# Removing or maintaining redundant topside equipment on offshore installations

A developed selection methodology supporting an early project phase comparative assessment between different execution strategies while taking the installation end of design life into consideration

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TU Delft

NAM

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consideration

by

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*DISCLAIMER: This is not the original research versions but modified due confidentiality reasons. But should not made public after the maximum extend as possible.*



TU Delft

# Preface

This report is the result of my research study conducted to finalize the Master of Science degree in Offshore and Dredging Engineering at the Delft University of Technology. This research study is supported by the ONEgas Projects and Technology department, part of the Nederlandse Aardolie Maatschappij B.V. in Assen.

My ten-month journey has been about exploring the field of topside simplification and decommissioning by assessing the opportunity to reduce operational expenditure with the focus on reduction related costs, risks and schedules.

I have been in touch with many interesting, friendly and collaborating colleagues working within different departments throughout the NAM organization. There were many highlights during my research and the site visits were probably the most exciting ones.

I got the opportunity to visit NAM's Great Yarmouth office (UK) , the Bacton gas terminal (UK), Europe's largest oil refinery in Pernis (NL), the gas terminal in Den Helder (NL) and the most unforgettable experience was visiting the Leman Alpha complex offshore.

This research would have been a lot more difficult without the support of the following people, who I would like to thank for their contribution:

- My NAM supervisors Herman Zant, Ton Wildenbeest and Hans van Kempen. Thank you for your supporting feedback and for continuously challenging and encouraging me into forming my own thoughts and opinions on my research topic, the company and the industry.
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- I was based in Assen but closely involved with the people working for our contractor in Great Yarmouth, so I would like to thank everybody in the Yarmouth office and all my Assen colleagues for supporting me and providing me with information throughout my research.
- Furthermore, I would like to thank my friends for all the distractions during my research. Especially my roommate who had to survive three to four nights a week on his own when I was in Assen.
- Finally, my special thanks go out to my mother, my sister and my father for their love and support. When times were difficult you always encouraged me to believe in myself. This report is definitely a result of that, thank you.

Since the very beginning, May 2016, I have experienced NAM and my department as a very pleasant and stimulating working environment where one is able to achieve goals and achieve personal and professional growth, me included.

The author,

Michiel Smit
Amsterdam, March 2017

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# Abstract

Fast growing offshore maintenance work scopes increase the demand for better insights in cost and risk reduction opportunities related to redundant work scope maintenance activities.

This report describes the research on developing a structured selection methodology to compare benefits between different strategies on removing or maintaining redundant topside equipment, while taking the installation end of design life into consideration.

The selection methodology is applicable in an early project phase and structured by three consecutive steps through which the 'no removal' and three different 'removal' execution strategies are analyzed and compared. This comparison is based on the work scope corresponding fabric maintenance and deconstruction activities.

To enable the comparative assessment a costs, risks and scheduling profile per strategy is created by their corresponding execution related activities. The differences between the execution strategies are defined by the amount of deconstruction related man hours, using the platform deconstruction capacities or support by a lifting vessel and the reduction in fabric maintenance work scope. A 'removal' execution strategy is optimized based on approaching the removal on an opportunity basis.

The selection methodology is applied to a case study to evaluate its capability to select and support an execution strategy to be used as a basis for minimizing the operational expenditure relating to maintaining or removing the redundant work scope.

From the case study application, it is found that the methodology is capable to select and support an execution strategy suitable for the specific redundant work scope and correlates with the early phase project application.

Further research on including a case-by-case strategy optimization and other affected operational expenditure contributing systems is recommended.

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# List of Acronyms and Abbreviations

| | |
|---|---|
| **AJS** | Amec, Jacobs and Stork |
| **ALARP** | As Low As Reasonable Practical |
| **ATEX** | Atmospheres Explosives |
| **CM** | Corrective Maintenance |
| **CoG** | Center of Gravity |
| **DG** | Decision Gates |
| **DR** | Discount Rate |
| **DS** | Design Safety |
| **E&I** | Electrical & Instrumentation |
| **EDP** | Emergency Depressurization |
| **EER** | Emergency Escape Routes |
| **EF** | Execution Fundamentals |
| **EoDL** | End of Design Life |
| **ESD** | Emergency Shutdown |
| **ESSM** | Execution Strategy Support Methodology |
| **FEM** | Finite Element Modeling |
| **FG** | Fire and Gas |
| **FM** | Fabric Maintenance |
| **HAC** | Hazardous Area Classification |
| **HAZID** | Hazard Identification |
| **HLV** | Heavy Lifting Vessel |
| **HP** | High Pressure |
| **HSSE&SP** | Health, Safety, Security, Environment and Social Performance |
| **HVAC** | Heating Ventilation Air Conditioning |
| **IMO** | International Maritime Organization |
| **ISC** | Installation Safety Case |
| **ISO** | International Organization for Standardization |
| **LP** | Low Pressure |
| **M0** | Present Value |
| **MI** | Manned Installation |
| **Mt** | Future Value |
| **NAM** | Nederlandse Aardolie Maatschappij BV. |
| **NDT** | Non Destructive Testing |
| **NORM** | Normal Occurring Radioactive Material |
| **NPT** | Non Productive Time |
| **NPV** | Net Present Value |
| **NUI** | Normally Unmanned Installation |
| **OF** | Opportunity Framing |
| **OPEX** | Operational Expenditure |
| **ORP** | Opportunity Realization Process |
| **ORS** | Opportunity Realization Standards |
| **OSPAR** | Oslo Paris |
| **P&A** | Plugging & Abandonment |
| **P&T** | Projects & Technology |
| **PDO** | Potential Dropped Objects |
| **PM** | Preventive Miantenance |
| **POB** | Personel On Board |
| **PSD** | Process Shutdown |
| **PSD** | Process Shutdown System |
| **RAM** | Risk Assessment Matrix |
| **RM** | Risk Management |
| **RR** | Risk Register |
| **SCE** | Safety Critical Elements |
| **SCI** | Safety Case Impact |
| **SCSI** | Safety Critical System Impact |
| **SHE** | Safety, Health and Environment |
| **SI** | Structural Integrity |
| **SIS** | Safety Instrumented System |
| **SNS** | Southern North Sea |
| **SPS** | Surface Process Shutdown |
| **SWL** | Safe Working Load |
| **TECOP** | Technical, Economic, Commercial, Organizational and Political |
| **TPS** | Total Platform Shutdown |
| **UOS** | Unplanned Overnight Shelter |
| **USD** | Unit Shutdown |
| **VH** | Very High |
| **VL** | Very Low |

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# 1

# Research Introduction

This chapter is an introduction that describes the philosophy behind decomplexing projects, how Shell realizes projects, the motivation to conduct this research, the research objective, the research approach and it states the report outline.

## 1.1. Decomplexing Philosophy

Many Southern North Sea (SNS) installations are installed in the late sixties and are become aging assets situated in fields that are declining in production while the cost of operating. Fortunately there are developments in the oil and gas industry, such as 2-phase pipelines, that enable the simplification of the oil and gas winning process creating new opportunities for these assets.

New developments in installation simplifications allow operators to continue producing beyond the installations End of Design Life (EoDL). In order to achieve this, gas-processing modification projects should be executed while keeping the structural integrity and safety on the platform to operating standards.

These simplification projects are called Decomplexing Projects and are defined by two phases necessary to complete the simplification philosophy, namely:

- Phase 1
  *The conversion of the process system by bypassing the gas drying equipment in order to export wet-gas to a nearby hub.*
- Phase 2
  *Converting the manned installation to a Normally Unmanned Installation (NUI).*

After the wet-gas conversion, large parts of the process is bypassed and become redundant. This results in reduced maintenance activities, reducing offshore exposure and its correlated risks resulting in a decrease in Operational Expenditure (OPEX). A reduction in inspection and Fabric Maintenance activities could be the result of removing this redundant work scope and decreases OPEX even more.

The redundant equipment is obsolete, meaning that it will no longer be in operation and it will not be used as an occasional back-up operating parallel to the process. It is out of use, mechanically and electrically isolated and all corrective and preventive maintenance activities have been stopped.

Offshore decommissioning is a widely used phrase for the removal of equipment offshore. Nowadays it is mostly associated with the removal of platform topsides, substructures and wells.

When an entire offshore installation is decommissioned it is most likely that the production of the field does not exceed the cost of operating any longer, reaching its End of Field Life (EoFL). Or the installation approaches its End of Design Life (EoDL) beyond which it is estimated not to be capable of producing.

## 1.2. Research Motivation

Simplifications in the gas-processing system result in isolated redundant equipment and the opportunity arises to act on this obsolete work scope. The offshore Production Operations team and the onshore Project Engineering team have different views on how to address this opportunity.

Operations handle deconstruction opportunities by a practical approach. Preferring to remove parts of the work scope ’opportunity based’ using the capacity of the installation and personnel available over time. This is based on the experience of the offshore team deciding what to remove and what to leave in place without using the ORS to construct the opportunity.

However, the Project Engineering team prefers to approach deconstruction opportunities by using the ORS. Trying to frame the opportunity and applying the ORS to get the highest value out of the opportunity even when the it is a small project.

The motivation for this research is to approach both the Project Engineering and Operations opinions by developing a methodology that supports selecting a preferred Execution Strategy on either removing or not removing the redundant equipment whilst taking the EoDL topside decommissioning into consideration. This selection is based on the different economic values and risks involved per strategy.

The scientific value in this research is found in the developed step-by-step methodology that approaches this business related topic. The Execution Selection Support Methodology enables the comparative assessment on different Execution Strategies and will be widely applicable to all sorts of offshore assets and enables high level decision making regarding redundant equipment in the offshore industry.

## 1.3. Research Objective

Removing equipment from offshore installations is not a new activity within the industry. Equipment could fail, the integrity of the items decline due to corrosion and the potential of objects dropping (PDO) increases. If this occurs, it is best to either increase the structure or equipment integrity by corrective engineering or remove the hazard.

However, it is a relative new idea to deliberately simplify the production process by wet-gas simplification projects, thus excluding large parts of the systems and equipment from the new operation. These systems and equipment are isolated, will not be used making them obsolete. To ensure no objects will fall, inspections and Fabric Maintenance activities (grid blasting and painting corroded areas) are still performed.

The following options for obsolete equipment are to be further investigated:

- Retiring, mothballing (isolate and purge with nitrogen), paint to show the equipment is obsolete and close-out the area so nobody will enter. Simply explained as leaving the situation as is and do nothing;
- Isolate and do minimum inspections and FM activities to prevent the accumulation and risks of PDOs. Executed according to the company maintenance philosophy for redundant equipment till the installation is removed at the EoDL;
- Remove the obsolete equipment.

It is assumed that the first option, due to the lack of inspection and maintenance, creates many risks on the integrity and safety of the platform. With part of the installation still operating and when considering future decommissioning of the entire installation, the first option will not be taken into consideration.

Therefore the objective of this research will be:

> *"To develop an Execution Selection Support Methodology capable of supporting an early phase comparative assessment between maintaining or removing redundant topside equipment from offshore installations, considering limited work scope information, continuous production and topside removal at the End of Design Life of the installation."*

## 1.4. Research Approach

The comparative assessment is based on the risks and economic values associated with the either keeping or removing a redundant equipment work scope. They are the result of analyzing four Execution Strategies considering three Boundary Conditions and four Execution Activities and translated into three business related Value Driver Profiles:

- Costs Profiles
- Risks Profiles
- Scheduling Profiles

Boundary Conditions depend on type of offshore installation. Two Boundary Conditions are general, HSE and Structural and System Integrity and will be addressed in the risk assessment. The third, Accessibility, is determined by the type of asset, accommodation availability, crane availability and type of installation and will set the applicable Execution Strategies by using a selection tree.

The four Execution Activities are based on the work scope and translated into the Value Drivers Profiles by the intensity of the activities. These activities are as follows:

- Dismantling;
- Fabric Maintenance;
- Lifting & Hoisting;
- Waste Management.

Whilst the focus in the Zero Case, the No Removal Execution Strategy lies on the minimum inspection and FM Maintenance activities that are set by the company guidelines and are estimated by the Inspection and FM team.

Three business Value Drivers are determined to create different profiles on all four Execution Strategies, namely:

- Risks Profiles;
- Costs Profiles;
- Scheduling Profiles.

These profiles enable the comparison between the Execution Strategies and their effect on the EoDL topside decommissioning will be qualitatively assessed and discussed. The Execution Strategy with the best overall value will be recommended as preference.

Supporting data will be gathered through Shell documents, literature, conducted interviews and different Shell projects will be used to benchmark necessary figures. A case study is conducted to test and validate the approach.

## 1.5. Research Outline

This section gives an overview and more detail on the chapters that structure this report.

1. Research Introduction
   *An introduction on the research opportunity and statements are explained in this chapter.*
2. Current Conditions on Offshore Installations
   *This chapter gives an overview of the current aspects and support in offshore operations.*
3. Evaluation of ONEgas Deconstruction Projects
   *Information on different Shell Decomplexing, Refurbishment and Decommissioning Projects is evaluated and its support to the methodology is discussed.*
4. Execution Selection Support Methodology to compare Strategies
   *This chapter describes and discusses the selection support methodology that enables the comparative assessment between No Removal Execution Strategy and the three Removal Execution Strategies.*
5. ESSM Case Study Application - Leman AK Redundant Compression System
   *The methodology is applied to a case study. This case study is an actual situation where better insights on either maintaining or removing a redundant equipment work scope with regards to its EoDL are wanted. The results of the case study will be discussed.*
6. Research Results, Discussion, Conclusions & Recommendations
   *The last chapter discusses the developed methodology, the conclusions and the recommendation on improvements and further research.*

# 2
# Current Conditions on Offshore Installation

This chapter will explain the general elements that are currently situated on offshore installations and are involved with executing deconstruction projects.

The first part introduces the typical ONEgas assets found in the SNS. Followed by a section that will explain redundant equipment and platform processes and systems. The third part gives a more detailed explanation on the Electrical and Instrumentation (E&I). The last part in this chapter will explain the different types of onshore and offshore support that is to be expected when opportunities regarding offshore installations will be assessed.

## 2.1. Typical ONEgas assets

There are three different types of offshore installations within the ONEgas assets in the Southern North Sea (SNS). Redundant equipment on these different types will result in different opportunities. The different assets are shown in figure 2.1 and are listed as follows:

- Monotowers
- Normally Unmanned Installations
- Manned Installations


Figure 2.1: Typical ONEgas Assets; Monotower, Normally Unmanned Installation and Manned Installation

The common high level difference between these assets are as follows:

- Topside
  - Topside design
    *There are many types of offshore assets but offshore topside are mainly designed in one of two ways:*
    - Modular Support Frame supporting modules
    - Integrated Deck Design

    *Integrated topsides are engineered in one piece to be single lifted onto a substructure. Modular topsides are engineered in separate modules and installed in a predetermined sequence onto a modular support frame.*

    *These design depend on the type of assets. Modular designs are common to large nodal and production processing installations that are manned or used to be manned. Integrated topsides are more common to newer, more simple production processing hubs that might only facilitate emergency overnight visits. The mass of an integrated topside is less than the modular topside.*
  - Processes and systems
  - Gas processing equipment
  - Emergency Escape systems
- Substructure
  - Jacket support
  - Monopile support
- Accessibility
  - Marine or Helicopter access
  - Crane
  - Accomodation
  - Supply vessel support
- End of Life Decommissioning Strategies
  - Single lift or multiple lifts
    *Common to Monotowers, NUIs*
  - Combining lifts with Piecemeal deconstruction of modules
    *Common to Manned Installations that are mostly designed as Modular Support Frames supporting different modules and packaged that can be removed Piecemeal.*

In this research, the different assets are approached by assessing the installation accessibility and its applicable method of End of Design Life topside decommissioning.

## 2.2. Platform Processes & Systems

An offshore platform is, apart from its primary, secondary and tertiary steelwork, equipped with many other components and systems to safely operate the mining operation. In general there are three different processes that complete the operation and they have to be accounted for when items are to be removed from the platform.

All the important aspects of an offshore platform and its processes and systems are described in its Installation Safety Case (ISC) detailing the installation, its operation safety provision and the identified hazards. In this chapter the Leman Safety Case document [8] is used as a example because this platform is producing from its own wells, importing from satellite wells and is processing the wet-gas before sending it through the export header to the gas processing plant onshore. Therefore, it is very suitable to generalize the three different processes.

The three processes are as followed and will be explained in more details in the sub chapters below:

- Hydrocarbon Process;
  *This process on the platform has everything to do with the production of hydrocarbons, the inflow, the processing and the outflow.*

  *The different systems that facilitate the hydrocarbon production processes on offshore gas-processing installations are summarized as follows:*

  - Gas & Liquids Processing System
  - Fuel Gas System
  - Purge Gas System
  - Chemical Injection System
  - Control System
  - Process Control System

- Safety Provision Systems;
  *Safety provision systems are in place to ensure that the integrity of the pressure envelope is maintained, any release is rapidly detected and alarms are raised, the inventory available for release is rapidly reduced, and if ignited, the consequences of a release will not impair the temporary refuge. [8]*

  *The different systems that facilitate the safety on offshore installations are monitored and supported by the following systems:*

  - Maintaining Process Integrity
  - Incipient Defect Program
  - Mechanical Impact
  - Over-pressurization
  - Area Classification
  - Fire & Gas System
  - Emergency Shutdown System
  - Emergency Blowdown System
  - Active Fire Protection System

- Utilities.
  *In order for the offshore installation to perform its primary function, there are a number of Utility Systems required to enable this. Some of these utilities are important in mitigating the effects of a potentially minor incident and others are required to enable Safety Critical Elements (SCE) to perform their function. SCE elements are any equipment items, structural components, plant or systems that cause major accidents when failing [9].*

  - Electrical Power Systems
  - Electrical Equipment Standards
  - Earthing and Bonding
  - Electrical Safety

- Hydraulic Systems
- Compressed Air Systems
- Heating Ventilation Air Conditioning (HVAC)
- Drains

More details on the hydrocarbon process and safety provision systems are found in Appendix A.

Most elements are connected by piping, valves, tanks, vessels, pumps, electrical cables and instrumentation. They are supported by either frames, other steel supports, scaffolding or cable trays that positioned on the deck or hanging down from the ceiling. Items such as the piping, vessels and valves are part of the pressure envelope.

When considering removing equipment from these three processes it should first become redundant.

## 2.3. Redundant Equipment

Redundant means that the equipment within different processes is no longer in service and can be one of the following options [3]:

- Redundant, leave in situ and make safe;
  *Make redundant equipment safe to leave in place for a long period of time by complete segregation, draining of liquids, flushing and cleaning and removing items that can corrode and cause future safety and environmental risks. Fabric Maintenance (FM) activities are performed on the surrounding and supports of the equipment to decrease the risks of Potential Dropped Objects (PDOs).*

- Redundant and remove from site (often termed demolition);
  *Necessary isolation and draining of liquids, flushing/cleaning, purging and venting will be required prior to the removal.*

In this research both options are considered and both options require the highest level of isolation. This level is called positive isolation and states the process, electrical, instrumental and hydraulic disconnection, meaning that the equipment should be physically disconnected on all these items. A double block and bleed configuration on the equipment is secured.

Operations makes sure that the equipment is isolated and purges by nitrogen in order to ensure a safe environment to enable the cleaning process as discussed in chapter 3.1.9

All the future Corrective Maintenance (CM) and Preventive Maintenance (PM) activities are stopped when redundant equipment is positively isolated.

## 2.4. Electrical & Instrumentation

The electrical and control instrumentation infrastructure are key components within the entire operation on the offshore installation. They provide the communication between all of the process systems and run throughout the platform. It is important to maintain these components while the field equipment is in service, but once equipment is redundant it becomes a question of at what point the equipment maintenance needs to stopped and if it should be disconnected from its power supply and control infrastructure.

When equipment is redundant signals will no longer be running from the cables to the instrumentation and communication loops will be closed. This will raise the opportunity to remove these parts so that they do not need to be inspected and maintained any longer.

The field equipment with electronic transmitters is controlled through cables that are spread around the installation on cable trays. These cables run to junction boxes that further send the signals to the instrumentation panels in the control rooms where they are connected to the necessary control systems. If the field end equipment is identified to be removed the question will be where to disconnect this equipment within each individual control loop.

The following three possibilities should be considered:

- Disconnect at the field end of the equipment item itself leaving the cables in the cable trays with adequate earthing;
- Disconnect cables from the field end of the equipment and removing entire cables from cable trays up until field junction boxes with adequate earthing;
- Remove the field end instrumentation and control panels with or without removing the cables to the junction box and to the equipment item.

Unfortunately it is not the case that cable trays only include cables coming from one specific equipment item. It contains many cables communicating with many systems. This will make it difficult to remove particular cables from the cable tray.

The upside of removing the instrumentation and control panels in the control room is that this will generate more space that can be used to install any other new panels. The downside is that the adjustments and updates to the existing system are time consuming and difficult to do.

It is therefore important to determine how the strategy regarding the electrical isolation will be. The Electrical Engineering and Control and Automation Engineering discipline will be able to support this task.

Note that when removing field instrumentation some of it is air driven or hydraulically driven so there is also some additional destruct to be considered beyond the cables for electronic components.

Beside control panels, elements of power supplies cover other elements to be considered as well:

- Trace heating
- Lighting
- HVAC
- Electrical motors in mechanical rotating equipment
- Control panels

## 2.5. Project Support

There are different supporting roles in project execution from both the company and contractor perspective. The contractor supports various disciplines but the focus will be on the support from the disciplines being involved from the operator perspective. The main supporting disciplines are Structural Engineering, Process Engineering, Control and Automation and Electrical Engineering. Project management support is delivered by Project Engineering and Project Services and HSSE and SP is delivered by the SHE.

Because this selection support methodology is to be used at the beginning of assessing different removal methods, it is important to understand that the exact detail of involvement by different disciplines could change. For instance, it could be the case that specific information is needed on mechanical equipment. The discipline Mechanical Engineering will be involved if this is needed. When pipelines are involved in the SoW than the discipline addressing piping will take part in the project.

The different elements that support the projects are described as follows:

- Discipline Engineering Support
  *Discipline engineers are the supporting engineers that have the responsibility to deliver the engineering documents and safeguard the execution of different tasks within their field of expertise. Many disciplines are involved when an equipment item or part of the structure needs to be removed. They play a crucial role in assessing the opportunities and limitations within the work scope.*

  *The following elements are part of the Discipline Engineering Support:*

  – Structural Engineering
  – Process Engineering
  – Drilling, Wells & Pipeline Engineering
  – Controls & Automation
  – Electrical Engineering

  *A more detailed description of these roles is given in Appendix A.3*

- Project Engineering Support
  *Project Engineering is the leading role in connecting all the deliveries within the project and provides guidance for the discipline engineers and operations to safeguard the projects progress. The necessity of project engineers throughout a project depends on the complexity of the project. When projects can be organized and supervised by Operations it can be less time consuming, however, when extensive guidance and support is needed it will be the Project Engineering that will fulfill this role.*

- Production Operations Support
  *Operations play a crucial role on the installation. They are the most aware of its systems and the opportunity on their platform. When the removal of an item can be organized by operations without the support of project engineering it can be less time consuming. Depending on the SoW and the complexity of the opportunity it is most suitable if operations take the lead in the project accompanied by the support of the engineers.*

- Project Services Support
  *Project Services provide cost estimations, planning, contracting and procurement, quality assurance and quality controls and waste management plans.*

  *The following elements are part of the Project Services Support:*

  – Planning
  – Cost Estimations
  – Contracting & Procurement

- Quality Assurance & Quality Control

*A more detailed description of these roles is given in Appendix A.3*

- HSE Support
*The support by HSE team is to define critical activities, ensure the identification of any hazards within the activities and to quantify the risks involved with the activities. The assurance should include that the HSSE management plan meets the requirements enabling the project to be As Low As Reasonable Practical (ALARP). Meaning that the risks that will be taken are as low as when cost of further reduction of these risks will be disproportional to the risk reduction obtained by this measure. The following elements are part of the HSE Support:*

  - Technical Safety
  - Environmental Engineering

  *A more detailed description of these roles is given in Appendix A.3*

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# 3

# Execution Selection Support Methodology to compare Strategies

The previous chapters stated the research opportunity, gave an introduction to offshore installations and explained about recent projects in the Southern North Sea (SNS).

This chapter explains the Execution Selection Support Methodology (ESSM) that allows for a step-by-step approach enabling to perform an early project phase comparative assessment between maintaining or removing redundant equipment from offshore installations, considering limited work scope information, continuous production and topside removal at the End of Design Life (EoDL).

Figure 3.1 shows a high level overview of the ESSM. More detail is found in figure B.1 in appendix B.1

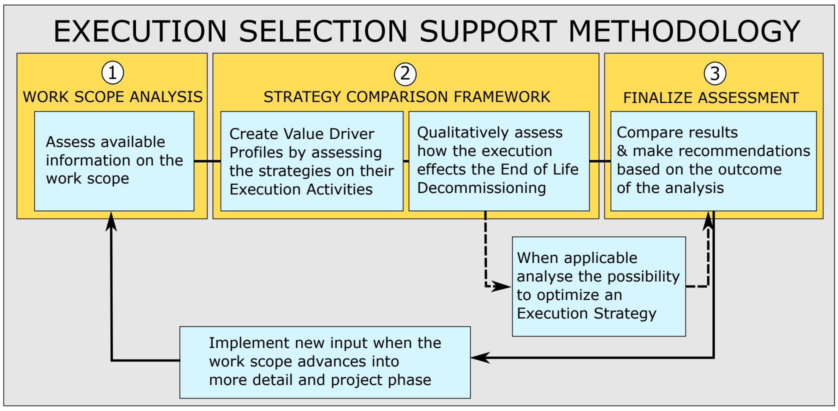


Figure 3.1: Execution Selection Support Methodology

## 3.1. ESSM step 1: Work Scope Analysis

The first step in the ESSM is to begin to analyze the high level work scope. This part will explain the first step in the ESSM in detail.

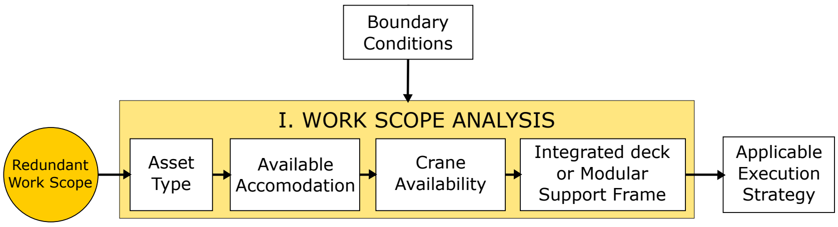


Figure 3.2: ESSM step 1: Work Scope Analysis

### 3.1.1. Work Scope Assumptions

Before the work scope is analyzed the following assumptions are made:

- It is assumed that the work scope is redundant meaning that it will not be used in the operation and that it will not stay idle to run parallel to overtake the operation as a back-up system.
- It is assumed that the work scope is isolated meaning that it is mechanically disconnected from the operating processes and electrically and instrumentally disconnected.
- The isolation is executed by Operations and allows for the removal of the Corrective (CM) and Preventive (PM) Maintenance activities from the system. Only Fabric Maintenance (FM) activities will be executed.

Work scope information is limited and will be according to the Identify and Assess phase as given in chapter **??**. High level information is information that:

- Describes the mass and dimensions of the redundant equipment. The redundant equipment are part of the primary and secondary systems and stated in the installation Safety Case;
- Describes the length and diameter of the pipework that is connected to the redundant equipment. The pipework is stated in the Load Case. The diameter should be at least six inch because four inch and two inch piping are considered as easy to dismantle and will not make a significant impact on the deconstruction man hours.
- Describes the mass and dimensions of the structural steel that supports the redundant equipment.

### 3.1.2. Execution Fundamentals

In this part seven Execution Fundamentals are discussed. After analyzing different Decommissioning, Decomplexing and Deconstruction Projects and conducting interviews with experienced engineers these six subjects have been identified to serve as the seven fundamentals in ESSM within this research. These fundamentals are re-occurring and interconnected subjects that cover the general approaches within the projects that are analyzed for this research.

The basis of the ESSM is defined by the Executions Fundamentals (EF) it consists of two elements:

- Boundary Conditions
  *The three Boundary Conditions are known beforehand and differ at each location.*
  - HSSE & SP

- Structural & Systems Integrity
- Accessibility

*The first two Boundary Conditions are set upfront and focus on the general sense of executing different strategies and are mainly represented in the Risks Profiles while the third Boundary Condition is more dynamic and will be assessed in the first step in the ESSM. Deferred Production by unplanned Shutdown is not taken into account as a Boundary Condition. The Execution Activities could create a longer deconstruction lead time exceeding a planned shutdown but loss of deferment will always be compensated in the Economic Value calculation.*

- Execution Activities
  *The four Execution Activities are variable, influenced by the Boundary Conditions and are focused on the removal of the redundant equipment.*
  - Dismantling
  - Fabric Maintenance
  - Lifting & Hoisting
  - Waste Management

  *Execution Activities are the fundamentals within that directly influence the outcome of the decisions by means of man hours translated into costs. The deconstruction lead time within the four Execution Strategies is primarily based on these variables and limited by the Boundary Conditions.*

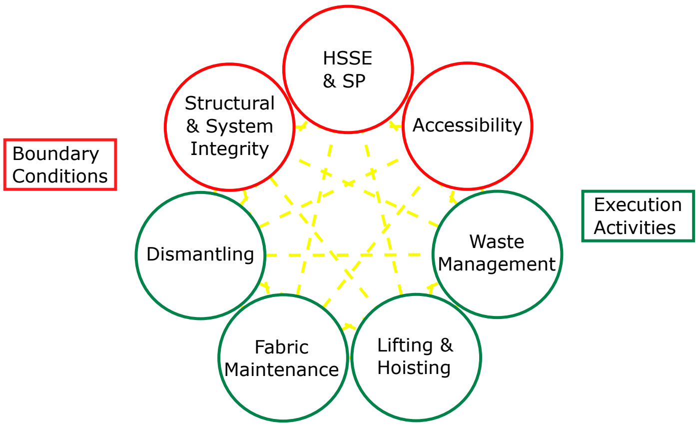


Figure 3.3: Execution Fundamentals

Figure 3.3 shows that all the fundamentals are connected because the Boundary Conditions determine the manner of executing the different activities. They allow for a certain way of dismantling, lifting and hoisting, how waste should be managed and define the amount fabric maintenance.

*For example, the structural integrity of an installation does not allow for containers to be stored during the execution thus limiting the lifting activity.*

The ways that Execution Activities affect the Boundary Conditions are through risks. An activity could endanger the Boundary Conditions or be able to set new Boundary Conditions.

*For example, space could be created by lifting away certain elements on the installation creating better access and increasing safety on the platform.*

The first step in the ESSM is linked to the Accessibility of the installation as shown in figure B.2 in Appendix B.2. This selection tree is used to find the applicable ways to remove the redundant equipment and is based on the following steps:

- Type of installation;
- Accommodation available to stay overnight;
- Crane available to support the removal of the equipment;
- Equipment installed to be dismantled as a complete modules.

The possibility to transport manpower by helicopter when there is a helicopter deck available is not included in the selection tree. This will not be part op the Accessibility Boundary Condition but will be described in the costs as a logistics element.

It could be possible that an installations does not have enough storage area to support the offshore storage during the Piecemeal Execution Strategy. This will result in an increase of the costs due to an increase in scheduling. This is not considered as an item in the Accessibility Boundary Condition

The result of the selection tree gives the applicable Removal Execution Strategies that will be compared to the No Removal Execution Strategy. The first step also results in the type of Removal Execution Support and whether it is necessary to include a floatel to provide accommodation.

The Removal Execution Support is the type of support that enables the work scope removal. It is set as follows:

- Support by a Heavy Lifting Vessel (HLV);
- Support by a Lifting Barge;
- Only fully utilizing the available platform deconstruction capacity.

Based on the type of assets, chapter 2.1, and the learnings in chapter **??**, the following decommissioning methods at the EoDL are assumed:

- Monotowers and NUIs with an integrated topside design are removed in a single lift.
- NUIs and Manned Installations with a Modular Support Frame design are removed in a combination of offshore Piecemeal deconstruction and lifts.

### 3.1.3. EF Boundary Condition: HSSE&SP

Health, Safety, Security, Environment and Social Performance (HSSE&SP) is the most important part in executing projects. In this section applicable mitigations to safeguard these factors within the offshore deconstruction projects are discussed.

It is the responsibility of Technical Safety to coordinate the projects from HSE point of view and to make sure it complies with all the restrictions. Therefore, it is necessary to carry out safety studies and reviews per work scope within different phases of the project.

These studies and reviews along with summaries and status of all actions raised, as recorded in the Safety, Health and Environment (SHE) register, will be stated in the so called SHE Close-out Report. Different contractors tend to have different procedures but a summary of the NAM procedure is given in Appendix **??**.

It is very important to adopt Safety, Health and Environmental (SHE) management from an early stage in the process by doing risk assessments and producing health and safety plans.[2]

In this research Risk Management (RM) is focused on the assessment of technical and non-technical risks specific to the Execution Strategies. The HSSE&SP Boundary Conditions are included as risks assessed on their potential impact on the Cost, Schedule, HSE and Reputation as explained in chapter 3.2.3.

### *Rules & Legislation in Decommissioning*

Rules and legislation have been developed over the years to safeguard the offshore operations and to ensure that the operations are executed within lines of agreement that have been set-up by governments and other institutions.

Both UK continental shelf and the Dutch continental shelf are part of the Southern North Sea (SNS). This means that different guidelines, rules & legislation are applicable on either side but international obligations are the driving force behind these.

International obligations have their origins in the United Nations Convention on the Law of the Sea of 1982. In 1994 the Convention entered into force and Article 60(3) includes the following:

*"Any installations or structures which are abandoned or disused shall be removed to ensure safety of navigation, taking into account any generally accepted international standards established in this regard by the competent international organization. Such removal shall also have due regard to fishing, the protection of the marine environment and the rights and duties of other States. Appropriate publicity shall be given to the depth, position and dimensions of any installations or structures not entirely removed".*

This is adopted by many countries and further developments are[13]:

- International Maritime Organization (IMO)
  *as the competent international organization adopts IMO Guidelines and Standards setting out the minimum global standards for the removal of offshore installations.*
- The Oslo Paris Convention (OSPAR)
  *A mechanism by which 15 Governments & the EU cooperate to protect the marine environment of the North-East Atlantic, unifies, updates and extends in 1992 both Oslo Convention (1972) and Paris Convention (1974)**
- OSPAR Decision 98/3 - reproduced at Annex B
  *In July 1998 at the First Ministerial meeting of the OSPAR Commission, a new regime for the decommissioning of disused offshore installations was established under the new Convention and a binding decision was created to ban the disposal of offshore installations at sea.*

*http://www.ospar.org/about

### 3.1.4. EF Boundary Condition: Structural & System Integrity

Structural and System Integrity is focused on the integrity and stability of the installations and the equipment before, during and after the execution of the strategy.

Assessments on the stability and integrity of the installations should be performed because failure in stability and integrity is an absolute showstopper.

### *Offshore Structures Steelworks*

Topside main characteristic steelworks [11] are defined by the following parts: :

- Primary steelworks: truss members, girders and horizontal bracing;
- Secondary steelworks: deck plate, grating, deck beams, walkways, stairs and crane pedestals;
- Tertiary steelworks: lifting beams.

The main characteristic steelworks [11] of the substructure are defined by the following parts:

- Primary steelworks: legs, diagonal bracings, horizontal bracings and piles;

- Secondary steelworks: cathodic protection, boat landing, barge bumpers, walkways, appurtenance support and mud mats;
- Tertiary steelworks: other steelworks.

Different Finite Element Modeling (FEM) software can be used in order to determine how and to what extend the removal method will impact the structure of the installation. The ongoing integrity of the structure is modeled in Structural Integrity (SI) models where the structural and hydrodynamic analyses are carried out by using SESAM FEM software. The results give the loads within the installation and are checked according ISO 19900, standards for fixed steel offshore structures, to assess if they comply to the safety margins.

### *Stability*

Stability describes the dynamic behavior of an object and there are different scales on an installation to which the stability during a Removal Execution Strategy could be assessed:

- Installation scale
  *The stability of the installation is affected by the increase, decrease and shifting of loads and how the loads are transferred into the piles in the jacket. Exceeding the safe compression limits and the shift from compression loads in the piles to tension loads in the piles are absolute showstoppers. This is the result of too much transfer of loads on the piles or too much removed mass.*

- Equipment and its surrounding scale
  *Stability of the equipment and its surroundings have to do with the transfer of loads on the primary and secondary steel. This results in the necessity of reinforcements or supports to transfer the loads that exceed the stability equilibrium*

- Material handling scale
  *When materials are being handled on the installation, the stability of the lifting appliances should be assessed. The loads must be within the SWL, deck and storage areas must be able to withstand the loads.*

### *Integrity*

Integrity implies the capacity of a material to withstand the transfer of loads on a certain area.

Incipient defect is an important factor that degrades the structural integrity of an installation and its systems. The offshore environment is a very harsh environment where the installation is exposed to elements such as wind, water and salts that damages the installation on a frequent basis. Therefore it is crucial to monitor the integrity of the installation and execute maintenance activities to safeguard the integrity. When a structure is affected by incipient defect it needs to be determined whether the piece could be removed or if it should be reinforced or repaired to increase the strength and decrease potential of affecting the safety.

An example of heavily corroded structural steel that affects the safety and structural integrity on an offshore installation is shown in figure **??**.

It is important to describe what the critical elements are to safeguard the structural integrity before, during and after removing the equipment items from its location.

Large pieces of equipment are supported by either a support frame of primary and secondary steel. Figure **??** shows a large piece of equipment that stands on a support frame and the support frame shows incipient defect. When this piece of equipment is to be removed it is important to assess the structural integrity of the support frame to check if this item is able to be lifted without any structural reinforcements.

The following FEM software is used for the types of integrity analyses:

- SACS
  - *Modeling the structure as 3D frame.*
  - *Solution for forces, displacements and reactions via stiffness analysis.*
  - *Post processing of results to perform buckling stability, hydro static collapse checks for structural members to API codes and punching shear checks of tubular joints to API requirements.*

- Staad/Pro
  *Linear elastic structural analyses and code checking.*

- ANSYS
  *Detailed analysis of complex structures, like the lifting points nodes, the finite element program.*

### *Redundant Equipment*

When redundant equipment is left in situ it is critical to assess and maintain the stability and integrity in order to keep the people and the operation safe.

PDOs are the highest concern for redundant equipment in situ. When large pieces of equipment are supported by structural steel it is most likely that they will not become major hazards as long as the integrity is maintained. However, smaller support steel such as piping supports and other small item supports are more likely to fail. When there is a lack of maintenance these items will raise concerns thus inspection and FM activities must be performed in order to decrease the possibility of PDOs to occur.

Therefore it is concluded that even when redundant equipment is removed, FM activities must be performed on the surroundings.

### 3.1.5. EF Boundary Condition: Accessibility

The Accessibility Boundary Condition is approached by:

- The type of asset and its accommodation;
- Whether there is a crane available;
- The method of installation: installed Modular Support Frame carrying multiple modules and packages or as an integrated topside installed by a single lift.

Accessibility by helicopter is another important aspect that could be implemented as an Accessibility Boundary Condition but in this research it is assumed that this condition only defines and affects the transportation to the installation during the execution.

Transportation to the installation is included in the Costs Profiles as a percentage estimated by execution lead time based on the team that is assumed to be involved in the offshore execution.

Accessibility is used to determine what type of installation is involved and what Removal Execution Strategies and applicable Removal Execution Support will be assessed.

## *Equipment location*

When the work scope includes many components on different decks it could be considered to start removing objects in a 'top-down' approach following a pre-determined sequence to create space to lift and to store equipment. In figure **??** you have a component standing on the mezzanine deck (second deck from the bottom up). This means that deck plates and secondary steel might have to be removed for the crane to reach all the way down below.

Another possibility is to cut the components into smaller pieces to increase the maneuverability and decrease the impact on its surroundings thus impacting the integrity of the platform.

The locations of the redundant equipment play a significant role in the decision making. It determines method of deconstruction and the necessary preparation activities.

***Deck level*** Offshore installations are complex systems in terms of accessibility and space. Some deck levels are more open while other levels contain complex piping arrangements that limit the maneuverability.

Cranes can only reach the lower decks when space through the deck levels is provided. An example of the layout plan of the top and main deck levels on the Leman AK installation is shown in figure **??**. It shows many components occupying two different levels. In order for the cranes to reach the compression trains on the main deck level (middle part of the figure), the cooling system on the top level (left part of the figure) should first be removed. The right part of the figure shows the complexity and the upper deck plating and support structure.

***Maneuverability*** Maneuverability is involved with the workforce executing the project on sight and the materials and equipment inflow, storage and outflow on site. It also determines the difficulty of supporting tools such as excavators and pick and carry cranes to move around. Risks of mechanically impacting equipment will decrease by increasing maneuverability.

***Removal sequence*** When there are many equipment items within the work scope, different Removal Execution Strategies will need different sequences of removing the items. The sequence of removal will be able to increase the accessibility to remove all the items. But when, for instance, many components are within one module, there might be an opportunity to remove the entire module in a single lift.

When making an assessment on the different removal sequences it is important to incorporate different equipment that is being used. Supporting appliances such as lifting tools and dismantling tools require space on the decks decreasing the accessibility to the items and decreasing the maneuverability to perform the execution.

## *Materials & Manpower Supply & Management*

The logistics on a platform during the execution consider the flow of materials and manpower. Different Execution Strategies have different needs of materials and manpower supplied and allow for different types of management in support.

A manned installation has got an accommodation module installed that allows people to stay overnight. The amount of beds available determines the amount of people working on different projects on the installation. This is a limiting factor because it will influence the time necessary to execute a project and thereby the cost. When an item is hard to reach it might take more manpower to remove the item and if there are no beds available it could be necessary to sail in an external accommodation vessel to supply room for overnight visits.

Another crucial part is the supply and storage of all of the equipment that is needed to execute the project. If the access to the item is difficult it could be difficult to maneuver the tools and materials around. The materials can be of support to the project but it also includes the waste and removed equipment.

There should be room to store materials in order to do the removal but the amount of room necessary is determined by the type of decommissioning method.

### *Shutdown*

An operational shutdown might be necessary in order to execute a project. If this is the case, there will be a limited time frame to perform the removal project. A shutdown means that the entire inflow and outflow of hydrocarbons is stopped so the installation is not producing. A direct consequence is that the operator will not make any money. However, a shutdown decreases many risks if large parts and smaller parts in hazardous areas should be removed.

During the lifetime of an installation many shutdowns are performed to clean the installation and to overhaul the equipment where necessary. Combining planned shutdowns with removing equipment items could allow better planning, less cost and create access to Execution Activities in hazardous areas.

In this research scheduled shutdown is taken into consideration as loss of deferment during the execution of the strategies and translated into the Costs Profiles in chapter 3.2.2.

## 3.1.6. EF Execution Activity: Fabric Maintenance

### *Types of Maintenance Activity*

There are three types of maintenance activities that occur offshore [7]:

- Preventive Maintenance
  *This type of maintenance activity is planned and performed on a regular basis in order to decrease the possibility of failure of the equipment.*
- Corrective Maintenance
  *This type of maintenance activity is required to correct a failure that occurred or is about to occur. This activity consists of repair, restoration or replacement of the equipment.*
- Fabric Maintenance
  *This type of maintenance activity is performed to recover the integrity and extending the lifetime of the structural steel supporting the equipment that has been damaged by the harsh offshore environment. The activity complies blasting and painting the necessary areas.*

Because the work scope is assumed to be redundant and isolated, Preventive Maintenance (PM) and Corrective Maintenance (CM) activities are not applicable any longer. However, in order to keep the installation safe to continue operating it is required to perform Fabric Maintenance (FM) to decrease the risks of PDOs and declining structural integrity of the installation.

Fabric Maintenance refers to the optimal maintenance of external coatings that could also include insulation.

A module is defined as a structural frame in which equipment is mounted. This could either be an entire deck, parts of a deck, an accommodation module, a helicopter deck, an entire coolerbank frame, platform crane or for instance a lifesaving module.

### *Types of Fabric Maintenance*

The FM Activity is defined by the area that needs to be painted. The degree to which FM should be performed depends on condition of the installation and the installation EoDL decommissioning. It is assumed that the status of redundant work scope should be in the state of integrity in which it will not affect the safe removal of the topside at the EoDL. Inspections should provide the estimated area that needs FM whilst considering the year of topside decommissioning.

Removing the work scope results in a decrease of the different FM activities. These type of FM activities are as follows [12]:

- Hot spot approach on piping, tanks and vessels
  *The hot spot approach is to an estimated area on piping, tanks and vessels that will be affected by incipient defect. These equipment types are not less sensitive to corrosion and their probability of becoming a PDO is very low compared to structural steel.*

- FM on structural steel
  *Primary, secondary and tertiary steel that surrounds and supports the redundant work scope should undergo FM to safeguard the structural integrity. The probability of becoming PDOs significantly increases when the structural integrity begins to fail due to incipient defect by lack of FM being a major safety showstopper.*

Chapter 3.2.2 gives the build-up in FM activity cost and how this is taken into account in the Cost Estimate.

### 3.1.7. EF Execution Activity: Dismantling

The type of dismantling methods affects safety, the dismantling activity lead time and the use of supporting tools and appliances such as scaffolding. The type of dismantling methods are limited by accessibility elements such as shutdown, location safety zones and area classifications.

Safety zones and area classifications are identified on installations and determine what steps should be taken to enable different methods of dismantling. These different classifications are given in appendix A.2.

There are two types of conventional dismantling methods used in the industry and they are described as follows:

- Conventional Hot Work
  *Conventional hot work are activities where tools are used that could behave as a potential source of ignition. It involves welding, cutting, grinding or drilling operations using welding or cutting torches and grinding tools. Risks of fire and explosions are increased when conventional hot work dismantling methods are used in hazardous areas. Therefore shutdown, equipment isolation or area isolation are necessary.*

  *Cold dismantling methods could avoid shutdown or area isolation. However, shutdown and area isolation are also limited by other activities such as lifting. Equipment isolation and its cleaning procedure is always necessary to ensure a safe dismantling environment.*

- Conventional Cold Work
  *Conventional cold work are activities such as dismantling by removing bolts or screws, activities where tools are used that have no potential source of ignition or from which the potential ignition source is removed or mitigated. Hydraulic shears could replace the torch cutting method and water cooled cutting is an example of risk mitigation by removing the potential source of ignition.*

  *Cold work reduced the risks of fire and explosions and could enable the dismantling operation to be performed in a hazardous area that is live during the dismantling activity.*

The dismantling methods on the equipment and structures are assumed to be by conventional hot and cold work because the figures used as educated guestimates are not specific to the types of dismantling. However, the piping is considered to be dismantled by using the State of the Art water jet cutting because benchmark figures on this activity are well known.

### *State of the Art Water Jet Cutting*

The figures shown in table 3.1 are the times necessary to cut a certain diameter and its corresponding wallthickness by using the water jet cutting method. These figures are from the company Curved Cuts that have executed dismantling operations in the Southern North Sea (SNS).

An average is used to determine the lead time of dismantling the work scope piping per size of diameter.

| Diameter [inch] | Wallthickness [inch] | | Cutting time per cut [minutes] | | Average Time per Cut [hours] |
|---|---|---|---|---|---|
| | minimum | maximum | minimum | maximum | |
| 30 | 0,375 | 1,531 | 7,66 | 19,02 | 0,25 |
| 24 | 0,25 | 2,344 | 6,13 | 56,94 | 0,3 |
| 18 | 0,25 | 1,78 | 4,59 | 32,44 | |
| 16 | 0,219 | 1,594 | 3,57 | 25,84 | |
| 14 | 0,21 | 2,5 | 2,96 | 35,6 | |
| 12 | 0,203 | 1,312 | 2,49 | 15,93 | |
| 10 | 0,188 | 1,125 | 1,91 | 11,4 | |
| 8 | 0,188 | 0,906 | 1,53 | 7,34 | 0,1 |
| 6 | 0,188 | 0,864 | 1,23 | 5,63 | |

Table 3.1: Curved Cuts average time to cut per inch diameter piping

Figure 3.4 shows a piece of equipment cut by using the water jet cutting technology. This is an example of cold work Piecemeal dismantling. The piece was supported by slings during the dismantling activity.

Figure 3.4: Piecemeal dismantling, state-of-the-art water jet cutting by the company Curved Cuts B.V.

## 3.1.8. EF Execution Activity: Lifting & Hoisting

Lifting takes place during the equipment dismantling as support or to transfer the pieces to another area. The types of lifting equipment depend on the capabilities on the offshore installation, the type of Execution Strategies executed and therefore the different need in lifting capacity.

Lifting is the means of supporting and transporting objects. This should be done in a safe and correct manner by people and equipment that have the right capacity to operate. Capacity does not only depend on the characteristics and SWL of the lifting devices but also on the people operating this and the accessibility to and from the equipment.

Structural integrity of the equipment should be in the condition that satisfies the guidelines and restrictions within lifting operations. If it not complies with the safety standards, it needs to be repaired, reinforced or removed.

### *Lifting Appliances*

There are many types of lifting appliances available that are useful in the operations. The appropriate appliance to be used depends on the accessibility, size, shape and integrity of the items to be lifted.

- Platform or vessel mounted cranes
- Mobile cranes
- Manual lifting appliances

Examples on these three lifting appliances are mentioned in the following paragraphs.

In selection methodology the deconstruction lead time depends on the lifting capacities of the available platform and vessel mounted cranes that support the different Execution Strategies. The lead time calculation is described in chapter 3.2.2.

***Platform or vessel mounted cranes*** First to discuss are the cranes that are permanent or temporarily mounted on a platform or a vessel. These cranes have been installed in one spot from which it operates. Typical mounted cranes operated during offshore executions are:

- Platform mounted crane
  *Many offshore installations have cranes installed. These cranes are installed to be able to lift equipment and other kind of supplies in containers or as loose objects from a supply vessel straight onto the installation or the other way around.*

  *Platform cranes differ in size and lifting capacity. The lifting capacity depends on the radius of the boom that determines the allowed SWL to be lifted at a certain angle. These cranes are able to rotate and slew around its axis.*

Figure 3.5: A permanent mounted platform crane

- Overhead crane
  *Overhead cranes are a type of crane that are able to move on rails in the horizontal and vertical plane hanging above a deck. They can be used to transfer materials from one side to another*
- Vessel mounted crane
  *A barge crane could be the solution for lifting heavy parts when there is no platform crane available or its mass exceeds the SWL of the platform mounted crane. Temporary mounted cranes on vessels allow for the lifting activities during temporary services.*

  *Barge cranes allow for heavier lifts than platform cranes but they are limited in a couple of ways:*
  - Accessibility by the barge, risk of collision;
  - Limited radius due to the barge location;
  - Operating window due to weather and sea conditions;
- Heavy Lifting Vessel
  *If the equipment or module is too heavy to remove by platform crane or barge crane, it could be removed by Heavy Lifting Vessel (HLV). Modules could exceed the SWL and the*

Figure 3.6: Jack-up barge Seafox 4 operating at K81 in SNS

*Reverse Installation Execution Strategy might be suitable. This is usually the case when complete topsides and jackets are being removed.*

*By removing equipment in the Reverse Installation manner, the most impact is being done on the installation because a lot of primary and secondary steel is being removed in a single lift causing a shift in stability on the installation.*

Figure 3.7: Heerema Marine Contractor its HLV Thialf installing a topside and system parts on the substructure

*Figure 3.7 shows the installation of the topside and the installation of a module on the substructure. This installation is executed by the HLV Thialf that is owned and operated by the company called Heerema Marine Contractors.*

***Mobile cranes*** Mobile cranes are used on site to support the lifting operation. They are capable to move around on the topsides and support where necessary. Their SWL are less than platform or vessel mounted cranes but prove to be very useful in lifting and supporting small pieces of equipment with a maximum mass of 10 tonne.

Mini mobile cranes are used offshore because space is limited. Area accessibility is the limiting factor and the deck must be able to withstand the dynamic loads that occur by operating these type of mini cranes.

Advantages of mobile mini cranes are their capability of operating with precision in difficult to access and confined areas. More detailed information on the characteristics of mobile mini cranes in support of offshore operations is found in Appendix B.3.

Figure 3.8: Examples of Mobile Cranes: Spider Crane, Mini Crawler Crane, Gantry Crane and a Pick and Carry Crane

***Manual Appliances*** Manual hoisting appliances primarily consist of chains, hooks and pulleys for the lift and locking mechanisms to hold the appliance in place. An arrangement of multiple hoisting appliances can generate a pathway to move the lifted equipment around the platform in a slinging fashion.

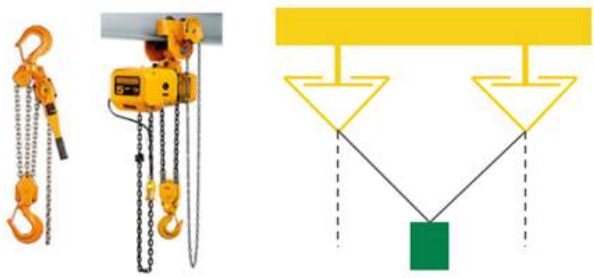

Figure 3.9: Manual hoisting appliances

## *Lift Support Tools*

There are various tools that support the lifting operation. These tools are attached to the equipment or attached to the lifting appliance by slings, chains and shackles. Multiple tools could be used during the lifting operation such as:

- Pad eyes
- Trunnions
- Spreader bars
- Rigging

All the lifting support tools necessary to execute the lifting activity is estimated in the Cost Estimate and included in the Deconstruction Cost element. More details on these four lifting tools are given in appendix B.4.

### 3.1.9. EF Execution Activity: Waste Management

In order to dismantle the equipment, assessments should be done to determine if there are any hazardous materials left in the system. In this research Waste Management is determined to be the Cleaning and Making Safe of the redundant work scope, onshore dismantling and disposal. Within the different Execution Strategies different intensity of Waste Management is necessary.

There is a difference between Cleaning and Waste Handling:

- Cleaning has to do with decontamination;
- Waste Handling has to do with safe distribution of waste caused by the cleaning and deconstruction activities.

#### *Types of Equipment Contamination*

There is a distinction between process equipment and non-process equipment. Due to operations, process equipment could be condemned by different kinds of contamination. Common types of contamination are:

- Mercury
- Hydrocarbons
- Glycol
- Pyrophorics
- Salts
- Asbestos
- Normal Occurring Radioactive Material (NORM)

Different types need different cleaning intensity and this is determined by the measure, intensity of occurrence and toxicity. The minimum cleaning requirement is defined by a safe transportation to shore and differs from making it hydrocarbon free by water wash or complete decontamination when hazardous materials are involved.

#### *Cleaning & Make Safe*

Before the system can be cleaned it is the task of Operations to create a safe environment to work on the redundant equipment. This step is the mechanically and electrically isolation of the redundant equipment from the processes.

A positive isolation is the highest level of mechanically isolating equipment and allows for safe deconstruction and transportation of the equipment.[3]

Positive isolation is done by installing blind flanges, a double block and bleed configuration and purging the system with nitrogen. The electrical isolation needs to be done to allow the instrumentation controls to continue to operate without alarms going off due to disruption in the communication system and is executed by disconnecting it from the facilities.

Cleaning has to be done to safely execute the deconstruction and make it safe for transportation. The cleaner the material the easier it is to distribute when arriving onshore.

Make safe of the system means that it will be cleaned properly for safe handling and ready to transport. It depends on the situation, method of removal and transportation. The type of dismantling affects the intensity of cleaning the pieces.

When something could be dismantled without hot work it could be sufficient to flush and shut before the transportation to shore. If cuts need to be made, cold work allows for a less proper cleaning of the system then hot work due to the increased risks of igniting flammable contamination.

Before the system is being flushed with water, assessments on the structural integrity should be checked. If water runs through the system, weight will be added and this will increase the live load on the installation. It might be impossible to clean the equipment with flushing water.

Specialist take over the cleaning the system when the contamination is radio-active or asbestos.

Cleaning cost depend on the type of contamination and the costs for the onshore materials disposal are adjusted to the type of cleaning and described by the unit [€/ton]:

It is assumed that in any case the redundant work scope is cleaned offshore. Offshore cleaning results in a known and safe state of the equipment instead of not cleaning and maintaining an unknown safety status till the EoDL.

At the EoDL offshore cleaning is an important factor that needs to be executed before the complete removal and onshore dismantling takes place.

### *Waste Handling*

Waste Handling defined as handling the removed materials for storage and onshore dismantling activities. It is limited by the SWL of the cranes that are used. There are three types of handling addressed:

- Mass of pieces within the SWL of the installation crane, stored on the installation in containers, directly shipped to shore and no further dismantling is necessary.
- Mass of pieces exceed the SWL of the installation crane but within SWL of a lifting barge crane, lifted directly onto barges, dismantled into smaller pieces on the barge, transported to shore where no further dismantling is necessary.
- Mass of pieces exceed SWL of a lifting barge crane, lifted by a HLV onto vessels and barges, transported to shore where further dismantling is necessary.

The waste that is involved during cleaning should be carefully handled and contained, stored offshore, removed and distributed onshore.

## 3.2. ESSM step 2: Strategy Comparison Framework

High level information on the redundant work scope and the applicable types of removal Execution Strategies are given after the first step in the Execution Selection Support Methodology (ESSM) and is input for the second step, In the second ESSM step, the Strategy Comparison Framework, the Execution Strategy Value Driver Profiles are assessed and their effect on the EoDL topside is discussed before the comparative assessment is finalized.

First to discuss are the Execution Strategies followed by parts on the Value Drivers Profiles. Execution Optimization is discussed after the profiles and the last part describes the advantages of the work scope deconstruction at the installation EoDL.

The Strategy Comparison Framework is shown in figure 3.10. Figure 3.1 in Appendix B.1 shows the entire ESSM.

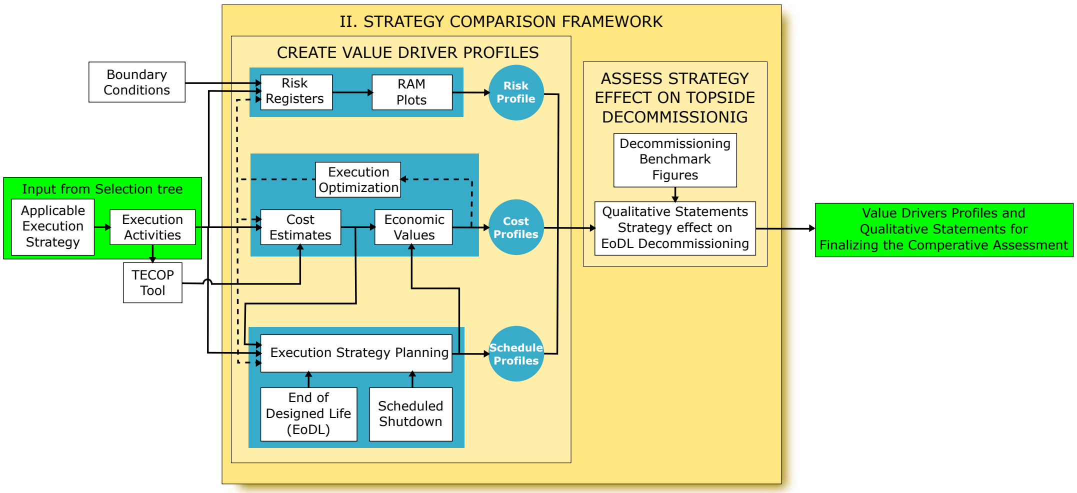


Figure 3.10: Execution Strategy Comparison Framework

### 3.2.1. Execution Strategies

In the ESSM there two types of Execution Strategies are analyzed:

- No Removal Execution Strategy
  *The redundant equipment work scope will not be removed until the EoDL. Only Fabric Maintenance (FM) Activities will be executed.*
- Removal Execution Strategies
  *These strategies are focus on different methods of redundant work scope deconstruction and result in FM activity work scope reduction.*

Their Execution Strategy characteristics are defined as shown in table 3.2.

Table 3.2: Execution Strategies and their characteristics

| Execution Strategy | Execution Strategy characteristics |
|---|---|
| Reverse Installation | • Load exceeds SWL of lifting barges<br>• Modules and packages removed in order of Reverse Installation<br>• No offshore storage, onshore dismantlind and disposal<br>• Reducing Fabric Maintenance activities by work scope removal |
| Heavy Lift | • Load within SWL of lifting barges<br>• Modules, piping, equipment & structures removed in pre-determined sequence<br>• Onshore dismantling or further dismantling on the barge before onshore disposal<br>• Reducing Fabric Maintenance activities by work scope removal |
| Piecemeal | • Load within SWL of platform crane capacity<br>• Offshore storage and direct onshore disposal*<br>• Reducing Fabric Maintenance activities by work scope removal |
| No Removal | No work scope deconstruction, only required Fabric Maintenance activities till EoDL |

* No offshore storage possible results in prolonging schedule increasing cost.

### *Removal Execution Support*

Support is necessary to remove the redundant work scope from the installations. In this research three types of Removal Execution Supports are defined:

- Support by a Heavy Lifting Vessel (HLV);
- Support by a Lifting Barge;
- Only using the platform deconstruction capacity.

As described in chapter 3.1, the support is linked to the type of Removal Execution Strategy and depends on the type of installation. It results from applying the selection tree to the work scope, shown in figure B.2.

Table 3.3 indicates which support applies to which strategy and three distinct differences can be seen:

- Support applicable during Reverse Installation
  - *The support of Reverse Installation is assumed to be executed by a HLV because the load of the modules exceed the SWL of a Lifting Barge resulting in less required lifts.*
- Support applicable during Heavy Lift
  - *Heavy Lift support by a HLV is applicable because the load is within the SWL of the crane but the day rates of HLVs are much higher compared to Lifting Barges making it less suitable when many lifts are required.*
  - *Heavy Lift support is assumed to be more suitable by a Lifting Barge because the load is withing the SWL and the day rate is less then a HLV.*
- Support applicable in Piecemeal
  - *Piecemeal support by a Lifting Barge is applicable because the load is within the SWL of the crane but the day rates of Lifting Barges are high and Piecemeal is focused on offshore storage after dismantling so many lifts are required. However, a lifting barge could execute the strategy if there is no crane on the installation.*
  - *Piecemeal is possible by using only the platform deconstruction capacity if there are platform mounted cranes and offshore storage areas available. A floatel is suggested if there are no accommodations available on the installation.*

Table 3.3: Removal Execution Supports per Removal Execution Strategies

| | | *Removal Execution Strategies* | | |
|---|---|---|---|---|
| | | **Reverse Installation** | **Heavy Lift** | **Piecemeal** |
| *Execution Support* | **HLV** | Applicable | Applicable | Not applicable |
| | **Lifting Barge** | Not applicable | Applicable | Applicable |
| | **Platform capacity** | Not applicable | Not applicable | Applicable |

Concluding from the statements on the applicability of the support per Removal Execution Strategy and considering the viable options in table 3.3 it is assumed that during the comparative assessment:

- Reverse Installation Execution Strategy is supported by a HLV;
- Heavy Lift Execution Strategy is supported by a Lifting Barge;
- Piecemeal Execution Strategy is supported by utilizing full platform capacity; *Supported by a Lifting Barge if there is no crane on the installation.*

### *No Removal Execution Strategy*

Within the No Removal Execution Strategy there are no deconstruction activities on work scope till the EoDL assumed. Nothing will be removed, only maintained at the minimum required level to safely operate and this is estimated by Inspections.

Only FM activities are addressed within this research because all the Preventive (PM) and Corrective Maintenance (CM) activities are stopped after the redundant work scope is positively isolated, as described in chapter 3.1.6.

## Removal Execution Strategies

***Piecemeal*** When dismantled pieces fall within the SWL of the platform mounted crane, the pieces could be lifted to the storage area or directly onto a supply vessel. This is part of the Piecemeal Execution Strategy that is framed as follows, table 3.2:

- Lift load is within the SWL of the platform crane, no lifting vessel required;
- Offshore storage on deck, in containers or direct load-in onto a supply vessel.

Items addressed as Heavy Lift, thus exceeding the SWL of the platform crane, might be dismantled into smaller pieces to fall within the platform crane SWL.

The dismantled pieces vary in size and there is a distinction between handling these parts:

- Piece Large items
  *Manually unmanageable pieces (>25kg). Large equipment handling tools could support the deconstruction execution, such as mini mobile cranes.*
- Piece Small items
  *Manually manageable pieces (<25kg).*

The Piecemeal deconstruction is supported by fully utilizing the platform deconstruction capacity in terms of accommodation, cranes, storage areas and supply vessels. This approach neglects the support of any lifting vessels and when there is no accommodation available it is considered to include a floatel to provide living space for the execution crew.

Many handling activities are required to remove the redundant work scope by the Piecemeal method. This results in an increase in risks and offshore exposure time due to the deconstruction lead time.

A storage area is necessary for the Piecemeal method. The ability to store and to maneuver dismantled pieces and materials throughout the installation translates into the deconstruction lead time.

The Boundary Condition Accessibility is a vital element within all the decommissioning methods that have been discussed. But considering the amount of offshore labor to prepare and execute the piece small removal, the use of many appliances and the time spent executing the removal it can be concluded that for the piece small decommissioning method accessibility, waste management and people and material flow and handling have the most impact.

Piecemeal dismantling needs many supporting equipment such as scaffolding and mini lifting equipment. This means that the integrity of the primary and secondary steel have to be inspected, assessed and adjusted to carry the static and dynamic loads of all these activities.

Complex pipe arrangements running across different deck levels and difficult to access vessels such as scrubbers are examples of equipment that can be removed in a Piecemeal manner.

***Heavy Lift*** The Heavy Lift Execution Strategy is determined to be as follows, table 3.2:

- Lift load is within the Lifting Barge SWL;
- Comprises modules, piping, equipment and structures removed in pre-determined sequence;
- No offshore storage but direct load-in on Lifting Barge, supply boat or support barge where further dismantling takes place before it is distributed onshore.

The redundant equipment could be supported on support frames that enable a direct hook-up to a crane. There is a possibility that the equipment items are hard to reach by crane because they are spread throughout different levels of deck. A pre-determined lifting sequence could be the solution to approach this limitation.

It might be necessary to dismantle large modules and equipment to reach the SWL of the Lifting Barge. Enough space to maneuver, install and operate the supporting and dismantling appliances should be available. An example of a an item suitable for a Heavy Lift are the two compressors on their support frame as shown in figure **??**. It also shows the complexity of the item accessibility due piping arrangements surrounding the items.

***Reverse Installation*** When the installation topside is designed as a Modular Support Frame that support different modules and packaged the opportunity arises to disconnect and lift entire modules. This dismantling strategy is the Reverse Installation Execution Strategy and is framed as follows, table 3.2:

- Load of the module exceeds SWL of Lifting Barge;
- Modules removed in order of Reverse Installation;
- No offshore storage but direct load-in on HLV or a support barge

The Reverse Installation could be used to remove entire cooler bank modules including their secondary support steel or removing entire decks that contains redundant equipment by a single lift. This is only possible when the surrounding systems and structures obstructing the lift can be relocated.

Different advantages and limitations between the Removal Execution Strategies are listed in appendix B.5

### 3.2.2. Value Drivers - Costs Profiles

Business related Value Drivers are the input in the ESSM that raises the quality of the comparative assessment. In this research three drivers per Execution Strategy will be analyzed that form the basis that enables the comparative assessment between the four Execution Strategies. The following three parts explain the input of these Value Drivers Profiles.

The first Value Driver is the Costs Profile. Because information is limited and assessed from a high level the Costs Profiles are supported by set assumptions.

Figure 3.11 shows three different options within the four Execution Strategies.

Both the Reverse Installation as the Heavy Lift strategy are linked to the first option that includes Onshore Dismantling.

Option 1 as a Heavy Lift strategy will not be assessed because the pieces removed will be significantly dismantled on the barge offshore making them easy to dispose onshore.

The Costs Profiles are constructed by the following three steps:

1. Determine the Execution Strategy Cost Estimates.
   *The Cost Estimates are focused on the offshore and onshore activities per strategy and contain the following cost elements:*
   - Offshore Cleaning activities
   - Fabric Maintenance (FM) activities till EoDL.
   - Deconstruction activities
2. Determine the Execution Strategy Contingencies and Accuracies.
3. Determine the Execution Strategy Economic Values considering the year of topside decommissioning.
   *The Economic Values are assessed to include the entire time frame till the EoDL. It determines the Net Present Value (NPV) that enables the comparison between the strategies in terms monetary value spent at a certain time.*

Qualitative statements on how the Removal Execution Strategies effect the EoDL topside decommissioning is included and supported by available information on topside decommissioning in the Indefatigable field.

### Execution Strategy Cost Estimates

The breakdown of the elements in the Cost Estimate are shown in figure 3.11 and described as follows:

- Offshore Cleaning Activities;
  *It is assumed that the Offshore Cleaning Cost are the same for every strategy to ensure a safe environment even when equipment will not be removed or removed on an opportunity bases. When the equipment is left only purged by Operations the risk that the state of the inside of the equipment is unknown increases and could heavily impact the safety and cost on the installation.*

- Fabric Maintenance Activities;
  *The Fabric Maintenance (FM) activity is included as the estimated area that needs to be maintained to safeguard the integrity and safety on the installation and to be able to safely execute the EoDL decommissioning.*

  *Inspections estimate necessary areas to undergo FM activities, described in chapter 3.1.6. The total FM Costs are multiplied by the average price per squared meters.*

  *Total FM Cost:*

$$Area_{total} = \sum Area_{hotspot} + \sum Areas_{structuralsteel} \tag{3.1}$$

$$Cost_{totalFM} = \sum Areas_{total} * Cost_{FM} \tag{3.2}$$

  *The FM activity execution should be estimated on a year to year basis to include the annual FM cost in the Economic Value assessment when the FM strategy is not clearly defined.*

  *Annual FM Cost:*

$$Cost_{annualFM} = \frac{Cost_{totalFM}}{Years} \tag{3.3}$$

  *When FM activities are completed they will ensure a safe coating for x years. This should be included in the Scheduling Profile to consider the EoDL decommissioning. It is not a good practice to paint an area just before the equipment will be removed. Therefore, no FM activities will occur during work scope deconstruction activities.*

- Deconstruction Activities;
  *Deconstruction Activities is the largest contribution to Cost Estimates.*

  *The cost figures are educated guestimates based on contractor benchmark figures from onshore deconstruction experience and Cost Estimator experience.*

  *The Piecemeal Execution Strategy is defined as the removal base case to assess the offshore deconstruction lead time of the the Heavy Lift and Reverse Installation strategies.*

  *Heavy Lift and Reverse Installation deconstruction lead times are defined by a certain deconstruction efficiency factor times the Piecemeal offshore deconstruction lead time.*

  *This efficiency factor is based on the assumption that the lead time in offshore deconstruction activities decreases as the increase in SWL of the available cranes increases allowing more load to be lifted at once.*

  *Piecemeal lead time is defined as the total amount of man hours necessary to deconstruct the Equipment, Piping and Remaining elements. The assumed lead times per Removal Execution Strategy are shown in table 3.4.*

Table 3.4: Lead Times per Removal Execution Strategies

| **Removal Execution Strategy** | **Lead Time = Efficiency Factor x Piecemeal Lead Time** |
|---|---|
| Heavy Lift | 0.6 x Piecemeal Lead Time |
| Reverse Installation | 0.2 x Piecemeal Lead Time |

*The Deconstruction Activities Cost element is structured by the cost items as given in table 3.5 and are described as follows[5][6][4]:*

1. Offshore and Onshore Deconstruction Costs
   *Offshore and Onshore Deconstruction Costs are based on assumptions on the following cost items:*
   - Equipment Deconstruction Cost
     *Equipment Deconstruction Cost are based on direct man hours necessary to deconstruct the equipment. The man hours are estimated by cost estimating experience and contractor deconstruction figures based on the mass and or dimensions of the equipment.*
   - Piping Deconstruction Cost
     *Piping Deconstruction Cost are based on benchmark figures from the state-of-the-art water jet cutting company Curved Cuts B.V. that state the amount of time it takes to cut a certain inch diameter of piping and is determined as follows:*
     - The dismantled pieces should fit a 20 ft container, a length of 5m is assumed.
     - The total amount of cuts necessary is the total length per inch diameter piping [m] divided by 5m.
     - The total amount of deconstruction time is the amount of cuts times the amount of cutting time per inch diameter of piping necessary.

     *It is assumed that the average time to dismantle the piping using conventional hot work is two times the water jet cutting man hours but the handling of the dismantled pieces remain the same. Therefore, the total cost to deconstruct the piping using the conventional method is not twice the amount of the water jet cutting method.*
   - Remaining Deconstruction Cost
     *Remaining Deconstruction Cost are the cost of removing remaining parts, structures or items that are not equipment and piping and are un-engineered. Supporting structures such as tank supports, walkways to elevated equipment, small bore piping, cable trays and controls.*

     *This cost element is based on contractor benchmark figures on the estimated time to deconstruct a similar amount of tonnage minus the time estimated on removing the equipment and piping in this work scope.*

   *The Onshore Deconstruction Costs are solely addressed in the Reverse Installation Execution Strategy where large modules are removed and transported to shore as a whole where it will be dismantled and disposed.*
2. Deconstruction Equipment Cost
   *The deconstruction work is supported by different tools such as mobile cranes, cutting shears, compressors and other sorts of support appliances. The Deconstruction Equipment Cost are based on demolition contracts and earlier projects and are escalated to 2017 figures.*

   *The offshore deconstruction figures are based on onshore deconstruction benchmark figures multiplied by two.*

3. Derived Cost
   *Derived Cost differ from the Remaining Deconstruction Cost.*

   *The Derived Cost account for the cost necessary to execute the project such as scaffolding, temporary facilities making safe of the area before the execution starts. The Derived Cost are estimated by an additional 35% of the Deconstruction Costs.*

4. Logistics Cost
   *The cost for Logistics are determined by the lifting, supply and accommodation vessel support and transportation by helicopter necessary per Execution Strategy and based on the amount of scheduled days, lead time, to perform the execution.*

5. Engineering Cost
   *Engineering comprehends the support in execution such as lift plans, rigging, drawings and reinforcements. The estimated cost for Engineering is assumed as an additional cost of 25% of the offshore and onshore Deconstruction Costs, Derived Cost and Logistics Cost.*

6. Allowances
   *Allowances are included for statistically known elements and events which have a high probability of occurrence and is also known as the Known-unknown cost. The allowances are estimated as an additional 30% of the Deconstruction Costs, Derived Cost, Logistics Cost and Engineering Cost.*

7. Owner Costs
   *Owners Costs represent all costs incurred by the Owners that relate directly to the development and delivery of an opportunity or project. The Owners Cost are an additional 20% of the Deconstruction Costs, Derived Cost, Logistics Cost and Engineering Cost.*

| | | Execution Strategy | |
|---|---|---|---|
| | | Deconstruction hours | Costs x €1000 |
| 1 | **Deconstruction Costs** | | |
| | *Equipment Deconstruction Cost* | - | € - |
| | *Piping Deconstruction Cost* | - | € - |
| | *Remaining Deconstruction Cost* | - | € - |
| 2 | **Deconstruction Equipment Cost** | | € - |
| 3 | **Derived Cost (40%)** | | € - |
| 4 | **Logistics Cost** | | € - |
| 5 | **Engineering Cost (25%)** | | € - |
| 6 | **Allowances (30%)** | | € - |
| 7 | **Owner Costs (20%)** | | € - |
| | | Lead Time [hours] | Total Cost [€] |
| | | 0 | € - |
| | | Deconstruction period | |
| | | - days | Offshore |

Table 3.5: Deconstruction Activities Cost items

- Onshore Dismantling;
  *This element is only applicable in the Reverse Installation strategy. There is aa possibility of Onshore Dismantling in the Heavy Lift option but this is not assessed because it is assumed that all the pieces will be dismantled into smaller pieces on the Lifting Barge that supports this strategy.*

  *A qualitative statement is made on the onshore dismantling after the complete topside is decommissioned at the EoDL.*

- Offshore Removal Topside;
  *At the EoDL the topside and substructure must be removed. To complete the Costs Profiles it is necessary to include the topside decommissioning as a qualitative statement because*

*it defines whether the cost of removing the work scope results in less cost at the EoDL decommissioning compared to only performing FM activities.*

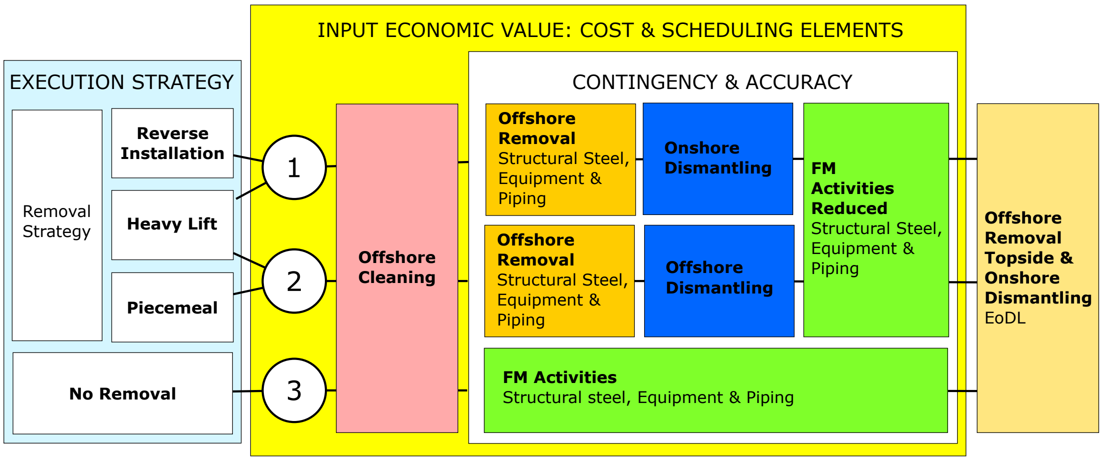


Figure 3.11: Cost Estimate and Scheduling elements per Execution Strategy

## *Execution Strategy Contingencies & Accuracies*

Estimates must always be considered with the qualifications and exclusions attached to them. The term estimate, by definition, means the figures are not firm and are always subject to a margin of uncertainty or inaccuracy. Contingency and Accuracy percentages are necessary to include these uncertainties and inaccuracies in the Execution Strategy Costs Profiles.

***Contingencies*** Contingency is the amount of money that must be added to an estimate to provide uncertainties due to incomplete project definition and specific project risks. Contingency generally decreases over the project phases as the scope definition and execution strategies mature[5][4]

Different Contingency percentages per Execution Activities are defined and correspond to the different Execution Strategies.

- The No Removal Execution Strategy
- The three Removal Execution Strategies

It is assumed that there are remaining FM Activities necessary till the EoDL after the work scope deconstruction in the Piecemeal and Heavy Lift strategy. This must be included in order to determine the Economic Value of the different projects. The Contingency value from the No Removal strategy applies the FM Activities in both the strategies.

Contingency is also known as the Unkown-Unknown cost.

***Accuracies*** During early project definition, a high quality estimate still has a wide accuracy range. Cost estimate accuracy normally increases with each subsequent phase of project development as scope definition improves and assumptions reduced.

- Worst Case Accuracy (+ve)
  *This is an additional accuracy percentage on the Contingency cost scenario resulting in the upper limit.*
- Best Case Accuracy(-ve)
  *This accuracy percentage is subtracted from the Contingency cost scenario resulting in the lower limit.*

### *Execution Strategy Economic Values*

The purpose of conducting an economic evaluation on the different Execution Strategies is to be able to compare the value of executing the strategies.

This is very important because it shows to the business what the value will be of spending money on project execution during a certain point of time and allows a better judgment on proposed options.

Economic Value is determined by the NPV which is a summation of the annual Cash Flow or annual Present Value ($M_0$).

The annual Present Value is calculated by the Future Value ($M_t$), the Discount Rate ($DR$) and the years in the future that you want to compare it with ($x$). Calculations are shown in the following formulas[10]:

Future Value:

$$M_t = (Revenue_t - Costs_t - Tax_t) \tag{3.4}$$

Present Value:

$$M_0 = \frac{M_t}{(1 + DR)^x} \tag{3.5}$$

Net Present Value:

$$NPV = \sum M_0 = \sum \frac{M_t}{(1 + DR)^x} \tag{3.6}$$

The necessary input for calculating the NPV is as follows:

- Costs Profiles including the contingencies
  - Cleaning Cost (no contingency)
  - Annual FM Activity Cost per Execution Strategy
  - Offshore Deconstruction Cost per Execution Strategy
- Scheduling Profile
  - Offshore Cleaning
  - FM Activities
  - Deconstruction Activities Lead Time
  - End of Design Life Decommissioning
  - Scheduled Shutdowns

The assumptions that form the basis of the Shell Economic Value modeling tool are given in appendix **??**. Methodology related assumptions are as follows:

- Cleaning Cost occur at the beginning of the schedule
- Cost on FM Activities is given as one figure assumed to cover the areas that need FM. No details on the execution time of FM activities thus assuming that the cost are equally spread per annum.
- Contingency is included within each cost element
- Project execution only during scheduled shutdown
- Execution lead time exceeding planned shutdown results in deferred production
- Deferred production recovered in the three years following execution in the Piecemeal Scenario

- Deferred production recovery as revenue to compensate the loss of production due to extra unscheduled shutdown
- No Revenue in Deconstruction Projects

Before performing a sensitivity analysis on all the Economic Values per Execution Strategy, it is necessary to look at the Economic Value per options by taking only the contingency into consideration. The Contingency based outcome will dismiss invaluable options. It is bad practice to model the Economic Values including the lower (-ve) and upper (+ve) accuracy percentages for all the different options.

The methodology will recommend either removing the redundant equipment or keeping the redundant equipment in-situ.

Preferred options are based on the Economic Values that take the Contingency into consideration because the probability of occurrence for the lower and upper accuracy are relatively low compared to the Contingency.

Only hen the No Removal and Removal Execution Strategies are much alike an optimization of the most obvious Removal Execution Strategy becomes valuable

A sensitivity analysis will be performed to include how the lower and upper accuracies of the Cost Estimation effects the Economic Values. This allows for the possibility to further optimize the work scope, to iterate into this selection support methodology and to show where the best value is reached. More on the strategy optimization in chapter 3.2.5

The best value of money is reached when it is spent in a later period of time. This is due to the return on investment when money is not spend. This is common economic practice and supports the decision of spreading the FM Costs over an annual basis for a longer period of time.

### 3.2.3. Value Drivers - Risks Profiles

Risks Profiles allow comparing between Execution Strategy risks with a certain probability of occurrence and a certain impact.

The risks are approached by a modified Risk Identification method [**?** ][1]:

- General risks should be assessed regarding the level of detail according to the phase in the ORP. Only high level of detail in the work scope, detailed knowledge of the status of the installation is limited.
- Probability of the execution related risks should be assessed from the execution period point of view. This period is the base for the impact on schedule.

In order to build the different Risks Profiles the following steps are to be taken:

1. Create a Risk Register (RR) per Execution Strategy that describes a **cause** to an **uncertain event** that will have a certain **impact**. These four RRs contain six types of risks:
    - General risks
      *These risks are common to each Execution Strategy.*
    - Execution Activities risks
      *These risks apply to the Execution Fundamentals and their applicability depend on type of Execution Strategy:*
        - Dismantling Activity risks
          *These risks apply to the Dismantling Activity per strategy.*
        - Fabric Maintenance Activity risks
          *These risks apply to the Fabric Maintenance Activity per strategy.*

  - Lifting and Hoisting Activity risks
    *These risks apply to the Lifting and Hoisting Activity per strategy*
  - Waste Management Activity risks
    *These risks apply to the Waste Management Activity per strategy.*
- Removal Strategy risks
  - Removal Common risks
    *These risks common between the removal strategies*
  - Removal Specific risks
    *These risks are specific for a removal strategy*

Identifying high level risks focused on these eight different types creates structured RRs that enable categorizing the probability of occurrence and their consequences on different categories in the Risk Assessment Matrix (RAM).

2. Assess the risks from the RR, determine the associated potential impact categories, make a qualitative estimation on the severance of the consequences and the probability of occurrence of the risks.

   In the RAM the impact severance is scaled to a certain range. This range must be precise enough to see a clear scatter in the risk plot. The range is too broad when all the risks are plotted at the same level and must be adjusted in order to visualize the spread between the risks. The scale is based on educated guestimates and other projects.

   The different impact categories in the RR are as follows:

   - Cost
     *This is an estimation of the impact on the cost when a certain event occurs.*
   - Schedule *This is an estimation of the impact on the schedule when a certain event occurs.*
   - Health, Safety & Environment (HSE): People, Assets, Environment & Reputation
     *This is an estimation of the impact on HSE elements when a certain event occurs.*

3. Plot the risks in a Risk Assessment Matrix (RAM) on a scale ranging from a very low (VL) impact to a very high (VH) impact and the probability of occurrence.

   It is very likely that risks will have a potential impact on a combination of categories. In these cases, the highest ranking impact scale will be used to plot the risk in the RAM matrix.

   An example of a Risk Assessment Matrix with the probability of occurrence and the potential consequences of an impact component as used in this research to plot the Risks per Execution Strategy is shown in figure **??**.

When the risks are plotted in the RAM, general conclusions on the risks, their probability of occurrence and their potential impact per Execution Strategy could be drawn.

This enables the comparison between different strategies on their associated risks and enables supporting statements on the preferred Execution Strategy.

However, these risk assessments are very speculative. Especially on this level of detail.

### 3.2.4. Value Drivers - Scheduling Profiles

Scheduling Profiles describe the entire planning till the stated EoDL topside decommissioning. It will show the lead time per Execution Strategy and is a result of the following input:

- The type of support during the different Execution Strategies.
- An assumption on the amount of people working in the execution team.

- An assumption on the amount of offshore and onshore execution days per member of the deconstruction team.
- Onshore activities are only addressed in the Reverse Installation method.
- Crew transportation methods available on the platform (helideck or marine access) will only be addressed in the Logistics Cost element.
- The Removal Execution Strategies are executed during planned shutdown of the installation. Indication of the planned shutdowns are written in the asset operating plans and is used the Economic Value assessment.
- The Offshore Deconstruction lead time that follows from the Cost Estimate is used to determine if the deconstruction exceeds the shutdown period.
- When the planned shutdown period is exceeded, deferred production is the result which will be taken into consideration in the Economic Value assessment.

The Scheduling Profiles are the input for calculating the Economic Values per Execution Strategy.

### 3.2.5. Execution Optimization

Two steps are taken to assess the optimization possibility from an Economic Value perspective:

1. Reduce the work scope and use the same method of deconstruction as the previous options while considering its effect on the FM activities.
2. Reduce the work scope and assess an Opportunity Based deconstruction approach by using the resources available over a long period of time. The assumptions should be as follows:
   - Deconstruction man hours are covered by the Non Productive Time (NPT) of Personnel on Board (POB) that cannot perform their own work scope.
   - Use the regular Supply Vessels to remove the material waste.
   - Assume that the Cost Estimate is based solely on the following elements based on the original reduced work scope:
     - Deconstruction Equipment Cost
     - Derived Cost
     - Engineering Cost
     - Allowances Cost
   - FM activities are postponed till after the deconstruction is completed due to increased safety risks.

   The lead time is a very uncertain event making it impossible to predict. It should be estimated in years, postponing FM activities for a longer time but increasing risks of the accumulation of Safety Critical Elements.

   An Economic Value assessment should be performed on both these options to assess their differences.

   Compare and evaluate the economic analysis of the preferred optimization work scope and the No Removal Execution Strategy and apply a sensitivity analysis on both these options in order to make a well supported decision.

### 3.2.6. Work Scope Deconstruction Advantages at End of Design Life

When equipment is redundant it needs to undergo FM activities to safeguard the integrity and safety on the installation. These activities are Operational Expenditures (OPEX).

Within this selection support methodology the direct impact of removing the redundant work scope on the FM activities is compared to not removing the work scope through the Costs Profiles, Risk Profiles and Scheduling Profiles.

To complete the comparative assessment, the possible deconstruction advantages on the End of Design Life topside decommissioning are included by qualitative statement since the projects evaluated in chapter **??** only delivered limited insights. The learnings in chapter **??** allows to form high level qualitative statements on how the Removal Execution Strategies effect the EoDL topside decommissioning.

An overview of advantages at the EoDL decommissioning is as follows:

- The possible advantage of simplifying topsides correlated to the mass reduction could result in:
  - Less onshore deconstruction lead time
  - Saving on vessel type due to the SWL reduction necessary to lift the topside
  - Saving on decommissioning preparation work scope and the necessary materials to support the structure
  - Saving on engineering and lifting appliances such as rigging and spreader beams
- Integrated topsides, Monotowers and Normally Unmanned Installations (NUI), are assumed to be lifted as a single lift. Monotowers are very compact but NUIs could contain overhanging equipment that obstruct the single lift such as helicopter decks and platform mounted cranes. Advantages could be achieved by removing these beforehand and saving on the HLV day rates. However, this advantage strongly correlates to the lifting barge day rates and deconstruction lead time and cost.
- The EoDL Piecemeal deconstruction of modules on the Modular Support Frame is translated into an estimated deconstruction lead time based on the mass supported on the frame. This results in the amount of man hours and could be translated into savings on:
  - Vessel day rates
  - Logistics
  - Decreasing risks in EoDL offshore deconstruction exposure, onshore deconstruction exposure and material disposal.
- The Costs Profiles results in the NPV in the year of the EoDL topside decommissioning. To deliver the most value on the preferred Execution Strategy, the cost on the work scope at the EoDL should be larger than the Economic Value from the Execution Strategy. However, Fabric Maintenance (FM) on the redundant work scope is assumed to be necessary.

#### *Work Scope Deconstruction Advantages till End of Design Life*

Next to the advantages at the EoDL, there are also advantages till the EoDL and an overview is as follows:

- Increase in sufficient open areas could be used to support other applications:
  - It could allow for future new energy applications

        - ⋄ Use the area to install equipment that operates as an energy hub for offshore wind parks
        - ⋄ Use the area to install equipment for producing hydrogen
    - – It could allow for other facilities such as temporary refuge that could support the NUI transformation
    - – It could allow for alternative power generation such as solar panels or wind turbines
- Installations that contain redundant equipment could decrease the sense of ownership of the Personnel On Board (POB) and result in bad housekeeping. Removing it could lift up the sense of ownership and motivate the POB. This could decrease risks during activities.

## 3.3. ESSM step 3: Finalizing Comparative Assessment

In the final step of the ESSM the Value Drivers Profiles end the effect on the EoDL decommissioning per Execution Strategies will be compared and discussed.

It is possible to perform a comparative assessment by generalizing the Execution Strategies through the Value Drivers Profiles as follows:

- Different Economic Values enable the comparison on the level of costs till the EoDL with qualitative statements by the effect of removing the work scope on the EoDL topside decommissioning;
- Plotted risks and their impacts enable the comparison between the different types of risks and show the execution showstoppers as critical and severe risks in the RAM;
- The Scheduling Profiles are a contribution to the Economic Value assessment and shows more about the execution activities lead time, exposure and planning till the EoDL decommissioning.

Figures from different executed projects are used to compare to the results achieved from the ESSM. It is checked whether these results are in line with Refurbishment Campaigns and Decommissioning Projects.

When the results are more or less in line with past projects it is possible to draw conclusions from the results and recommendations achieved by applying the ESSM.

When they are not in line, it is advised to check the level of detail by which the assessment is made and compare it to the level of detail in the same phase in the ORP from the finished projects in the past.

However, since most of the input is based on educated guestimates this comparison is difficult to make. This is translated back into the phase in the Opportunity Realization Standards (ORS) and the high Contingencies and Accuracies percentages.

It is possible that the level of detail does not comply with the phase in the ORS resulting in an inaccuracy of the prospected figures thus decreasing the value of opportunity assessment.

## 3.4. Guidelines to use the ESSM

All the elements within the Execution Selection Support Methodology (ESSM) have been explained in detail in the previous part of this chapter. This part explains the general guidelines to implement the ESSM and their references to the detailed information in this report.

### 3.4.1. ESSM step 1: Work Scope Analysis

The first step in this implementation guideline is the Work Scope Analysis, chapter 3.1. This step is as follows:

1. Analyze the redundant work scope through the Accessibility Selection Tree based on the Accessibility Boundary Condition, chapter 3.1.2. The selection tree is found in Appendix B.2
   *Input: Redundant work scope*
   *Output:*
   - Applicable Execution Strategies, chapter 3.2.1
   - The Execution Strategies define the intensity of the Execution Activities, chapter 3.1.2.

Both the Boundary Conditions as the Execution Activities are part of the Execution Fundamentals, chapter 3.1.2

### 3.4.2. ESSM step 2: Strategy Comparison Framework

This second step in the ESSM is divided into two parts and is set to create the different Value Driver Profiles per Execution Strategy to compare while taking their effect on the EoDL topside decommissioning in account, chapter 3.2.

Input for this step is the output from the first step and will be assessed as follows:

1. Create Value Driver Profiles per Execution Strategy.
   - Create the Risk Profiles, chapter 3.2.3
     (a) Create Risk Registers per Execution Strategies
     *Input: Boundary Conditions, Execution Strategies and Execution Activities.*
     *Output: Cause, Event and Impact ranked on Probability and Consequences.*
     (b) Plot Risk Registers in Risk Assessment Matrix (RAM)
     *Input: Ranking per risk.*
     *Output: Risk Profiles by plotted risks in the RAMs*
   - Create the Cost Profiles, chapter 3.2.2
     (a) Assess Execution Strategy Cost Estimates
     *Input: Offshore Cleaning Cost, Fabric Maintenance Cost, Deconstruction Cost and Execution Activity Contingencies*
     *Output: Cost Estimate per strategy and deconstruction lead time*
     (b) Assess Execution Strategy Economic Values
       i. Assess Economic Values based on Contingencies
       *Input: Cost Estimates including Contingencies.*
       *Output: Range of Economic Values giving the best Removal Execution Strategy to optimize and compare to the No Removal strategy.*
     (c) Optimize best Removal Execution Strategy
     *Input: Reduced work scope and Opportunity Based approach Output: New Cost Estimate and Economic Value*
     (d) Perform Sensitivity Analysis between the optimized strategy and the No Removal strategy
     *Input: Best and Worst case Accuracies processed in optimized Cost Estimate.*
     *Output: Cost Profiles of the No Removal Execution Strategy and best Removal Execution Strategy.*

- Create the Schedule Profiles, chapter 3.2.4
  *Input: Deconstruction lead time, year of Offshore Cleaning, estimated years of Fabric Maintenance activity, year of EoDL topside decommissioning and scheduled shut-down years and duration.*
  *Output: Schedule Profiles that show the planning per Execution Strategy until the EoDL topside decommissioning.*

2. Assess the effect of the Removal strategies and the No Removal strategy on the EoDL topside decommissioning, chapter 3.2.6
   *Input: Decommissioning benchmark figures, Execution Strategy Value Driver Profiles from the previous step.*
   *Output: A qualitative statement on the benefits of the Execution Strategies based on the Value Driver profiles and compared to the EoDL topside decommissioning.*

### 3.4.3. ESSM step 3: Finalizing Comparative Assessment

In the final step of the ESSM it possible to finalize the comparison between the No Removal Execution Strategy and the best Removal Execution Strategy based on their Value Driver Profiles and the qualitative statements on their effect on the EoDL topside decommissioning.

Conclusions are drawn from the results achieved by this methodology. Recommendations on the appropriate Execution Strategy to the redundant work scope opportunity are supported by these conclusions.

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# 4

# ESSM Case Study application

## *- Leman AK Redundant Compression System -*

In this chapter the Execution Selection Support Methodology (ESSM) guidelines, described in chapter 3.4, will be used to apply the research methodology to a case study.

The Leman AK case study is performed to assess which Execution Strategy has the most value to execute before while taking the installation End of Design Life (EoDL) into account.

Three Value Driver Profiles per Execution Strategy will be assessed and their effect on the EoDL decommissioning will be discussed. This case study is performed to test the methodology applicability in practice.

When the methodology steps result in proper output and when this output allows making supported conclusions and recommendations, the methodology proves to be applicable in practice. The results of applying the methodology is discussed in chapter 5.

Figure 4.1: Leman Alpha Complex

## 4.1. Case Study Summary

The research objective is to develop a selection methodology capable of supporting the comparative assessment between different execution strategies of maintaining or removing redundant topside equipment while taking the installation end of design life into consideration.

This case study is conducted to evaluate the selection methodology its capability to support the comparative assessment by assessing the Leman AK redundant work scope. The process follows three structured consecutive steps.

These three steps are set as follows:

1. The work scope analysis, based on three boundary conditions and an 'accessibility' selection tree, results in the applicable execution strategies to assess in the second step.
2. The strategy comparison framework is structured to support assessment of strategies using four execution activities, the results provide their corresponding costs, risks and scheduling value driver profiles. Based on these profiles, the strategy effect on the end of design life decommissioning is qualitatively stated.
3. Finaly, a comparative assessment based on the profiles and statements from the comparison framework provides a preferred selection that is supported by the steps from the selection methodology.

From the results of applying the three consecutive on the Leman AK redundant work scope, the following conclusions are drawn:

- Not removing the redundant work scope is delivered by the selection methodology as the preferred execution strategy.
- Not removing the work scope has the same economic value as removing it on an opportunity basis but has the preference because its variation is more robust.
- The application for this project phase results in large contingency and a low level of accuracies when assessing the costs profiles.
- Assessed risk profiles are based on input from decomplexing, refurbishment, decommissioning and other deconstruction related projects but remain speculative.
- The qualitative statements on the effect on end of design life topside decommissioning are not sufficiently supported due to assumptions and limited amount of benchmark information.
- General strategy risks shift from large spread of low consequence and high probability risks, correlated to no removal, to a narrower spread of high consequence low probability risks when the safe working load increases and more mass is removed at once.

Given these conclusions, the following recommendations are made:

- Further research on benchmark information to optimize the assumptions creating the value drivers profiles and the effect on end of design life decommissioning is recommended.
- Research on execution optimization by combining the opportunity based approach with a practical case-by-case work scope assessment is recommended.
- The risks profiles are speculative, therefore it is recommended to do more research on a general risk comparison framework that is capable of standardizing the risk assessment with a structured approach.
- Boundary conditions and execution activities are identified to support the selection methodology. Further research on other execution activities and boundary conditions is suggested to further develop and structure the input.

## 4.2. ESST step 3: Finalizing Comparative Assessment

Results on the Value Drivers per Execution Strategy and the Execution Optimization have been obtained and qualitative statements on their effect on the EoDL topside decommissioning are stated in chapter **??**.

This final ESSM step will compare and discuss these results and draw conclusions on their outcome. The recommendations are given in the final chapter because they highly correlate with improving the ESSM.

### 4.2.1. Discussion Case Study Application

The discussion in this chapter focuses on the results achieved by applying the ESSM to the case study. Methodology related discussion is not given in this section but is found in chapter 5.2.

#### *Discussion Case Study ESSM step 1 - Work Scope Analysis*

The first ESSM step delivers as expected. Nonetheless it could be argued that a better analysis on the platform mounted crane and available accommodations should be made to use as better input on the team size and deconstruction lead time. This is fairly reasonable and could be better incorporated once this methodology is further structured. However, at this level of detail it does not limit the input for the next step. The next step uses assumptions on the team size and lifting capabilities in a comparative way and only uses the first step as a suggestive approach to support the applicable Execution Strategies and extra Removal Execution Support.

#### *Discussion Case Study ESSM step 2 - Strategy Comparison Framework*

***Scheduling Profiles*** The Scheduling Profiles are the input for the Economic Values stating when the different Execution Activities are executed. This helps the economic evaluation to create the Cost Profiles.

It could be argued that using different time ranges per Execution Activities should be used as input because the results are currently only based on speculative executions in years. The result of input in ranges will help the development of an implementation tool that can perform the economic comparative assessment on a more sensitivity based analysis.

The possibility to perform all the piping cold work dismantling activities outside of the scheduled shutdown period is not taken into consideration during the lead time assessments. This creates other economic outcomes because no deferred production is the result during the Piecemeal Execution Strategy. However, the loss by deferred production is compensated over the years following the exceeded shutdown so there will not be a significant difference.

***Costs Profiles*** The Costs Profiles deliver the Economic Value and supports selecting the preferred Execution Strategy.

It was expected that the Reverse Installation was dismissed due to the high vessel rate. The similar Economic Values between the Piecemeal and Heavy Lift was not expected. This is a direct consequence of factoring the lead time. When the lead time was assumed to be higher, it would have resulted in more offshore deconstruction days and an increase on the deconstruction costs, for instance, due to the high Seafox 4 day rates.

Using the Piecemeal Execution Strategy as a base case for the Removal Execution Strategies is a good starting point. From the lifting and dismantling perspective, the strategies using vessel mounted cranes have a decrease in their deconstruction activities due to the amount of mass they can handle at once. However, a more structured approach on the lead time efficiency will create better deconstruction lead time and costs estimates.

The Opportunity Based approach as an optimization is supported by the Decomplexing strategy. This case is based on the Piecemeal work scope reduction that was assumed by only removing the upper deck piping and equipment. A more case-by-case approach on the work scope could lead to a better practice in the methodology.

***Risks Profiles*** A Risks Profile has been created for each Execution Strategy. The results of these profiles are as expected, the more activities, the higher exposure to the risks. Increasing handling mass results in higher consequences but lower probabilities due to the scale of the project and its lead time.

Statements on the risks involved in the Execution Optimization are arguable. They have been stated without applying the structured approach as described in the methodology. To create a better understanding of the risks involved during the optimization case, it seems better to assess it as if it has no relation to the other strategies. However, the optimization case was modified based on a Piecemeal Execution Strategy Costs Estimates with a reduced work scope. The difference between strategies was focused on the decrease in deconstruction activities and the uncertainties of the deconstruction lead time. Based on this knowledge, it might be better to focus the risks more on the execution uncertainties than the deconstruction activities.

The results from the Risks Registers supporting the Risks Profiles are questionable. They are based on experience but maintain to be speculative. After the risks are plotted they create a high level sense of the risks but do not create a solid sense in the differences. However, since the application of this methodology is considered to be used in an early project phase, many risks stay speculative. Only when the work scope evolves in more detail, better risks assessments can be made.

***Execution Strategy Effect on End of Design Life Decommissioning*** When comparing the Removal Execution Strategy effects on the EoDL topside decommissioning, qualitative statements are made by using learnings from past decommissioning projects.

The result of this comparison was expected. The Opportunity Based approach was estimated to be less effective that the Piecemeal Execution Strategy. This statement is supported by the assumption that more benefits are achieved when there is a large decrease in offshore deconstruction exposure at the EoDL. However, this is only suitable when these benefits exceed the costs Execution Strategy Costs Profiles. No comparison is made between the risks during the Removal Execution Strategies and the risks at the Piecemeal deconstruction at the EoDL topside decommissioning.

### 4.2.2. Conclusions Case Study Application

Based on the Case Study results and the discussion, the following conclusions are stated:

- The first ESSM step delivers the applicable strategies based on the type of installation as is a good input for the second ESSM step.
- The No Removal Execution Strategy is the delivered as the preferred strategy. It creates the best value in the Costs Profile at the EoDL. The Risks Profile show a higher risk probability but the impact consequences are low compared to the Removal Execution Strategies.
- The EoDL topside decommissioning benefits the most from the Piecemeal Execution Strategy. But it is not sufficiently supported to address this strategy as the preferred outcome of the comparative assessment.
- The risk assessment is more focused on the risks that occur during the execution rather than how they are affected by the Execution Strategies.
- Based on the Contingency scenario, the Opportunity Based approach has the similar NPV as the No Removal Execution Strategy but it has a less robust variation in the sensitivity analysis.
- The assessed Risks Profiles are based on input from decomplexing, refurbishment, decommissioning and other deconstruction related projects but remain speculative.
- A more case-by-case approach on the work scope removal could result in a more optimized FM activity reduction.
- Heavy Lift & Reverse Installation costs are highly driven by vessel day rates.

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# 5

# Research Results, Discussion, Conclusions & Recommendations

The objective of this conducted research, stated and supported in chapter 1, is defined as:

> *"To develop an Execution Selection Support Methodology capable of supporting an early phase comparative assessment between maintaining or removing redundant topside equipment from offshore installations, considering limited work scope information, continuous production and topside removal at the End of Design Life of the installation."*

This chapter discusses the results of the developed methodology in relation with the research objective, draw conclusions on the results and make recommendation for future implementations and improvements.

## 5.1. Results Execution Selection Support Methodology

The Execution Selection Support Methodology (ESSM) is described in detail in chapter 3 and applied to a case study in chapter 4. This section describes the ESSM results delivered by its first two consecutive steps.

### 5.1.1. Results ESSM step 1 - Work Scope Analysis

The objective of the first ESSM step is to deliver the Removal Execution Strategies, applicable to the type of installations, that will be compared with the No Removal Execution Strategy in the second ESSM step. This selection is based on the Accessibility Boundary Condition that forms the basis of the selection tree.

Three Boundary Conditions and four Execution Activities form the Execution Fundamentals which are the elements used to assess the Execution Strategies to create their corresponding Value Drivers Profiles necessary for the comparative assessment.

#### *Execution Fundamentals - Boundary Conditions*

The results on the Boundary Conditions are as follows:

- The Accessibility Boundary Condition is capable to deliver the applicable Execution Strategies through its corresponding selection tree.
- HSSE&SP and Structural & System Integrity Boundary Conditions are predominantly used to assess the Execution Strategies on their relevant risks. HSSE&SP are the ele-

ments that are affected by the risks while the System & Structural Integrity resulted in being the risks causes.

### *Execution Fundamentals - Execution Activities*

The results on the Execution Activities are as follows:

- Fabric Maintenance (FM) Activity is directly influenced when a work scope reduces or increases. It is determined to be the driver of the Operational Expenditure (OPEX) and a large contribution to the Costs Profiles.
- Dismantling, Lifting & Hoisting Execution Activities resulted in being the dominant main deconstruction contributors because they determine the deconstruction lead time, based on the work scope and the Safe Working Load (SWL) that determines the amount of mass lifted at once translated in lifting efficiency.
- Waste Management Execution Activity resulted in the cost necessary to clean the redundant work scope resulting from the assumption of no Hg contamination and the assumption that the system not contained Hg contamination.
- The four Execution Activities are large contributors to the risk assessment. The risk assessment is successfully implemented and resulted in plotted Risk Assessment Matrices, based on the risk consequences and probability of occurrence of the Execution Activity corresponding risks during the Execution Strategies.

## 5.1.2. Results ESSM step 2 - Strategy Comparison Framework

The objective of the Strategy Comparison Framework is to structure assessing the Execution Strategies to deliver the Value Drivers Profiles necessary to perform the comparative assessment. When the Value Drivers Profiles are delivered, the effect by the strategies on the End of Design Life (EoDL) topside decommissioning can be investigated and qualitatively stated.

### *Execution Strategies*

The results on the Execution Strategies are as follows:

- The Execution Strategies delivered as expected. The only contributors to the Value Drivers Profiles are the FM and Wast Management Execution Activities during the No Removal execution. All the three Execution Activities contributed during the Removal Execution Strategies.
- The Removal Execution Strategies only delivered by input from experience based guestimates and benchmark figures.
- Different Removal Execution Support was defined to support the deconstruction activities and was successfully taken into consideration in the Value Drivers Profiles assessment.
- The Execution Strategies resulted to act more as a reference on variation of the Execution Activities intensity per strategy.

### *Value Drivers Profiles*

The results of the Value Drivers Profiles are separately discussed in the following paragraphs.

***Value Drivers Profiles - Costs Profiles*** This profile supports the different Execution Strategies based on their Execution Activity related costs. The results are as follows:

- The Costs Profiles successfully deliver the Net Present Value (NPV) at the EoDL per Execution Strategy based on economic evaluation of the Contingency based Cost Estimates related to the Execution Activities. The results clearly show the effect of the intensity variation of the Execution Activities between the strategies.
- It shows that the difference between strategy Cost Estimates are directly related to the work scope deconstruction lead time and highly affected by the Removal Execution Support costs.
- The lead time efficiency factors, based on the Piecemeal Execution Strategy, are difficult to confirm by benchmark figures. They clearly influence the offshore deconstruction lead time, more efficient Dismantling and Lifting & Hoisting Execution Activities results in less offshore deconstruction man hours.
- Starting the Execution Optimization by assessing a reduced work scope proved to support the Opportunity Based approach.
- The Cost Estimates support the Execution Optimization. The contribution per Cost Estimate Element changes by the work scope reduction and the Opportunity Based philosophy and results in different Economic Values.
- The economic evaluation shows that lost by deferred production is compensated for in the following three years after it occurred.

***Value Drivers Profiles - Risks Profiles*** This profile supports the different Execution Strategies based on their Boundary Condition and Execution Activity related risks. The results are as follows:

- Assessing the Execution Strategy related risks by using the Risk Registers is proved to be a useful structured approach before the risks are plotted in the Risk Assessment Matrix (RAM).
- Risks Profiles result from the RAM risk plots. It is confirmed that the method of risk assessment is appropriate to create a general sense on the involved risks but its ability to support the comparative assessment is speculative.
- By assessing the strategy related risks it is found that the Execution Fundamentals have a mixed contribution to the assessment. They are either the activity to which risks are assigned, causes to a risk event or elements impacted by the risks.
- The cost and schedule ranges in the RAM are based on experience guestimates and proved to be valid for the case study and a good spread of plots are the result.

***Value Drivers Profiles - Scheduling Profiles*** This profile supports the different Execution Strategies based on their Execution Activities planning. The results are as follows:

- Execution Activity lead times, scheduled shutdown periods and year of installation EoDL are proved to be critical input in the Economic Evaluation. They are taken into consideration on a fixed or annually spread basis which seem to correlate to the early phase application.
- Especially the lead times are highly based on assumptions and directly influence the possibility of exceeding scheduled shutdown periods.

#### *Execution Strategy Effect on End of Design Life Decommissioning*

After the Execution Strategies have been analyzed and their corresponding Value Drivers Profiles are created the effect by the strategies on the EoDL topside decommissioning is qualitatively assessed and stated. The results are as follows:

- Qualitative statements on the EoDL topside decommissioning have been delivered and are supported by benchmark projects.
- Qualitative statements on the benefits of work scope deconstruction have been delivered.
- There is a lack of qualitative statements on the benefits of not removing the redundant work scope.
- Only decommissioning project learnings supported the qualitatively assessed effect on the EoDL topside decommissioning.
- Learnings from decomplexing and refurbishment projects resulted slightly applicable information to support Execution Strategy related Execution Activities.

## 5.2. Discussion Execution Selection Support Methodology

The Execution Selection Support Methodology (ESSM) is described in detail in chapter 3 and applied to a case study in chapter 4. This section discusses the ESSM results delivered by its first two consecutive steps.

### 5.2.1. Discussion ESSM Application & Validation

Due to the high amount of assumptions it is found to be difficult to validate the developed ESSM. Predominantly when the deconstruction lead times are assessed. However, the purpose of the research objective is to support the selected Execution Strategy to address to the redundant work scope opportunity in the early phase assessment. This is proved successful when the limitations of these assumptions are taken into consideration. For the early phase application this is valid because the input information is bound by the level of details.

Input sensitivities, such as ranges in cost and time, are not specifically addressed in the ESSM. Fixed estimates and assumptions are used for the Costs Profiles assessment. It can be argued that the ESSM needs to analyze all these variations to support the strategy selection. However, it is the purposes to perform a comparative assessment based on a structured approach with the available information on the work scope. When variations occur, for instance by market demands, they can easily be implemented and new profiles can be created.

### 5.2.2. Discussion ESSM Step 1 - Work Scope Analysis

It can be argued that a more detailed work scope or a better defined Cost Estimate improves the ESSM delivery. But increasing the level of work scope details demands more time and effort and this will no longer be in line with the early phase applicability.

### *Execution Fundamentals*

The only assessed OPEX reducing opportunity is the FM Activity. Not only FM activities are affected by removing redundant equipment. There are other secondary systems that can benefit from positive equipment isolation and its removal. Fire and Gas systems are a predominantly factor in maintenance activities caused by errors, They have a large contribution to the maintenance OPEX and this is another opportunity to include in the work scope and as an Execution Fundamental.

It can be argued that the Waste Management Execution Activity should be included more specifically. There are many forms of contamination that could occur. This is a valid point and could be better addressed. However, Operations should be able to confirm what contaminations could occur in the redundant work scope. It will only be a matter of stating the worst case contamination in the Cleaning Cost and the upper estimated limit is included.

## 5.2.3. Discussion ESSM Step 2 - Strategy Comparison Framework

This section discusses the Execution Strategies, Value Drivers Profiles and the qualitative statements of the effect on EoDL topside decommissioning as part of the Strategy Comparison Framework.

### *Execution Strategies*

The relation between the different Execution Strategies could raise a discussion. The Execution Strategies have been set to differ on their deconstruction capabilities but a combined strategy approach has not been addressed. The situation could occur that nearby lifting barges could lift pieces unsuitable for the platform mounted crane while other redundant work scope equipment is removed in a Piecemeal manner. Using a combination of methods and available resources could result in an optimized strategy that delivers the most value. However, this can only be the result after doing a case-by-case study on the redundant work scope and available resources in the area.

### *Value Drivers Profiles*

Using Water jet cutting as a cold work piping dismantling method as a basis is considered to be part of the deconstruction lead time. This method could also be applicable to vessels and tanks. This will have an effect on the deconstruction cost and offshore lead time since this dismantling method is not bound to shutdown. This is related to performing a more case-by-case study on the redundant work scope. The basis of the ESSM is to take all the Execution Activities in one period of execution. By approaching it by an Opportunity Based approach many uncertainties start to occur that translate back to the Scheduling Profiles and is used in the Costs Profiles. A next step in the development could be to implement the difference in shutdown bound Execution Activities and translate it in the Scheduling Profiles as long as it does not comply with the early phase applicability.

The EoDL topside decommissioning is implemented by a fixed date and taken into consideration by anticipating on the years where the Execution Activities are performed. Variation in the year that the EoDL is reached can be a valuable parameter to create more sense in the economics of the Execution Strategies. However, this probably does not affect the ESSM. The ESSM is already capable to qualitatively state the effects of EoDL changes by looking at the Cost Profiles,

The lead time efficiencies result in distinguishes between the Removal Execution Strategy offshore deconstruction lead times. During the Reverse Installation, the onshore deconstruction lead time is a result of subtracting the offshore deconstruction man hours from the Piecemeal offshore deconstruction man hours. It can be argued that this is not the correct way to assess the onshore deconstruction work scope. However, the assumption is made that for a fixed work scope the deconstruction man hours are the same but the offshore costs are higher. Removing large lumps of equipment has to me dismantled into smaller pieces onshore for distribution. Therefore, in this early phase application it is an assumed method to enable the high level comparison between the costs.

Only large diameter piping is taken into consideration in Dismantling Activity. It can be argued that the small diameter piping should be taken into consideration as well. This is only valid when it is proofed by Inspections that small bore piping will have a significant effect on the OPEX reduction. Small bore piping is easily dismantled on an opportunity basis and will not impact the deconstruction costs significantly.

### *Execution Strategy Effect on End of Design Life Decommissioning*

The effect on the EoDL topside decommissioning assessment is based on the assumption that only installations with a Modular Support Frame are decommissioned using a combination of Piecemeal deconstruction and single lifting the support frames. Integrated topsides are considered to be decommissioned in a single lift. It can be argued more research should be done on the type of EoDL decommissioning methods. This is a valid point and it will be relevant to do more research on a structured and general applicable assessment framework on the EoDL decommissioning methods per type of installation.

## 5.3. Conclusions Execution Selection Support Methodology

Based on the ESSM results and the discussion, the following conclusions are stated:

- The ESSM provides high level insights in the Costs, Risks and Scheduling Profiles related to the Execution Strategies and can be used as an early phase application to select and support a preferred strategy for minimizing OPEX related to a redundant work scope. The Costs Profiles deliver the most support.
- Minimizing operational expenditure is very complex and depends on many factors and opinions.
- Increasing the level of work scope detail does not comply with an application to the early project phases. The methodology variables are limited and mostly based on assumptions and experience based guestimates. These uncertainties are taken into consideration in the Costs Profiles.
- This selection methodology is capable of providing broad and general insight but in practice redundant work scope should be addressed on a case-by-case approach.
- The Scheduling Profiles are valid inputs necessary to support the comparative assessment but are more applicable to support the Costs Profiles than directly relating it to a preferred Execution Strategy.
- Currently the FM Activity is taken into consideration as an annual spread where the costs are divided by the amount of years. More insights in the estimated FM strategy can result in a better Scheduling Profile and Costs Profile in terms of executing the FM activities.
- Production competitiveness is driven by reducing operational expenditure; there is a high demand for better insights in optimizing this reduction. Decreasing this expenditure could lead to prolonging the end of design life.

## 5.4. Recommendations Execution Selection Support Methodology

Recommendations for ESSM improvement and further research, based on both the ESSM and its Case Study application results, are stated as follows:

- It is recommended to assess and implement the impact by the redundant work scope on other systems, such as fire and gas systems, that largely contribute to the operational expenditure.
- Research should be done on the lifetime benefits of creating open areas by removal to be used for other offshore applications such as energy hubs, power generation or other market demands.
- It is recommended to implement the possibility of combining Execution Strategies based on the resources available in the region and taking the opportunity to assess the work scope on a case-by-case manner to optimize the Opportunity Based approach.
- It is recommended to conduct further research on benchmark information to optimize the assumptions that support the Execution Strategy assessment and create the Value Drivers Profiles.
- The methodology has potential, further research into creating a solid implementation tool, based on the variable input ranges and general asset applicability, is recommended.
- It is recommended to do further research into optimizing which Removal Execution Strategy is most suitable per asset type and how the risks are affected by removing the work scope from the asset.
- Since the work scope deconstruction is based on experience based guestimates and a limited amount of benchmark deconstruction figures, it is recommended to do research on general equipment deconstruction characteristics to make the deconstruction more solid,
- Reducing OPEX could result in prolonging production. It is recommended to conduct further research on how the equipment removal effects the production.
- Further research on how the available lifting resources affect the deconstruction lead times.

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# A

# Detailed information on Offshore Processes

## A.1. Hydrocarbon Process

In this part the systems that facilitate the hydrocarbon production processes situated on offshore gas-processing installations are explained in more detail.

### Gas & Liquids Processing System

An offshore installation can produce and process natural gas and liquids from its own wells and import it from surrounding wells. A typical gas processing flow scheme can be found in figure A.1 and consist of many components. Typically wet gas is flowing into the system and is dried before entering the compression system.

Due to new innovations such as two-phase piping, it is now possible to export all wet gas from different fields to one connecting hub to dry and export it to the onshore gas processing plant. Thus creating the opportunity to simplify the process and reduce operational expenses.

The condensate head tank receives water and condensate from the scrubbers, the slug catcher and process utilities. When the water is separated from the condensate it is guided overboard and the condensate is injected in the main gas export header.

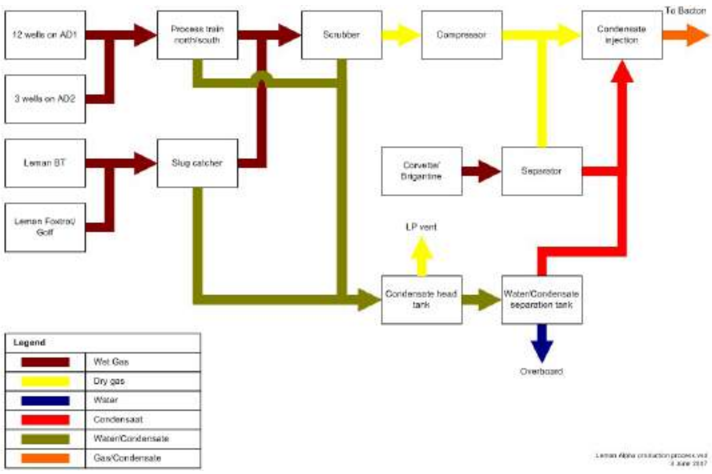


Figure A.1: Leman Alpha Production; A typical gas production process offshore

### Fuel Gas System

The fuel gas system filtrates and heats the fuel gas to deliver natural gas that is treated to be clean and at the right pressure for gas-driven equipment such as generators and turbines. The gas-turbines drive the gas-compressors, power generators and pumps.

This is necessary to protect gas-fueled systems, such as gas-turbines, against over-pressure, solids, liquids and aerosols so they can operate safe and efficient.

### Purge Gas System

Purge gas makes sure that the gas-mixture has a hydrocarbon-rich atmosphere and is supplied when needed.

### Chemical Injection System

The chemical injection systems enable the injection of chemicals necessary to treat the mixture against the formation of hydrates and corrosion. These chemicals are injected by the use of pumps.

### Control System

The control system enables the continuous monitoring of the process and alarms from inside the control room and onshore locations.

### Process Control

Process control systems monitor and control the mass flow and suction pressure in automatic and manual mode. It also monitors process gas discharge temperatures and pressures initiating a shutdown on high temperatures or overpressure.

In the event of an process upset, the Process Shutdown System (PSD) ensures that items of machinery or sections of the process are safely shutdown.

## A.2. Safety Provision

### Maintaining Process Integrity

Maintaining the integrity of the pressure within the system is the first importance in reducing risks from fires and explosions.

The integrity of the piping and equipment is threatened by different types of causes like incipient defect, mechanical impact such as dropped objects, erosion and escalation from an existing hydrocarbon hazard.

### Incipient Defect Program

Incipient defect is caused by corrosion or fatigue within the system. There is an integrity assurance program in place on every installation to monitor and control the incipient defect.

This program is very extensive and involves continuous inspection, maintenance, testing and painting. When equipment is removed from the installation it will result in a decrease in the integrity assurance program resulting in a decrease in OPEX. If equipment stays, while being redundant, it has to be inspected and maintain. This will keep up the cost while the equipment is not in operations any longer.

### Mechanical Impact

The pressure envelope is very robust, robust enough to withstand minor mechanical impacts associated with the working environment. Unfortunately the equipment is still vulnerable to damage by dropped or swung loads.

Therefore, during inspection there is always a lookout for Potential Dropped Objects (PDO) and there are very strict controls on lifting operations. This also includes lifts using temporary hoists and lifting beams as well as large cranes.

This is a direct influence on the decision making regarding what kind of lifting equipment will be used during the removal methods.

### Over-pressurization

This system protects the over-pressure within the pressure envelope.

### Area Classification

On installations there are different areas that contain flammable liquids of combustible gasses. These areas are identified according the probability of the occurrence of hydrocarbon gasses and labeled zone 0-2 and non-hazardous.

- Zone 0, flammable atmosphere is present continuously or for a long period of time;
- Zone 1, dangerous atmosphere is likely to occur under normal operating conditions;
- Zone 2, dangerous atmosphere is not likely to occur under normal operating conditions. If it happens it will only be for a short time;
- Non-hazardous, any areas not classified as zone 0-2.

If there are equipment items to be removed it is important to check how the area it stands in is labeled. This will determine what tools are able to be used to cut and remove the different objects and if this should be done during a shutdown or while the installation is still producing.

## Fire & Gas System

The fire and gas (FG) detection system its main objectives are to continuously monitor for fires or gas accumulations, initiate the alarms and to initiate the shutdown systems to protect the installation.

Throughout the entire installation there are many types of detectors to monitor the operation. The installation is divided into different zones that determine the appropriate detectors to install.

The signals from the detection devices, together with the signals from the manually operated switches, are connected into the FG panel to automatically initiate actions and raise the visual and audible alarm. There are different types of audible alarms that vary in frequency explaining the action that needs to be taken.

### Emergency Shutdown System

When hazardous situations occur, affecting the safety on the installation, the Safety Instrumented System (SIS) is required to maintain a safe state by shutting package units down.

The SIS compromises four very important that are immediately affected by the removal of parts of the installation. These are the Emergency Shutdown (ESD), FG detection, Emergency Depressurization (EDP) and the PSD.

When the SIS system is initiated it ensures the protection of personnel, the plant and equipment and the minimization of pollution. This is a crucial part of the installation its safety system.

The ESD shuts down the platform by closing the ESD/PSD valves and shutting down prime movers. It is designed to operate through the following hierarchical levels of shutdown:

- Total Platform Shutdown (TPS), isolating all process systems;
- Surface Process Shutdown (SPS), shuts down all process systems and wellheads but leaves the utility systems operational;
- Unit Shutdown (USD), shutdown of individual process or utility systems or subsystems.

## Emergency Blowdown System

This system provides means of evacuating the process gas and fluids relieved from the equipment and to discharge them safely to the atmosphere at sufficient rates as to fulfill rules and legislation requirements.

A blowdown is triggered by SPS or TPS and there is a possibility to delay the system when it is necessary to close the ESD valve first. The blowdown systems discharges through a high pressure vent system for high pressure operating systems, as well as through a low pressure vent system for low pressure operating systems like the fuel gas system.

## Active Fire Protection

Active fire protection is provided to control or extinguish fire on the installation by using manually or automatically activated fire-fighting systems to protect personnel, equipment and structures. The active fire protection on installations usually comprises three types of systems:

- Fire Water System
  *This system feeds into the deluge system, sprinkler system, fine water spray systems, hydrants and hose-reels at different points on the installation.*

- Automatic Fire-fighting Systems
  *Automatic fire-fighting facilities comprise integral water mist systems, usually for enclosures, fine water spray systems and CO2 extinguisher systems.*
- Manual Fire-fighting Systems
  *Some automatic fire-fighting systems can be operated manually as well. There are also portable extinguishers mounted throughout the installation that comply with different types of fire.*

## A.3. Project Support

### Discipline Engineering Support

Discipline engineers are the supporting engineers that have the responsibility to deliver the engineering documents and safeguard the execution of different tasks within their field of expertise. Different Discipline Engineering roles are described as follows:

- Structural Engineering
  *The structural engineering discipline assesses and supplies the different SI models, delivers the engineering to maintain the SI of the installation during and after the projects. The impact on the SI of the installation depends on the types of decommissioning methods that are being assessed by the SoW.*

  *Structural engineers are able to confirm that the safety standards are being pursued in regards of the integrity of the equipment and the impact on its surrounding structure during and after the removal.*

- Process Engineering
  *Process engineers assess the impact on the systems in terms of the processes and flows that run throughout the installation. If part of the process is bypassed this will have a significant effect on the operation on the platform. Process engineers are the ones to determine whether pieces of the process can be bypassed, if they can be isolated and how they can be isolated.*

- Drilling, Wells & Pipeline Engineering
  *Drilling, Wells and Pipeline Engineering has to do with all the subsurfaces engineering that concern the hydrocarbon field production process from its discovery until the field abandonment.*

- Controls & Automation
  *Controls and automation are primarily focused on delivering engineering plans on the systems controls. Different systems are described in the first chapter and an important part is for instance the F&G system on the installation. After removing equipment there might be an impact on the different hazardous areas that will allow for a reduction in the control system for the F&G detection.*

- Electrical Engineering
  *Electrical engineers make sure that the systems on the installation have a constant supply of power. When equipment is being removed there will be a decrease in the demand of power within the systems.*

### Project Services Support

Project services provide cost estimations, planning, contracting and procurement, quality assurance and quality controls and waste management plans described as follows:

- Planning
  *The planning within the project execution is crucial. There are many components that should be taken into account. The planner is able to assess, for instance, the options for project execution during shutdown and the windows of opportunity for vessel support.*

- Cost Estimations
  *The cost estimators monitor the expenditures of the project. The project cost estimations are being done according to the different phases within the project. Each phase will allow a certain level of detail in the cost estimation. Note that these phases are not the same as the different phases that are identified in this dissertation.*

- Contracting & Procurement
  *The contracting and procurement supports the different types of contracts with vendors*

*and other companies that are involved with the project, as well as the procurement of materials and appliances. Contracts can be on a reimbursable basis or lump sum basis.*

*A cost reimbursable contract states that the contractor is reimbursed with the cost that incurs in the execution of the project. An additional fee is also included. Contracts on a lump sum basis account for a 'lump sum' price at the beginning of a project. For reimbursable contracts the SoW contain risks regarding the work that needs to be done whilst a lump sum contract states a detailed explanation of the work scope.*

- Quality Assurance & Quality Control
  *Quality Assurance is defined as the part of Project Services that focus on providing confidence that quality requirements during projects will be fulfilled.*

  *Quality Control is responsibility for both the supplier and customer deliverables. The customer is responsible for specification, scheduling delivery, receiving inspection, storage control and preservation. The supplier is responsible for producing to product specification, use of qualified and competent personnel*

## HSE Support

The support by HSE team is to define critical activities, ensure the identification of any hazards within the activities and to quantify the risks involved with the activities. The roles are described as follows:

- Technical Safety
  *During projects Technical Safety focuses on hazard identifications and risk analysis to use to decide on the best solutions to reduce risks by means of non-technical and technical standards. It is about following up on safety systems in operation to safeguard the safety on the installation*

- Environmental Engineering
  *Environmental Engineering is focused on the environmental aspects during projects.*

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# B

# Execution Support Selection Methodology

## B.1. Execution Support Selection Methodology

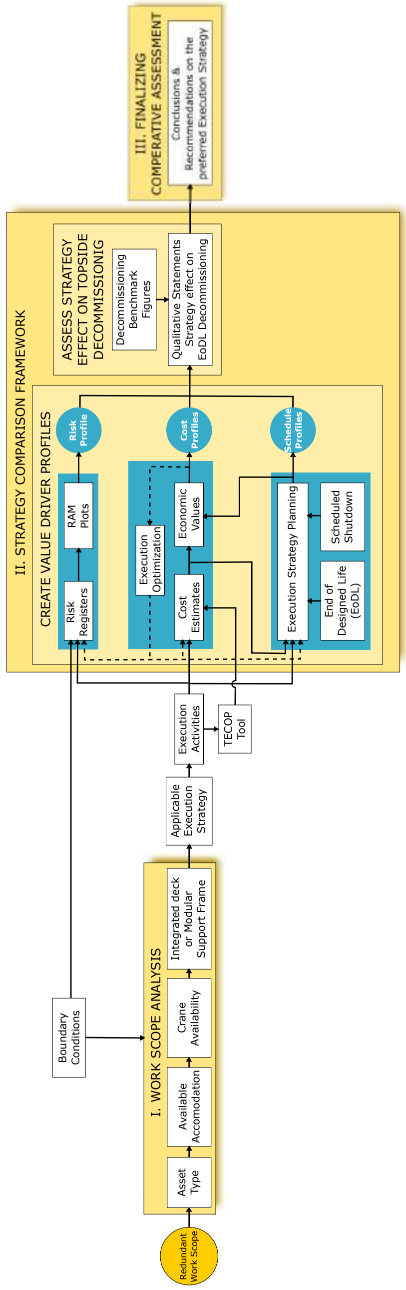


Figure B.1: Execution Selection Support Methodology

## B.2. ESSM step 1: Accessibility Selection Tree

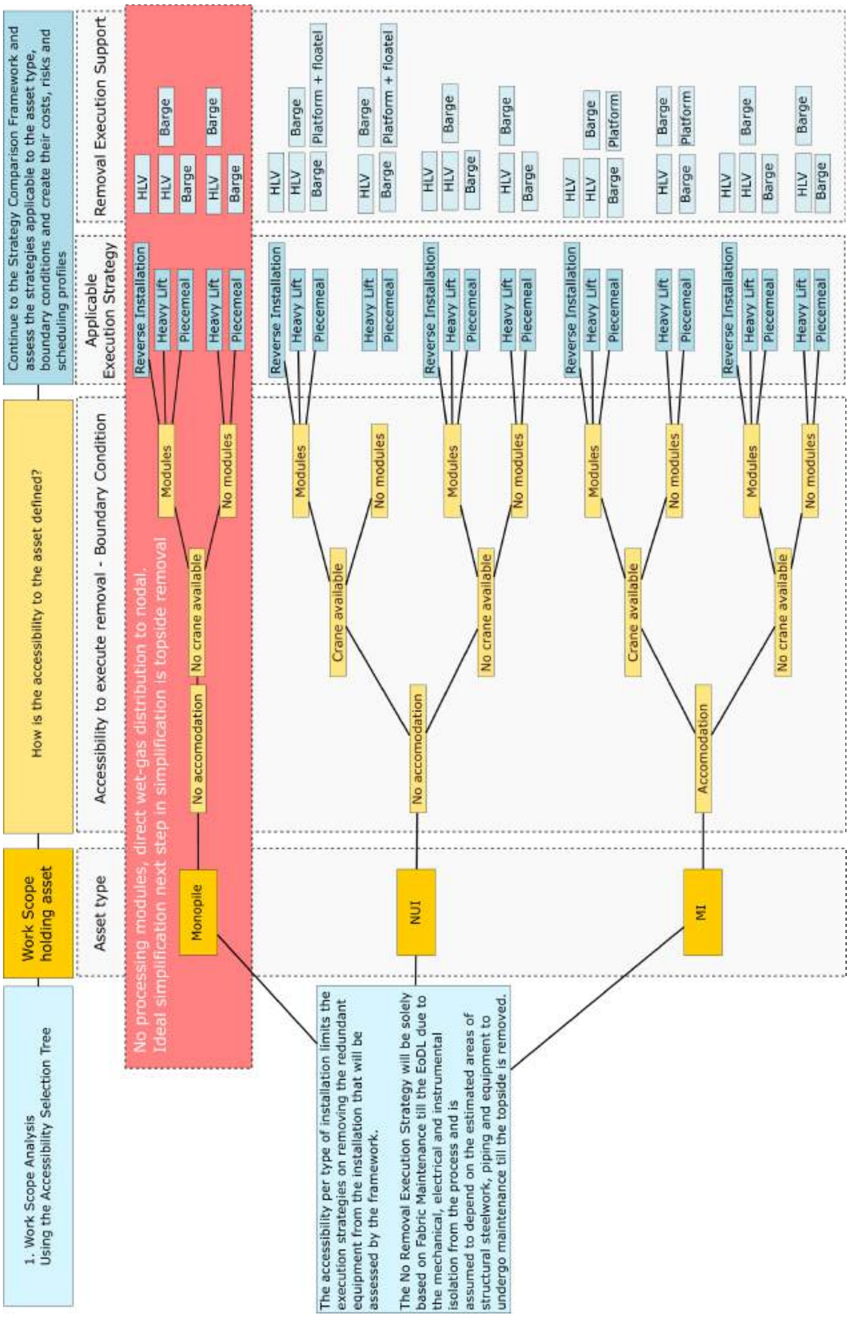


Figure B.2: Accessibility analysis selection tree

## B.3. Lifting Appliances

### Mobile Cranes

***Spider Cranes*** Spider cranes allow for a fixed position after it is brought to the location. The legs can be spread in any position allowing it to maneuver across difficult to reach places. Its legs are not only limited to a position in the horizontal plane but can be placed at different points in the vertical plane as well.

***Mini Crawler Cranes*** Normal sized crawler crane are rather large and only useful when there is sufficient space on the deck. When operating within deck levels a mini crawler crane is more suitable. The limitation of the mini crawler the needs for sufficient space to move around on the deck. Reinforcement on the decks need to be installed in order to withstand the loads created by the caterpillar movement.

***Gantry Cranes*** Small gantry cranes are able to support and lift smaller items. It is to be put into place and moved around manually. Limiting in using a mobile gantry crane is its lifting capacity and manual handling.

***Pick and Carry Cranes*** Pick and carry cranes are smaller in size compared to the mini crawlers but their SWL is relatively high but is limited to a back and forth motion.

Figure B.3: An example of a Spider crane, a mini crawler crane, a gantry crane and a pick and carry crane

Table B.1: Characteristics of common used crane types in offshore projects

| | **Max lifting capacity [t*m]** | **Max working radius [m]** | **Footprint [m*m]** | **Max height [m]** | **Crane weight [t]** |
|---|---|---|---|---|---|
| **Spider crane, Unic URW-094** (1) | 1t x 1.5m | 5.2 | 1.9m x 0.6m | 5.6 | 1 |
| **Mini crawler crane, Maeda LC785** (2) | 4.9t x 2.5m | 14.5 | 5.2m x 2.4m | 16.4 | 10.3 |
| **Gantry crane, Cisco-Eagle A-Series** (3) | 10t | 11.8 | 2m x 11.9m | 4.9 | 2.5 |
| **Pick & carry crane, Reedyk PC4405EX** (4) | 2.7t x 1m | 5.7 | 2.5m x 1m | 9 | 2.8 |

1. http://www.uniccranes.com/spider-cranes/urw-094/
2. http://www.maedaminicranes.co.uk/application/pdf/lc785.pdf
3. http://www.cisco-eagle.com/catalog/c-5345-ten-tons.aspx
4. http://www.reedyk.eu/minikraan/reedyk-pc4405ex/

# B.4. Lifting Tools

## Pad Eyes & Trunnions

Pad eyes and trunnions are engineered pieces on the equipment that enable the attachment of shackles and slings to enable lifting the equipment. These parts should be checked for their strength and standards compliance. Pad eyes and trunnions could be welded on the lifting frames or on the steel of the equipment itself.

It is possible that the pad eyes and trunnions, which came with the equipment during the installation, not comply with the standards any longer. This is due to the degradation of the steel or due to the changes in the standards. In that case they should be replaced when considered to be used.

Figure B.4 shows both pad eyes on the equipment itself as pad eyes on the support frame. The left piece of equipment is a valve and the right piece of equipment is part of a compression train. These items differ in weight and size and accessibility.

Figure B.4: Pad eyes on the equipment and the support frame

## Spreader Bars

Spreader bars or so-called spreader beams are structural members in the horizontal plane that allow multiple slings to be attached to the beam transferring the loads in the slings. This will not only decrease the load per lifting point but also increase stability to make the operation safer. Allowing pieces of equipment with an irregular shape in loads to be lifted.

When the lifting operation is complex it is common to use multiple beams stacked to spread the load. If multiple beams are being used it becomes necessary to use cranes in order to create enough hook height for all the slings in the rigging.

## Rigging

Rigging is used in order to connect the shackles attached to the pad eyes, trunnions and spreader beams to the hooks. Beforehand different rigging plans should be developed and assessed to determine the safest way to perform the lifts.

Figure B.5 shows an example of a rigging plan that shows a spreader bar, the hook, slings, shackles and the load.

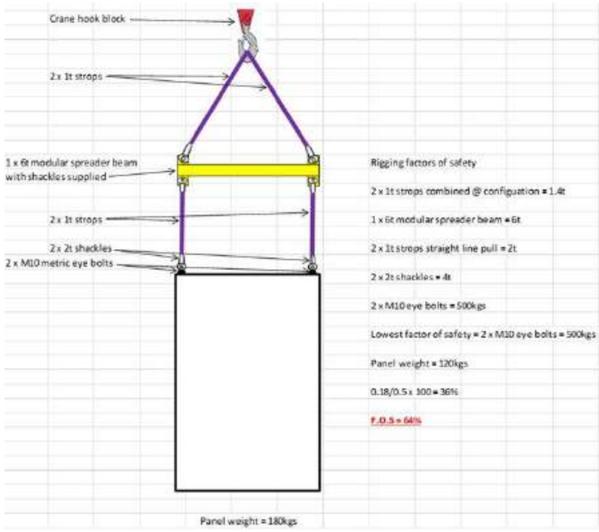


Figure B.5: Rigging plan including spreader bar

## B.5. Removal Execution Strategies Advantages & Limitations

- Removal Advantages
  - Reduction in FM activities decreases long term offshore exposure;
  - Mass reduction decreases EoDL decommissioning activities;
  - Increase in deck area for other purposes;
  - OPEX reduction could result in prolonging production activities;
- Piecemeal Removal
  - Advantages
    - Deconstruction during shutdown could be prevented by type of dismantling;
    - It allows for an Opportunity Based approach using the Non Productive Time (NPT) of personnel on board, saving on execution cost
    - No lifting barge of HLV necessary to support the deconstruction
    - Least weather dependent due to no support vessel day rates
  - Limitations
    - More deconstruction activities compared to other removal strategies, increasing safety risks exposure
    - Supply boat visiting frequency limits the deconstruction lead time
    - Available storage capacity limits the deconstruction lead time
    - Crane SWL limits the load of the lifts
    - Amount of people working on the deconstruction activities could limit the work efficiency and increase safety risks exposure
    - Deconstruction activities depend on the available accommodation
- Heavy Lift Removal
  - Advantages
    - Shorter deconstruction lead time than Piecemeal due to an increase in SWL;
    - Accommodations not depending on beds on the installation;
    - Little utilization of deck space due to direct load-in;
    - Less likelihood and quantities of non-redundant systems and cables to be rerouted;
    - Offshore deconstruction;
    - Potential to use lifting barge during other nearby barge campaigns;
    - Increase in deck area for other purposes on multiple deck levels.
  - Limitations
    - More weather dependent than Piecemeal
    - Decrease in offshore exposure due to an increase in dismantling, lifting and FM activities;
    - Continuing FM activities on the structural steel surrounding the work scope;
    - Weather dependent operation
    - Offshore deconstruction
    - High day rates for lifting barge

    - More shutdown dependent comparing to Piecemeal

- Reverse Installation Removal
  - Advantages
    - Accommodations not depending on beds on the installation;
    - Less offshore execution time than Heavy Lift and Piecemeal Execution Strategies;
    - Decrease in FM activities on work scope and its surroundings thus in offshore exposure;
    - Onshore deconstruction and disposal
  - Limitations
    - Very limited by the likelihood of rerouting non-redundant systems and cables to other areas;
    - Shutdown is necessary to execute this strategy;
    - High day rates for HLV;
    - HLV availability and costs highly depends on market supply and demand;
    - Weather dependent operation;
    - Very complex and intensive engineering, onshore and offshore preparations to perform the lifts;
    - Likely demand to perform overdue maintenance and to apply structural reinforcements;
    - More weather dependent than Piecemeal

# C

# Case Study

## C.1. Case Study ESSM step 1: Accessibility Selection Tree

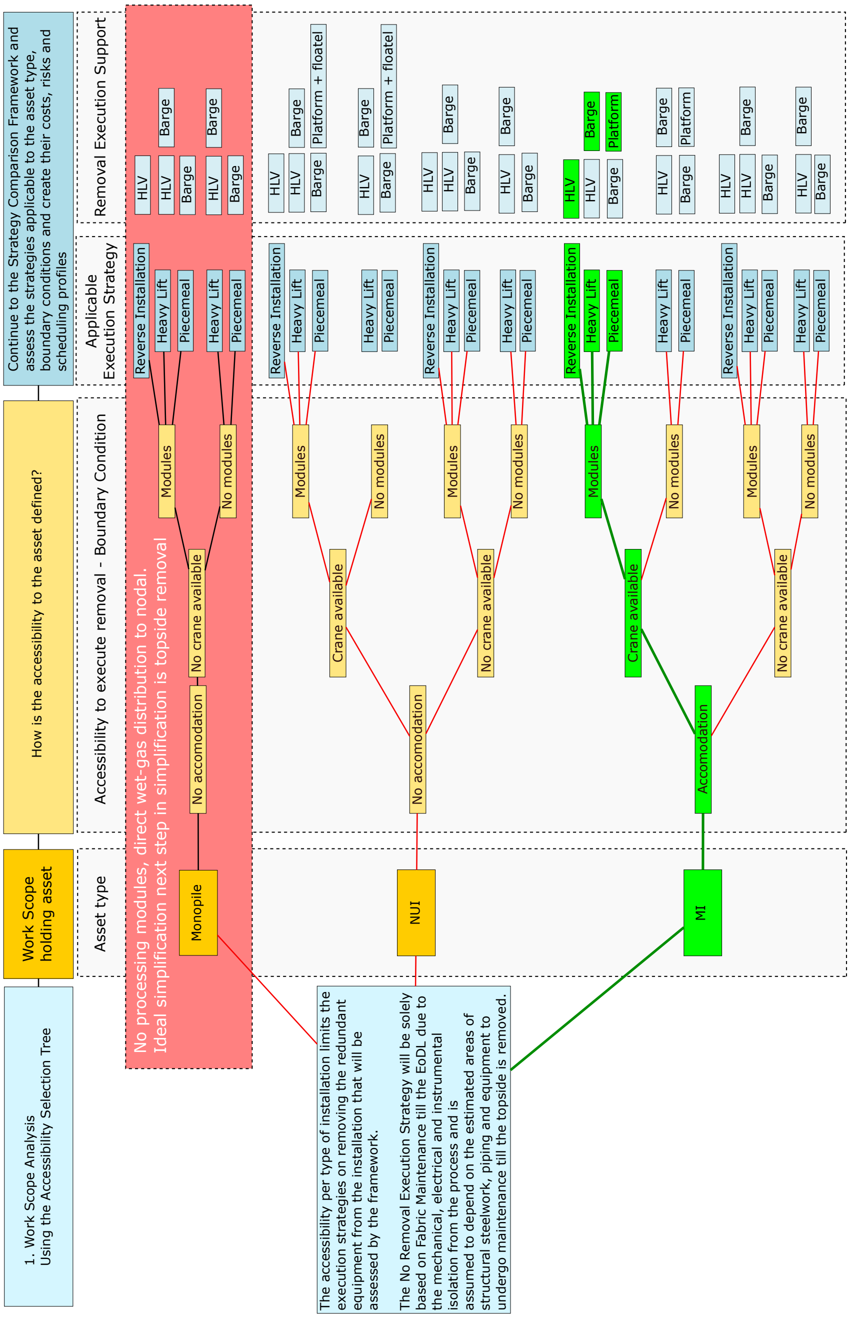


Figure C.1: Result of the Case Study applied Accessibility Selection Tree

# C.2. Risk Registers

## Execution Strategy Common Risks Registers & RAM Plots

### *Execution Strategy Common Risks Register*

| Execution Strategy Common Risks | | | | | Ranking per Execution Strategy (Probability, Consequence) | | | |
|---|---|---|---|---|---|---|---|---|
| # Risk | Execution Activity | Cause | Uncertain event | Impact | No Removal | Piecemeal | Heavy Lift | Reverse Installation |
| 1 | General | Bad weather conditions | Unsafe work environment | Schedule | P4,C1 | P4,C1 | P2,C2 (Cost) | P1,C5 (Cost) |
| 2 | General | Bad maintenance, inspections, engineering | Extra required structural reinforcements | Cost | P4,C2 | P4,C2 | P4,C2 | P5,C5 |
| 3 | General | Bad housekeeping | Slips, trips, falls | People | P3,C2 | P4,C2 | P3,C2 | P2,C2 |
| 4 | General | Oil price | Change in oil price affects the availability of resources and prices | Cost | P3,C4 | P3,C4 | P3,C5 | P3,C5 |
| 5 | General | Bad logistics. lack of heli & supply boat support & bed availability | Execution delays | Schedule | P4,C1 | P4,C2 | P3,C2 | P2,C3 |
| 6 | General | Lack of interface management | Inefficient project execition | Cost | P2,C1 | P2,C1 | P3,C4 | P3,C5 |
| 7 | General | Bad maintenance, inspections, engineering | Increase PDOs | HSE | P4,C3 | P2,C2 | P2,C2 | P1,C1 |
| 8 | General | Offshore exposure | Damage to person | HSE | P2,C1 | P4,C3 | P4,C3 | P4,C2 |
| 9 | General | lack of attention, inexperience, bad material handling | Injuries, damage to equipment | HSE | P3,C2 | P3,C3 | P3,C3 | P3,C3 |
| 10 | General | Lack of inspection, bad material handling, collision agains scaffolding | Scaffolding failure | Assets | P2,C2 | P3,C3 | P3,C4 | P2,C5 |
| 11 | General | Increase or Decrease in OPEX, change in oil price | Prolonging or decreasing year of topside decommissioning | Cost | P3,C5 | P3,C5 | P3,C5 | P3,C5 |
| 12 | General | Misinterpretation of the area accessibility | Extensive scaffolding necessary to execute the strategy | Cost | P2,C2 | P3,C3 | P3,C4 | P2,C5 |
| 13 | Dismantling | Dismantling Activity | Cutting debris | People | | P4,C1 | P4,C1 | P3,C1 |
| 14 | Dismantling | Elevated cutting tools | Dropped Objects | Assets | | P4,C2 | P3,C2 | P2,C2 |
| 15 | Dismantling | Unsufficient cleaning | Fire<br>Explosions | People | | P2,C5 | P1,C5 | P1,C5 |
| 16 | Dismantling | Working hights | Falls | People | | P2,C4 | P1,C4 | P1,C4 |
| 17 | Dismantling | Working inside modules, conquested area's | Explosion, gas, cutting fumes | HSE | | P3,C4 | P3,C4 | P2,C4 |
| 18 | Fabric Maintenance | Lack of interest and ownership, lack of inspection | Unexpected increase in FM activities | Asset | P4,C4 | P4,C2 | P4,C2 | P4,C2 |
| 19 | Fabric Maintenance | Maintentance, working at heights | Accident, injuries | People | P2,C4 | P2,C4 | P2,C4 | P2,C4 |
| 20 | Fabric Maintenance | Lack of inspection, bad housekeeping, equipment and scaffold handling | Accumulation of scour & painting debris | People | P4,C2 | P3,C2 | P3,C2 | P3,C2 |
| 21 | Fabric Maintenance | Lack of inspection<br>Bad maintenance | Sudden decrease in EoDL, loosing license to operate | Cost | P2,C5 | P2,C5 | P2,C5 | P2,C5 |
| 22 | Fabric Maintenance | Misinterpretation long term strategy inspection and maintenance | Failure in long term inspection, excessive engineering for abandonment | Cost | P2,C3 | P2,C3 | P2,C3 | P2,C3 |
| 23 | Fabric Maintenance | Lack of inspection<br>Misinterpretation of requirements | Failure to meet statutory requirements | Reputation | P1,C3 | P1,C3 | P1,C3 | P1,C3 |
| 24 | Lifting & Hoisting | Lifting Activity | Crane Failure | Schedule | | P3,C2 | P2,C4 (Cost) | P2,C5 |
| 25 | Lifting & Hoisting | Lifting Activity | Dropped Objects | Assets | | P1,C3 | P1,C4 | P2,C2 |
| 26 | Lifting & Hoisting | Uncertainty of CoG | Lifting incedent | Assets | | P3,C2 | P3,C3 | P1,C5 |
| 27 | Lifting & Hoisting | Miscalculations of necessary utilities or exceedance of SWL crane | Extra support lifting appliances necessary | Cost | | P4,C2 | P4,C2 | P3,C3 |
| 28 | Lifting & Hoisting | Miscalculation of available space | Insufficient lifting space | Schedule | | P2,C2 | P2,C3 | P1,C5 |
| 29 | Lifting & Hoisting | Decrease in crane SWL, load exceeds SWL | Unable to perform lift | Schedule | | P3,C3 | P1,C4 (Cost) | P1,C5 |
| 30 | Waste Management | Lack of inspection<br>Bad maintenance | Insufficient cleaning, loss of containment on in-situ work scope | HSE | P2,C2 | P2,C1 | P2,C1 | P2,C1 |
| 31 | Waste Management | Misinterpretation of contamination within the redundant equipment work scope | Increase in cleaning activity | Cost | P3,C1 | P3,C1 | P3,C1 | P3,C1 |
| 32 | Waste Management | Unsufficient cleaning | Unexpected contamination in equipent resulting in spills | HSE | P2,C3 | P3,C3 | P3,C3 | P1,C3 |
| 33 | Waste Management | Improper planning | Increase mob/demob events | Schedule | | P2,C2 | P2,C3 (Cost) | P2,C5 |
| 34 | Waste Management | Bad inventory of sequence of removal, lack of workspace accessability, miscalculation of piece weight and dimensions | Failure in demobilisation of dismantled equipment | Schedule | | P2,C2 | P1,C3 (Cost) | P1,C4 |
| 35 | Removal Common | Collision | Structural collapse | Assets | | P2,C5 | P2,C5 | P2,C5 |

Table C.1: Common Risks Register per Execution Strategy

### Removal Strategy Specific Risks Registers & RAM Plots

#### *Piecemeal Specific Risks Registers & RAM Plots*

| Removal Strategy Specific Risks - Piecemeal | | | | | |
|---|---|---|---|---|---|
| # Risk | Execution Activity | Cause | Uncertain event | Impact | Ranking (Probability, Consequence) |
| A | Dismantling | Misinterpretation Piecemeal pieces | Inability to handle piecemeal dismantled equipment | Schedule | P3,C2 |
| B | Dismantling | Misinterpretation of water jet cutting capabilities and limitations | Inability to use water jet cutting | Cost | P2,C4 |
| C | Lifting & Hoisting | Misinterpretation of dismantled pieces | Piecemeal lifting applications not applicable to support and handle the equipment | Cost | P2,C3 |
| D | Waste Management | Exceeding offshore storage capacity | Failure in container logistics | Schedule | P3,C3 |
| E | Waste Management | Delay in vessel support and exceeding storage capacity | Lack of space to handle materials and dismantled equipment | Schedule | P4,C2 |
| F | Waste Management | Temporary storage: Deck loading/space and integrity. | Structural collapse | Assets | P1,C5 |
| G | Removal Specific | Insufficient bed availability on the installation to execute the strategy | Need for a floatel | Cost | P4,C5 |

Table C.2: Piecemeal Specific Risks Register

### *Heavy Lift Specific Risks Registers & RAM Plots*

| Removal Strategy Specific Risks - Heavy Lift | | | | | |
|---|---|---|---|---|---|
| **# Risk** | **Execution Activity** | **Cause** | **Uncertain event** | **Impact** | **Ranking (Probability, Consequence)** |
| **A** | Dismantling | Misinterpretation Heavy Lift pieces | Inability to handle dismantled Heavy Lift equipment on the installation | Schedule | P2,C3 |
| **B** | Lifting & Hoisting | Misinterpretation of access | Unable to remove the equipment | Cost | P4,C2 |
| **C** | Lifting & Hoisting | Structural integrity insufficient to support lifting the Heavy Lift pieces | Inability to lift the dismantled Heavy Lift pieces and extra structural reinforcements are necessary | Cost | P3,C4 |
| **D** | Removal Specific | High market demand | Rig pricing | Costs | P1,C3 |

Table C.3: Heavy Lift Specific Risks Register

### *Reverse Installation Specific Risks Registers & RAM Plots*

| Removal Strategy Specific Risks - Reverse Installation | | | | | |
|---|---|---|---|---|---|
| # Risk | Execution Activity | Cause | Uncertain event | Impact | Ranking (Probability, Consequence) |
| A | Dismantling | Misinterpretation of modules | Inability to handle dismantled modules | Schedule | P3,C3 |
| B | Lifting & Hoisting | Misinterpretation of access | Unable to remove the equipment | Cost | P1,C2 |
| C | Lifting & Hoisting | Due to insufficient survey work, insufficient structural integrity to support lifting the modules | Inability to lift the dismantled modules and extra structural reinforcements are necessary | Cost | P3,C5 |
| D | Waste Management | Misinterpretation of contamination within the redundant equipment work scope | Increased onshore disposal costs | Cost | P2,C2 |
| E | Waste Management | Wrong disposal of assets by contractor | Contractor is subject to prosecution for disposal on our behalf | Reputation | P2,C3 |
| F | Removal Specific | High market demand | HLV pricing | Cost | P2,C4 |
| G | Removal Specific | Misinterpretation of work scope and estimations | Complications in rerouting non-redundant equipment | Cost | P4,C5 |

Table C.4: Reverse Installation Specific Risks Register

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