, Umbilical, Riser and Flowline (SURF). Some notable awarded subsea asset installation projects are the world's first subsea compression for Åsgard field, the biggest awarded subsea asset installation project on NCS: 800 MUSD Martin Linge development, and the world's biggest Spar for Aasta Hansteen field.

Due to deeper water depth, more remote location and increasing technical complexity, the costs of offshore production system development in Norway have an increasing trend (Ernst &Young, 2012). The associated risks are also increasing. Additionally, O&G companies that newly operate on NCS have insufficient resources in house to manage all activities related with offshore production system development. Responding to these facts, O&G companies on NCS now tend to package the scope of subsea asset installation projects into EPIC (Engineering, Procurement, Installation and Commissioning) framework. This framework enables O&G companies to pass through to subsea contractors the cost efficiency initiative and the risks associated with offshore production system development.

From potential revenue perspective, subsea asset installation (especially subsea EPIC) projects are beneficial to subsea contractors because the contract value may be up to hundreds millions US dollar per project. However, the intensity of subsea asset installation projects is volatile and heavily depends on how active O&G companies do offshore production system development in a particular period. Moreover, the project risks associated with subsea EPIC project including technical and supply chain management risks are also increasing. The risks may cause enormous loss if are not identified and managed properly. For example, Guara-Lula NE is an ongoing subsea EPIC project performed by Subsea 7 in Brazil which on August 2013 was estimated would cause total loss 300 MUSD to the contractor (Offshore Energy Today, 2013).

On the other hand, subsea asset maintenance is a stable segment. Regardless of the volatility of the activities in offshore production system development, O&G companies always need to continuously maintain their existing subsea assets. Moreover, considering recent initiative of O&G companies on NCS to focus on cost efficiency which subsequently delays a number of subsea asset installation projects, the contribution of subsea asset maintenance to subsea contractor becomes more important.

1.2 Scope

The scope of this master thesis is to analyse subsea asset maintenance on NCS, to describe the Life of Field (LoF) concept, and to study the fitness of LoF to the future subsea asset maintenance on NCS. The thesis uses an industrial case of Subsea 7's LoF, which refers to various services offered by Subsea 7 to O&G companies once a field has started production

1.3 Objectives

There are two main objectives of this master thesis. The first objective is to identify organizational and technical aspects of the future subsea asset maintenance on NCS. This identification combined with the LoF analysis will enable the achievement of the second objective, which is to analyse the fitness of LoF to the future subsea asset maintenance on NCS.

1.4 Tasks

The tasks of this master thesis include the followings:

- Description of subsea asset maintenance.
  In order to have a comprehensive overview, the description will include several relevant aspects of subsea asset maintenance, including its role in O&G field development and its enablers.
- Overview and analysis of existing subsea asset maintenance projects on NCS.
  The main aspects of the overview and analysis will be the contract's nature, scope of work, and vessel's technical capabilities.
- Overview and analysis of subsea asset installation projects awarded on NCS in the last 10 years to predict the trend of subsea asset maintenance on NCS.
  The main aspects of the overview and analysis will be the field development's strategy, scope of work, and offshore operation.
- Analysis of organizational and technical requirements of the future subsea asset maintenance on NCS.
- Description of LoF, and analysis of its fitness to the future subsea asset maintenance on NCS.

1.5 Limitations

First, subsea assets discussed in this master thesis are the assets that are used during production phase. Thus, subsea assets refer to offshore production system.

Second, this master thesis studies not all aspects, but only organizational and technical aspects of subsea asset maintenance on NCS, in particular related to its offshore operation. Since the offshore operation of subsea asset maintenance requires specialized equipment which need to be deployed on a specialized vessel, the technical aspect will focus on the technical specification of the vessels including their main equipment.

The last limitation is the inputs regarding the Life of Field concept are gathered only from Subsea 7’s perspective.

1.6 Methodology

This master thesis consists of six chapters. Chapter one describes the background, scope, objectives, tasks and methodology of the thesis. Chapter one is developed through discussions with both faculty and external supervisors.

Chapter two is dedicated for literature study on subsea asset maintenance with main focuses on several aspects of subsea asset maintenance: its role in O&G field development, its enablers, its offshore operation and its object. The literatures include academic books and papers, lecture notes of University of Stavanger, and a number of documents found on the websites of several companies in O&G industry.

The literature study is then succeeded by chapter three which presents the current main projects and the trend of subsea asset maintenance on NCS. Chapter three is developed through discussion with both supervisors and data collection from various trusted sources on internet, including the websites of several subsea contractors, Norwegian Petroleum Directorate (NPD) and several publishing companies whose main issues are related with O&G industry.

Afterwards, chapter four describes the findings on the LoF. The findings are gathered from Subsea 7’s LoF documents, and also through discussion with the LoF tender and project teams in Subsea 7 Norway.

Analysis will be conducted in chapter five. The approach of the analysis will be first determining the criterions of the future subsea asset maintenance on NCS. Afterwards, the fitness of LoF to the future subsea asset maintenance on NCS will be measured qualitatively with respect to the criterions. Based on the analysis, chapter five will be closed with the recommendation, which is subsequently followed by discussion in chapter six.

This master thesis will be ended with presenting the conclusion in chapter seven.

2. SUBSEA ASSET MAINTENANCE

2.1 Role of Subsea Asset Maintenance in O&G Field Development

The main goal of O&G field development is to enable O&G companies to have profitable long-term production of hydrocarbon. This goal is achieved through various investments performed by O&G companies in all phases of O&G field development, which span over many years.

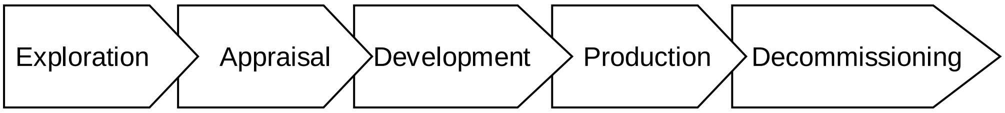

Figure 2.1 Phases of O&G field development (BP, no date)

As shown in figure 2.1, O&G field development can be grouped into five phases. BP (no date) describes that “Exploration” is the search for a petroleum reservoir either onshore or offshore, which primarily uses seismic surveys and drilling wells. After a petroleum reservoir is discovered, “Appraisal” is conducted where more wells are drilled and another seismic survey might be conducted to better understand the reservoir and then assess its feasibility for petroleum production. Once the decision to develop the petroleum field takes place, the company will come into “Development” phase where it establishes and executes a field development plan. The plan determines the number and design of production and injection wells, and the design of petroleum production system. Afterwards, “Production” is the phase when O&G company does operation: extract petroleum, process it and then sell the processed petroleum. During “Production" phase, O&G company also does maintenance to maintain the effectiveness and efficiency of the operation. The final phase of O&G field development is “Decommissioning” where O&G company restores the production infrastructure.

Ernst and Young (2013) indicates that subsea contractors such as Subsea 7 and Technip traditionally provide services to O&G companies during “Development” phase. Subsea contractors do design, fabricate and install offshore production system. Meanwhile, subsea asset maintenance is performed during “Production” phase to maintain what subsea contractors have installed during “Development” phase. In other words, the scope of work of subsea asset maintenance is to maintain offshore production system.

By definition, maintenance is a combination of technical, administrative and managerial actions done during life cycle of an asset with objective to retain the asset in or to restore it to a state where it can perform the required function. Maintenance is actually a compensating process to compensate for unreliability and loss of quality of an asset (Markeset, 2013). This is supported by ABS Consulting (no date) which indicates that the objective of asset maintenance is to ensure that the asset performs its function effectively and efficiently while protecting health, safety and the environment. Going further, in relation to O&G field development, subsea asset maintenance has the following goals (SGS, 2012):

1. Maximizing O&G field production

   Well-maintained subsea assets will perform their functions at the required levels, which make the assets able to fully support O&G field to achieve its production target.
2. Reducing lost income due to unplanned production shutdown

   Well-maintained subsea assets will have minimum downtime, which subsequently reduces the possibility of unplanned production shutdown that causes enormous lost income.
3. Maximizing the value of subsea assets.

   Well-maintained subsea assets will have good expected lifetime, which minimizes the possibility of unnecessary replacement of the subsea assets. Thus, from life cycle perspective, well-maintained subsea assets will have high value.
4. Optimizing maintenance costs of subsea assets.

   Maintenance is traditionally seen as "necessary evil", and hence the costs are always budgeted for. Therefore, one of the challenges for subsea asset maintenance is to optimize maintenance costs by maximizing the number of well-functional assets and minimizing the number of unplanned maintenance activities.
5. Maintaining an auditable system

   Subsea asset maintenance should be able to track the current properties of subsea assets, including performance, maintenance program and activities, and maintenance costs. Thus, the system used for subsea asset maintenance can also be used for audit purposes.

From the explanations above, we can conclude that the main role of subsea asset maintenance in O&G field development is to support safe, reliable and high productive "Production" phase.

2.2 Enablers of Subsea Asset Maintenance

In order to effectively do its role in O&G field development, subsea asset maintenance relies on the continuity of the steps in the maintenance process. It means that from organizational perspective, management should ensure that all steps are aligned with and collaborate to achieve the maintenance objective.

According to Markeset (2013), the management's efforts to enforce the continuity are started by setting maintenance objective, which is assigning target to maintenance functions. Afterwards, management uses maintenance strategy as a method to transfer the maintenance objective to maintenance activities, which are defined as the actions to maintain or restore asset in serviceable condition. As shown in figure 2.2, maintenance objective is translated by maintenance strategy into a schedule of maintenance actions. Once a maintenance action is executed, the responding result will be reported and recorded for analysis, which subsequently feeds the findings back to maintenance strategy. Figure 2.2 also shows that maintenance activities form a closed loop system while maintenance objective continuously guides maintenance activities through maintenance strategy.

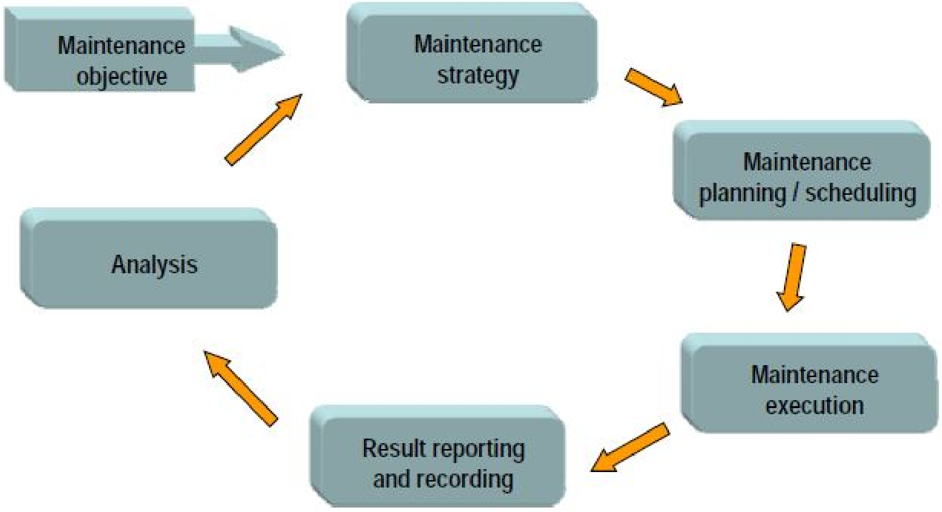

Figure 2.2 Maintenance process (Markeset, 2013)

As previously indicated in the definition of maintenance, the maintenance process should occur continuously during life cycle of an asset. This is aligned with the idea of asset integrity management which, as shown in figure 2.3, emphasises that the improvement of process capability should be applied in all steps during life cycle of an asset. This will ensure the continuity in maintenance process, which subsequently improves asset capability to better achieve company objectives, including maintenance objectives.

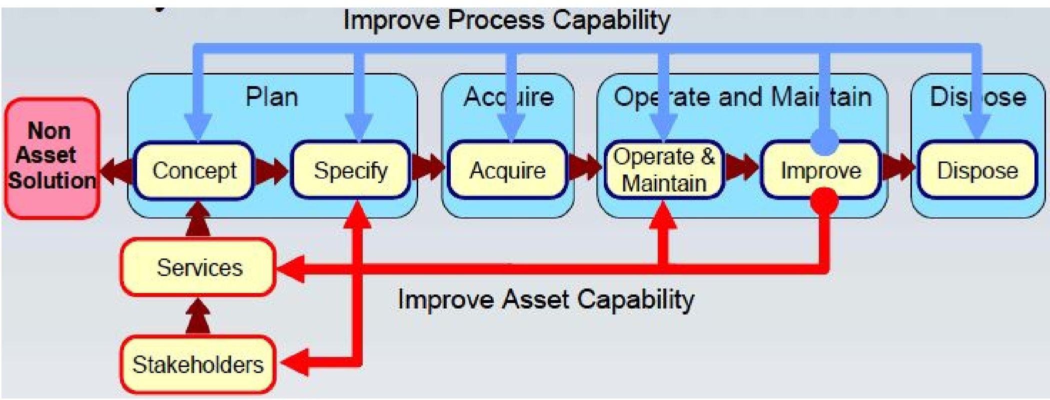

Figure 2.3 Continuous improvement of asset integrity management (Kennedy, 2007)

In addition to organization (maintenance process and the management), subsea asset maintenance also needs technology which enables it to effectively perform its role in O&G field development. Liyanage (2010) describes how information technology (IT) provides an automated data management system which systemizes and couples the processes in operation and maintenance of O&G production system. Thus, IT supports the continuity of processes, including streamlines continuous maintenance process. Furthermore, correct maintenance plans and actions can only be performed if the data management system is up-to-date. Therefore, data management system should be continuously updated through the life cycle of an asset (DNV, 2014).

Additionally, because its object is offshore production system, subsea asset maintenance needs technical capabilities which enable its offshore operation. The technical capabilities include specialized equipment deployed on a specialized vessel and expertise of the crew onshore and offshore.

As a summary, there are two enablers which are essential for the success of subsea asset maintenance:

1. Organizational capabilities

   Management system should ensure that maintenance process is continuous, including ensure that there is continuity from subsea asset installation to subsea asset maintenance phase.
2. Technical capabilities

   There are two main technical capabilities. First, IT capability provides an automated data system which streamlines continuous maintenance process. Second, subsea asset maintenance needs technical capabilities which enable its offshore operation, e.g. technical specification of the vessel and its main equipment, and the expertise of its crew.

There are costs associated with these two enablers, which unfortunately can be substantial. In particular, a special vessel which is needed to do the offshore operation is very expensive and has very limited schedule availability. On the other side, reducing costs such as by hiring the vessel for only a fixed short period to maintain various subsea assets in various fields in fact introduces risk to the O&G company. There are some unpredictable situations which may affect the schedule of offshore operation that the company needs to take into account, e.g. weather, unplanned maintenance, etc. If the vessel is hired for only a short period, there is a possibility that it is not available when the O&G company needs most.

Therefore, in practice, subsea asset maintenance involves a trade-off between cost, risk and benefit. For subsea asset maintenance project, O&G company (in particular Statoil as the major owner of subsea assets on NCS) usually implements medium- to long-term frame contract to mitigate the risk of vessel unavailability. The establishment of medium- to long-term frame contract is also due to high volume, i.e. there are enormous amount of subsea assets which O&G company needs to continuously maintain. Additionally, to manage costs, the frame contract uses light-construction vessels which are cheaper than normal construction vessels.

2.3 Offshore Operation of Subsea Asset Maintenance

"Maintenance", as defined in section 2.1, refers to a general understanding of maintenance as part of the operation and maintenance phase. On the other side, the term "maintenance" in industry has a narrower context and is usually used to refer to periodic maintenance. For unplanned maintenance, industry usually uses the terminology "repair". This separation creates an industry term Inspection, Maintenance and Repair (IMR).

In relation to offshore operation, which is the focus of this thesis, there are differences in both criteria and terminology used by O&G companies and subsea contractors to categorize the offshore operation of subsea asset maintenance. However, combining different perspectives from Statoil (2012), DeepOcean (2012) and Subsea 7 (2014), the offshore operation of subsea asset maintenance can be grouped into three categories:

1. Survey and Inspection

   The scope of work includes mainly seabed mapping and inspection of subsea assets. Seabed mapping will produce the information of seabed condition to be further assessed for a possibility of adverse impact to the integrity of existing subsea assets. The information of seabed condition is also used to determine the proper methods for the installation of new subsea assets. Meanwhile, inspection of subsea assets is mainly performed using remotely operated vehicle (ROV) which may be equipped with camera and several non-destructive testing (NDT) capabilities. The scope of work may also include pre-survey and as-built survey to support the installation of existing new subsea assets. Additionally, survey and inspection vessel usually has also capability to do light construction services, such as installing clamps and flying leads.

2. Inspection, Maintenance and Repair (IMR)

   This category is enhancement of the category 1 above. IMR vessels may have the same survey and inspection capabilities as what the vessels of category 1 have. In addition, IMR vessels have better technical capabilities to maintain and repair subsea assets because the vessels have bigger crane capability for heavier lifting, Module Handling System (MHS) for higher operating criteria and more stable construction operation, and commissioning support features. A recent trend for Statoil's long-term frame contract is the inclusion of performing scale squeeze operation from a new-build IMR vessel. Currently, the scale squeeze operation is performed by Seven Viking of Subsea 7 and Edda Fauna of Deep Ocean.

3. Diving

   Some subsea assets are designed for IMR with diver assistance, for example diving based tie-in system. The mobilisation and operation of diving solution is also faster, which is preferable when there is unplanned maintenance required. However, normal diving operation on NCS is limited up to 180 m water depth.

As mentioned in section 2.2, offshore operation of subsea asset maintenance relies on technical capabilities of vessel, equipment on board the vessel, and crew. The following parameters are relevant to define the technical capabilities of the vessel and its main equipment:

1. Main crane's capacity

   Offshore operation involves frequent lifting activities, e.g. move items across deck, put items in launch system, put items on seabed. Crane's capacity determines the heaviest weight that the crane can lift and the deepest water depth that the crane's lifting activities can reach. There are usually several cranes on board the vessel. The crane with the biggest capacity is called main crane and located on deck. Typical heavy construction vessel has main crane which is able to lift product up to 400 tons. However, this type of heavy lifting crane is very expensive and hence is not suitable for vessel for subsea asset maintenance which is usually hired for medium- to long-term frame contract.

2. Deck area

   Offshore operation, particularly construction work, involves various items which can occupy significant deck space. Deck area is also a place to put recovered item/module from seabed to be transported to shore for repair. Thus, large deck area is beneficial for offshore operation and can avoid unnecessary frequent trips back and forth between the port and the field which drive the costs higher.

3. Remotely Operated Vehicle (ROV)

   ROV is a robot which is powered and remotely controlled from the vessel. It can easily manoeuvre and do various works from surface to seabed. Its operating depth determines the deepest water depth where the ROV can operate. There are two main types of ROV: Observation class ROV (OROV) and Work class ROV (WROV). OROV is usually equipped only with camera and used for inspection work. Meanwhile, in addition to camera, WROV has also manipulator and grabber. WROV is also supplied with big electric and hydraulic powers which enable it to do various construction works.

4. Module Handling System (MHS)

   MHS is a special lifting and handling equipment for modules of subsea assets. The most common method is having MHS tower over vessel moonpool. This method offers launch and recovery of modules through moonpool with high tolerance to adverse weather. Thus, vessel with MHS can have higher operability, in particular to withstand harsh weather on NCS. MHS' capability is usually represented by capacity and operating depth, which describe the heaviest module it can lift and handle and the deepest water depth it can reach.

5. Ready For Operation (RFO) support

   RFO operation is performed in the end of subsea installation to ensure the integrity and functionality of the newly installed subsea asset. Some vessels used for subsea asset maintenance are equipped with chemical tank and high capacity pumping which can be used to support RFO operation, e.g. gelling, flushing, pressure testing and dewatering.

6. Scale squeeze

   Well intervention is one of the main challenges in the operation of wet trees. Scale can form inside production tubing which subsequently reduces hydrocarbon production rate. Scale squeeze injects chemicals into the well from a pumping spread on board the vessel to dissolve and remove this unwanted scale (DeepOcean, no date).

2.4 Offshore Production System: the Object of Subsea Asset Maintenance

As mentioned in section 1.2.4, subsea assets in this master thesis refer to offshore production system. Thus, subsea asset maintenance is intended to maintain facility and infrastructure which enable oil and gas production from an offshore field.

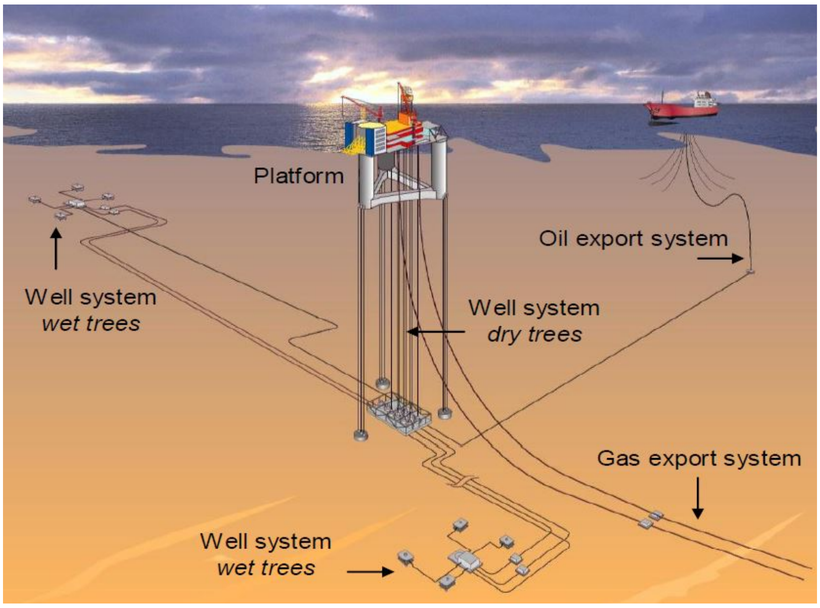

Figure 2.4 Typical components of offshore production system (Odland, 2012)

Figure 2.4 shows that an offshore production system is built upon three main components: well system, production platform (fixed or floating), and export facility. Bai and Bai (2010) adds infield flowline and umbilical as the fourth main component of an offshore production system, particularly for the one with wet tree well system. The infield flowline in this master thesis includes riser since riser is essentially a dynamic section of the flowline which connects the static section of the flowline on seabed to a facility on surface. By using the same analogy, the umbilical in this master thesis refers to both static and dynamic umbilicals.

2.4.1 Well System

Well system mainly comprises of wellhead and manifold. As described in Devold (2009), wellhead is installed on the top of the actual well hole leading directly down to reservoir, which functions to complete the well. The process to complete the well includes strengthening the well hole with casing, enabling measurement of pressure and temperature of the formation, and supporting the installation of proper equipment to ensure efficient hydrocarbon flow from the well. The wellhead structure is usually called a christmas tree.

Depending on where well completion takes place, wellhead may be dry tree or wet tree. Dry tree is located onshore or on the deck of offshore structure, while wet tree is below sea surface. Wellhead is connected to manifold, which consists of network of pipes and control system. The main function of manifold is to allow optimized hydrocarbon flow with respect to reservoir utilization and hydrocarbon composition.

For wet tree, well system consists of wellhead, manifold, and template as the base on seabed to insert wellhead and manifold. When manifold is mounted onto template, the integrated structure is commonly known as Integrated Template Structure (ITS).

Figure 2.5 ITS for Ormen Lange field (Matre, 2008)

The dimension and weight of ITS can vary depending on the requirement of particular field development. Figure 2.5 shows ITS for Ormen Lange field on NCS which has dimension of 46 m x 44 m x 18 m and weight of 1150 tons.

2.4.2 Infield Flowline and Umbilical

Infield flowline consists of pipe laid on seabed and riser. The later component is usually a flexible pipe installed from seabed to platform. In general, there are two main types of pipes which are based on the pipe strength properties: rigid and flexible pipes. As described in NCPI (2014), rigid pipe has significant crushing strength to withstand considerably more load than unsupported flexible pipe before failing when it is exposed to three-edge bearing test. On the other side, flexible pipe has significant stiffness which measures its ability to transfer vertical load imposed on it to a horizontal direction and hence limit its vertical deflection.

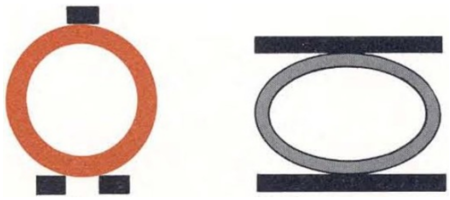

Figure 2.6 Three-edge bearing test for rigid pipe and stiffness test for flexible pipe (NCPI, 2014)

Pipes can also be classified based on their functions in offshore production system. There are three main types of pipes according to this classification: production, injection, and service pipes. Production pipe transfers hydrocarbon from wet tree well system to production platform. For flow assurance, production flowline can be equipped with a heating system. Injection pipe injects water, gas or chemical towards well system to increase hydrocarbon recovery rate. Meanwhile, service pipe carries various liquids to maintain the efficiency of hydrocarbon flow. An example of service line is MEG line which supplies Mono-Ethylene Glycol (MEG) to inhibit hydrate inside and to give better corrosion protection to production pipe.

In addition to infield flowline, there is also umbilical connecting well system and production platform, which provides electric, hydraulic and chemical lines to control the operation. Umbilical consists of static umbilical on seabed and dynamic umbilical from seabed to platform.

Further development of rigid and flexible pipes creates several alternative pipes, including Pipe-in-Pipe (PiP) and bundle. PiP is essentially a package of an inner pipe inside an outer pipe. The main purpose of PiP is to isolate inner pipe from direct contact with seawater and hence gives a better insulation system. The insulation capacity can be even further improved by coating outer pipe with insulation layer and also installing heating system in the dry space between inner and outer pipes.

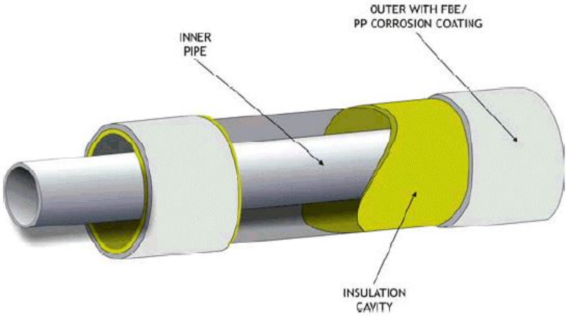

Figure 2.7 Example of Pipe-in-Pipe (JP Kenny, no date)

Bundle is a package of various pipes (production, injection and service pipes), umbilical and supporting systems (e.g. heating system) inside a big carrier pipe. Since many infrastructure components are incorporated in one big pipe, bundle avoids unnecessary field layout congestion and gives better stability in particular from pipe walking. The dimension and material of the carrier pipe offer protection for the contained components from drop objects and pipe buckling.

2.4.3 Production Platform

Production platform can be fixed or floating. The main function of production platform is to separate extracted hydrocarbon into oil and gas to be subsequently transferred to respective export facilities. Production platform may also function as a temporary storage, particularly to store produced oil. In addition, production platform acts as the control centre in the field. Various production platforms with their typical suitable water depths are shown in figure 2.8.

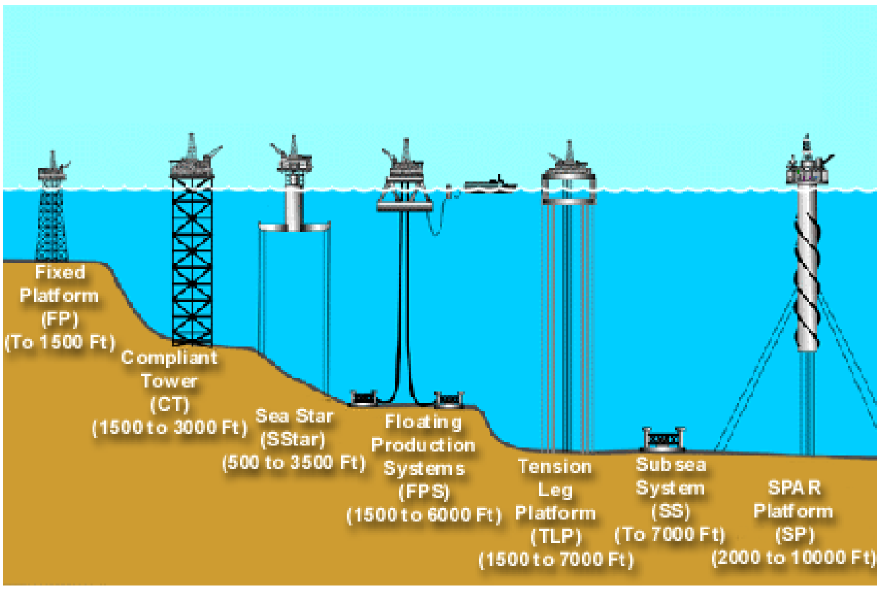

Figure 2.8 Various production platforms (Naturalgas.org, 2014)

As described in Devold (2009), fixed platform has its legs made of rigid pipes or concrete structures which are placed on seabed. Fixed platform is typically used for dry tree well system where all production activities are performed on the deck of the platform.

A variant to fixed platform is a compliant tower. It also has its legs placed on seabed, but the legs are narrower which allow the platform to sway. This small flexibility gives compliant tower more resistance to the pressure exerted by wind and sea wave, and hence it can operate in deeper water than a fixed platform.

Sea star is an example of semi-submersible platform. It has a large hull which enables the platform to float and move, but when the lower hull fills with water it sinks deeper and has better stability while keeping the facilities on the platform deck remaining dry. Sea star is attached to seabed by tension legs which prevent vertical motion but allow horizontal motion.

Floating production system is either a semi-submersible platform or a ship which can relatively stay in the position because it is using a dynamic positioning system or attached to seabed by a mooring system. The most common floating production system currently used in offshore production system is Floating Production, Storage and Offloading (FPSO). FPSO processes hydrocarbon received from the well, and then offloads oil regularly to a shuttle tanker and transfers gas through gas export pipe.

Tension leg platform is a big version of sea star. However, unlike sea star, tension leg platform has its legs all the way connected to platform. Due to the length of its legs, tension leg platform experiences more vertical and horizontal motions.

Subsea system refers to wet tree well system, which functions to extract hydrocarbon from reservoir and transfer it to surface for processing. Subsea system is connected to a floating production system through infield flowline. It can be also directly connected to a processing plant onshore through an export pipe.

Spar comprises of a deck and a single tall floating cylindrical hull as its supporting structure. The cylindrical is significantly long that stabilizes the platform in the water and allows for movement to absorb external forces due to severe weather condition.

2.4.4 Export Facility

Before being exported to shore, extracted hydrocarbon from an offshore field usually needs to be first separated by a separator on the production platform into oil and gas. Oil is usually offloaded to tankers which will carry it for further processing onshore or directly sales to customers. Because the offloading can only be done in a particular interval, the production platform should have temporary oil storage. On FPSO, its upper hull is usually used to temporarily store oil before having it offloaded to a tanker.

Figure 2.9 shows an oil offloading method where a tanker is remotely connected to the FPSO. A Catenary Anchor Leg Mooring (CALM) buoy is installed which acts as a connector and allows the tanker to freely weathervane without damaging the FPSO. This method enables the offloading operation to still be performed in a high sea state condition.

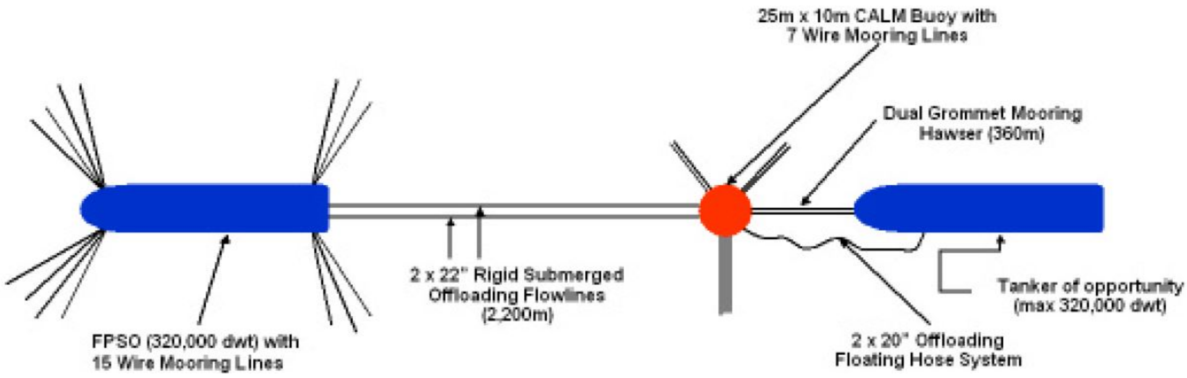

Figure 2.9 Remote oil offloading from a FPSO through a buoy (Ihonde et al., 2002)

The same export method will be much more expensive if it is applied to gas. It will need specialized processing plant on the production platform and specialized gas tankers, which are more costly. Therefore, gas is usually directly transferred to gas export pipe which may be further tied to other platform, bigger gas export pipe, or directly a processing plant onshore.

3. SUBSEA ASSET MAINTENANCE ON NCS

3.1 Current Main Projects

As mentioned in section 2.2, to ensure the availability of specialized vessel and equipment for its offshore operation, subsea asset maintenance project is usually managed as a frame contract. It means that the specialized vessel and equipment are hired for a specific firmed period per year. For Statoil who has tremendous amount of subsea assets supporting its various O&G fields on NCS, the specific firmed period can be even up to full 365 days per year with the total contract period of 3-8 years.

As indicated in also section 2.2, to fully ensure the continuity of maintenance process, the maintenance of a particular subsea asset in a particular O&G field should ideally be performed by the subsea contractor that has installed that asset. However, considering high number of O&G fields on NCS and a fact that assets in a particular field can be installed by more than one subsea contractor, the ideal scenario is not practical, not flexible and very costly. The most common approach used in current subsea asset maintenance on NCS is to establish only few subsea asset maintenance projects to manage all subsea assets in all fields that an O&G company has.

Section 3.1.1 – 3.1.3 present the current main subsea asset maintenance projects based on the three categories mentioned in section 2.3.

3.1.1 Survey and Inspection

There are currently three main survey and inspection frame contracts on NCS:

1. Yearly call-off for Volstad Surveyor of DeepOcean

   The scope of work includes seabed mapping, survey for construction support, light construction and pipeline inspection. The seabed mapping is performed by utilizing hull mounted Multi Beam Echo (MBE) sounder. Meanwhile, survey to support construction work can be done with ROV and camera, or without ROV by using MBE sounder (DeepOcean, 2012). The estimated hired period is 300 vessel days per year.

2. Yearly call-off for Acergy Viking of Subsea 7

   The scope of work includes seabed mapping, geotechnical sampling, pre-survey, construction support, light construction, pipeline and subsea structure inspection, trenching support, and light IMR. The work was initially performed by Acergy Petrel, and then the special purpose vessel Acergy Viking took over in third quarter of 2007 (Subsea 7, 2013). The estimated hiring period is 270 vessel days per year.

3. Yearly call-off for Geosund of DOF Subsea

   The scope of work includes seabed mapping, pipeline inspection, lay support, and light construction (gCaptain, 2014). The estimated hiring period is 180 vessel days per year.

All three projects above are managed by Statoil. This is understandable since Statoil is the O&G company who owns most subsea assets on NCS, and thus it needs high vessel availability. In 2012, Statoil already had 490 wells with different generations of subsea equipment (Statoil, 2012). To maintain their subsea assets, other O&G companies on NCS may use spot contracts, or probably use these Statoil frame contracts because many fields on NCS are joint share between Statoil and other O&G companies.

The specifications of the three vessels and some permanent equipment on board the vessels for these Statoil frame contracts are shown in table 3.1.

Parameter	Volstad Surveyor	Acergy Viking	Geosund
Main crane's capacity	70 tons AHC with operating depth up to 2000 m.	100 tons AHC with operating depth up to 2000 m.	100 tons AHC with operating depth up to 2000 m.
Deck area	650 m2	770 m2	720 m2
ROV	1 WROV, 1 mobile WROV with operating depth up to 3000 m.	1 WROV with operating depth up to 3000 m.	2 WROVs with operating depth up to 4000 m.
MHS	No	No	No
RFO support and scale squeeze	No	No	No

Table 3.1 Technical specifications of three vessels for Statoil Survey, Inspection and Light Construction

Currently, the deepest subsea development on NCS is for Aasta Hansteen field at water depth of 1300 m. Since the three vessels above have main crane with operating depth up to 2000 m, it seems that they will find no difficulty to reach subsea assets of all fields on NCS.

However, those three vessels do not have Module Handling System (MHS). Consequently, when doing light construction operation, these vessels need to rely on “over the side” method which is less tolerant to withstand possible adverse weather. Thus, the operability of these vessels for light construction operation can be very low during winter or in the Norwegian Sea and the Barents Seas which historically have challenging weather. As the result, these three vessels mainly perform survey and inspection works.

3.1.2 Inspection, Maintenance and Repair (IMR)

There are currently four main IMR frame contracts on NCS:

1. 5-year firmed contract for Seven Viking of Subsea 7

   The scope of work includes inspection and ROV operation, module replacement on Statoil’s subsea facilities, light construction, scale treatment and pumping operation, RFO operation, and air diving support (Serck-Hanssen, 2013). The hiring period is 365 vessel days per year for the firmed period. Additionally, there are also yearly options after the firmed period ends.

2. 5-year firmed contract for Rem Ocean of Deep Ocean

   The scope of work covers various IMR services on all Statoil operated fields on NCS. The work is initially performed by Edda Flora, and then will be succeeded by the special-built vessel Rem Ocean. The hiring period is 365 vessel days per year for the 5-year firmed period, which will be followed by options for another three years (DeepOcean, 2013).
3. Yearly options for Edda Fonn of DeepOcean

   The scope of work covers various IMR services with estimated hiring period 365 vessel days per year.
4. Yearly options for Edda Fauna of DeepOcean

   In addition to various typical IMR services, Edda Fauna shall also perform scale squeeze operation. The estimated hiring period is 365 vessel days per year.

All four projects above are managed by Statoil. For Statoil, IMR is the subsea emergency and fast response corps. The IMR spreads need to be flexible, readily available to do prompt action and cost conscious (Statoil, 2012).

All four IMR vessels mentioned above are hired for 365 days per year. Thus, Statoil has a high flexibility to use any of these vessels to maintain subsea assets in one of its O&G fields at a particular time, for both planned and unplanned operations.

Other O&G companies use shorter IMR contract because the number of their fields is not as many as Statoil's. They may also cooperate with their joint partners to share IMR contract for particular fields.

The specifications of the four IMR vessels currently used for these Statoil frame contracts are shown in table 3.2.

Parameter	Seven Viking	Rem Ocean	Edda Fonn	Edda Fauna
Main crane's capacity	135 tons AHC with operating depth up to 2000 m.	150 tons AHC with operating depth up to 2000 m.	100 tons AHC with operating depth up to 2000 m.	100 tons AHC with operating depth up to 2000 m.
Deck area	850 m2	1170 m2	700 m2	610 m2
ROV	2 WROVs, 1 OROV	2 WROV, 1 OROV	1 WROV, optional additional WROV/OROV	2 WROVs, 1 OROV
MHS	MHS supporting up to 70 tons and 2000 m.	Yes	MHS interface	MHS supporting up to 60 tons and 2000 m.
RFO support and scale squeeze	Yes	No	No	Yes

Table 3.2 Technical specifications of four vessels for Statoil IMR

IMR offers more capabilities and more complete scope of work than category in section 3.1.1 which mainly focuses on survey and inspection. 3-out-of these four vessels have integrated MHS, while the other one has MHS interface. The MHS supports the vessels to keep working in adverse weather. Integrated MHS enables the vessels to do a wide scope of IMR works in all fields on NCS with high operability along the year.

Edda Fonn does not have integrated MHS. Thus, its main work is to perform ROV-based inspection. Meanwhile, other three vessels mainly perform the following maintenance and repair services:

- Module handling up to 70 tons.
- Light construction and repair.
- Lifting operation.
- RFO support and scale squeeze operation (by Seven Viking and Edda Fauna).

In addition to the IMR projects mentioned above, there is also a special IMR project which has been awarded by Statoil to Technip, but will be started in 2015. This IMR project is special because its main focus is to maintain the world's first subsea compression stations in Åsgard field. North Sea Giant of Technip, the vessel that will install the subsea compression stations by 2015, is contracted for the IMR project. The vessel will be hired for 365 days to maintain several fields operated by Statoil, and will maintain the subsea compression for estimated 5-10 days.

North Sea Giant is a heavy construction vessel equipped with Special Handling System (SHS), a purpose-built system for installation and recovery of heavy subsea compression modules (up to 400 tons). It has 2 WROVs on board and very large main deck area of 2900 m^2. Additionally, the vessel has capabilities to perform well intervention, module handling and coiled tubing intervention.

3.1.3 Diving

Currently, the biggest diving frame contract on NCS is awarded by Statoil to Technip and estimated to have 50 vessel days per year. The scope of work includes diving assistance for maintenance, repair, modification and installation works.

The frame contract utilizes Skandi Arctic, a Diving Support Vessel (DSV) with heavy construction capability. The vessel has main crane's capacity of 400 tons with operating depth up to 2000 m. It has 2 WROVs, 1 OROV and large deck area of 1700m^2. The vessel has no MHS, but has optional Vertical Lay System (VLS) for flowline installation. For diving operation, Skandi Arctic is equipped with 6 chambers for 24 divers and 2 off 3-man diving bells with depth rating of 350 msw (meters of sea water).

3.1.4 Summary of the Current Subsea Asset Maintenance on NCS

Based on the findings in sections 3.1.1 – 3.1.3, the summary of the current practices of subsea asset maintenance on NCS is as follow:

1. Only few frame contracts to maintain all subsea assets.

   The offshore operation of subsea asset maintenance relies on the availability of specialized vessel and equipment. To ensure their availability, the specialized vessel and equipment are hired for specific firmed period per year in the form of medium- to long-term frame contract. The establishment of medium- to long-term frame contract is also due to high volume, i.e. there are enormous amount of subsea assets which O&G company needs to continuously maintain. Consequently, all subsea assets on NCS are maintained through only few frame contracts.
2. Installation and maintenance of particular subsea asset is not necessarily performed by the same subsea contractor.

   Currently, the main frame contracts of subsea asset maintenance on NCS are categorized based on only the scope of work: survey and inspection, IMR, and diving. All main frame contracts are intended to cover subsea assets in all fields operated by Statoil on NCS. Consequently, subsea contractor who installs a particular subsea asset is not necessarily the one who will maintain the asset. DeepOcean, the current market leader of subsea asset maintenance on NCS, in fact traditionally does not perform main installation of subsea assets on NCS.
3. Cooperation among O&G companies to maintain their subsea assets.

   Not all O&G companies have significant number of subsea assets on NCS to justify the establishment of their own frame contract of subsea asset maintenance. Some O&G companies who have joint share with Statoil in particular fields may also use the Statoil frame contracts to maintain their subsea assets.
4. The vessels hired for the current main frame contracts have sufficient technical capabilities to generally maintain existing subsea assets.

   With respect to water depth, the vessels are able to support operation in all current O&G fields on NCS. The current IMR vessels support lifting operation up to 135 tons through “over the side” method, which is less tolerant to withstand possible adverse weather. In order to have a high operability for lifting operation along the year, some vessels are equipped with MHS which supports for up to 70 tons. Additionally, some current IMR vessels are able to perform scale squeeze and RFO support.

3.2 Trend of Subsea Asset Maintenance on NCS

Since subsea asset maintenance is a subsequent phase of subsea asset installation, the trend of subsea asset maintenance on NCS can be identified by analyzing the subsea asset installation projects awarded on NCS in the last ten years.

3.2.1 Main Subsea Asset Installation Projects Awarded on NCS in The Last Ten Years

3.2.1.1 Marathon – Alvheim and Volund Developments, and Norsk Hydro – Vilje Development

Alvheim is an oil and gas field located in the central part of the North Sea and at water depth of 120 – 130 m. The field is developed with a production and storage vessel "Alvheim FPSO" and subsea wells of four fields: Boa, Kneler A and B, and East Kameleon. Each of these fields is small and requires a joint development approach to be economically viable.

Alvheim development uses wet tree well system by installing a 4-slot manifold in the drilling centre of each field. Each manifold has almost identical configuration, size (12m x 19m x 5m) and weight (170 tons in air). The water depth where the fields are located enables diving operation, which is preferable because it is generally cheaper and faster. Since Alvheim development uses diving operation, the manifold is designed to enable access for diver, in particular to perform tie-in operation.

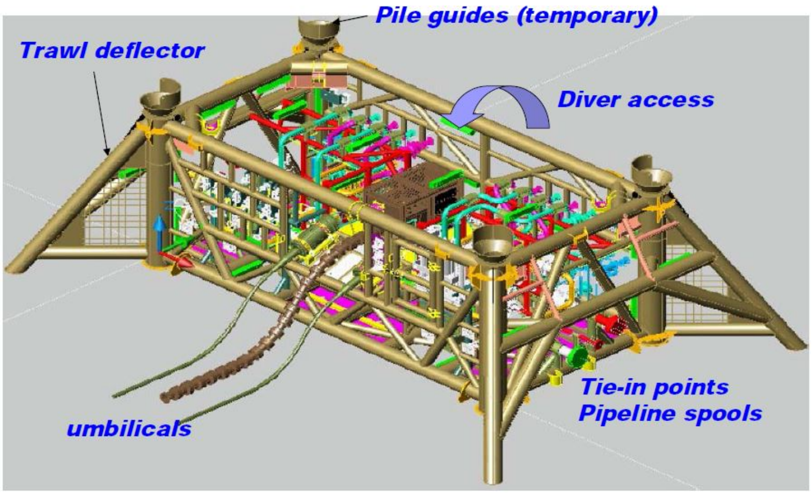

Figure 3.1 Manifold for Alvheim development, roof removed (Burgos, 2006)

All manifolds are tied to the Alvheim FPSO through production flowline and umbilical. The recovery strategy uses active aquifer support and no injection performed into the production reservoir.

From the Alvheim FPSO, oil is transferred to tanker for further processing onshore or direct sales to customers. Meanwhile, gas is transferred through 24 mile of 14" gas export pipeline to the Scottish Area Gas Evacuation (SAGE) pipeline which ends at St Fergus gas plant at the UK.

In total, the length of flowlines installed on seabed for the Alvheim development is 75 km with outer dimensions vary from 4” to 14”. For protection and to mitigate upheaval buckling, rock dumping is performed on some sections of the flowlines.

Meanwhile, Volund is an oil field located about 10 kilometres south of Alvheim. The field is developed as a subsea tie-back to Alvheim FPSO. Since its water depth is the same as the Alvheim’s, Volund development also utilizes diving operation.

Volund development uses wet tree well system by having a 4-slot manifold in the Volund field. The manifold is tied to the Alvheim FPSO through about 10 km of 12” production flowline. Power and control are supplied from Kneler B through 9.2 km of 5” umbilical. Since water injection is used as a recovery strategy for Volund, there is also corrosion resistant water injection flowline from the Alvheim FPSO to the Volund manifold.

In addition to Alvheim and Volund developed by Marathon, there is Vilje developed by Norsk Hydro but is also tied to the Alvheim FPSO. This example of the cooperation among O&G companies is able to minimize each company’s capital expenditure (Capex) in establishing offshore production system and also to minimize operational expenditure (Opex) in operation and maintainance of the subsea assets.

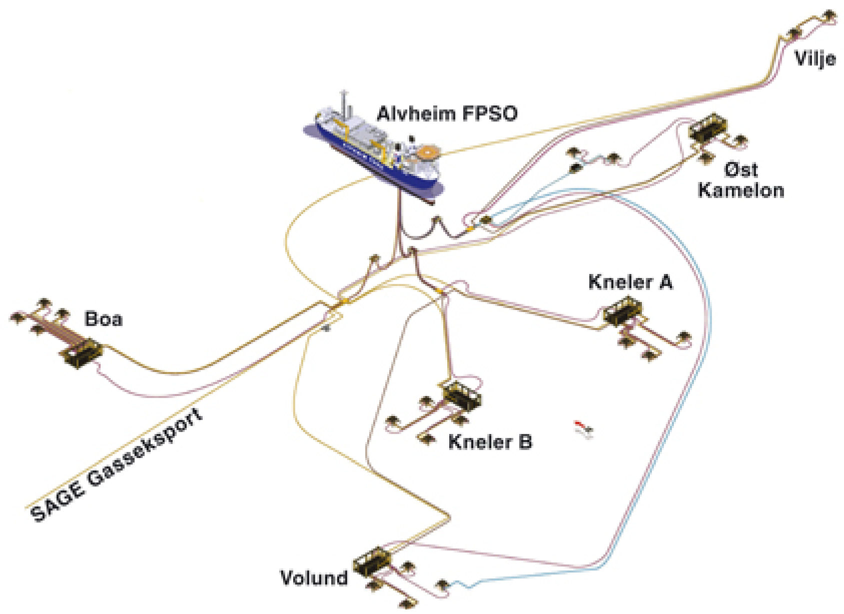

Figure 3.2 Alvheim, Volund and Vilje developments (Norwegian Petroleum Directorate, 2012)

Vilje is an oil field located in the central part of the North Sea and at water depth of 120 m. It is located about 19 km northeast of Alvheim. As of 1 October 2012, the operatorship for Vilje has been transferred from Statoil to Marathon.

Vilje is developed with 2 templates weighting approximately 110 tons each. The field is connected with the Alvheim FPSO through 19 km of production flowline (including riser) and 19 km of umbilical (including dynamic umbilical). The same as Alvheim, Vilje uses water drive for hydrocarbon recovery. However, even though the field is located at the same water depth as Alvheim, Vilje development utilizes ROV for tie-in operation. It is not clear why Vilje development does not utilize diving operation.

3.2.1.2 Statoil – Skinfaks/Rimfaks IOR (Improved Oil Recovery)

Skinfaks and Rimfaks are oil and gas fields located in the northern part of the North Sea, which are part of the Gullfaks village. Both lie at water depth of 130 – 140 m. The Skinfaks/Rimfaks IOR is intended to improve oil recovery of the Gullfaks village.

Skinfaks development consists of 2 new templates: satellite template N5 and template N. Both templates are connected each other through 4.5 km of 8” production flowline and 4.5 km of umbilical. Template N is subsequently tied back to existing templates L/M through 2 off 12 km of production flowlines and a tie-in manifold. The new templates and tie-in manifold provide extra hub for future field developments. Dual production flowlines between template N and templates L/M give a full flexibility of hydrocarbon route from Skinfaks to Gullfaks C platform.

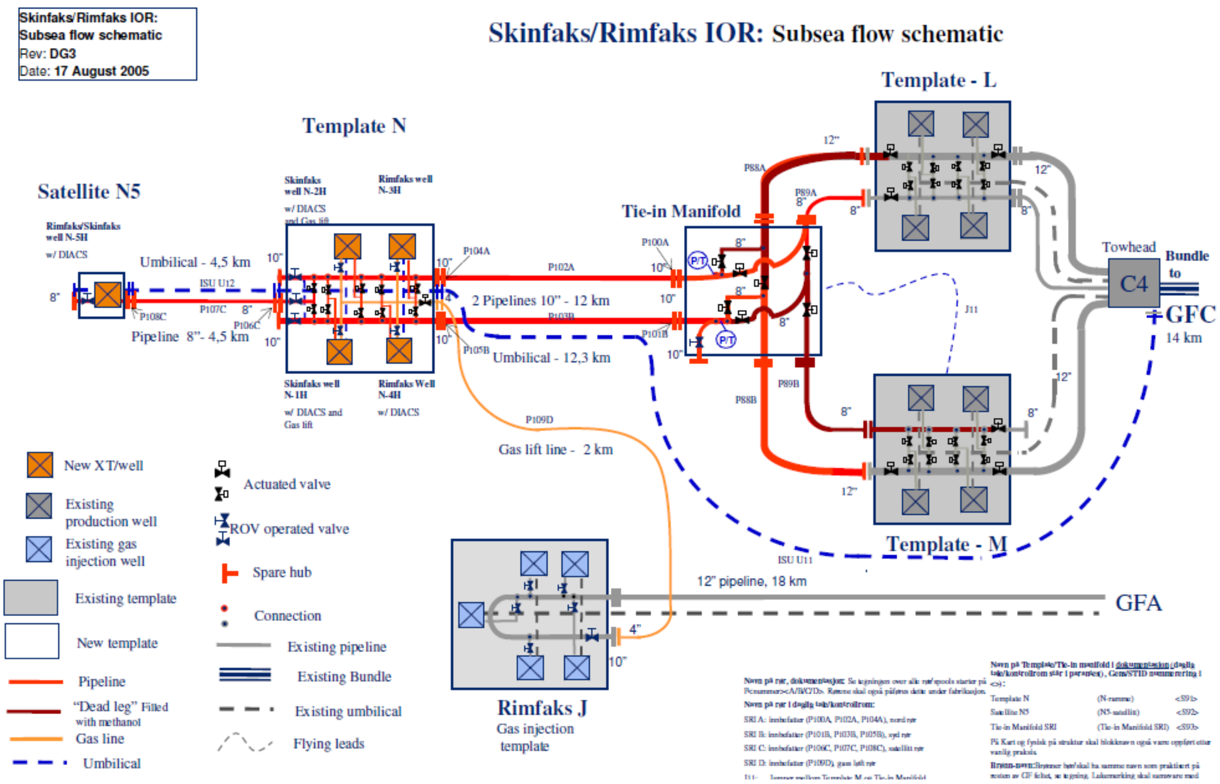

Figure 3.3 Subsea flow schematic of Skinfaks/Rimfaks IOR (Ånes et al, 2006)

Power and control for template N are supplied through 12.3 km of umbilical from existing towhead C4. The towhead C4 is connected through 14 km of bundle to Gullfaks C platform.

Meanwhile, Rimfaks is already operating and has 3 templates: J, I and H. All of the tree templates send hydrocarbon to Gullfaks A platform. The term IOR is introduced because of installation of a new 2 km of gas lift flowline, which injects gas from template J of Rimfaks to template N of Skinfaks.

3.2.1.3 Statoil – Snøhvit Development

Snøhvit is a gas field located in the Barents sea and at water depth of 310 – 340m. Snøhvit is developed by exploiting gas resources from Snøhvit, Askeladd and Albatross fields to be tied back to onshore processing plant 140 km away in Melkøya which processes the gas into LNG, condensate and LPG.

Snøhvit is the first gas development in the Barents Sea and the first major development on NCS where field is directly connected to shore without getting through a fixed or floating platform. Both subsea production system and pipeline transport are monitored and controlled from a control room at Melkøya through fibre-optic cable, high-voltage electrical and hydraulic power lines (Offshore Technology, 2014).

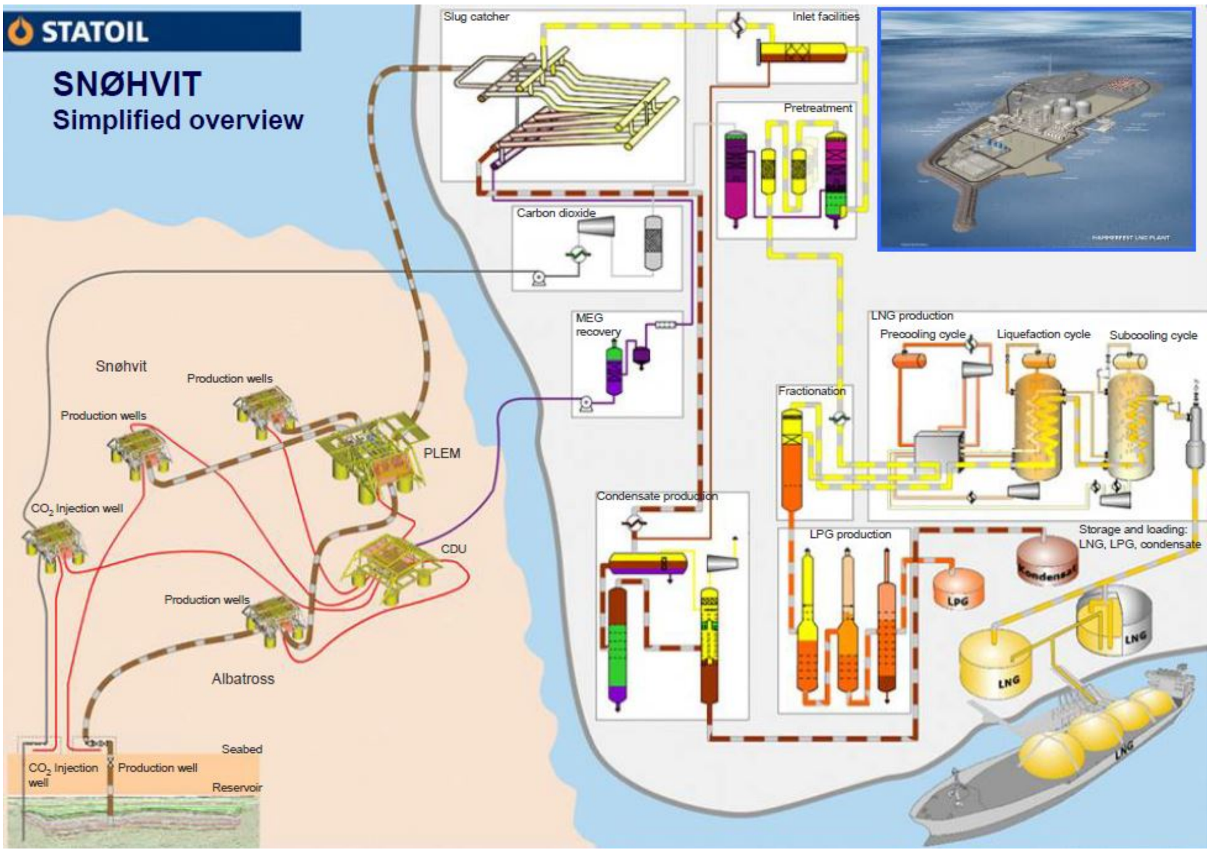

Figure 3.4 Simplified overview of Snøhvit development (Pettersen, 2011)

Produced gas from the three fields is transported through 14” production flowline to Pipeline End Manifold (PLEM), which is connected to the gas plant in Melkøya through 143 km of 27” production flowline. Due to long distance and varying water depth profile (460 to 0 m), maintaining gas pressure and flow assurance are the main challenges for the Snøhvit operation. To maintain gas pressure, the onshore gas plant extracts CO_2 from the produced gas and injects it to Snøhvit field through 160 km of 8” CO_2 flowline.. Meanwhile, to maintain flow assurance, MEG is kept continuously flowing in the production flowlines. MEG is an anti-freeze and anti-corrosion agent which is mixed in with the produced gas before it is transported to reduce the gas’ freezing point, to inhibit hydrates and to have better corrosion protection. MEG is supplied from the onshore gas plant through Control Distribution Unit (CDU), which subsequently supplies MEG to each field through 4” service line.

3.2.1.4 Statoil – Tyrihans Development

Tyrihans is an oil and gas field located in the Norwegian Sea and at water depth of 285 m. It consists of Tyrihans Nord and Tyrihans Sør. Tyrihans is developed as a complete subsea solution tied back to existing installations and infrastructure on the Kristin and Åsgard fields.

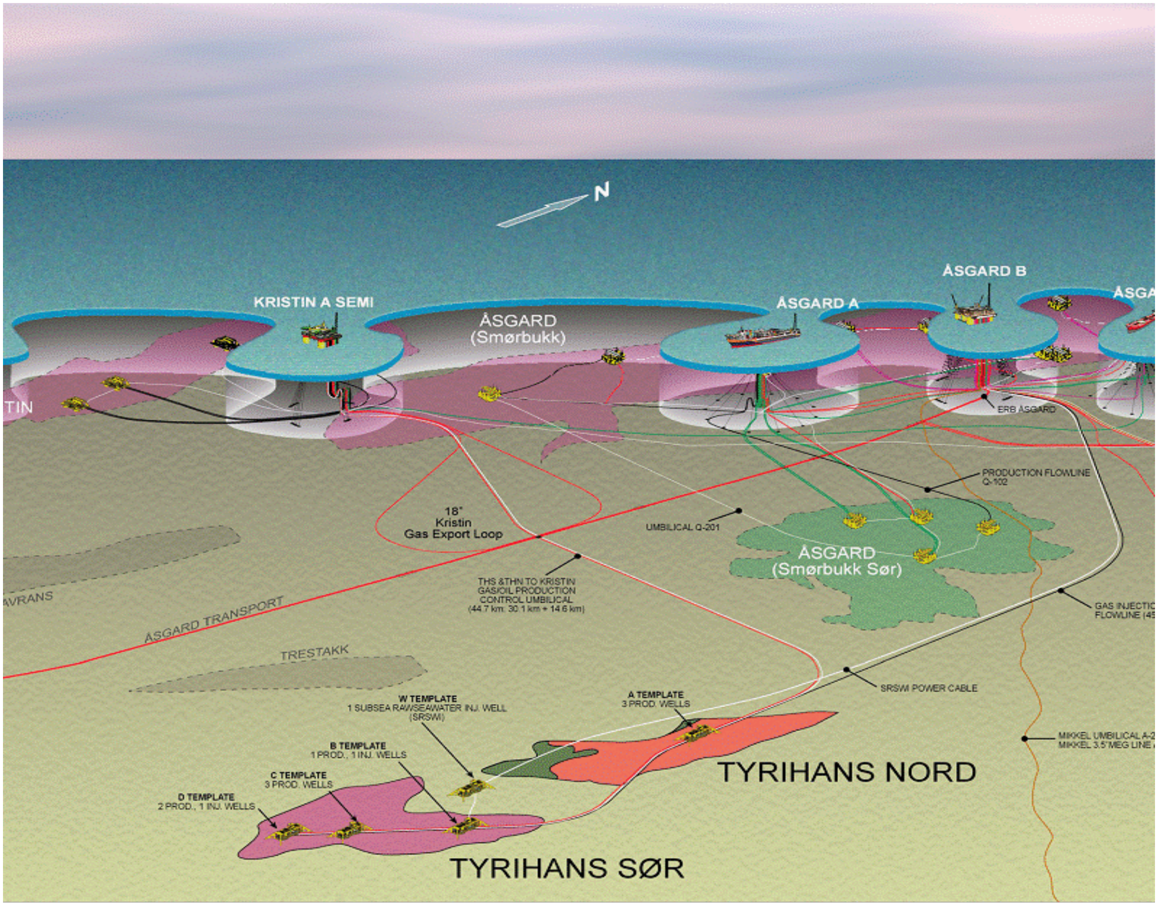

Figure 3.5 Tyrihans field layout (Offshore Technology, 2014)

Tyrihans is developed using 4 off 4-slot templates. The hydrocarbon from Tyrihans is sent through 43 km of BuBi® pipe to Kristin platform for processing. BuBi® pipe consists of two metals which are bonded mechanically, which is cheaper than if using metallurgical bond. The inner pipe is made of high corrosion resistance, while the outer pipe is resistant to high pressure. The BuBi® pipe used in Tyrihans development has inner diameter 16” and outer diameter 18”. The pipe is also equipped with Direct Electrical Heating (DEH) system for hydrate inhibition.

Tyrihans uses gas and sea water injection as the recovery strategy. Gas injection is supplied by Åsgard B platform through 43 km of 10” flowline to the four templates of Tyrihans. In addition, there is fifth template which is intended for only water injection.

3.2.1.5 Statoil – Tordis IOR

Tordis is an oil and gas field located in the northern part of the North Sea and at water depth of around 200 m. Tordis is connected to 10-km-away Gullfaks C to process its produced hydrocarbon. However, the accelerated production from Tordis results in too much water for the production facilities at Gullfaks C to manage. As the mitigation, Tordis IOR project is established to maintain reservoir pressure and manage the amount of water in the production stream.

The main component of Tordis IOR is Subsea Separation, Boosting and Injection (SSBI) station. SSBI station for Tordis IOR is the world’s first of its kind. It separates bulk water from Tordis field and re-injects it into a separate satellite well through a PLEM. Meanwhile, its pump boosts gas and oil from Tordis field to the Gullfaks C platform.

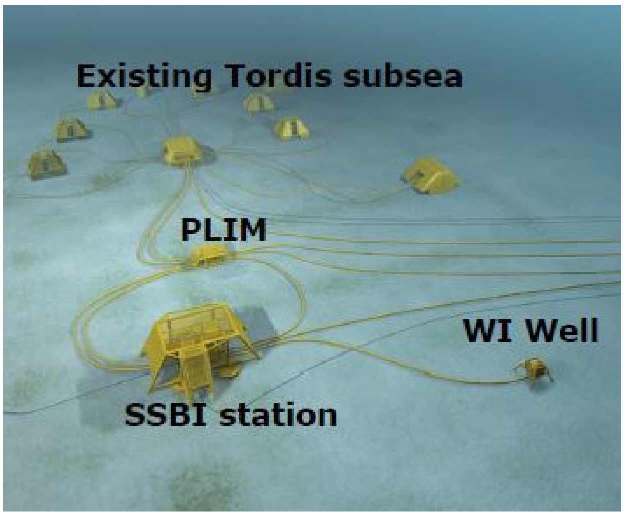

Figure 3.6 Tordis IOR (Gjerdseth et al., 2007)

SSBI station is designed in modular basis with each module can be retrieved individually to ease its maintenance. The station is made of the following six modules: separator, manifold, de-sander, multiphase and water injection pump, water flow, and multiphase meter. The heaviest module is the separator module whose weight is about 250 tons. In total, SSBI station has a dimension 40 x 25 x 19 m and weight 1,250 tons.

To connect SSBI station and existing Tordis Central Manifold (TCM), a Pipeline Inline Manifold (PLIM) is installed. The connection (tie-in) is performed using two diverless solutions: Vetco/KOP and ROVCON MK11.

3.2.1.6 BP – Skarv & Idun Development

Skarv is an oil and gas field, while Idun is primarily a gas field. Both are located in the Norwegian Sea and at water depth of 350 – 450 m. The fields are developed using 5 subsea templates which are connected to the Skarv FPSO. From the Skarv FPSO, oil is exported by shuttle tanker while gas is exported through 80 km of 26” gas export pipeline to the Åsgard Transport System (ÅTS).

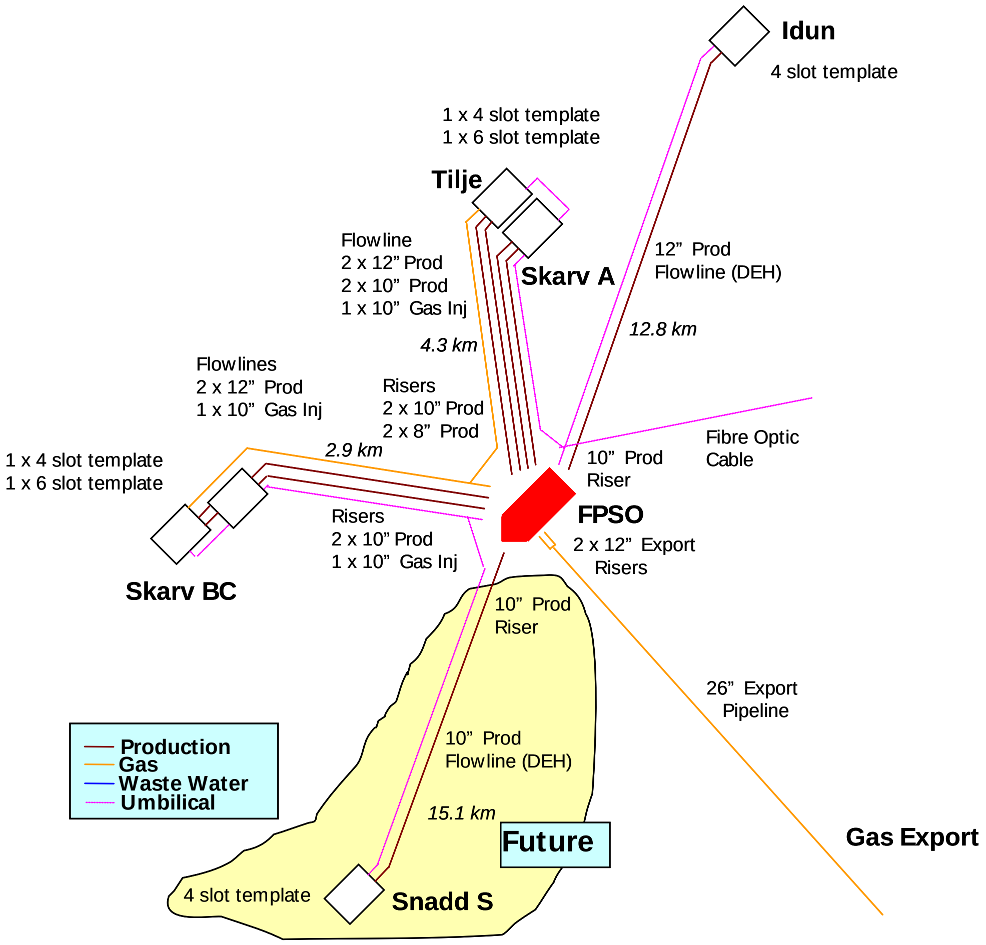

Figure 3.7 Field subsea schematic of Skarv & Idun development (BP, 2007)

As shown in figure 3.7, the 5 subsea templates are called Skarv A, Skarv B, Skarv C, Tilje and Idun. Skarv A is only for production and connected to the Skarv FPSO through 2 off 4.3 km of 10" production flowlines and 2 off 8" production risers. Skarv B receives gas injection from the Skarv FPSO and transfers its production through Skarv C, which is subsequently connected to the Skarv FPSO through 2 off 2.9km of 12" production flowlines and 2 off 10" production risers. Tilje also receives gas injection from the Skarv FPSO and transfers its production through 2 off 4.3 km of 12" production flowlines and 2 off 10" production risers. Idun lies 12.8 km away from the Skarv FPSO and needs a production flowline which is equipped with DEH to inhibit hydrate formation. In addition to these 5 templates, Skarv & Idun development also opens for a future tie-in with the gas field Snadd, which is 15.1 km away from the Skarv FPSO.

The seabed in the field is heavily contoured and scoured. As the mitigation, intensive sea bed intervention including rock dumping is performed.

3.2.1.7 ENI – Goliat Development

Goliat is an oil and gas field located in the Barents Sea, about 50 km southeast of the Snøhvit field, and at water depth of 360-400 m. Goliat may play an important role in the Barents Sea because several new potential oilfields discovered north of Goliat are possibly tied back to the Goliat platform. Goliat development comprises mainly of eight subsea templates, infield flowlines and a circular FPSO, Sevan 1000.

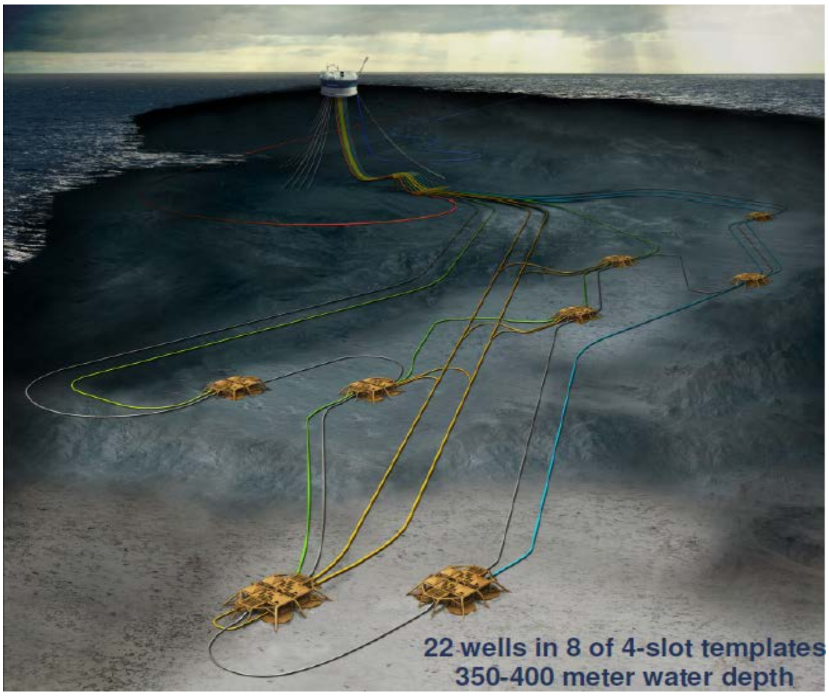

Figure 3.8 Goliat field arrangement (Tangvald, 2010)

The Goliat FPSO will be powered from Hammerfest substation onshore through 1065 km of subsea power cable. The recovery strategy for Goliat is mainly using water injection through 2 off 10” water injection flowline with total length of 17 km. Due to cold climate, 17 km of 12” production flowlines are equipped with DEH for flow assurance. Until a possible gas export pipeline is in place, the produced gas will be re-injected through 7 km of 10” and 9 km of 6” gas injection flowlines.

Arctic condition is the main challenge in the operation of Goliat. Thus, the Goliat development puts very strong focus in safety and environmental aspects. Goliat FPSO and shuttle tankers are specifically designed to withstand extreme winter. The Goliat development also introduces advances oil spill detection by having sensors and detectors on critical equipment, infrared radar surveillance of area, and a stand-by vessel which is powered by gas.

3.2.1.8 Dong – Oselvar Development

Oselvar is an oil and gas field located in the southern part of the North Sea at water depth of 72 m. Oselvar is developed as a subsea tie-back to the 27-km away Ula Platform, which is operated by BP. The extracted hydrocarbon is transported by pipeline to Ula for processing. The gas is used for re-injection to Ula for improved recovery, while the oil is transported by pipeline to Ekofisk for further export to Teeside in UK through the Norpipe system. The injection of produced gas from Oselvar is estimated to be able to double the production lifetime of Ula.

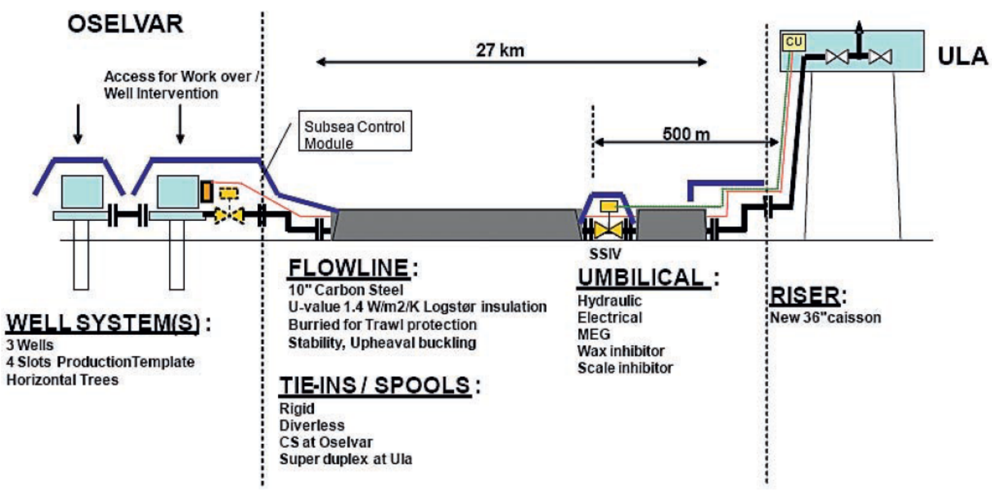

Figure 3.9 Oselvar development concept (Norsk Oljemuseum, no date)

1 off 4-slot manifold is installed in Oselvar and connected to the Ula platform through 27 km of 10” production flowline. Electricity to Oselvar is supplied through 27 km of umbilical, which also supplies chemical flow for flow assurance.

3.2.1.9 Statoil – Marulk Development

Marulk is a gas field located in the Norwegian Sea at water depth of 370 m. Marulk is developed with a subsea template tied back to the Norne FPSO. There is no injection flowline installed since the recovery strategy for Marulk is to use natural pressure relief.

Figure 3.10 Marulk development (Norwegian Petroleum Directorate, 2012)

1 off 4-slot template is installed in Marulk and connected to the Norne FPSO through 30 km of pipe-in-pipe with inner diameter of 10.5”. The Norne FPSO is connected to Kårsto processing plant onshore through Åsgard Transport System. Thus, gas from Marulk is sent to Kårsto for further processing. Additionally, 13 km of umbilical and chemical injection flowline connect Marulk and the Alve field, which is subsequently also connected to the Norne FPSO. For tie-in, diverless operation using ROVCON MkII is performed.

3.2.1.10 Statoil – Skuld Development

Skuld comprises of oil field Dompap and oil and gas field Fossekall. Both are located in the Norwegian Sea at water depth of about 360 m. Skuld is the largest Statoil fast track project. The term fast track refers to standardized solutions to develop small and marginal fields. A fast track project is able to reduce normal development time from typically 5 years to just 2.5 years.

Skuld is developed with three subsea templates tied back to the Norne FPSO. The three templates are template S at Dompap and templates P and R at Fossekall. Each template along with its manifold weighs about 280 tons. Template S at Dompap is connected to the Norne FPSO through 27 km of 12”/14” production PiP (including riser). The Pipe-in-Pipe (PiP) passes through the in-line tee at Fossekall, which means that the 2 templates at Fossekall are also connected to the Norne FPSO through the PiP. For flow assurance, the PiP is equipped with DEH. 3 off DEH feeder cables (including DEH risers) are installed from the Norne FPSO to power DEH system embedded to the PiP.

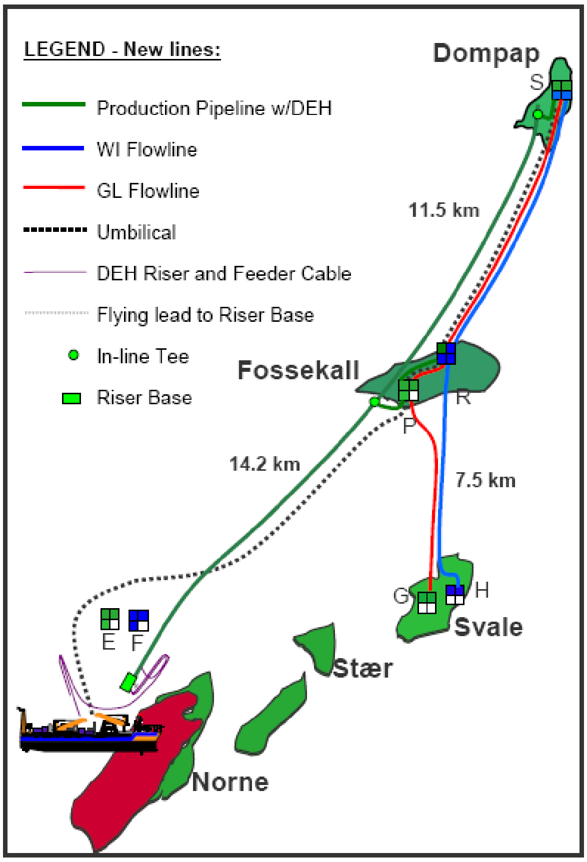

Figure 3.11 Skuld development (Subsea 7, 2012)

Skuld uses both water and gas injections as the recovery strategy. 19 km of 260 mm water injection flowline is installed from template H at Svale to template S at Dompap through template R at Fossekall. Meanwhile, 19 km of 160 mm flexible gas injection flowline is installed from template G at Svale to template P at Fossekall and then continues to template S at Dompap.

3.2.1.11 Statoil – Åsgard Gas Compression

Åsgard comprises of gas field Midgard, and oil and gas fields Smørbukk and Smørbukk South. Åsgard lies in the Norwegian Sea at water depth of 240 to 300 m. The production is done through Åsgard A FPSO for oil production and semi-submersible Åsgard B platform for gas production.

Natural pressure declines as the hydrocarbon production ages. When the gas production rate is too low, surge waves of liquid may also arrive at the platform causing flow instabilities in the processing facilities at Åsgard B. The Åsgard Subsea Compression Project (ÅSCP) is established to maintain the gas production rate from the Midgard and Mikkel reservoirs above a critical minimum. This prevents the liquid (MEG, water and condensate) to accumulate in the pipeline which will decrease the gas production further. The gas compressor does not only maintain minimum production rate, but may also function to increase pressure in the pipeline to increase the production rate.

The Åsgard subsea compression facility is the world's first project of its kind. It comprises of 2 off 11.5 MW subsea gas compressors which will be installed in the field in 2015. The subsea compression system eliminates the need for a new submersible compression platform weighing around 30000 tons. Meanwhile, the subsea compression system consists of a compression station at 4752 tons, 74 m x 45 m x 26 m and a manifold station at 865 tons, 34 m x 27 m x 15 m. Thus, subsea compression system is a cost effective way to improve the recovery rate of Åsgard.

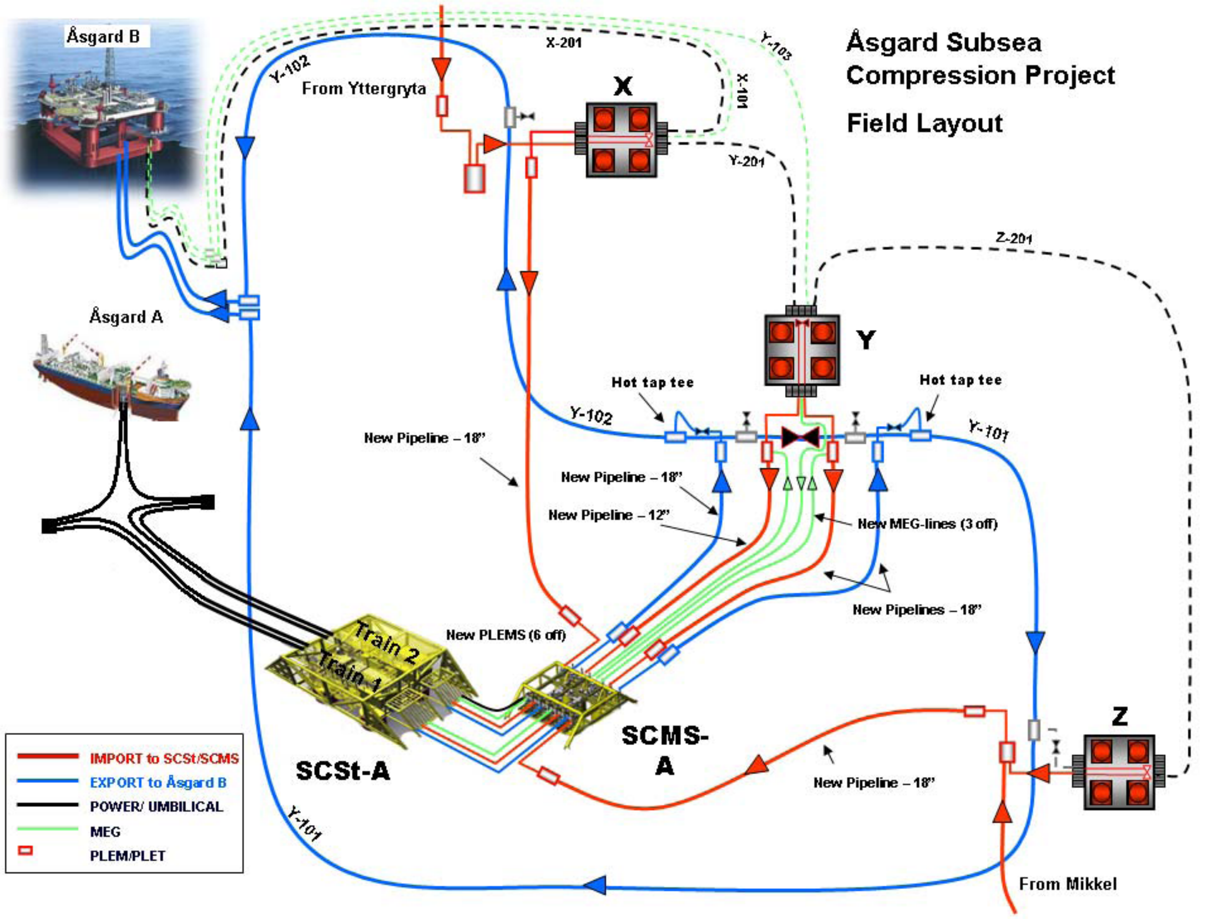

Figure 3.12 Field layout of Åsgard Subsea Compression Project (Vinterstø, no date)

As mentioned in section 3.1.2, the IMR project for ÅSCP has has been awarded to Technip, which will be started in 2015. The IMR project will utilize North Sea Giant, a heavy construction vessel which is able to do well/tubing intervention and recover heavy subsea compression modules.

3.2.1.12 BG – Knarr Development

Knarr (formerly Jordbær) is an oil and gas field located in the northern part of the North Sea and at water depth of 130 m. The field will be developed with subsea wells tied back to the "Knarr FPSO".

Knarr uses water injection as the recovery strategy. Hence, in addition to 1 off production template, there is also 1 off water injection template installed in the field. Each template weighs about 170 tons, and there also a manifold and a template protection structure for each template. The weight of a template protection structure is about 270 tons. The two templates are connected to a manifold towhead that is complete with cooling spools. The 2 km of water injection flowline and umbilical which connect the water injection template to the manifold towhead are protected by rock dumping.

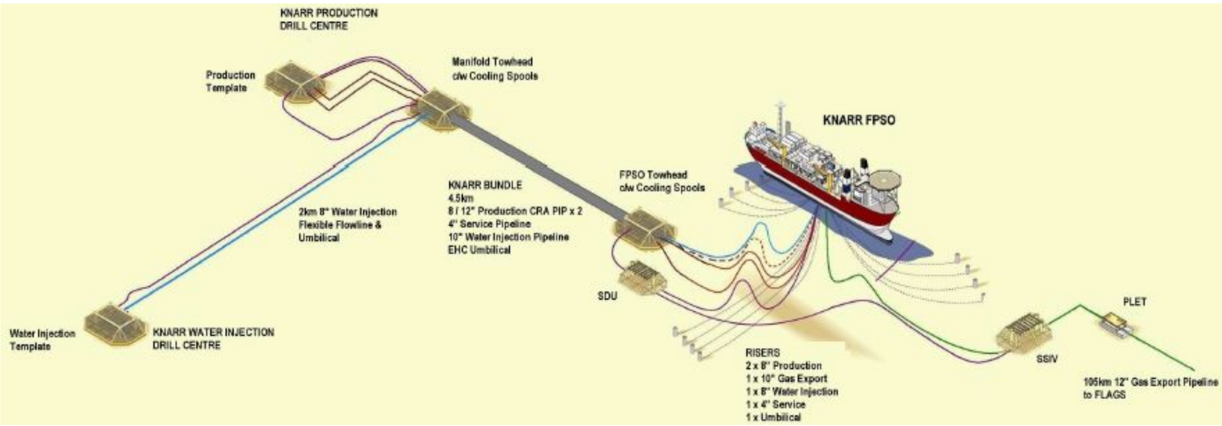

Figure 3.13 Knarr field layout (Eide et al., 2012)

The manifold towhead is part of a 4.5 km bundle which connects the two templates to the Knarr FPSO. The bundle comprises of 2 off 8"/12" production PiP, 10" water injection flowline, 4" service flowline, and umbilical which provides electrical, hydraulic and control signals. Since all lines are packaged in one big integrated pipe, it gives better stability to avoid pipeline walking on seabed. Meanwhile, the casing layers of bundle provide integrated protection and insulation.

From the Knarr FPSO, gas will be exported through 110 km of 12" pipeline tied to the UK's 36-inch FLAGS (Far North Liquids and Associated Gas System), a pipelines system which ends at St Fergus gas plant. There are various crossings along the route of the gas export pipeline, including with Snorre Gas Export Pipeline, Gullfaks Gas Export Pipeline, Statline, and Brent South Pipeline. Meanwhile, oil will be exported through shuttle tankers.

The type of tie-in operation depends on the location. The tie-in will be performed by divers at FLAGS and using ROV solution at other locations.

3.2.1.13 Statoil – Gullfaks Wet Gas Compression (WGC)

Gullfaks is an oil and gas field located in the northern part of the North Sea and at water depth of 130 – 220 metres. To increase the recovery rate on Gullfaks C platform from 62% to 74%, a subsea wet gas compression will be installed on Gullfaks Sør, a satellite field linked to the Gullfaks C platform.

Unlike the one for Åsgard, the subsea gas compression for Gullfaks does not first do separation between gas and liquid, and therefore is called wet gas compression. The wet gas will be compressed on the seabed to make it flow faster to the Gullfaks C platform, where it is processed. This solution will enable more oil and gas to be brought up from the reservoir, and hence improve the field's recovery rate.

Figure 3.14 Wet gas compressor for Gullfaks (Wadel-Andersen, no date)

The subsea wet gas compression for Gullfaks is a solution for small and medium-sized fields because it comprises of only 2 off 5 MW wet gas compressors, which are able to handle a production flow rate up to 10 million standard cubic meters per day. The subsea WGC for Gullfaks comprises of 1 off WGC Station at 400 tons and 20 m x 13.6 m x 9 m, 1 off WGC Protection structure at 320 tons and 38.5 m x 16.6 m x 13.8 m, 2 off WGC modules (2 x 56 tons), and 2 off Gas Coolers (2 x 60-ton hatches and 140-ton side covers). The WGC is designed for moonpool installation.

Power for the WGC will be supplied from Gullfaks C platform through 17 km of Infield Power Service Umbilical (IPSU). The IPSU includes a large Umbilical Termination Assembly (UTA). For protection, the IPSU will be rock dumped.

3.2.1.14 Total – Martin Linge Development

Martin Linge is an oil and gas field located in the northern part of the North Sea and at water depth of 120 m. It will be developed with a platform, a floating storage and offloading (FSO) vessel and gas export facility.

According to Subsea 7 (2013), the Martin Linge platform will be a manned wellhead jacket platform containing integrated wellhead, production and living quarter. Martin Linge will significantly utilize the benefit of IT implementation as its operations will be controlled remotely from shore (Stavanger) via the optical fibers incorporated in the power-from-shore (PFS) cable. As a contingency, there will also be 55 km of fiber optic cable from Huldra platform which connects the Martin Linge platform to the Tampnet communication network. The PFS supplies 145 kV / 55 MW electrical power from 163-km-away power station in Kollsnes, and will be the world's longest subsea high voltage cable.

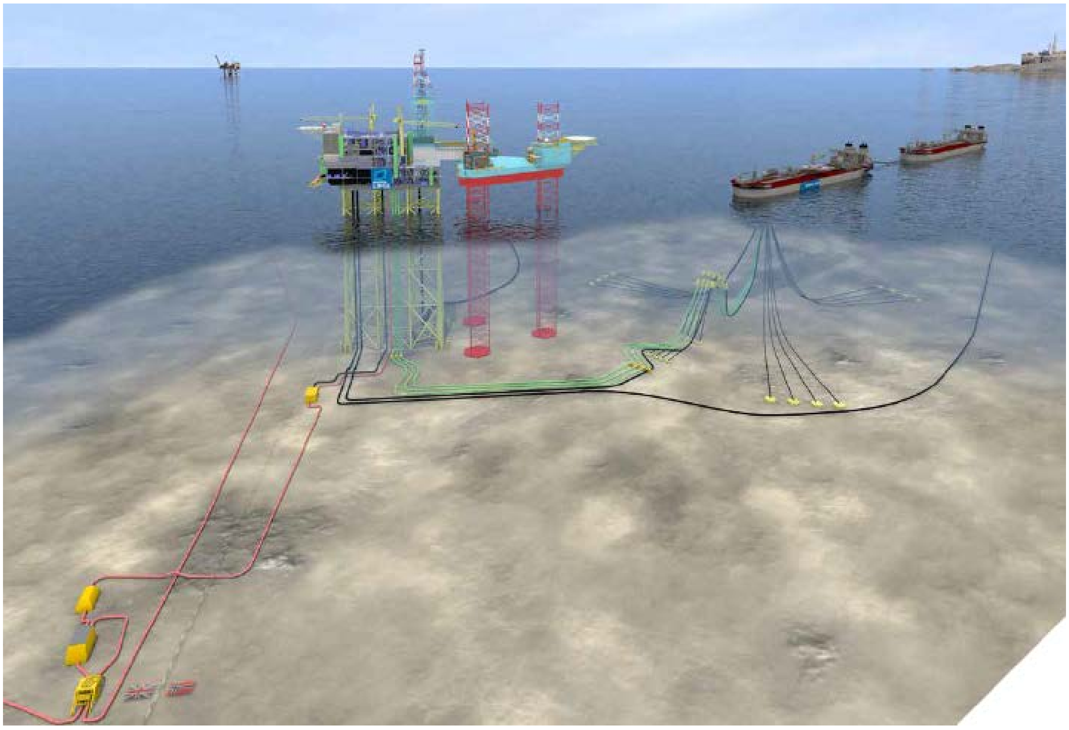

Figure 3.15 Martin Linge development (Subsea 7, 2013)

Extracted hydrocarbon from the field will be processed on the Martin Linge platform. From the platform, gas will be transferred through 70 km of 24" gas export pipeline. The gas export pipeline will be tied to the 32" FUKA pipeline for further transport to the St Fergus gas plant in the UK.

Meanwhile, oil will be transferred from the platform to the FSO which are connected through flexible infield flowlines and risers. The oil will be transported further to shore by vessel tankers.

3.2.1.15 Statoil – Aasta Hansteen Development

Aasta Hansteen comprises of gas fields Aasta Hansteen, Haklang and Snefrid, which are located in the Norwegian Sea at water depth of 1300 m and about 300 km to shore. Aasta Hansteen development is the frontier of deep water development on NCS, which involves Steel Catenary Riser (SCR) system and the world's largest Spar platform to respond to the challenges of deep water installation in harsh environment. Aasta Hansteen will be developed with three templates tied to the Spar, while the rich gas will be exported through the Polarled flowline to Nyhamna.

Figure 3.16 Aasta Hansteen field layout (Subsea 7, 2013)

2 off 4-slot templates will be installed in Luva and Haklang. Additionally, 1 off 1-slot template will be installed in Snefrid Sør and act as a satellite structure to the template in Haklang. 2 off 12” production flowlines will connect Luva to the Spar, while 1 off 12” will be installed between Haklang and the Spar.

The connection between the infield flowlines on seabed and the Spar will be SCR, which has high resistance to internal and external pressure, large diameter, and economically attractive since it is mainly made of steel. In total, there will be four SCR installed for Aasta Hansteen: 3 off 12.75” SCR to accommodate the three production flowlines from Luva and Haklang, and 1 off 14” SCR for gas export which will be subsequently connected to a 480-km gas pipeline to a Shell-operated gas plant at Nyhamna. For data communication, there will also be 140 km fiber optic cable installed from the Norne platform to Aasta Hansteen.

3.2.2 The Findings Which Determine the Trend of Subsea Asset Maintenance on NCS

The findings on the main subsea asset installation projects awarded on NCS in the last 10 years which determine the trend of subsea asset maintenance on NCS are summarized as follows:

1. Joint development of several fields

   In order to minimize development costs and optimize existing infrastructure, some fields are jointly developed. Alvheim FPSO was installed to initially serve as the production platform for the Alvheim development. Later, Marathon developed Volund which was also tied to the Alvheim FPSO. Afterwards, Norsk Hydro also used the Alvheim FPSO as the production platform for its Vilje development (now, Vilje is also operated by Marathon).

   Due to strongly connected infrastructure, subsea asset maintenance in one field may affect the activities/maintenance in other field. Furthermore, since the fields are operated by the same O&G company and located relatively close to each other, it is natural to have one contract for subsea asset maintenance in those fields.

2. Joint development by several O&G companies

   The fields which are jointly developed are not necessarily owned by the same O&G company. Dong developed Oselvar by tying it to the Ula platform operated by BP. Statoil operated Aasta Hansteen will have its gas production transferred to a Shell-operated gas plant at Nyhamna. Therefore, joint subsea asset maintenance contract among O&G companies becomes more important.

3. Continuous usage of both diving and non-diving methods for offshore operation.

   It is not uncommon that one offshore production system development may use both diving and non-diving methods. BG – Knarr development uses mainly non-diving method i.e. ROV-based method for all tie-ins, except the tie-in of its gas export pipeline to the UK's 36-inch FLAGS which is done by divers. Diving offers quicker response and can be a cheaper method, but has limitation with respect to scope of work and water depth. Meanwhile, non-diving method has technical capabilities to perform wider scope of work and is able to work in very deep water. Thus, both diving and non-diving will be continuously used for subsea asset maintenance.

4. Increasing trend of the installation of subsea assets, in particular subsea processing system.

   Some examples of subsea processing system which have been or will be installed are 1250-ton SSBI station for Tordis, 5500-ton subsea gas compression system for Åsgard, and 1100-ton wet gas compression system for Gullfaks. Consequently, there may be a need to have specialized subsea asset maintenance for these unique subsea structures.

5. More pipe alternatives for flowline.

   Flowline choices are now not only simply rigid and flexible pipes. Statoil – Tyrihans development uses BuBi® pipe which is made of two pipes bonded mechanically. Statoil – Marulk development uses PiP for its production flowline, which offers better insulation system than ordinary coated pipe. BG – Knarr development uses bundle which incorporates various pipes, umbilical and supporting systems in one big pipe package. Since its variety increases, maintaining flowline becomes more technically challenging.

6. Power from shore becomes more common.

   More subsea facilities are installed in the field, which creates a need to have a plant to supply huge electrical power to the field. Developing a big power plant in the field is not cost effective as it requires a very big platform. Meanwhile, existing platform in vicinity may not have sufficient capacity to supply the required electrical power. As the mitigation, supplying power from shore becomes more common, such as for ENI – Goliat and Total – Martin Linge development. Therefore, the object of subsea asset maintenance also now includes very long cable from shore which supplies high voltage electrical power.

7. Information technology utilization to enable remote operation.

   Production operation in Snøhvit field is controlled remotely from a control room at Melkøya through fibre-optic cables. Total – Martin Linge development will also intensively utilize IT as its operation will be controlled remotely from shore (Stavanger) via optical fibres incorporated in the PFS cable. Thus, the object of subsea asset maintenance also now includes subsea fibre-optical cables.

8. More focus on flow assurance.

   As mentioned in Horn Publishing (2013), there has been a constant pressure to increase the recovery rate from fields on NCS. Rather than using conventional pig system, flow assurance activities need to be performed more frequent. Additionally, deeper water depth or significantly varying water depths of one offshore production system has driven the installation of a heating system embedded to flowline for flow assurance. Thus, in addition to performing more frequent flow assurance activities, subsea asset maintenance also needs to be able to maintain flow assurance systems such as the heating system.

9. More active development in the Norwegian Sea and the Barents Sea

   This area has harsher weather and less-developed infrastructure than the North Sea, which are technically challenging for the offshore operation. Moreover, the Barents Sea is an environmental-sensitive area, and hence the offshore operation in this area should be performed carefully.

4. LIFE OF FIELD

4.1 Subsea 7

Subsea 7 is a global leader in seabed-to-surface engineering, construction and services to offshore energy industry worldwide. Subsea 7 is traditionally known as a global subsea contractor focusing on subsea asset installation with its expertise lies on the following capabilities (Subsea 7, 2014):

- Flowline fabrication: rigid (including pipe-in-pipe) and bundle.
- Flowline installation: rigid reel-lay, J-lay, S-lay, flex-lay and bundle-lay.
- Construction: supported by a wide range of construction vessels and storage facilities.
- Diving services and remote intervention: supported by a number of diving support vessels and extensive ROV.
- Heavy lift: up to 5000 tons.

The wide range of expertise enables Subsea 7 to deliver high-quality services which now are focused in the following four core segments (Subsea 7, 2014):

1. SURF (Subsea, Umbilical, Riser and Flowline)

   SURF installation is traditionally the main expertise of Subsea 7, which is supported by a wide range of vessels and equipment. As O&G companies now tend to package SURF into EPIC framework, Subsea 7 responds to this change by optimizing its non-vessel assets, including the offshore base and fabrication yard.
2. Life of Field

   The expertise developed during subsea asset installation gives Subsea 7 strong organizational and technical capabilities which enable the company to provide high quality subsea asset maintenance services. In Subsea 7’s terminology, the subsea asset maintenance services refer to Life of Field (LoF). Its status as the largest saturation diving company in the world and one of the largest global ROV operators also gives Subsea 7 strong advantages in this segment.
3. Conventional

   This segment refers to conventional subsea assets deployed in shallow water environment. The scope of work includes fabrication, installation and refurbishment of fixed platforms and associated pipelines.
4. Hook-up

   This segment refers to installation of modules on new platforms and the refurbishment of topsides of existing fixed and floating platforms.

4.2 Life of Field (LoF)

As mentioned in section 4.1, Life of Field (LoF) is one of the Subsea 7's core segments. It refers to various subsea services that O&G companies require once a field has started production. LoF's objective is to optimize production, improve efficiency and maximize the value of subsea assets by making additional investments to recover incremental reserves (Subsea 7, 2014).

Integrity Assurance		Intervention	Incremental Capex
Integrity Management		Specialist Tooling	FEED/Design
Data Management		Handling Equipment	Procurement & Logistics
Inspection & Survey Services		Flexible Risers - Inspection & Intervention Tooling	Installation
Survey & Positioning		Deepwater Mooring - Inspection & Intervention Tooling	Commissioning
Inspection	AIV	Diving Intervention	
Maintenance	ROV		
	Diving		

Figure 4.1 LoF categories in Subsea 7 (Cawson, 2010)

As shown in figure 4.1, LoF in Subsea 7 is grouped into three categories: Integrity Assurance, Intervention, and Incremental Capex. The grouping is based on the scope of work, in particular the type of offshore operation that the LoF performs. Figure 4.1 also shows typical discrete services associated with each category. The details of the categories are described in sections 4.2.1 – 4.2.3.

4.2.1 Integrity Assurance

This category refers to planned actions to assure the structural and operational integrity of subsea assets. As shown in figure 4.1, the discrete services of integrity assurance offered by Subsea 7's LoF range from simple inspection or planned maintenance operation performed by Autonomous Inspection Vehicle (AIV), ROV or diving to a comprehensive integrity management.

Survey and positioning are associated with seabed mapping and subsea assets mapping. Seabed mapping is typically performed during pre-installation to determine feasible flowlines routing and required seabed intervention prior to the installation of subsea assets. It can also be performed during operation of subsea assets to look for seabed condition changes which may affect the integrity of the subsea assets. Meanwhile, subsea assets mapping are done to map the locations of subsea assets on seabed. It is typically performed for as-built survey to determine whether a particular subsea asset has been installed in the correct location.

It is not uncommon to combine survey and inspection. In addition to the survey to locate the position of subsea assets, inspection can also be performed to determine the condition of those assets. Inspection can be performed by either AIV, ROV or diving. The method to be used is usually determined by the water depth of which the subsea asset is located. The inspection methods can be visual using camera, or utilizing several NDT tools such as specialized electrical and magnetic tools for subsea NDT.

As indicated in DNV (2014), integrity assurance relies on continuously updated data management. Thus, LoF also offers a discrete service to maintain updated data of subsea assets to be incorporated into a data management system to enable correct maintenance plans and actions.

In order to provide comprehensive benefits of integrity assurance, LoF offers integrity management, which integrates the discrete services that have previously been described. The work flow of integrity management is presented as integrity assurance cycle as shown in figure 4.2.

Figure 4.2 LoF integrity assurance cycle (Subsea 7, no date)

Integrity assurance cycle shows that the critical deliverable of integrity management is Integrity Management System (IMS), a data management system which allows users an instant access to bathymetric data, condition of subsea assets, pipe track, inspection events, and digital video. Hence, first, IMS shall be established using standard data format. In order to maintain it, IMS shall be easily accessible and updated from onshore and offshore.

Based on the guidance from the manufacturers of subsea assets and combined with the knowledge regarding installation operation of those subsea assets, the criteria and procedures of annual inspection and planned maintenance are defined in IMS. Once the definition is set up, inspection plan can be established, which incorporates information such as schedule and the supporting spread (vessel, equipment and crew) that will perform the inspection and planned maintenance. Afterwards, the offshore spread executes the inspection plan according to IMS, and then generates report of their findings to be stored back to IMS.

The latest data in IMS which has incorporated the findings from the offshore spread are assessed and analyzed by integrity assurance team onshore. The team will determine if there is any need for action and intervention. Any recommendation from the team is inputted to IMS, and then the updated IMS will be used as a starting point for another integrity assurance cycle. Meanwhile, a recommendation to do intervention will be sent to the intervention team. The communication between the integrity assurance team and the intervention team is ideally performed through the same IMS.

4.2.2 Intervention

Based on the input from the integrity assurance team, there may be a need to do intervention. The term intervention refers to unplanned actions to mitigate identified failure or anomaly that may have adverse impact to the integrity of subsea assets.

As shown in figure 4.1, the discrete services of intervention offered by Subsea 7’s LoF vary, including specialist tooling, handling equipment, and diving intervention. Specialist tooling is required to do various interventions to subsea assets. For example, scale squeeze operation utilizes specialized pumping spread including injection hose in balanced flexible configuration to inject chemicals from vessel into subsea connection point to dissolve and remove scale build-up inside production tubing of subsea wells (DeepOcean, no date). Specialized handling equipment such as MHS may be needed to do modular recovery and installation, for example to replace control module, or to recover and re-install tree of subsea well. Meanwhile, diving intervention can be performed, for example to repair valves or to weld pipeline in shallow water.

The work flow of intervention is presented as intervention cycle as can be seen in figure 4.3. The intervention cycle starts when the intervention team receives a recommendation to do intervention from the integrity assurance team. In reality, both integrity assurance team and intervention team may be the same team, i.e. the IMR team do both integrity assurance cycle and intervention cycle.

The intervention team receives a notification that a failure or anomaly occurs which needs to be mitigated by performing intervention. There may be more than one failure/anomaly at the same time which may occur at various subsea assets and at various locations. Additionally, intervention can be time consuming and very costly. Thus, the intervention team needs to assess the impact of the failure/anomaly and determines the prioritization.

Figure 4.3 LoF intervention cycle (Subsea 7, no date)

Once an intervention is decided, a plan for further inspection may be established to validate the findings. Afterwards, further inspection is executed and then reported. These two steps can be eliminated to make the process more efficient if the integrity assurance cycle and the intervention cycles are performed by the same team/subsea contractor, or managed through the same IMS.

The intervention team does assessment of the findings and then develops possible solutions to mitigate the failure/anomaly. The team screens various possible solutions and chooses the best one with respect to technical reliability, schedule and cost. Afterwards, an intervention plan is established, including specifying the schedule and supporting spread (vessel, equipment and crew) that will do the intervention.

The intervention of subsea assets is performed by supporting spread. The result of the intervention is inspected to ensure that the failure/anomaly has been successfully mitigated.

The inspection data (prior and after intervention) and intervention actions are reported through IMS. Afterwards, the intervention team signs off the case and updates IMS, which will be used as a starting point for another intervention cycle.

4.2.3 Incremental Capital Expenditure

The main idea of this category is to offer LoF spread to do incremental capital expenditure for incremental development in a particular field. The LoF spread has the following two advantages compared to SURF spread (Subsea 7, no date):

1. The LoF team has been maintaining the field in 24/7 basis. Consequently, they have better knowledge regarding the field and the associated subsea assets, and hence are able to execute projects which fit better within ongoing operation.
2. The LoF spread is usually hired for a long period using a frame contract. Consequently, it offers better cost structure than SURF spread. Additionally, the LoF spread does not offer premium construction capabilities, and hence can be a cost-efficient solution for a number of incremental field developments.

As shown in figure 4.1, there are various discrete services of incremental field development offered by Subsea 7’s LoF: FEED study, procurement and logistics, installation, and commissioning. Front End Engineering Design (FEED) study is a critical step in field development. The FEED study for incremental development of a field will be more detailed and accurate if it is performed by the LoF team who has been maintaining the field in a continuous basis.

There are procurement and logistics activities associated with incremental field development. The LoF team, in particular if its company has strong EPCI organization, will be able to offer better supporting team to procure and mobilize required products for incremental development in a particular field.

Incremental field development involves installation of new subsea assets. Since LoF spread usually has better cost structure than SURF spread, it is more beneficial to use the LoF spread for the installation work within the spread’s capabilities.

Commissioning is needed to ensure the readiness for operation of the newly installed subsea assets. Some LoF vessels are equipped with ready for operation (RFO) support capability. Thus, utilizing existing LoF spread for commissioning support may be the best solution for incremental development of a particular field.

4.2.4 Interconnection within LoF Services and LoF Categories

As indicated in sections 4.2.1 – 4.2.3, the full benefits of LoF services will be exploited if the services are integrated. It means that rather than contracting a number of individual LoF discrete services, it would be beneficial for O&G companies to contract LoF integrated service, which is an integration of various LoF discrete services and/or LoF categories.

LoF integrated services is advisable because various LoF discrete services and/or LoF categories are essentially strongly interconnected. The interconnection exists not only between discrete services in the same LoF category, but also between LoF categories.

The Statoil IMR frame contracts mentioned in section 3.1.2 are contract examples of LoF integrated service. The subsea contractor that is awarded the contract needs to perform various LoF discrete services to ensure that particular subsea asset functions well. The LoF discrete services are connected to each other as they are glued by the same project management and engineering.

<table>
<tr><td>Integrity Service</td><td>Intervention Service</td><td>Incremental Capex Service</td></tr>
<tr><td colspan="3">Flexible Pipe System Service
Rigid Pipe System Services
Subsea Structure System Service
Control System Service</td></tr>
<tr><td colspan="3">Project Management & Engineering</td></tr>
</table>

Figure 4.4 Integrated LoF services (Cawson, 2010)

For example, to ensure that a rigid pipe system functions well, first, the subsea contractor needs to do pipe inspection (which is an integrity service). If a leak is found on the pipe, the mitigation may be having the contractor do pipe welding (which is an intervention service). The mitigation may also be having the contract procure and install a new pipe section (which is an incremental capex service).

4.2.5 LoF Vessels and Equipment

The offshore operations of LoF projects are mainly performed by LoF vessels. Currently, there are seven LoF vessels in Subsea 7's fleet. The technical specifications of those vessels are shown in table 4.1.

All vessels in table 4.1, except Grant Candies and Ross Candies, are frequently used for offshore operation on NCS. Additionally, since many subsea assets on seabed are protected using trenching or/and rock dumping, there is also Skandi Skansen which is frequently utilized for LoF offshore operation. Skandi Skansen is a medium construction vessel with 250 tons main crane's capacity and has large deck area of 1070 m^2 to accommodate big trenching equipment.

Parameter	Seven Petrel	Acergy Viking	Normand Subsea	Havila Subsea
Main crane's capacity	20 tons AHC with operating depth up to 1500 m.	100 tons AHC with operating depth up to 2000 m.	140 tons AHC with operating depth up to 2000 m.	150 tons AHC with operating depth up to 2000 m.
Deck area	350 m2	770 m2	705 m2	600 m2
ROV	1 WROV	1 WROV	2 WROV	2 WROV, 1 OROV
MHS	No	No	MHS supporting up to 60 tons and 1200 m.	MHS supporting up to 60 tons and 1000 m.
RFO support and scale squeeze	No	No	Yes	No

Parameter	Seven Viking	Grant Candies	Ross Candies
Main crane's capacity	135 tons AHC with operating depth up to 2000 m.	165 tons AHC with operating depth up to 3000 m.	110 tons AHC with operating depth up to 3000 m.
Deck area	850 m2	820 m2	3280 m2
ROV	2 WROV, 1 OROV	2 WROV	2 WROV
MHS	MHS supporting up to 70 tons and 2000 m.	No	No
RFO support and scale squeeze	Yes	No	No

Table 4.1 Technical specifications of LoF vessels

Some LoF vessels are equipped with MHS to enable high operability on NCS along the year. The currently most advanced LoF vessel is Seven Viking which has MHS that supports module handling up to 70 tons and 2000 m water depth. Thus, Seven Viking can have high operability to support all current O&G fields on NCS.

Figure 4.5 Seven Viking (Ship Technology, 2014)

Additionally, Subsea 7 has i-Tech division, which is specialized in subsea intervention technology, in particular for deep water and harsh environment. It has various ROV spreads and also AIV which can be used to support LoF operation. Unlike ROV, AIV is not powered and controlled through wire. It carries its own battery power source for up to 24 hours autonomous inspection and potential intervention. Since it does not need control wire from the host, it has enhanced maneuverability and the capability to access confined spaces.

To support offshore operation on NCS, Subsea 7 has three logistics bases in Norway, which are located in Dusavik (Stavanger), Kristiansund and Oslo. The bases are used to store Subsea 7's equipment and can also be used for vessel mobilization and demobilization.

5. ANALYSIS

5.1 Criterions of the Future Subsea Asset Maintenance on NCS

The findings in section 3 give an overview of the future subsea asset maintenance on NCS. In order to have a structured approach to ease the later analysis in section 5.2, Moreno-Trejo et al. (2012) is used to map the findings from section 3. As shown in figure 5.1, Moreno-Trejo et al. (2012) maps several success factors which influence the installation and maintenance of offshore production system.

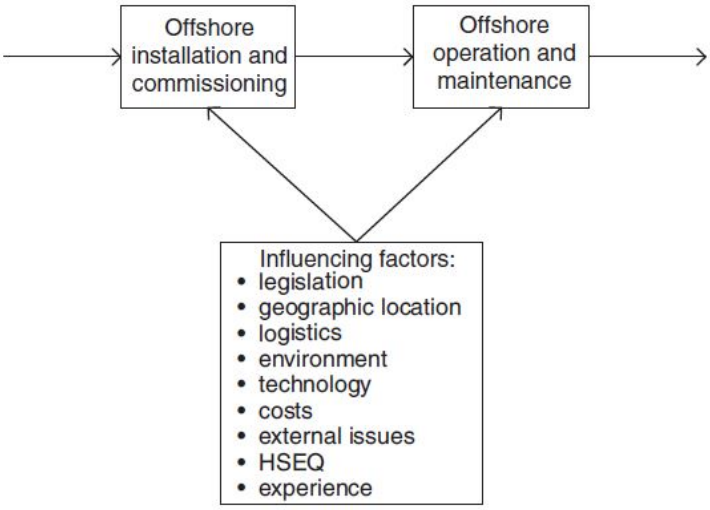

Figure 5.1 Success factors of the installation and maintenance of offshore production system (Moreno-Trejo et al., 2012)

HSEQ, legislation and external issues are not discussed in this thesis. Geographic location refers to local presence and local content, which are also not discussed in this thesis. Thus, the criterions of the future subsea asset maintenance on NCS are described as follows:

1. Logistics – increasing need to have reliable logistics up north NCS.

   More active development in the Norwegian Sea and the Barents Sea which have relatively less-developed infrastructure than in the North Sea creates an increasing need to have reliable logistics to support subsea asset maintenance in the area. The logistics reliability which is combined with the offshore spread's availability and capability are essential to ensure that high quality subsea asset maintenance can be delivered and even with a possible short lead time.

2. Environment – high operability in harsher weather and with increasing focus on environmental aspect.

   Increasing number of subsea assets and wider area of operation on NCS create a need to have the offshore spread that has high operability and can withstand harsher weather than the one that the spread typically faces in the North Sea. Additionally, more active development in the environmental-sensitive Barents Sea pushes O&G companies to have more focus on the impacts of offshore production to the environment, including emphasizing more prevention actions to be embedded into offshore operation. Consequently, subsea asset maintenance strategy and practices will be more environmental-conscious.

3. Technology – increasing technology complexity.

   In order to respond to increasing challenges in offshore production, the offshore production system is more dependent on technology than before. The increasing technology complexity includes growing use of subsea processing system and power from shore, more pipe alternatives available for flowline, extensive IT utilization to enable remote operation, and more focus on flow assurance. Consequently, subsea asset maintenance should also be equipped with appropriate technology to maintain various more-complex-technology subsea assets.

   There may be a need to change the strategy and practices of subsea asset maintenance. One of the required changes may be establishing a stand-alone contract to maintain several technology-breakthrough subsea assets, in particular subsea processing systems.

4. Costs – constant need for cost efficiency.

   Due to increasing number of subsea assets to maintain, the need for cost efficiency will be continuously enforced. Several fields are jointly developed and their subsea asset maintenance is managed through the same contract. Furthermore, several jointly-developed fields are not owned by the same O&G company, which opens an opportunity for several O&G companies to establish a joint contract to manage their subsea assets.

   On the other side, subsea contractors are also expected to manage their costs as they will directly drive the costs of subsea asset maintenance. The cost efficiency initiative may also drive more frequent involvement of subsea asset maintenance spread for incremental field development.

5. Experience and competence – increasing need to have integrated experienced and competent subsea asset maintenance spread.

   Due to increasing technical complexity, sufficient experience and competence are needed more than before in order to produce high quality, effective and efficient subsea asset maintenance. Subsea contractors need to have experience and competence which are able to cover various subsea assets and various methods, e.g. diving and non-diving. The experience and competence are not necessarily developed in house. They can also be acquired through strong partnership with 3rd parties. Thus, there will be more active involvement of 3rd parties, not only during execution, but also when setting up the strategy. The experience and competence should also be able to streamline the maintenance strategy carried over from subsea installation phase to ensure that the strategy and operation of subsea asset maintenance are inline with the O&G company's objectives. Thus, there may be a need to have an integrated subsea asset installation and subsea asset maintenance, i.e. both phases are performed by the same contractor. Consequently, IT utilization will be more extensive as it can function as a collaboration tool between those two phases.

5.2 The Fitness of LoF to the Future Subsea Asset Maintenance on NCS

The analysis in section 5.1 has mapped the criterions of the future subsea asset maintenance on NCS. Thus, the fitness of LoF to the future subsea asset maintenance on NCS will be analyzed by comparing the criterions against the findings in section 4.

<u>Logistics – increasing need to have reliable logistics up north NCS</u>

Subsea 7 has logistics bases in Dusavik, Kristiansund and Oslo. Dusavik is located in Stavanger, which lies in around the southern and center parts of the North Sea. Thus, the Dusavik base is in a good location to support offshore operation in the North Sea. Meanwhile, Kristiansund is in about between the northern part of the North Sea and the southern part of the Norwegian Sea. Currently, the Kristiansund base is relatively adequate to support offshore operation in the Norwegian Sea and the Barents Sea since the number of offshore production system in the area is relatively still low. However, more active field development in the area may create a need to have additional logistics base in further north of Norway.

On the other side, since subsea asset maintenance can be managed through a long-term frame contract, the offshore operation can also be supported through the bases owned by the O&G company. For example, Statoil has a base in Harstad, which is in a good location to support offshore operation in the Norwegian Sea and the Barents Sea.

<u>Environment – high operability in harsher weather and with increasing focus on environmental aspect</u>

Some LoF vessels are equipped with MHS to enable high operability on NCS along the year, including Seven Viking which supports module handling up to 70 tons and 2000 m water depth. Subsea 7 has also i-Tech division which provides various ROV spreads and AIV to support offshore operation for deep water and in harsh environment.

The impact to the environment has always been taken into account in all offshore operations performed by Subsea 7. However, this particular sub-issue is not discussed in this master thesis.

Technology – increasing technology complexity

As a leading global subsea contractor, Subsea 7 has high focus in technology development. Advancement in technology enables various challenging subsea works to be successfully performed. For example, bundle pipeline has been successfully delivered by Subsea 7 since 1980. Bundle avoids unnecessary congestion in the field, manages upheaval buckling, provides protection from drop objects, and gives better stability on seabed.

Subsea 7 also establishes partnership with a number of technology providers. For example, the collaboration with ITP InTerPipe produces Electrical Trace Heated Pipe-in-Pipe (ETHP) for cost-effective flow assurance in subsea pipelines. For the Total – Martin Linge development that it has won, Subsea 7 subcontracts the 163-km subsea high voltage cable package to ABB.

As one of the company's four core segments, LoF can obviously exploit the Subsea 7's high focus in technology development. Thus, as the summary, LoF has technical capabilities to perform subsea asset maintenance to various more-complex-technology subsea assets.

Some technology-breakthrough subsea assets may be so unique that need more specialized offshore spread than typical spread to maintain those assets. The uniqueness may relate with heavy modular weight, specialized maintenance operation, etc. Thus, there may be a need to establish a stand-alone contract to maintain several technology-breakthrough subsea assets, in particular subsea processing systems. However, this obviously should be decided by O&G companies.

Costs – constant need for cost efficiency

The LoF vessels are designated mainly to continuously maintain subsea assets. Thus, cost efficiency is one the LoF philosophies. For example, offshore crane is one of the main cost drivers of vessel's day rate. The currently most advanced LoF vessel, Seven Viking is equipped with "only" 135-ton crane. This is much lower compared to for example the construction vessel Skandi Acergy which has a crane on board that can lift up to 400 tons. Thus, it will be cost efficient to use LoF vessels for incremental field development. However, obviously it depends on O&G companies' decision.

It will be beneficial to analyze LoF cost structure to see if there is any further potential cost efficiency. However, this sub-issue is not discussed in this master thesis.

Experience and competence – increasing need to have integrated experienced and competent subsea asset maintenance spread

Subsea 7 is traditionally known as a leading global subsea installation contractor. It has long-time experience and competence in subsea installation which can be used in subsea asset maintenance, including the strong presence of diving and non-diving spread.

As mentioned previously, Subsea 7 also acquires experience and competence through partnership with a number of technology providers. Further improvement to the quality and efficiency of offshore production can be achieved if there is also more collaboration between subsea asset installation and subsea asset maintenance phases, and between subsea contractor and O&G company. This can be governed through the nature of the contract. Thus, the level of collaboration depends heavily on O&G companies' decision.

5.3 Recommendation

As mentioned in section 5.1, there are several success factors of subsea asset maintenance (referring to Moreno-Trejo et al. (2012)) which are not discussed in this master thesis. Thus, additional analysis with respect to HSEQ, legislation, geographic location and external issues will be beneficial to further improve the comprehensiveness of this study.

There are also several success factors which are partially discussed in this thesis. Consequently, there are some sub-factors which are not discussed in this thesis and can be used for other analysis to further improve the comprehensiveness of this study. The sub-factors include LoF cost structure and the impact of offshore operation to the environment.

In order to further improve the fitness of LoF to the future subsea asset maintenance on NCS, there may be a need for Subsea 7 to establish additional logistics base in further north of Norway. The base is intended to better support offshore operation in the Norwegian Sea and the Barents Sea.

As mentioned in section 5.2, there are some initiatives which can further enhance the fitness of LoF to the future subsea asset maintenance on NCS. However, these initiatives heavily depend on O&G companies' decision. The initiatives include:

- A stand-alone contract to maintain several technology-breakthrough subsea assets.
- More frequent LoF spread utilization for incremental field development.
- More collaboration between subsea asset installation and subsea maintenance phases, and between subsea contractor and O&G company.

The improvement on the fitness of LoF to the future subsea asset maintenance on NCS will subsequently improve the quality and efficiency of offshore production, which is obviously beneficial for O&G companies on NCS.

6. DISCUSSION

The idea to conduct this study is coming from the writer’s work experience in Subsea 7 Norway. The writer sees that O&G is a very volatile industry, which also causes volatility in subsea industry. There were some years where there were several big subsea asset installation projects, but there were also some years where there were only few and small subsea asset installation projects were awarded to subsea contractors.

On the other hand, subsea asset maintenance is a stable segment. Regardless of the volatility of the activities in offshore production system development, O&G companies always need to continuously maintain their existing subsea assets. Moreover, considering recent initiative of O&G companies on NCS to focus on cost efficiency which subsequently delays a number of subsea asset installation projects, the contribution of subsea asset maintenance to subsea contractor becomes more important.

The growing importance of subsea asset maintenance motivates the writer to analyze how LoF fits to the future subsea asset maintenance on NCS. LoF is a Subsea 7’s segment which refers to various subsea services that O&G companies require once a field has started production.

There are several limitations in this study, in particular regarding some factors which are not discussed. Thus, the writer recommends additional analysis on those factors to further improve the comprehensiveness of this study.

The writer also recommends some initiatives to further enhance the fitness of LoF to the future subsea asset maintenance on NCS. However, these initiatives heavily depend on O&G companies’ decision.

The writer finds that this study is a very good exercise to link between academic literatures and industrial practices. The academic literature provides theoretical background and systematic and holistic method which can be used to better analyze an industrial case.

On the other hand, the writer also finds that it is very challenging to find academic literatures on subsea asset maintenance. This happens probably because subsea industry in general is a relatively new and emerging industry.

7. CONCLUSION

O&G companies always need to continuously maintain their existing subsea assets. The analysis of the fitness of LoF concept to the future subsea asset maintenance on NCS will aid subsea contractor to offer suitable added values and make the contractor relevant to the subsea market on NCS. The analysis will also be beneficial for O&G companies since the improvement of the fitness of LoF to the future subsea asset maintenance on NCS will subsequently improve the quality and efficiency of offshore production on NCS.

The findings of the analysis are summarized as follows:

1. <u>Logistics – increasing need to have reliable logistics up north NCS</u>

   Current LoF bases are relatively adequate to support offshore operation on NCS. However, more active field development in north NCS may create a need to have additional logistics base, in particular to better support offshore operation in the Norwegian and Barents Seas.
2. <u>Environment – high operability in harsher weather</u>

   LoF have vessels and equipment which have capabilities to support offshore operation for deep water and harsh environment with high operability on NCS along the year
3. <u>Technology – increasing technology complexity</u>

   As one of the company's four core segments, LoF can exploit the Subsea 7's high focus in technology development. Thus, LoF has technical capabilities to perform subsea asset maintenance to various more-complex-technology subsea assets.
4. <u>Costs – constant need for cost efficiency</u>

   The LoF vessels are designated mainly to continuously maintain subsea assets. Thus, cost efficiency is one the LoF philosophies.
5. <u>Experience and competence – increasing need to have integrated experienced and competent subsea asset maintenance spread</u>

   Subsea 7 has long-time experience and competence in subsea asset installation which can be used in subsea asset maintenance. Subsea 7 also acquires experience and competence through partnership with a number of technology providers.

There are some initiatives which can further enhance the fitness of LoF to the future subsea asset maintenance on NCS. The initiatives depend heavily on O&G companies' decision, which include:

- A stand-alone contract to maintain several technology-breakthrough subsea assets.
- More frequent LoF spread utilization for incremental field development.
- More collaboration between subsea asset installation and subsea maintenance phases, and between subsea contractor and O&G company.

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