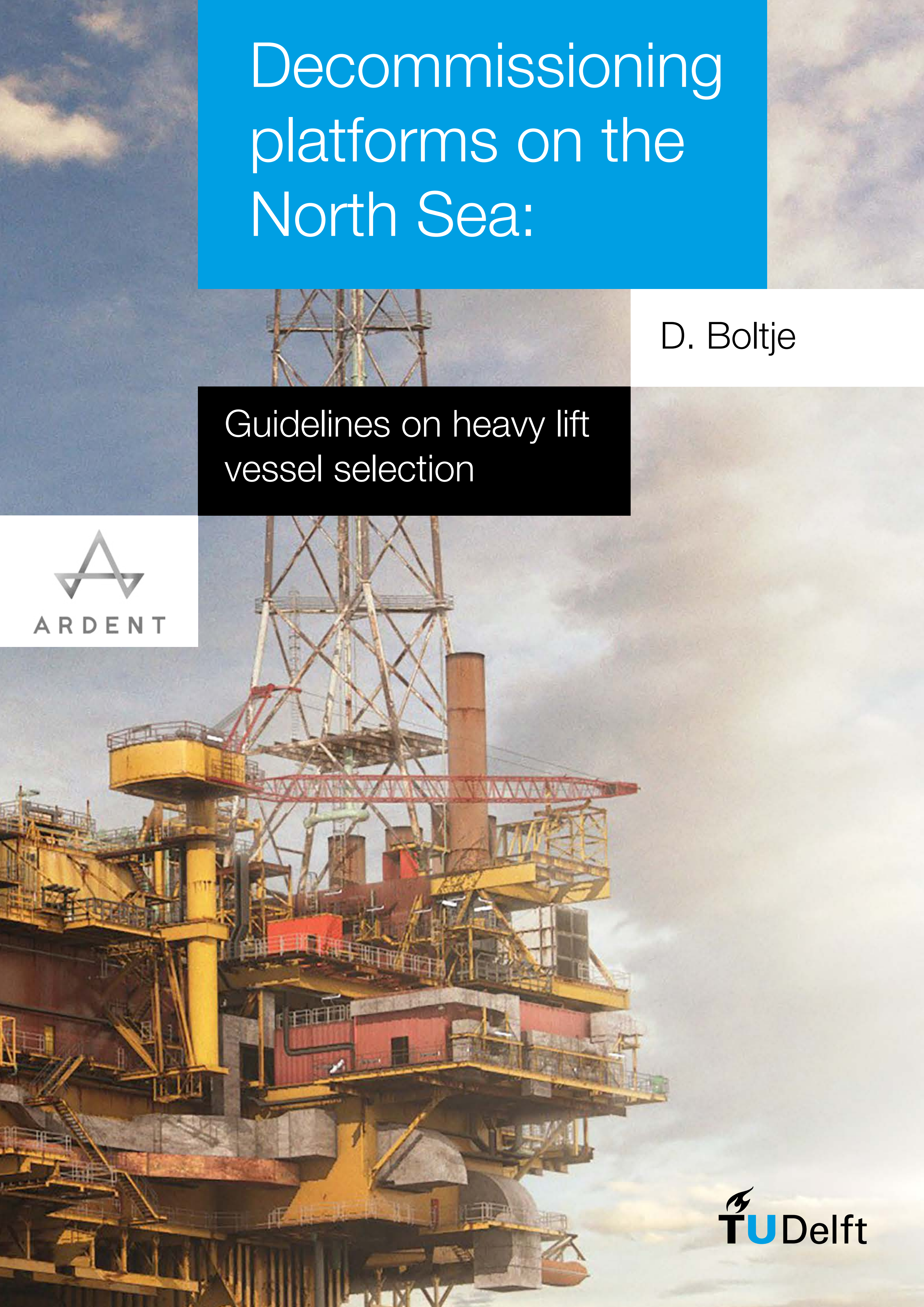

Decommissioning platforms on the North Sea:

Guidelines on heavy lift vessel selection

D. Boltje

ARDENT

TU Delft

Decommissioning platforms on the North Sea:

Guidelines on heavy lift vessel selection

by

D. Boltje

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Thesis for the degree of MSc in Marine Technology in the specialization of Ship Production.

Decommissioning platforms on the North Sea: **Guidelines on heavy lift vessel selection**

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D. Boltje

Performed at

Ardent Global

This thesis SDPO.17.017.m. is classified as confidential in accordance with the general conditions for projects performed by the TUDelft.

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Confidentiality Statement

This research project contains information of strategic and commercial importance. The contents of this thesis are to remain confidential and are *not* to be circulated for a minimum period of *five years*. After this period please contact the author to obtain permission before any part of this thesis is published.

Sincerely,

D. Boltje
Delft, The Netherlands
21 June 2017

Preface

This thesis report is the result of my research project to conclude my Master ”Ship Production” at the faculty of Mechanical, Maritime and Materials Engineering at Delft university of Technology. The problem owner of this research project is marine salvage company Ardent Global where I performed most of the thesis work in their quarters in IJmuiden, The Netherlands.

The work outlined in this thesis was carried out over the period from September 2016 to July 2017. This thesis is the result of my original, unpublished and independent work and includes nothing which is the outcome of work done in collaboration.

D. Boltje
Delft, June 2017

Acknowledgements

First of all I would like to offer my sincerest gratitude to my thesis supervisor, Dr.ir. Jenny Coenen. Without her guidance throughout the whole project, I would not have been able to keep a swift pace in my work. Through the multiple stages of this research she supported me with the right milestones, tools and feedback to reach this report as a final result.

Secondly I would like to thank ir. P.M.L. van der Sanden, my supervisor within Ardent. Although his profession requires him to travel the world, he was still able to support me with his feedback, observations and critical notes. Also his detailed observation, commonly followed by some difficult questions, have kept me focussed throughout the project.

Many colleagues within Ardent have supported me by sharing knowledge about both decommissioning and the salvage industry.I would like to thank Richard, Dirk and Wouter for their support and handing me quick guidelines to get familiar with the North Sea decommissioning market. I would also like to thank Boaz and Rob for patiently answering my many questions concerning the salvage operations.

Fourthly I would like thank my father for supporting me in the final stages before completion of this report. His advice allowed me to conclude the endless re-shaping process of the report, to the report as is presented.

Finally I would like to thank my girlfriend Lieke, her patient listening, discussing and clever observations have aided me throughout the project.

D. Boltje
Delft, June 2017

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List of abbreviations

CAPEX	capital expenses
COG	Centre of Gravity
CRI	Cruciality Index
DWCV	Deep Water Construction Vessel
DECC	Department of Energy & Climate Change
DP	Dynamic Positioning System
EEZ	Exclusive Economic Zone
FPSO	Floating Production, Storage and Offloading facility
HLV	Heavy Lift Vessel
IMO	International Maritime Organization
MC model	Monte Carlo simulation model
NDT team	Non Destructive Testing team
OPEX	operation expenses
OSPAR	Oslo and Paris Convention for the Protection of the Marine Environment of the North East Atlantic
Prep	Preparation
ROV	Remote Operated Vehicle
SECV	Self Elevating Crane Vessel
SodM	Staatstoezicht op de Mijnen
TLP	Tension Leg Platform
WBS	Work Breakdown Structure

Abstract

Many North Sea platforms face the end of their life-cycle as the profitable exploitation of the oil and gas reaches exhaustion. Hence the upcoming decades, many obsolete North Sea offshore platforms have to be removed. Promising decommissioning market forecasts have drawn the attention of many companies such as Ardent Global (Ardent).

The key asset required for these projects is a Heavy Lift Vessel (HLV). For participation in the decommissioning market, Ardent must charter this key asset since Ardent does not own a HLV. A market study for Ardent by the consultancy firm Deloitte, made Ardent focus on projects concerning the decommissioning of small platforms. In this market of platforms with a topside weight of less than 1.400 [tons], Ardent is able to cooperate with smaller HLV owning companies, as larger HLV owning companies are able to execute decommissioning single-handedly.

As Ardent is not restricted in selecting its own assets for decommissioning, many possible configurations for a project proposal are feasible. Thus, the purpose of this thesis is to develop a model to identify a optimal heavy lift vessel configuration for North Sea decommissioning projects, concerning platforms with a topside weight of less than 1.400 [tons]. To realize this purpose multiple steps have been taken. A generic work-breakdown-structure (WBS) is established to capture any platform decommissioning project. Secondly a decision making standard is created based on submitted project proposals. Lastly a Monte Carlo simulation model is developed to implement risks in the project duration and costs calculations. Three platforms have been tested in 42 scenarios, for an optimal heavy lift configuration.

An offshore platform can be removed by four methods: single lift, piece medium, piece small and innovative approaches. Through literature and project proposals, a generic WBS was created which captured the three first mentioned methods. A risk register was created that excluded the piece small method from this research, due to risks identified as unsatisfactory. The remaining single lift method requires the HLV to lift the top part of an offshore platform (topside) and the supporting tubular frame (jacket) in one go. For the piece medium method the topsides and jacket are cut and lifted in multiple modules, requiring less crane capacity. From the WBS three major phases could be identified in a project: Preparation, Topside removal and Jacket removal phase. The asset configuration in the preparation phase consist of cheaper assets, as used in the topside an jacket removal phases.

The generic WBS is used to develop a decision making standard. Based on a HLV database, resource allocation, costs database and platform data, a project is estimated on duration and costs for any HLV selection. In these estimations, no risks are considered.

To decrease the uncertainty in the results, a Monte Carlo simulation model is developed. This model incorporates operational risks and weather delay in the duration and costs calculations. Operational risks where estimated by Ardent's experts in a survey, weather delay is calculated through statistical data. A set of 42 scenarios have been set up that incorporate three platforms, four HLV categories, three positioning methods and two offloading methods. The scenarios have been tested for their commercial viability, and risk characteristics. Risks are analysed through Pearson's Cruciality Index, to identify the portion of risks in the preparation phase versus the topside plus jacket removal phase combined. As maximum risk in the preparation phase instead of the lifting phase, is preferable in terms of risk consequences and costs.

This research project makes a decision making standard and a Monte Carlo simulation model available to Ardent. At this stage, these models can be used for first estimates of optimal heavy lift configurations in new project proposals. In order to increase the accuracy and reliability of these models in the future, Ardent is to import additional data[1] in these models.

From the tested scenarios two conclusion are drawn. Firstly it was found that the ”Crane Barge” HLV category showed to be the cheapest and thus optimal option for projects. Whether this option is executable in terms of operational complexity or not is a decision Ardent has to make. Secondly the ”Self Elevating Crane Vessel” HLV category showed to be the most preferred configuration in terms of risks. HLV owning companies are proposed as potential ”strategic partners”.

Two additional concluding remarks are made. First, the scenarios have been calculated in ideal weather and seasonal conditions. Due to differences in risk sensitivity per scenario, new insights might be found in varying seasonal conditions. This would require an updated model containing: day-rates that vary through the year, new iteration of the weather risk calculations and a review of the operational risks. Secondly, in the expert survey, many variations are found in the activity duration estimates. This implies that no collective knowledge on decommissioning project durations is shared within Ardent. Meetings to discuss and define procedures for decommissioning activities are advised.

[1] Through either experiences in decommissioning projects or from previous salvage projects showing similarities to decommissioning projects.

1 Introduction

The offshore oil and gas market is facing economically hard times compared to their successful period in the 1990s. A lot of offshore oil and gas sites were built many years ago. Nowadays these old sites are reaching the end of their production life. Maintaining a constant flow of either gas, oil or both gets increasingly difficult over the years of production, and thus requires large investments. As a result of the decreased oil prices, oil companies find it hard to maintain economically feasible production. As a consequence, old offshore oil and gas production sites are shut down.

International law requires the oil companies to remove their production equipment when production has stopped. The removal of these offshore sites is known as **'decommissioning'**. The market for the the decommissioning of offshore structures in the North Sea is expected to grow. As a result companies try to secure a market share is this potentially expanding market. One of the players in this market is the company: *Ardent Global*.

1.1. Ardent Global

Just like any other man made structure on land, ships and offshore structures can break down. On land there are multiple services that can help out reduce the structure destruction or loss of life. But offshore, there is only one type of company to respond: a salvage company. Similar to emergencies on land, salvage companies try to save life, vessels and cargo from loss at sea. Ardent Global is this type of company.

Although Ardent Global, in short Ardent, is a relative young company, merged from a few long lasting companies. Ardent Global has been formed by a merger between the Danish company Svitzer Salvage, and the USA based Titan Salvage.

Em. Z. Svitzer Bjergningsentreprise was founded by Emil Zeuthen Svitzer in 1833. The company now known as Svitzer, maintained two fields of expertise: salvage and towage. In 1979 the company was bought by the Maersk Group, also of Danish origin. In order to explain the Dutch participation within Svitzer, Wijsmuller should be introduced. Wijsmuller was founded by Johannes F. Wijsmuller in 1906. Through the years Wijsmuller got involved in salvage and settled in IJmuiden, The Netherlands. In 2001 Wijsmuller was bought by Svitzer Salvage. Svitzer kept the former Wijsmuller head office in IJmuiden as a main office.

Titan Salvage is a company founded by David Grey Parrot in 1980. This American salvage company was bought by the Crowley Group in 2005. Titan and Svitzer Salvage merged into Ardent Global in 2015, with their headquarters in Houston, Texas (USA). Ardents offshore operations on the North Sea are managed from their quarter in IJmuiden (NL).

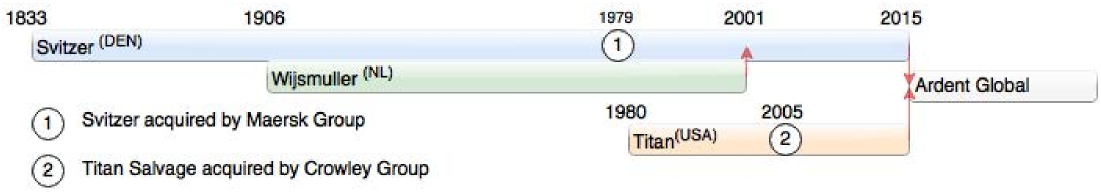


Figure 1.1: History and shareholders of Ardent Global

1.2. Problem background

Ardent has gained experience in the removal of structures from the sea due to their wreck removal activities. These wreck removal projects have multiple similarities with decommissioning projects. The knowledge gained within these wreck-removal project should offer *Ardent* a stepping stone to enter the decommissioning market. But the decommissioning market shows many facets. All these facets requiring different topics of expertise and resources.

The extent of a decommissioning project is dependent on multiple factors. Firstly, the characteristics of the field influence the amount and type of “to be removed” structures. Secondly, the local legislation sets requirements for the removal of the structures. As a result, decommissioning projects can be divided into multiple activities. All of these activities require a different set of assets and resources. This makes the decommissioning projects very versatile.
In order to get to a proper problem definition, a part of Ardent’s strategy needs to be explained. Ardent has set one strategic constraint defining this research project: minimize its own operational assets. The operational assets is defined as all materials and machines used in order to fulfil a project task. These materials and machines concern: floating equipment, mechanized tools, transportation equipment, steel inventory. Operating with minimized assets is known within Ardent as ’assets light’.

Projects cannot be accomplished with only assets. Finishing a project requires resources, which can be categorized by: assets, man-hours and services handled by specialized companies. From these, Ardent only owns the employees capable of fulfilling these man-hours. Therefore, Ardent cooperates with many “asset owning companies” and ”specialized service companies”. These companies are also known as “strategic partners”. The strategic partners each take their own part in the project, as requested by Ardent.

In contrary with this “assets light” strategy, there is competition within the market with an “asset owning” strategy. Some of these companies use their owned assets in their operations, which makes them self-supporting and eliminate the need of “strategic partners”. The consultancy firm ”Deloitte” performed market research for Ardent. From this research it was found that heavy lift vessels with a lifting capacity of more than 3.500 [tons], where likely to be owned by companies that could perform decommissioning projects by themselves. Deloitte considered the actual offshore lifting performance of these vessels to be 1.400 [tons], due to the extensive reach required to rig a topside. From these conclusions this research has focused on the decommissioning market of platforms with a topside weight of less than 1.400 [tons]. Selection of the decommissioning solutions should require a heavy lift vessel with a lifting capacity of approximately 3.500 [tons] or less.

1.3. Problem definition

The content of a decommissioning project is dependent on multiple factors. Firstly, the characteristics of the field influence the structures that are to be removed. Secondly, the local legislation sets requirements for the removal of the structures. As a result there is no optimal project set-up for every decommissioning project, but an optimal solution has to be found per individual decommissioning project. In these terms the project set-up is the configuration of the heavy lift vessel along with additional required assets.

The versatility of the project makes it difficult for Ardent to estimate project risks, economical feasibility and duration. Ardent does not have a specified strategic approach to tackle these decommissioning projects. Therefore, guidelines have to be set. This thesis will research the heavy lift vessel selection that Ardent requires in order to successfully fulfil decommissioning projects. To this end a supporting model will be designed to optimize the selection of these heavy lift vessels for Ardent.

1.4. Purpose

The purpose of this thesis is defined as:

The purpose of this thesis is to develop a model to identify an optimal heavy lift vessel configuration for North Sea decommissioning projects, concerning platforms with a topside weight of less than 1.400 [tons].

A standard project format for the decommissioning of offshore structures at the North Sea will be set up. This creates the possibility to run multiple heavy lift vessel configurations through the modelled decommissioning project. By modelling, multiple asset configurations and risks in the projects can be tested. Hence, Ardent is able support their decision making process by simulated asset configurations.

In order to create a sound model, a literature study has resulted in background information on the decommissioning market for the North Sea. A definition of decommissioning is given, influencing factors identified, an inventory of the market size made and the legislation have been summarized. Then the planning and costs calculations are modelled in a decision making standard. As a result a Monte Carlo simulation model will be developed to model risks, uncertainties and different heavy lift vessels.

1.5. Significance

The opportunity to forecast the effects of asset selection on a decommissioning project will help Ardent to gain commercial leverage in the decommissioning market. Also the collaboration with strategic partners could be enforced by use of the model since the requirements for these strategic partners will be more obvious.

1.6. Sub-questions

The sub-questions supporting the main purpose are defined as:

- Background and constraints of research (Chapter 2 & 3)
  - What is decommissioning?
  - What external factors influence decommissioning?
  - What is the size of the North Sea decommissioning market?
  - What legislation is implemented for decommissioning projects on the North Sea?
  - Which methods could be considered for decommissioning?
- Generic decommissioning project (Chapter 3 & 4)
  - What activities are required to perform a project?
  - What resources are required to perform a project?
  - Which Heavy Lift Vessel properties influence the project?
  - How can the costs and duration of a project be estimated?
- Risk implementation and simulation model (Chapter 5 & 6)
  - How can operational risks be quantified?
  - How can weather delay be quantified?
  - What output should the simulation model give to support the selection process?
  - What are feasible scenarios to chose from?

2
Background

This chapter provides the background information for a basic understanding of removal of offshore structures in the North Sea. The reader with experience in the decommissioning or offshore sector is advised to skip this chapter and continue with chapter 3.

The first part of this chapter describes the cause of decommissioning. The second part describes the factors that influence the decommissioning environment. A third part describes the type of offshore installations that can be found on the North Sea. As a fourth part the size of the North Sea oil and gas industry is quantified. The fifth describe the decommissioning experience in the North Sea so far. The sixth part of this chapter describes the forecasts given for the decommissioning market. As a final and seventh part, the legislation for decommissioning on the North Sea is explained.

2.1. Cause of decommissioning

Offshore oil and gas, is exploited in an oil and/or gas field. This field is positioned above or near one or multiple subsoil reservoir(s) buried deep under the sea floor. Such a reservoir is the final destination of hydrocarbons traveling upwards in the soil. By creating one or multiple wells these hydrocarbons can be reached and brought to the surface. At the surface multiple installations are required to control and transport the hydrocarbons. For this research the oil and/or gas field is defined as the assembly of all hydrocarbon exploiting or transporting installations for one or more reservoirs.

The life-cycle of an offshore oil and gas field starts off with an operator or oil company that acquires a license from a government to exploit hydrocarbons from a defined area. The operator then researches the area for commercially viable oil or gas reserves. This phase of the life-cycle is called the 'Pre Development' phase [17]. When commercial viable reserves are found, the 'Development phase' is initiated.

The operator will design and build facilities to cope with the fields' specific requirements. These facilities will ensure hydrocarbon production. Once the facilities are in place, the operation starts gaining turnover. Over a longer period, the operator will gain a profit. This profit should also make up for the costs of the pre development of the field. The turnover of the platform is influenced by the oil price. The Operational Expenses or OPEX are influenced by the geographical features of the reservoir. [30]

Over time the pressure in the reservoir drops. Extra measures are required to keep the hydrocarbons coming to the surface. These extra measures are costly investments, increasing the capital expenses (CAPEX) and OPEX. The field reaches the end of its life-cycle when the operational expenses exceed the turnover. From this moment exploitation of the field is not economical viable anymore. As a result, the field reaches the final stage of its life-cycle and enters the decommissioning/abandonment phase. Thus, the economic feasibility of the field determines when a field is ready for decommissioning, and is therefore identified as the cause of decommissioning. Figure 2.1 summarizes the oil or gas fields life-cycle.

This research only covers the last phase of the offshore oil and gas field life-cycle, which is the decommissioning phase or abandonment phase.

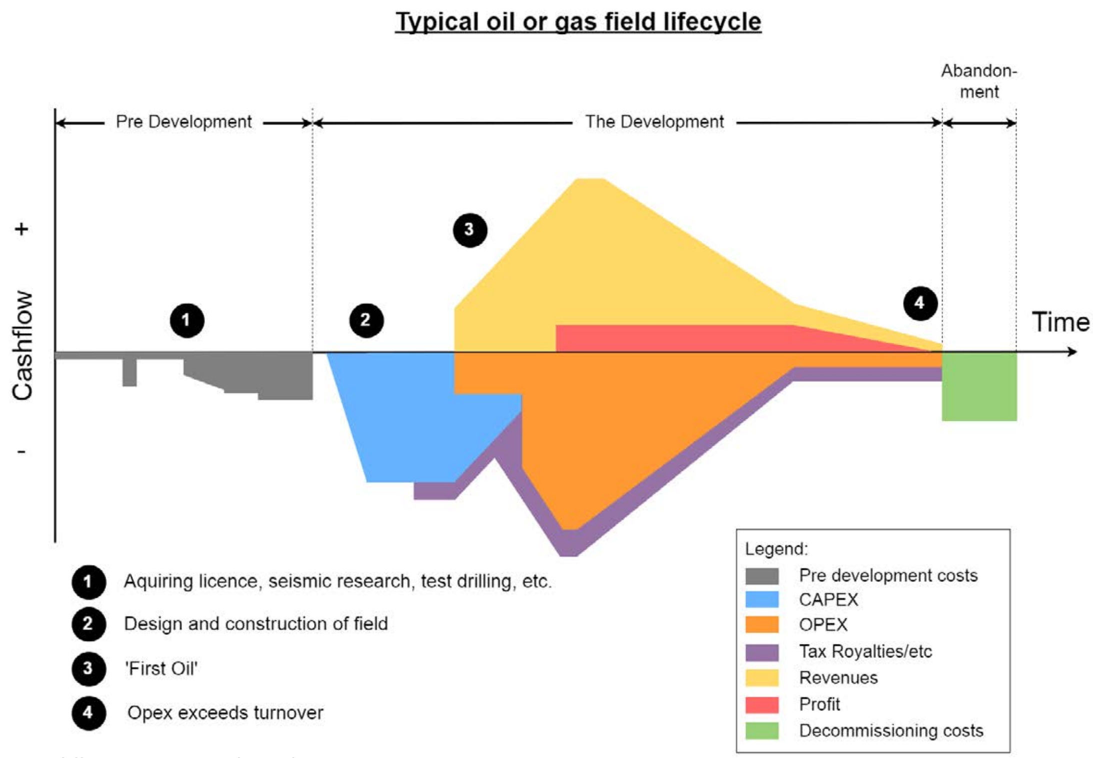


Figure 2.1: Offshore oil or gas field life-cycle[17]

As a result of worldwide offshore oil and gas exploration, decommissioning of offshore structures occurs all over the world. The locations where the very first offshore structures were built, are also the locations where decommissioning activities have been increasing over the past years. The Gulf of Mexico and the North Sea are two of these locations. Although these locations share a rich offshore structure history, there are many differences concerning the specific decommissioning activities. In order to explain these differences the influencing factors on decommissioning will be explained.

2.2. Environmental factors

The end of a structures life-cycle can result in numeous outcomes. These outcomes can vary from abandonment without any removal, to complete removal where the site is left as if the structure was never there. This ‘degree of removal’ highly influences the actions required for decommissioning projects of offshore structures. There are three factors [20] that influence this ‘degree of removal’ for decommissioning activities:

- Regulations/Law
- Public opinion
- Decommissioning costs

Although the individual importance of these factors are fixed, their content vary per nation. A graphic representation of these varying factors is shown in figure 2.2. Here it is shown that these factors ’shape’ the decommissioning process, from the stop of oil and gas production, to the eventually decommissioned offshore structure. In order to minimize this variance the North Sea is selected as region for this research project. More specific the project only includes all offshore structures within the ’Exclusive Economic Zones’ of the United Kingdom, Norway, The Netherlands, Denmark and Germany.
An ’Exclusive Economic Zone’ (EEZ) is a term defined by the United Nations that describes the sea zone in which a state is allowed to exploit any marine resources. It is important to note that oil and gas exploration within the EEZ of a nation are managed by specialized departments

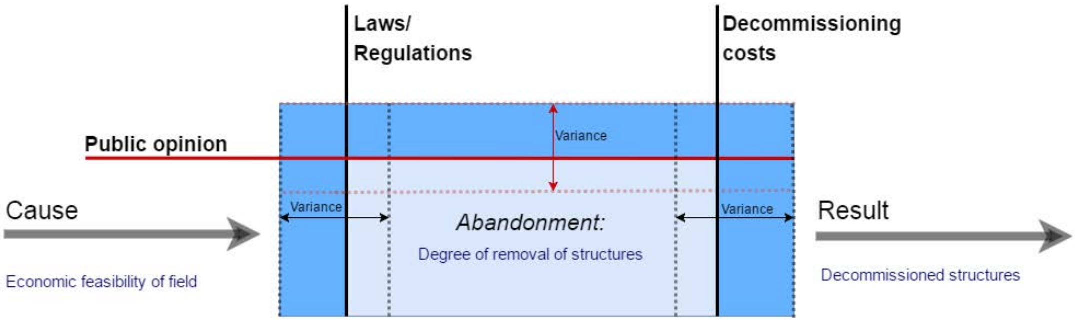


Figure 2.2: Factors influencing the local decommissioning process

within the nations' government. An example of these departments are: the United Kingdom's 'Department of Energy & Climate Change' (DECC) and the Dutch 'Staatstoezicht op de Mijnen' (SodM). These specialized departments or any government bodies that regulate the national oil and gas industry will be referred to as 'government'.

2.2.1. Regulations and Laws

Regulations and law set a framework for all decommissioning projects. They set when and how an offshore structure field should be decommissioned. The regulations vary per location. Therefore the spectrum in which requirements are set for decommissioning are ranging from, removal as if the structure was never there, to leaving the structure for derogation.

The regulations can be divided into three categories: international, regional and local. International regulations cover a significant part of the world, provided by the IMO, as discussed in section 2.7. Regional regulations are regulations that are set by adjoining countries. Local regulations are laws only applicable in the concerning country.

It is the government's task to choose and set the specific requirements within decommissioning regulations. This can be done either by local regulations or implementation of international/regional regulations. Since many oceans and seas are trans-boundary in nature, such as the North Sea, international cooperation has emerged. Subsequently, regional laws and international regulations influence national decommissioning policy. As a part of this policy, requirements are set for the execution of decommissioning projects. Therefore, one of the main influences on the decommissioning market are the international, regional and local laws and regulations.

The regulatory framework can be visualized as a decision tree, as shown in figure 2.3. The first choice determining the faith of the obsolete offshore structure is whether the structure may stay in place, or has to be removed. When the structure is left in place, it can either be left intact or 'Toppled'. 'Toppling' is the demolition of structural part just above the seabed, after which the structure will collapse under its own weight and end up submerged on the seabed [1]. If the structures are to be removed, they can be removed partially or completely. The complete structure or parts of the structure can then be transported to land, or relocated to either shallow or deep water. When the transport to land is chosen, there are three options: reuse, recycling or scrapping of the structure.

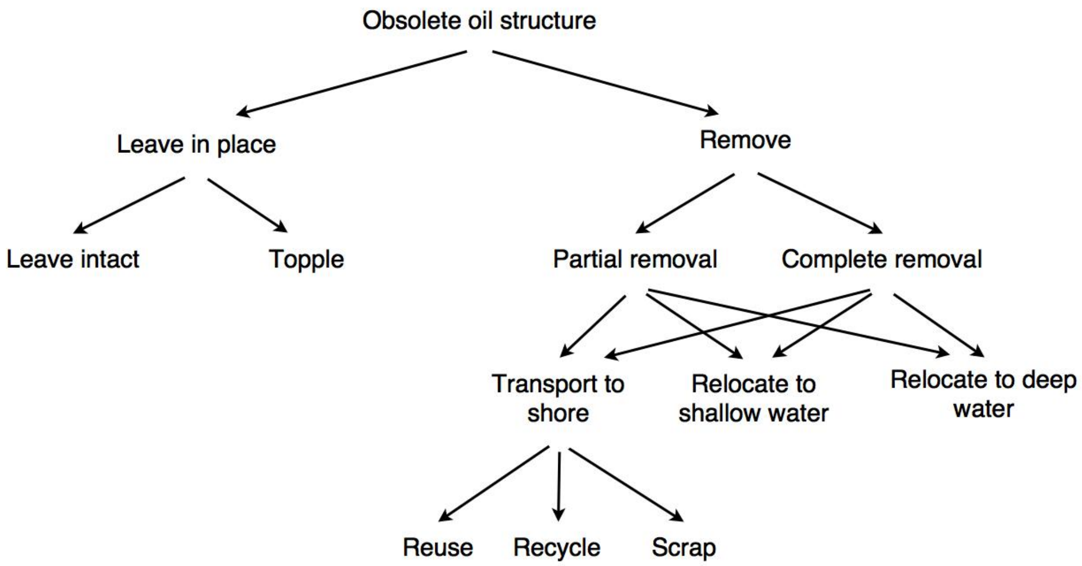


Figure 2.3: Decommissioning options [14]

2.2.2. Public opinion

The removal of an offshore oil and/or gas installations is both a technical and a financial challenge. Based on multiple close-out reports it is concluded that most operators underestimate the costs of the decommissioning of their field [38][35][32][11][3]. In order to get the operators moving towards removal of their facilities, all governments promise tax concessions to the operators [14]. Also most countries are part owner of offshore fields, which further involves them in the removal of the offshore structures. Hence in countries, general public money is being spend on these decommissioning challenges. This makes the general public a stakeholder in the decommissioning industry.

Behavior of governmental institutions is influenced by the 'public opinion'. By means of representative governmental systems, as well as direct influence in the form of media outlets or protests, the general public is able to change the policy. Hence, the general public and their voiced opinions can be seen as an important driver in the decommissioning industry.

This influence can for example be expressed, in the concerns for environmental risks during the disposal of offshore structures. A historical event has been the controversy that build around Shell's disposal of the Brent Spar platform [16]. Back in 1995, Shell tried to dispose one of their offshore facilities by sinking it to a deep-water trench. The UK government had approved this disposal. But then the non-governmental organization Greenpeace had found many bystanders in their claim to stop the disposal by boycotting. Shell was forced to stop the operation. Both the eventual disposal of the platform on land and the loss of reputation has had a noteworthy effect on Shell. Since then governments and offshore operators have been more sensitive for the public opinions and demands concerning the decommissioning or disposal of offshore structures, as explained in section 2.2

2.2.3. North Sea as geographical constraint

As mentioned in this paragraph three influencing factors highly influence the actions required for a decommissioning project. These factors are dependent on the location of the decommissioning project. In order to create a generic model for the resource selection for decommissioning projects, only one set of requirements can be implemented in the model. Ardent has decided to enter the decommissioning market in the North Sea, since this is a growing and developing market as shown in paragraph 2.4. Therefore the geographical constraint for this research is the North Sea.

2.3. Type of offshore installations

In general, the structures in the North Sea can be categorized into six types [30].

- Fixed steel	- Floating steel
- Floating concrete	- Gravity based
- Subsea	- Others

Fixed steel platforms are the most common offshore structures in the North Sea. These platforms use large open tubular steel frames to support a topside above the sea-level. A topside is an accumulation of steel box shaped modules, each module serves a specified purpose such as living quarters and oil and gas production modules. The large open tubular steel frames are also known as jackets. Fixed steel structures are generally used in shallow water up to 300-meter water depth.

Floating steel offshore structures are kept in place by either anchors or constantly compensating own propulsion. These floating structures come in many shapes. A FPSO is a floating production, storage and offloading facility which is shaped like a vessel. A Semi-submersible (semi-sub) floats with the use of two submersed pontoons. Steel columns support the operating deck on these pontoons. Another type of floating steel structure is a spar platform. Which is a large diameter cylinder ballasted to stand upright. These spar platforms carry a similar type of topside as used with fixed steel platforms. The final type of steel floating offshore structure is a tension leg platform (TLP's). These platforms show some shape similarity with spar platforms, but are not fixed by anchors. TLPs are fixed by tendons, these tendons are hollow steel tubes, anchored to the sea-bed by suction anchors. A tension load is applied to these tendons by de-ballasting the platform during installation. This tension load keeps the platform in place.

Floating concrete structures is a rare type of installation, showing similar shape to a semi-sub, but constructed mainly from concrete. Floating steel and floating concrete structures are generally used in deep water, exceeding 300-meter water depth.

Gravity based structures are supported by the sea-bed as fixed steel platforms, and include the same topsides. The main difference is that the gravity based structures are connected to the seabed by use of large concrete pillars. At the sea-bed, these pillars rest on a foundation of concrete suction anchors and tanks. The deepest positioned gravity based structure is the Troll A platform in Norway, at 302-meter water depth.

The very first offshore production sites, were designed to have all oil or gas producing equipment, above water, on deck. As the technology evolved, more and more of this equipment was placed on the sea bottom. Thus platforms could be connected to multiple fields, without being positioned right above the oil and gas well. These pieces of equipment on the seafloor are called 'subsea structures' and vary between manifolds, control stations, pump stations and wellheads. They are mostly used in deep water areas or fields that required expansion without the building of new platforms.

In the category others, are all structures that do not fit into the previous mentioned categories. This includes offshore loading and storage units and a German platform/island built in tidal waters.

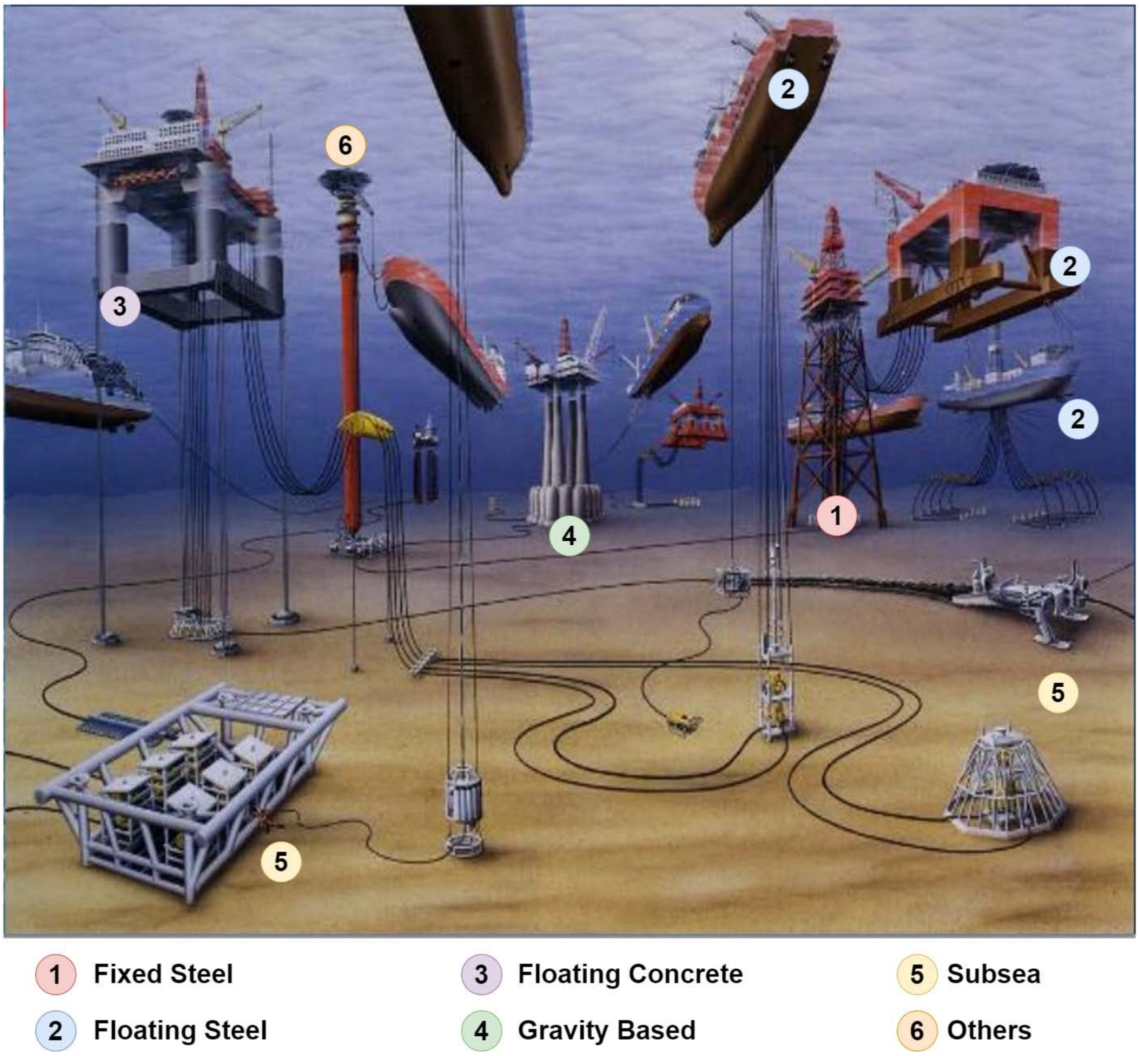


Figure 2.4: Overview of types of offshore structures

source: www.2b1stconsulting.com

2.4. Size of the North Sea oil and gas industry

The oil and gas exploitation in the North Sea has been developing for over 45 years. In the North Sea the first oil and gas field started production in 1967. The North Sea oil and gas industry peaked in a ten-year period from 1984 to 1993, in which on average 20 offshore installations where built each year. This brings the average age of a North Sea platform to 20 years [7]. Usually an offshore field is developed for a lifetime of approximately 20 years. But due to improved technology, offshore platforms have extended their life-cycle between 30 and 40 years [23]. As a result, many 'early built' platforms in the North Sea will face abandonment in the near future. In order to get a gasp of the size and growth of this decommissioning market, two key quantities are given: amount of structures, steel weight of structures.

In 2014 the branch organization of decommissioning contractors in the North Sea, 'Decom North Sea', shared their database of offshore structures, identifying 1355 offshore installation [8]. These installations are divided over the five countries that are defined in section 2.2. These installations include fixed steel, floating steel, floating concrete, gravity based platforms and subsea structures. Within these 1355 installation, 157 structures have been in place for longer than 35 years. With a lifetime of 35 years they could be qualified as at the end of their life-cycle. The amount of offshore installations in the North Sea are quantified in figure 2.5.

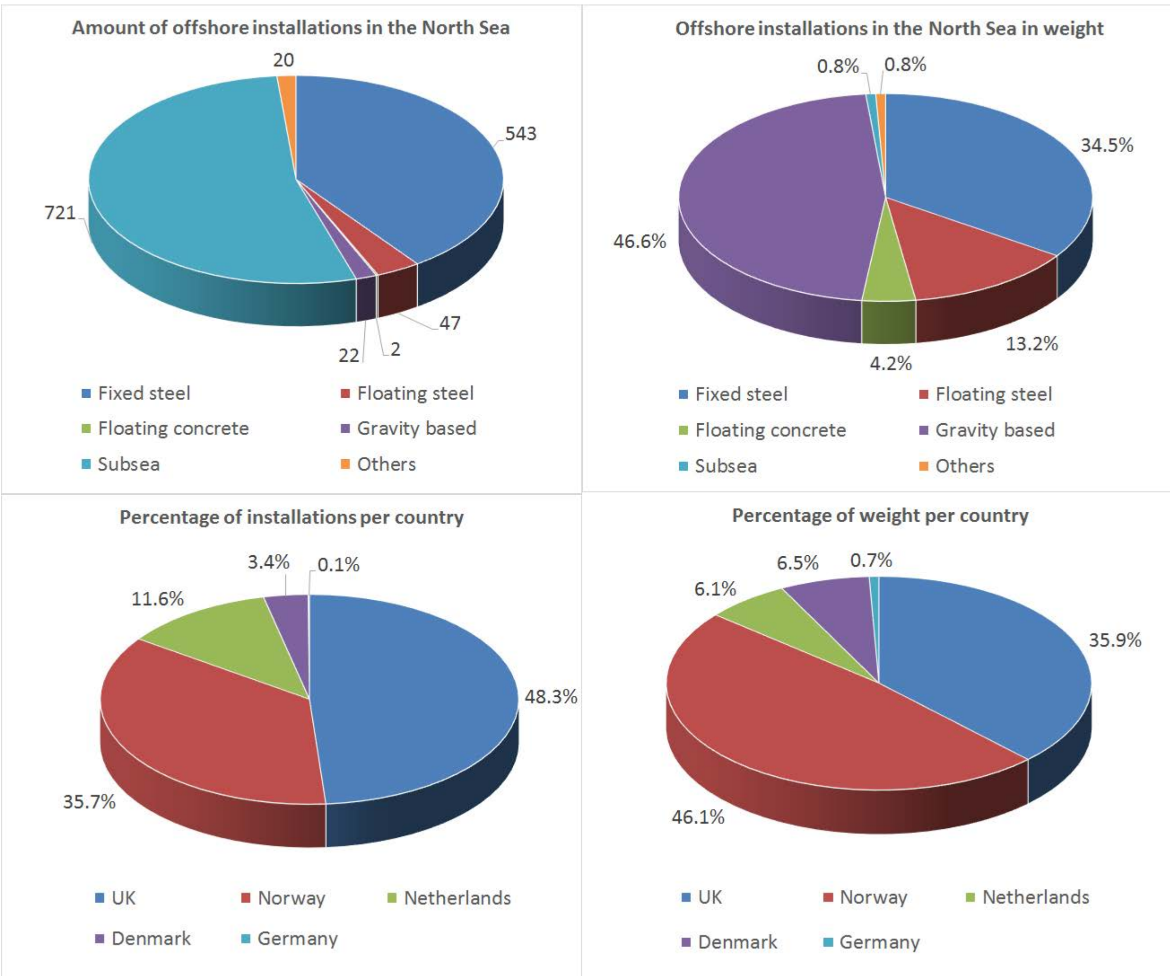


Figure 2.5: Overview of quantities of offshore structures in the North Sea

The quantities percentages show a difference from the weight percentages per country. The majority of the installations consist of the 'lightweight' subsea structures. The heaviest installations in the North Sea are the fixed platforms, especially the gravity based structures in the Northern part of the North Sea. The total weight of all offshore installations within the North Sea is approximately 12.374.939 tons. Without all floating equipment this number changes to an approximate of 10.133.140 tons. To put this in perspective, that is equal to approximately 1000 Eifel Towers. It has to be noted that the 'Decom North Sea' database is missing some weights of subsea structures, giving the percentage of weight for subsea installations a slightly underestimated value.

2.5. Decommissioning experience in the North Sea

In the 2014 Decom North Sea database, 156 installations are qualified as decommissioned. But decommissioning could better be quantified as complete projects in which multiple installations are removed. According to "Decom North Sea" [7], 88 decommissioning projects have been fulfilled, counting the 55 fixed steel, 22 floating steel, 3 gravity based and 7 other installations. The majority of these decommissioning projects concerns relatively lightweight shallow water structures. With the challenges of the removal of the heavier type of platforms in the near future, the decommissioning experience can be assumed as 'in development'.

2.6. Decommissioning market forecast

In the period of 2014 to 2022, the overall decommissioning expenditure in the North Sea will be approximately € 19.000.000.000, according to 'Decom North Sea' [7] and the 'Oil & Gas UK' [27] 2014 market forecasts. Based on several market reports, published in 2013. The annual expenditure increases over the years, starting at € 1.100.000.000 in 2014, increasing up to € 2.600.000.000 in 2019. This increase is mainly caused by the expectancy that an increasing number of structures will be abandoned in the United Kingdom and Norway. In the Netherlands and Denmark region, a more constant request for decommissioning is expected.

Currently the market has deviated from these forecasts. This is shown in a 2015 report from the Dutch national authority responsible for the Dutch tax income from hydrocarbon exploitation, called 'EBN'. This report [10] shows the forecasted and actual decommissioned platform is the Dutch EEZ.

Year	2010	2011	2012	2013	2014
Forecast	5	13	5	3	11
Actual	0	1	2	2	1

Table 2.1: Forecasted versus actual decommissioned platforms in Dutch EEZ

The deviation of forecasted decommissioning is caused by the wait-and-see tendency in the offshore market. This is stated in the same Dutch 2015 report [10]: *"It is important to delay decommissioning of infrastructure so as to extend the window of opportunity for (near-field) exploration and make it possible to bring existing and new discoveries on stream by implementing both CAPEX and OPEX reduction."* The OPEX and CAPEX of the offshore facility are explained in section 2.1. In this case it is meant that waiting with decommissioning could result in the extend of economic feasibility for an offshore facility. Whether the other researched countries share the positive attitude towards the postponing of offshore structure decommissioning, is not available in any data. But it does show that not all governments and influenced offshore operators show an intention to start the decommissioning of their facilities.

2.7. Legislation

The decommissioning of offshore structures is a global activity. Still the legislation can vary per region. This is caused by the 'layers' of regulations that apply to a region. The international legislation will shape the upper layer. This international legislation will set the global standard for decommissioning. Then an additional 'layer' of regional legislation will set the standards for the countries that exploit oil and gas within that region. Finally, the legislation of the country itself will shape the last 'layer' of requirements for the decommissioning within their territorial waters. Resulting in a final set of requirements for the decommissioning projects within the EEZ of a country. In case of the North Sea these layers are visualized in figure 2.6.

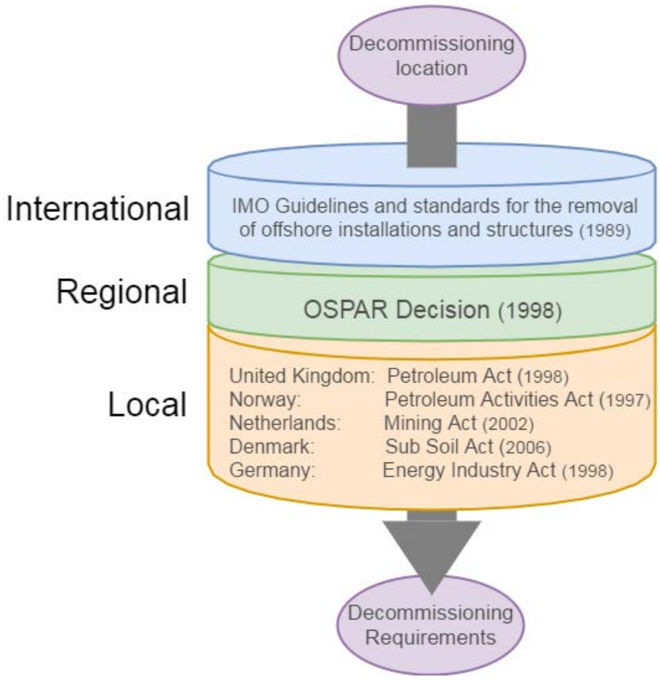


Figure 2.6: Visualisation of decommissioning legislation layers in the North Sea

It is the location of the decommissioning that results in the concluding requirements. In the case of the North Sea, Oslo and Paris Convention for the Protection of the Marine Environment of the North East Atlantic (OSPAR) can be seen as the most important legislation, since the OSPAR supersede most of the IMO rules. Also the North Sea exploiting countries have agreed to adopt the OSPAR regulations within their national law. Therefore, the national law only adds additional requirements to the OSPAR agreement.

The international regulations are formulated by the International Maritime Organization (IMO). In summary IMO states the following:

The choice whether or not to remove an offshore structure is to be made by the coastal state, based on a case by-case evaluation. This evaluation should include:

- *Potential effects on safety of surface or subsurface navigation.*
- *The potential rate of deterioration of the materials, and its effects on the environment.*
- *The potential effect on marine life.*
- *The risk that the material will shift from position.*
- *The costs, technical feasibility, risk of injury to personnel associated with removal.*
- *New use or other justification for allowing the remains on the sea-bed.*

The standards that should be taken into account regarding the decision-making:

- *All abandoned structures standing in less than* $75[m]$ *water depth and weighing less than* $4.000[tons]$ *(topside excluded), are to be completely removed.*
- *All abandoned structures built after 1 January 1998, standing in less than* $100[m]$ *water, weighing less than* $4.000[tons]$*(topside excluded), are to be completely removed.*
- *If a structure can serve a new use, even though specified above, a coastal state can decide to remain the complete or parts of the structure at site.*
- *A partly removed structure should leave an unobstructed water column of at least* $55[m]$.
- *When a structure is partly removed, the maintenance and survey of the structure will be done by the coastal state identified party.*

The OSPAR agreement shows a more specified requirement for decommissioning. The OSPAR in summary:

Two main decisions are stated by the OSPAR:

- *The topsides of all offshore installations have to be removed to shore.*
- *All jackets, sub-structures and subsea structures weighing less than* $10.000[tons]$ *are to be removed to shore.*

For all other cases a case-by-case evaluation shall be made similar to the IMO guidelines. Such an evaluation can result in a the derogation of an offshore structure, where parts or the whole offshore structure is left in place. This derogation decision must be consolidated with the other OSPAR countries before approval. Within national regulations these cases are also referred upon as 'derogation class' cases. The OSPAR legislation does not include: offshore installations which are located below the surface of the seabed, concrete anchor base structures and pipelines

The IMO and OSPAR regulations show well defined guidelines on the topsides and substructure removal. Therefore an overview is given of the sub-structure requirements, as shown in figure 2.7.

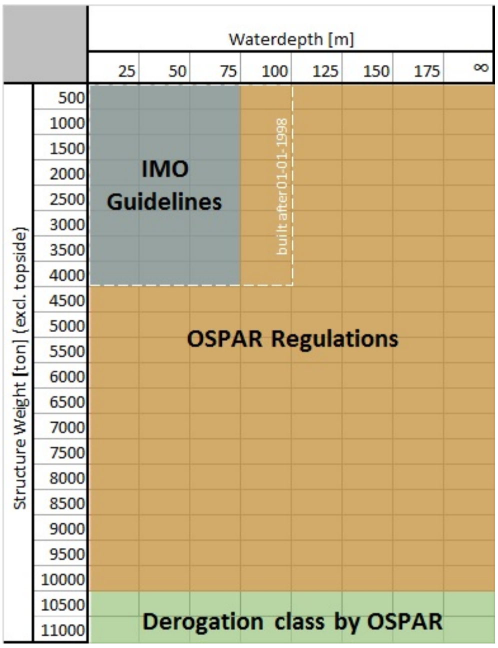


Figure 2.7: Overview of international legislation requirements for sub-structures

The offshore structures that are not included in this international legislation are: pipelines and any further debris on the seabed. Countries are free to set legislation for these excluded subjects. In the North Sea, it is the United Kingdom that setup a detailed guideline for these subject. The other countries (Norway, Denmark and The Netherlands) set a case-to-case decision making strategy for their decommissioning legislation. With strategy the operator can try to prove that the removal of an installation is not technically or economically viable, and derogation of the installation will not be a hazard to other users of the sea. This might result in ”in-situ” decommissioning, which means that the structure is actually derogated or left in place. The local decommissioning legislation of the North Sea countries is summarized in table 2.2.

	United Kingdom [9]	**Norway** [4]	**Netherlands** [34]	**Denmark** [13]
Jacket Structures	Piles of footings to be cut at adequate level under seabed. Dependent on prevailing,seabed conditions and currents.	None	Every offshore installation should be removed, unless minister choses differently. His/Her decision based on OSPAR	None
Topsides	None	None	None	None
Floating Structures	Can be removed before hand in of ’Decommissioning Programme’ (DP). All other equipment should be dealt with in DP.	None	None	None
Subsea Structures	Are considered as steel substructures, and thus apply to OSPAR regulations.	Are considered as steel substructures, and thus apply to OSPAR regulations.	All should be removed unless minister states differently	Are considered as steel substructures, and thus apply to OSPAR regulations.
Gravity Based	Derogation class by OSPAR	Derogation class by OSPAR	Derogation class by OSPAR	Derogation class by OSPAR
Pipelines	Guidelines for pipeline removal documented. In general: buried or trenched –>in situ decom, all other pipelines removed, including grout bags or matrasses.	leave in situ	Choice made by minister to remove or leave in situ	Nothing specified
Debris removal	500 [m] around structure, 200 [m] on each side of pipeline.	Nothing specified	Nothing specified	Nothing specified

Table 2.2: Additional national legislation to the OSPAR convention

2.8. Summary

In this chapter the background information is given on the decommissioning of offshore structures in the North Sea. The life-cycle of an offshore oil and/or gas field is explained. The field reaches the end of its life-cycle when the operational expenses exceed the turnover. The final stage of the field's life-cycle will then commence: decommissioning/abandonment phase.

Within this decommissioning phase, the offshore installations are removed according to a network of international, regional and local legislation. The decommissioning activities are influenced by three factors: regulations/laws, public opinion, decommissioning costs.

In 2014, 1355 offshore installations where identified within the North Sea. With an average life-cycle between 30 and 40 years, 157 installations have been identified older than 35 years. It is therefore assumed that multiple installations will be decommissioned in the upcoming years. Market forecasts show optimistic estimated decommissioning expenditures, in perspective of the offshore contractors.

The legislation on the decommissioning of offshore structures in the North Sea can be divided into three categories: International, Regional and Local legislation. International legislation is formulated by the "IMO Guidelines and standards for the removal of offshore installations and structures (1989)". This legislation states case-by-case evaluation for the removal of structures, and sets guidelines for the complete removal for structures located in a water depth of less than 100 $[m]$ and a weight lower than 4.000 $[tons]$.

Regional legislation within the North Sea is formulated within the OSPAR Convention. All North Sea hydrocarbon exploiting countries have agreed to this convention, and are therefore obligated to implement the convention into their national law. In contrast with the IMO guidelines, the OSPAR legislation is paramount. The OSPAR regulation require all structures to be removed, unless the structure is heavier than 10.000 $[tons]$. In these heavier cases, derogation of the structure will be analysed using a similar case-by-case evaluation as recommended by the IMO guidelines. The OSPAR does not include any regulation on pipelines and structures bellow the seabed (wells).

Regional legislation are laws that countries have formulated themselves in addition to the obligatory OSPAR laws. The analysed countries in this research show two approaches. The first approach is only chosen by the United Kingdom, their legislation show additional guidelines on subsea installation and pipeline removal. The second approach is the case-by-case approach chosen by Denmark, Norway and The Netherlands. All non included structures in the OSPAR will be evaluated by a specialized department through a similar decision schematic as shown in figure 2.3.

3
Work Breakdown Structure

Since every offshore installation is unique, so are the decommissioning projects. But when decommissioning projects are compared, they show a similar sequence of tasks. In this chapter, these sequences of tasks are referred to as ”elements” of the project.

There are multiple ways to visualize these elements of a project. In this case the chronological order of these elements will be expressed in a work-breakdown structure. First of all this chapter presents the general work-breakdown structure of a decommissioning project. Every element is explained separately with the use of the ’black-box-approach’. Secondly a selection of the elements is used to review the separate parts that form the element. These parts are defined as activities. These activities are also shown in a work-breakdown structure, referred to as the ”detailed work breakdown structure”. The third and last part of this chapter, risk is added to the project activities by the use of a risk register.

3.1. General Work-breakdown Structure

The work breakdown of a decommissioning project is specified in figure 3.1. This is a figure published by the branche organisation: Decom North Sea. The figure is based on the original Oil & Gas UK branche organisation work breakdown structure, made by the industry to define a common decommissioning language [7]. This work breakdown structure is therefore widely accepted within the industry and assumed as a valid starting point for the model development of this thesis.

Within figure 3.1, two left boxes defined under ”A” are elements performed by the platform owners (operators). These tasks concern the project management and financial management of the decommissioning project. These operator elements are excluded from this research since the project is engaged from the contractor perspective.

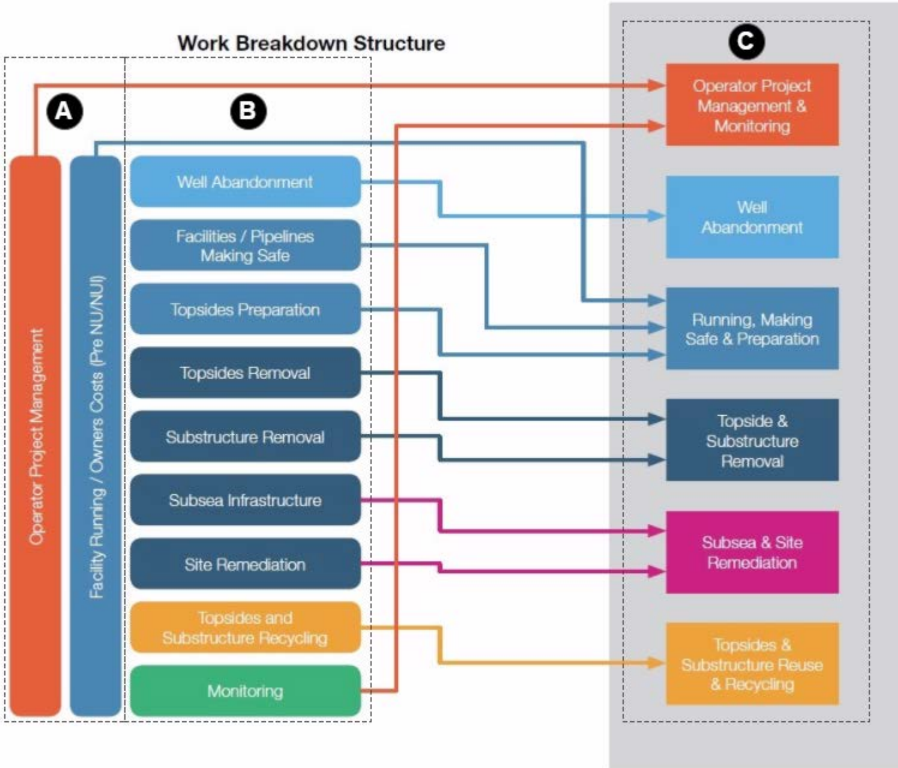


Figure 3.1: General work-breakdown structure for a decommissioning project

The boxes defined under ”B” show the required elements for a decommissioning project in chronological order. Some of these elements are bundled into a category as defined under ”C”. This chapter analyses every element as defined under ”B”, one per paragraph.

The analysis of every element is done through a ’black-box-approach’ . This ’black-box-approach’ analyses an element as a process with in- and output, and neglects the details of the actual transformation of this input into output. [37]. This method is chosen, since the projects are quantified in a standard format, without many details. More details would force the model to become case dependent and not generic.

For every element the purpose and function are described. The function of an element is the reason why the element is part of a decommissioning project. The purpose of an element is the description how the element is part of a decommissioning project.

3.1.1. Well Abandonment

The first element performed in a decommissioning project is the well abandonment. The purpose of this element is to physically block the connection between the subterranean hydrocarbon reservoir and the surface of the seabed. The function of this element is to prevent hydrocarbons coming to the surface in the future.

This task is performed through three possible methods. These methods are:[24]:

- Well abandonment from a fixed platform.
- Well abandonment from a Diving Support Vessel (DSV) or support vessel with dynamic positioning system (DP3 or DP2).
- Well abandonment from a floating installation (semi-sub or jack-up rig).

The asset required to perform well abandonment in general is a drilling derrick or drilling rig. These assets are operated by specialized drilling companies. Ardent does not have experience in any of these operations. When Ardent enters a decommissioning project, the well abandonment will be contracted separately to a specialized company by the platform operator. Therefore well abandonment is excluded from the detailed work breakdown structure.

3.1.2. Facility/Pipelines Making Safe

After an offshore structure has been plugged and abandoned as described in the previous step, the structure has to be cleaned to ensure safe decommissioning. Therefore the task of Facility/Pipelines Making Safe is to remove all hydrocarbons and hazardous materials from the offshore structure. Since decommissioning will include ”hot works” like steel cutting and welding, all hazardous materials have to be removed. The function of this element is therefore described as: ”Create a safe, hazardous material free work-space for further activities.”

For these activities it is required to accommodate the personnel offshore. Since the to-be-removed platform has been abandoned, the accommodation on the platform itself will not be suitable. Therefore an accommodation alongside to the platform is required. This accommodation is supplied by a ”preparation vessel”. From this preparation vessel a workforce is dispatched to do several tasks on the offshore structure.

3.1.3. Topsides Preparation

Once the facility has been made safe, the preparation for the removal works of the topside can commence. The task of Topside Preparation is to prepare the topside to be lifted off the substructure. This is a part in the project where materials can be added to the platform. Examples of these materials are: lifting points and reinforcements. As far as possible, cutting activities are performed. The main constraint for these cutting activities is the structural integrity of the platform. The function of all these activities are to minimize the downtime for the Heavy Lift Vessel (HLV) and maximize the safety for the removal of the topside. These activities require the same resources as required for facility/pipelines making safe.

3.1.4. Topsides Removal

Topside removal is the first element in decommissioning that is removing large parts of the platform. The task of this element is to remove or lift the topside of the substructure either as a whole, in modules, or in pieces loaded into containers. From a more logistic perspective the function of this element is described as: Lifting steel from a fixed position above sea-level onto a floating asset.

The assets required for the topside removal are all based on the HLV. The capabilities of an HLV is split in crane and vessel capabilities. First of all the crane capabilities determines the size and weight that can be lifted. Second, the capabilities of the vessel determine how many additional assets are required to perform the task. Two of these vessel capabilities are: the position keeping method and their deck space. The position keeping can be done with dynamic positioning, jack-up legs and anchors. In the case of anchors an anchor handling tug will be required to handle the anchors of the HLV. The deck space of the HLV determines whether it is required for the offshore structures to be carried to shore onboard the HLV or a separately chartered barge.

Since the capabilities of the HLV has so many influences on the project, the selection of an HLV for a project will highly influence the planning and costs outcome. Some competitors for decommissioning project are asset owning companies. These companies are to adjust their HLV choice to their own vessels, where Ardent can select any available HLV. This might give Ardent an strategic advantage. The importance of the HLV selection is herewith proven, and shall be further explained in chapter 4. Because of this importance, this element is seen as one of the main elements in the detailed work breakdown structure.

3.1.5. Substructure Removal

This element removes the last above-sea-level visible part of the offshore structure. The task of this element is to terminate the connection between sea-bed and the substructure and remove the substructure in parts or as a whole. When this element is placed in a more logistical perspective, the function of this element is to lift a steel structure from a fixed position on the sea-bed, onto a floating asset. The floating asset will then transport the steel to a recycling facility or dismantle yard.

Similar to the topside removal the HLV is the key factor within this element. The selection of a HLV and its corresponding constraints play a similar role within the substructure removal as explained with topside removal. Because this element is also highly influenced by the HLV selection, this element is seen as one of the main elements in the detailed work breakdown structure, just like the topside removal element.

3.1.6. Subsea Infrastructure

Although visually the offshore structure has been removed, there can still be offshore installations positioned on the seabed. These structures mainly consist of pipelines and structures that protect these pipelines such as concrete mattresses. The task of this element is to remove all installations positioned on the sea-bed. The function of this element is to connect a floating structure to a fixed structure on the seabed. Terminate connection of the subsea structure with the sea-bed and lift the structure onto a floating structure. The floating structure will transport the steel to recycling facilities.

The assets required for these operations is a diving support vessel (DSV) including small crane and remote operated vehicle (ROV). The ROV is used to connect the crane to the structure and terminate the potential connection with the sea-bed. Since this operation could be identified as a stand alone operation, the mobilization, demobilization and the operations by the DSV is exploited thought a third party contract. Therefore this element is not interesting for the asset selection strategy of Ardent, and is not included in the detailed work breakdown structure.

An important note to this element is that for floating offshore platforms such as FPSO's and SPAR platforms, most installations are positioned on the seabed. These installations are heavier that the pipelines and mattresses as explained about. For the decommissioning of these heavier subsea structures a HLV might still be required. Therefore it can be assumed that for decommissioning of floating offshore structures such as FPSO's or SPAR platforms, the element of Subsea Infrastructure does play an important role in the decommissioning asset selection strategy. But these installations are excluded from this research and thus not included in the detailed work breakdown structure.

3.1.7. Site Remediation

Once the structures are removed from the sea-bed, the sea-bed is not assumed clean. Debris has sunk to the sea-bed due to installation, operations and decommissioning activities throughout the years. Therefore the task of this element is to remove all debris. The function of this element is described as: ”to obtain a clean and hazardous free sea-bed for other users of the sea.”

The site remediation is generally done with the use of a trawling fishing system, where structured sweeps through the designated site are performed by any vessel able to carry the trawling system. The site is afterwards surveyed with a sonar like system, to prove the seabed is delivered ”cleaned”. Similar to the subsea infrastructure element, this task will be fully assigned though third party contract by Ardent. Therefore this element is not included in the detailed work breakdown structure.

3.1.8. Topsides and Substructure Recycling

The removed structures are to be recycled at a designated yard. The task of this element is to lift the transported steel to the recycling yard onto land and dismantle the structure there. The function of this element is to recycle the transported steel structures by separating specified materials for either destruction or re-use.

Within this research two methods of steel structure transport have been excluded. The first method is the transport of the steel structure while being lifted by the HLV. This method requires an increased crane capacity due to the dynamic loads occurring in the crane during transit. Since this research aims to minimize the crane capacity used in a project, to minimize costs, this method of transportation is excluded from the research. The second method is the use of skids to transport the steel structures from moored asset to the quay. Since Ardent does not own the equipment to skid these structures to shore, the transport would be contracted to a third party. Thus this method will not be part of the asset selection strategy of Ardent and is excluded from the research.

The remaining method to transport the topside and jacket to shore, is to be lifted by the HLV. The HLV will therefore sail to the dismantle yard after lifting operations offshore, to lift the steel structures either from the barge or its own deck, to shore. Only the transit to the yard, and the lifting by HLV is included in the work breakdown structure. This excludes the actual recycling and re-use of the platform materials by the dismantling yard.

3.1.9. Monitoring

The final task of the decommissioning project is mainly focused on compliance with local law. In this element a final observations of the site is done by a third party, monitoring the site for any missed debris. Moreover the plugged and abandoned wells have to be monitored for multiple years. The task of this element is showing the local government that the decommissioning project has been fulfilled in compliance with the legislation. The function of this element is to ensure that the former offshore site, stays environmentally hazardous free for years to come.

The monitoring of the site is at first performed by a vessel equipped with a sonar and trawling installation. After surveys with these tools, a certificate is given if the site complies with the legislation. This survey is payed for by the platform owner. In addition periodic surveys shall be done throughout the years to check the abandoned wells for leakage. This is performed by the offshore operator/last user of the platform. These activities are not included in the detailed work breakdown structure.

The work breakdown structure as described above does not include any engineering, planning and project management done by the decommissioning contractor. Since these tasks will not determine the asset or strategic partner selection within the process, they are not of any interest to this research. But it must be noted that these were not explained in this general overview.

3.2. Methods for Decommissioning

Before getting into technicalities on the detailed work-breakdown structure, the methods applied to the decommissioning structures have to be explained. From close-out reports it can be concluded that there are four methods currently used for decommissioning of offshore structures [11][3][33][35]. A close-out report is a post-decommissioning report, which is required to be published in United Kingdom legislation. These methods are:

- Single Lift
- Piece Medium
- Piece Small
- Innovative approaches

3.2.1. Single Lift

In case a fixed steel platform is decommissioned with the single lift method the topside and jacket are each removed in one single lift. For this method, the utilized heavy lift vessel will have capabilities beyond the total topside weight and total jacket weight.

Figure 3.2: Single Lift Method (this case installation of topside)

Source: http://www.offshorewindindustry.com

3.2.2. Piece Medium

In case a heavy lift vessel is used with insufficient capabilities to lift the topside or jacket as a whole, the piece medium method is used. Within this method the topside and jacket are cut into pieces conform the HLV capabilities. Within this thesis pieces are defined as modules. Within this definition modules can vary in size, depending on the total topside size. Since this research only includes platforms in the Southern North Sea with a topside weight limited to 1400 [$tons$], the minimal module weight is defined as a fourth of the topside weight. Decommissioning in modules smaller is defined in the Piece Small method.

Figure 3.3: Piece Medium Method

Source: http://www.swaei.com/

3.2.3. Piece Small

The piece small method shows a big difference compared to the single lift and piece medium methods. The difference is in the decommissioning of the topside. In piece small no heavy lift vessel is used for the decommissioning of the topside. Instead the topside is dismantled on site with tools similar as used on dismantle yards. In a way piece small can be interpreted as dismantling the topside offshore. Containers and a platform supply vessel are used to bring the scrap metal to shore. This is a labour intensive method. The dismantling by hand is stopped once the final deck of the topside and jacket remain. The remaining deck and jacket can be removed with heavy machinery that is operated from an asset alongside the platform. An example of this machinery would be an hydraulic shear. The remaining deck and jacket can also be removed using either the single lift or the piece medium method.

Figure 3.4: Piece Small Method

Source: https://www.oilandgaspeople.com

3.2.4. Innovative approaches

Innovative approaches are generally done with assets specially built for the decommissioning of offshore structures. Examples of these assets are the ”Pioneering Spirit” by Allseas and ”Jacket buoyancy tanks” by Aker Solutions. Since Ardent does not currently own a device like this, and is not planning to built any, this method is excluded from this research. In addition these innovative assets do not follow the generic decommissioning work breakdown structure as explained in section 3. For these two reasons the innovative decommissioning approaches are not included in this research.

3.3. Detailed Work-breakdown Structure

From section 3 four elements remain to be included into the detailed work breakdown structure. These elements are:

- Facility/Pipelines Making Safe
- Topsides Preparation
- Topsides Removal
- Substructure Removal

These elements are now divided into three different phases: a preparation, a topside removal and a substructure removal phase.

To research the detailed activities performed in a decommissioning project, an additional source is required. The work-breakdown structure as shown in section 3 is the most detailed description of a decommissioning project in literature. An alternative source for information on decommissioning project activities would be other companies involved in decommissioning. But companies see their knowledge on decommissioning as a market advantage, and do not share information on their performed decommissioning jobs. Therefore a source of information was found within Ardent.

At the time of this research, Ardent has no experience in decommissioning projects. But Ardent did create offers for so called ”tenders” in the decommissioning market. These tenders are potential projects where the offshore operator requests several companies to present their planning, price and operational specifications for the removal of one or multiple platform(s). After companies like Ardent have handed in their ”tender quotes” the offshore operator will chose which companies to further negotiate with. As a result of this process, the project is awarded to a company and actual decommissioning can commence.

From the tenders that Ardent offered, two where within the 1400 [$tons$] topside weight constraint of this research. Within these research these tenders are defined as tender A and tender B. The characteristics of the platforms in tender A and B are defined in table 3.1.

These tender quotes contain a lot of information on the planning, costs and operational aspects of a decommissioning project. For tender A, Ardent researched the possibilities for Single Lift and Piece medium removal of the platform. Therefore each method had its own detailed planning for removal. For tender B only the Single Lift method has been considered. The detailed work-breakdown structure of this research is therefore based two tenders, containing two plannings for Single Lift and one for Piece Medium decommissioning. Although the information has never been validated by testing in reality, it is the only information available on these subjects. Irrespective of the inadequacies of this information it is still used as a basis for the detailed work-breakdown structure.

	Tender A	**Tender B**	*Units*
		Weights	
Topside weight	1232	721	*[tons]*
Modular Support Frame?	No	No	*[Yes/No]*
Jacket weight	844	734	*[tons]*
Jacket pile weight	697	46	*[tons]*
Riser/Conductor weight	305	196	*[tons]*
		Dimentions	
Topside lenght	23	20	*[m]*
Topside width	37	25	*[m]*
Topside height	34	35	*[m]*
Number of wells	7	5	*[-]*
Jacket height	50.5	37.4	*[m]*
Number of piles	4	4	*[-]*
		Location	
Location	Southern Northsea	Southern Northsea	*[-]*

Table 3.1: Platform characteristics from Ardent tenders

Within Ardent, no research has been done on the possibilities of Piece Small decommissioning. In order to formulate a detailed work-breakdown structure for piece small, the close-out report for the Shell Indefatigable Field was used. A close-out report is a post-decommissioning report, which is required to be published in United Kingdom legislation. In this report Shell is explicit about the tasks performed and durations in the project. Therefore this close-out report is the main source for the Piece Small activities and durations [33].
In order to make a detailed work breakdown structure every method of decommissioning explained in section 3.2 must be analysed separately. Their individual work breakdown structure is shown in appendix A. A simplified visualization of these work breakdown structure is shown in figure 3.5. Some activities within these work breakdown structures are similar. All activities are numbered with three numbers. The first number corresponds to the phase of decommissioning. The second number corresponds to the sub-category of the activity. The third number corresponds to the individual activity.

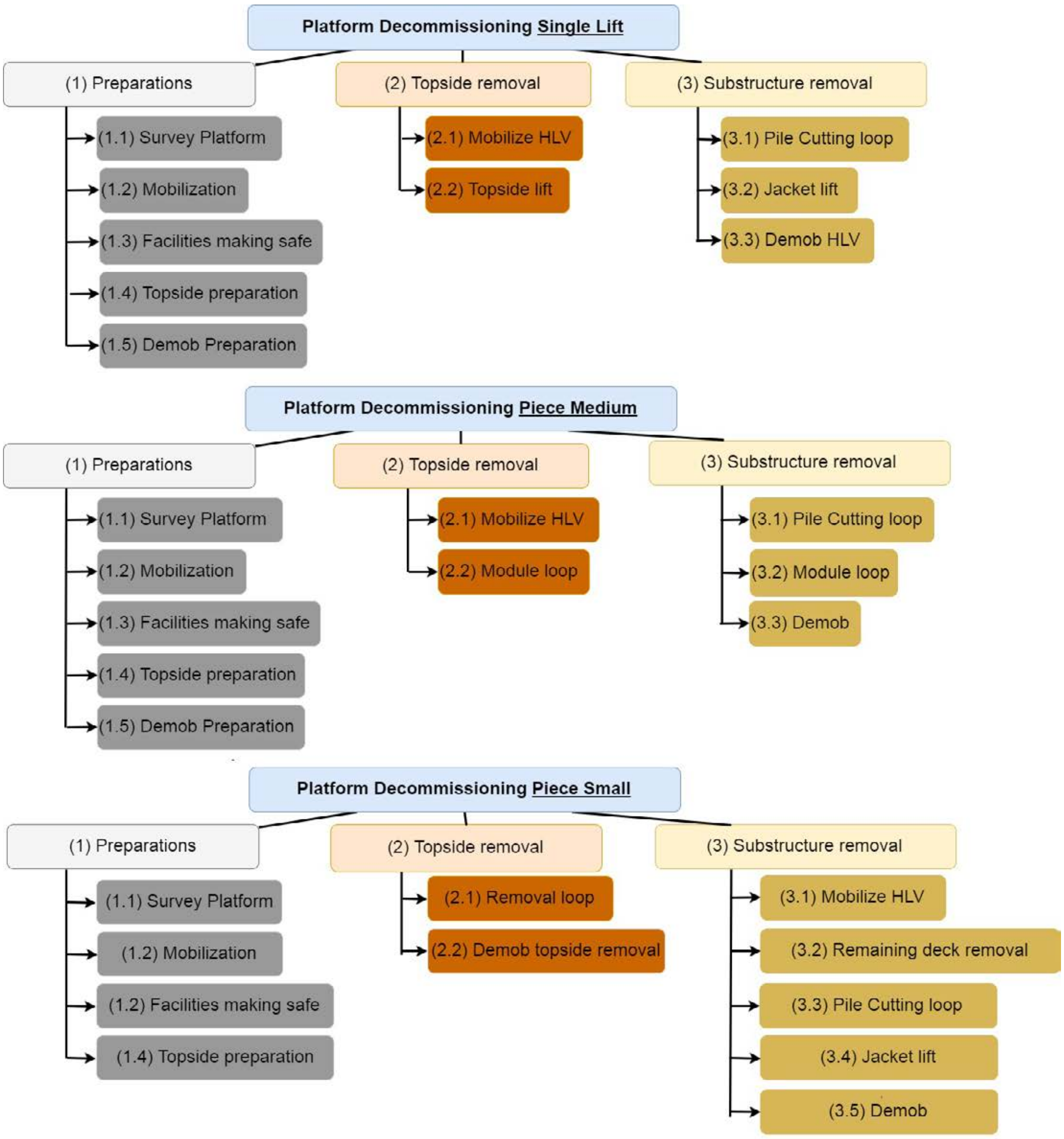


Figure 3.5: Simplified visualization of WBS per decommissioning method

3.3.1. Preparation Phase

The preparation works for the actual decommissioning does not require a heavy lift vessel. Since no heavy lifts will be performed during this phase, a vessel with accommodation ,power supply and an estimated 100 [*ton*] crane will be sufficient. This vessel will be referred upon as ”preparation vessel”. Within the Preparation phase, five sub-categories of activities are made. These sub-categories are shown in table 3.2.

Single Lift & Piece Medium

(1.1.1) Mobilize Survey team

Within this task a team that will review the ”as is” status of the offshore platform will be transferred from shore to the platform.

(1.1.2) Platform Survey

Once the survey team is aboard the platform, multiple assessments will be made. The team will survey current accessibility, structural conditions and other requested aspects. This information can then be used for further engineering and planning.

(1.1.3) Demob Survey team

After surveys the team will be transferred from the platform back to shore.

Single Lift	Piece Medium	Piece Small
(1.1) Survey platform	(1.1) Survey platform	(1.1) Survey platform
(1.2) Mobilization	(1.2) Mobilization	(1.2) Mobilization
(1.3) Facilities making safe	(1.3) Facilities making safe	(1.3) Facilities making safe
(1.4) Topside preparations	(1.4) Topside preparations	(1.4) Topside preparations
(1.5) Demob preparation	(1.5) Demob preparations	

Table 3.2: Sub-categories for Preparations phase

(1.2.1) Load equipment
The equipment and team required to perform the upcoming preparation works are gathered and installed on the prep vessel.
(1.2.2) Sail to site
Prep vessel sails from shore to platform location
(1.2.3) Positioning on site
Prep vessel is positioned alongside the platform. A safe passage from vessel to platform is created.

(1.3.1) Install lighting/temp. power supply
In order to work on the platform, temporary lighting is installed. Temporary power supply for other tools is installed.
(1.3.2) Install navigational lighting
The navigational lighting installed on a topside is replaced for a battery/solar powered navigational lighting system. This is done for both regulations and safety requirements.
(1.3.3) Scaffolding
On both the topside and the jacket, scaffolding is required to access areas where the initial access is limited. These scaffolds will support work until the end of the project.
(1.3.4) De-energize platform
Once all lighting and power supply is provided by the prep vessel, the original power supply of the platform a can be shut off and all hydrocarbons are collected.
(1.3.5) Flush clean and remove hazardous materials
All hazardous materials are to be removed off the platform before the project can proceed. Materials such as loose asbestos is to be collected. A hydrocarbon free structure must be reached as far as reasonably possible. This is essential since ”hot-works” later in the project will cause fire and explosion risks if hydrocarbons are still present.
(1.3.6) Secure loose items
All loose items on the platform are to be secured in order to ensure no objects falling of the platform into the sea. Also loose items can cause injury or worse through tripping danger.

(1.4.1) Strengthening works
Now that the platform is safe for hot-works, welding of the platform can commence. Welding is required to reinforce lifting points or other structural members under heavy lifting loads. Also structures are not allowed to collapse after cutting operations. Therefore some area’s surrounding the cut should be supported.
(1.4.2) Disconnect caissons/risers
The oil or gas well has a connection between the seabed and the topside. Now that the platform is plugged and abandoned, these connections can be removed. By removing these connections, the topside will not carry many meters of piping dangling beneath the deck when lifted. These connections are called the risers or caissons.
(1.4.3) Disconnect pipework & wiring Jacket/Topside
Any other pipework or wiring connecting the topside to the jacket should be removed. This ensures a clean lift off the jacket, without any obstructions.

(1.4.4) Prepare as many cutting works as possible
Since the dayrate of a heavy lift vessel will be higher than the dayrate of a prep vessel, the activity of cutting the topside is done as early in the project as possible. The main constrained for this activity is the structural integrity. The topside must maintain its ability to withstand heavy weather and other loads. Therefore the cutting works can only be done to a certain extend, and final cuts have to be made with the heavy lift vessel standby.
(1.4.5) Prepare as many lifting pad-eyes as possible
Considered the same cost advantage as with the cutting works, lifting pad-eyes are installed as early in the project as possible.

(1.5.1) Sail to port
The prep team, equipment and vessel sails back to shore.
(1.5.2) Unload equipment
The prep team and equipment are discharged from the prep vessel.

All previously mentioned activities are planned using either the Single Lift or the Piece Medium method of decommissioning. In case of Piece Small decommissioning the similar tasks are performed up until activity (1.3.1). From this moment the piece small will only add two different activities as shown bellow. With the Piece Small method the prep vessel will not demobilize but stay alongside the platform until the end of the topside removal phase.

(1.4.2) Prepare mobile/platform crane or excavator
Within this activity the tools used for the Piece Small decommissioning activities are loaded onto the platform.
(1.4.3) Prepare deckspace for scrap containers
With the Piece Small methods the minimal area of the platform topside must be utilized for the logistics similar to a dismantle yard. Therefore the deckspace has to be organized and containers placed for material storage.

3.3.2. Topside removal

Similar to the preparation phase, the topside removal phase shows different activities for each decommissioning method. Therefore first all corresponding activities will be explained, and afterwards all unique activities are shown. Within the topside removal phase the following sub-categories of activities are mentioned:

Single Lift	Piece Medium	Piece Small
(2.1) Mobilize HLV	(2.1) Mobilize HLV	(2.1) Removal loop
(2.2) Topside Lift	(2.2) Module loop	(2.2) Demobilize topside removal

Single Lift & Piece Medium
(2.1.1) Install grillage
The grillage for a decommissioning project is the frame on which the topside and jacket will be carried to shore. In port, the grillage is welded to the deck on the vessel that will carry the topside and jacket: either heavy lift vessel or barge.
(2.1.2) Load equipment
The equipment and team required to perform the heavy lifting works are gathered on the heavy lift vessel.
(2.1.3) Sail to site
Heavy Lift Vessel sails from shore to platform location
(2.1.4) Positioning on site
Heavy Lift Vessel is positioned aside the platform. Also a safe passage from vessel to platform is created.

Piece Small

(2.1.1) Remove Steel
The topside is dismantled piece by piece.
(2.1.2) Fill containers
The steel scrap is loaded into containers
(2.1.3) Load conainters to PSV
The filled containers are loaded upon a Platform Supply Vessel.
(2.1.4) Sail PSV to dismantle yard
As described, the Plaform supply vessel sails to the dismantle yard.
(2.1.5) Unload PSV
The containers are lifted onshore.
(2.1.6) Sail PSV to site
The PSV sails back to site where new containers have been filled, and the loops starts over again until only the last deck of the topside remains.

Single Lift

(2.2.1) Rig topside
The connection is made between crane hook and topside.
(2.2.2) Cut topside from jacket
Using specialized equipment, the topside is cut from the jacket.
(2.2.3) Lift topside
The topside is lifted of the jacket.
(2.2.4) Load topside to grillage
The topside is layed down on the specially designed grillage.
(2.2.5) Sea-fast/de-rig topside
The topside is welded/fixed to the grillage. Also the connection between the crane hook and the topside is terminated.

Piece Medium

(2.2.1) Rig module
The connection is made between crane hook and module.
(2.2.2) Cut module from topside
Using specialized equipment, the module is cut from the topside.
(2.2.3) Lift module
The module is lifted of the topside.
(2.2.4) Load module to grillage
The module is layed down on the specially designed grillage.
(2.2.5) Sea-fast/de-rig module
The module is welded/fixed to the grillage. Also the connection between the crane hook and the module is terminated. Then the loop starts again until all modules are sea-fastened.

Piece Small

(2.2.1) Remove remaining equipment
All equipment used to dismantle the topside is loaded onto the prep vessel.
(2.2.2) Sail to shore
The prep vessel sails back to shore
(2.2.3) Unload equipment
All equipment is unloaded from the prep vessel.

3.3.3. Substructure removal

Similar to the Topside removal phase, the Substructure removal phase contains different activities per method. In this case the Single Lift and Piece Medium method show the two ways of substructure removal. The Piece Small method is mainly focused on the topside removal, and adopt either the Single Lift or Piece Medium method for the substructure removal. Therefore this paragraph only explains the Single Lift and Piece Medium activities. Within the Substructure removal phase, three sub-categories of activities are made. These sub-categories are:

Single Lift	**Piece Medium**
(3.1) Pile Cutting loop	(3.1) Pile Cutting loop
(3.2) Jacket lift	(3.2) Jacket loop
(3.3) Demobilization	(3.3) Demobilization

Table 3.3: Sub-categories of activities in Substructure removal phase

Single Lift & Piece Medium

(3.1.1) Dredging of pile
It is assumed that all jackets in this research are piled onto the sea bed. In order to reach the OSPAR [28] required five meters bellow the seabed, where the cut is made, dredging has to be performed. This dredging provides access for the cutting tool.

(3.1.2) Install cutting tool in pile
In this activity the cutting tool is lowered down, and installed in the pile.

(3.1.3) Cut pile
The pile is cut using the cutting tool, five meters bellow the seabed.

(3.1.4) De-install cutting tool in pile
The cutting tool is de-installed and lifted out of the pile.

Single Lift

(3.2.1) Install lifting pad-eyes
With the topside removed from the jacket, lifting pad-eyes can be installed.

(3.2.2) Rig jacket
The connection is made between crane hook and jacket.

(3.2.3) Lift jacket
The jacket is lifted from the sea floor above sea level.

(3.2.4) Load jacket to grillage
The jacket is layed down on the specially designed grillage.

(3.2.5) Sea-fast/de-rig jacket
The jacket is welded/fixed to the grillage. Also the connection between the crane hook and the jacket is terminated.

Piece Medium

(3.2.1) Install lifting pad-eyes
Lifting pad-eyes can be installed either above or bellow the water, depending on the location of the jacket module.

(3.2.2) Lift Jacket
The connection is made between crane hook and jacket module.

(3.2.3) Lift jacket module
The jacket module is lifted from the jacket or sea floor, and is hoisted to above sea level.

(3.2.4) Load jacket module to grillage
The jacket module is layed down on the specially designed grillage

(3.2.5) Sea-fast/de-rig jacket module
The jacket module is welded/fixed to the grillage. Also the connection between the crane hook and the jacket module is terminated.

Single Lift

(3.3.1) Sail HLV to dismantle site
The Heavy Lift Vessel sails from the former offshore site to the dismantle yard.
(3.3.2) Lift jacket to shore
The jacket is lifted from the HLV or barge to shore.
(3.3.3) Lift topside to shore
The topside is lifted from the HLV or barge to shore.
(3.3.4) Unload equipment
All equipment and personel is discharged to shore.

Piece Medium

(3.3.1) Sail HLV to dismantle site
The Heavy Lift Vessel sails from the former offshore site to the dismantle yard.
(3.3.2) Lift jacket modules to shore
The jacket modules are lifted from the HLV or barge to shore.
(3.3.3) Lift topside modules to shore
The topside modules is lifted from the HLV or barge to shore.
(3.3.4) Unload equipment
All equipment and personel is discharged to shore.

3.4. Risk Register

All activities within a decommissioning project have now been identified. Up until now the activities have not been influenced by any external event, for example weather or operational delays. But a real decommissioning project will be influenced by many uncertainties. In order to get a grip on these uncertainties, risks can be estimated. By estimating risks, appropriate expectations and actions can be prepared.

Therefore this section evaluates the risks in a decommissioning project by using a ”risk register”. Within a risk register risks are categorized, described, and quantified. The risks are quantified by estimating their probability of happening and their impact on the project. In order to compare risks with one and other, a risk score is calculated. This is done by: $Probability\ score \times Impact\ score = Risk\ score$. The $Probability\ score$ and $Impact\ score$ are both scores ranging from 1 to 5. These scores and possible $Risk\ score$ outcomes are summarized in the ”Risk Categorization Matrix” as shown bellow:

Risk Categorisation Matrix

					PROBABILITY				
				Probability: (Single activity)	< 1%	1% - 10%	10% - 25%	25% - 50%	> 50%
					1	2	3	4	5
	Cost	Schedule			Very Unlikely	Unlikely	Possible	Likely	Very Likely
IMPACT	< US$10k	< 1 day	1	Slight	LOW (1)	LOW (2)	LOW (3)	LOW (4)	MEDIUM (5)
	US$10k - US$100k	< 1 week	2	Minor	LOW (2)	LOW (4)	LOW (6)	MEDIUM (8)	MEDIUM (10)
	US$100k - US$1M	< 1 month	3	Moderate	LOW (3)	LOW (6)	MEDIUM (9)	MEDIUM (12)	HIGH (15)
	US$1M - US$10M	1 - 3 months	4	Major	LOW (4)	MEDIUM (8)	MEDIUM (12)	HIGH (16)	HIGH (20)
	> US$10M	> 3 months	5	Massive	MEDIUM (5)	MEDIUM (10)	HIGH (15)	HIGH (20)	HIGH (25)

Satisfactory	The control environment is operating effectively, providing a reasonable level of assurance that objectives are being achieved.
Some Weaknesses	The control environment has some weaknesses/ inefficiencies. Although these are not considered to present a serious risk exposure, improvements are required to provide reasonable assurance that objectives will be achieved.
Unsatisfactory	The control environment is not at an acceptable standard, as many weaknesses / inefficiencies exist. Reasonable assurance does not exist that objectives will be achieved.

Figure 3.6: Risk Categorization Matrix and Risk Categories

As shown in the figure 3.6, there are three risk categories. These categories are individually explained in a control effectiveness table. The ”Satisfactory” and ”Some Weaknesses” categories of risks are accepted in a project. ”Unsatisfactory” is the one category of risk set as unacceptable.

Since there are three methods considered within decommissioning the risk register identifies the same risk for each method, but quantifies the risks individually. Once a risk score is found, a risk response is chosen. This risk response is an effort to decrease the corresponding risk. From this risk response a new $Probability\ score$ and $Impact\ score$ can be found. Resulting in a final $Risk\ score$. Based on this final score conclusion on the project risks can be drawn. [18]

The resulting risk register is shown in appendix B. The register contains 62 risks. In total: $62\ risks \times 3\ methods = 186\ Risk\ scores$. From these scores the percentage of risks per category where calculated.

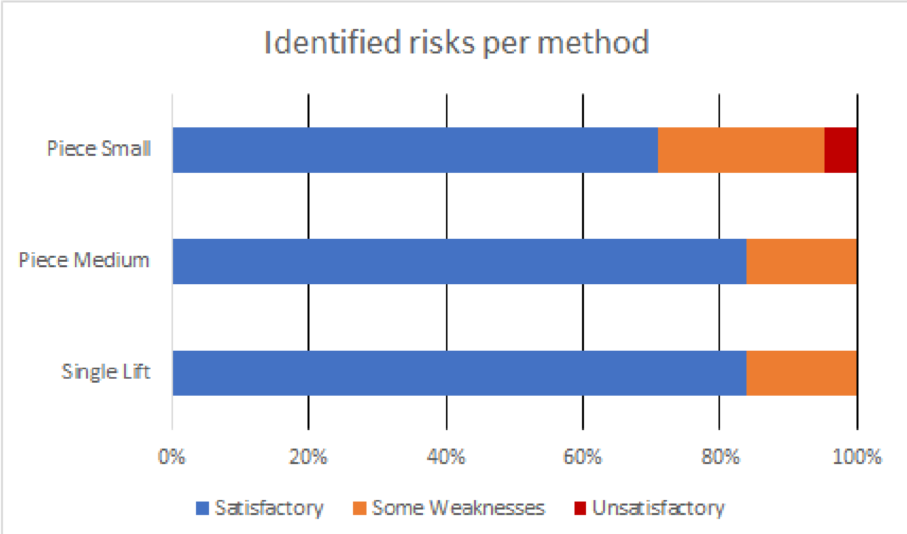


Figure 3.7: Risk category percentage per decommissioning method

As shown in figure 3.7 the Single Lift and Piece Medium method both show manageable risks, although some weaknesses are identified. the Piece Small method is the only method containing unsatisfactory risks. These risks are identified as:

- (1L) Slips and trips during operations
- (1M) Fire/explosions onboard
- (1N) Personnel injury resulting in government/press involvement

These three risks are categorized in the risk register as general project risks and are applicable to all activities within the project. The elevated risks levels are caused by the following reasons:

- Piece Small method requires a large group of employees on the offshore structure compared to Single Lift and Piece Medium method. Assuming that an abandoned offshore structure is not safety-hazard free location, the increased number of people results in an increased risk.
- In extend to the amount of people, the time spend on the offshore structure is also longer than other methods. More people in combination with increased exposure time increases the risk even further.
- Since the platform has been working with oil and gas for many years, the chance of hydrocarbon residues is likely. With the Single Lift and Piece medium method only limited hot-works are required to prepare the platform for removal. Piece small on the other hand will take apart every element of the topside. The chance of finding hydrocarbon residues is therefore increased and so does the chance of fire or explosions.

Single Lift and Piece Medium, share the same final risk scores. This is caused by the similarity in activities as explained in section 3.3. Therefore both Single Lift and Piece Medium show similair exposure times to risks during operations. This results in an equal final risk score.
There is an additional source that identifies the risks for Piece Small decommissioning. This source is a "Close-out report", which is a by UK legislation mandatory, public report on the completion of a decommissioning project. The close-out report on the Total E&P UK MCP-01 platform shows numbers on the safety incidents during the 13.500 [$tons$] topside removal project. During the 2005 till 2009 lasting project a number of safety events where recorded. This is shown in figure 3.8.

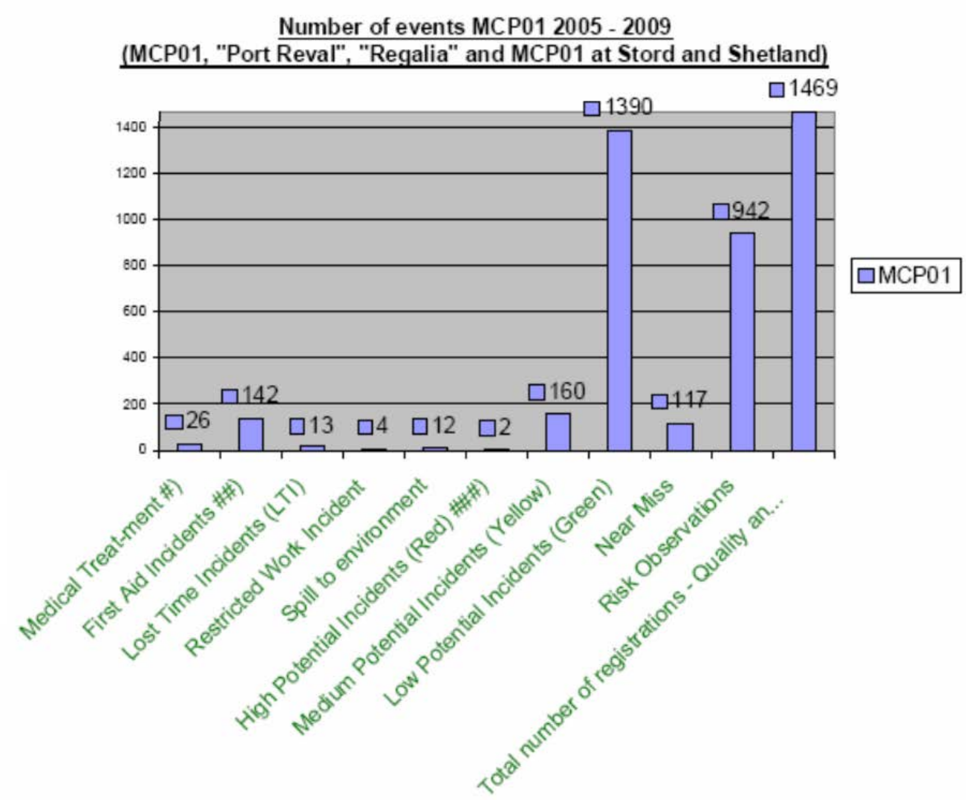


Figure 3.8: Incidents happend during MCP-01 decommissioning project

Considering that this graph might be an strictly monitored safety-event graph, the numbers should be looked at critically. For example the strict definition of ”Low Potential Incidents (Green)” is not known. Therefore this number can not be counted as a ”unsatisfactory risk” incident as described in the risk register definitions. But considering the numbers more aligned with the ”unsatisfactory risks” definition, such as Lost Time Incidents and incidents requiring medical attention, 155 in total, the numbers are convincing. This makes the Piece Small method unsatisfactory in terms of risks, and thus unfit for Ardent. Therefore the Piece Small method is not included in the model.

3.5. Summary

In this chapter the activities within a decommissioning project have been presented. At first a general work-breakdown structure by the North Sea branch organization was applied. From this work-breakdown structure the elements applicable to Ardent's capabilities and interests have been selected.

Secondly, the methods applied to decommissioning a fixed steel platform are explained. These methods are: Single Lift, Piece Medium, Piece Small and Innovative approaches. From these methods, innovative approaches are not considered in this research.

In chapter 3.3 a detailed description of all activities within a decommissioning project are given. Some activities show an overlap in in multiple decommissioning methods, and some do not. Especially the piece small method shows a more labour-intensive topside removal compared to the other considered methods.

As a final part of this section, risk is analyzed for every decommissioning activity and method. The risk is quantified using a risk register. From the risk register it could be concluded that the Piece Small method contained unsatisfactory risks. This conclusion was supported by an inventory of safety events, published in a close-out report. From this conclusion the Piece Small method is further restrained from this research.

4 Decision making standard

This chapter will describe the development of a decision making standard that represents the decision-making process in the tender phase of a decommissioning project. In the previous chapter all activities within such a project are explained. For further analysis on decommissioning asset selection, a standard approach is required to create a planning and costs estimate for a decommissioning project.

The first part of this chapter describes the method used by Ardent to develop a project proposal based on tender-information. The second part presents the input and output required for the decision-making process. As a third part all variables and assumptions for the decision standard are presented. The last part of this chapter describes the specific steps made in the decision making process to come to results.

4.1. Tender approach

At the time of this thesis research, Ardent has committed itself to deliver two project proposals for the decommissioning market in the North Sea. For both these two proposals only one method has been used to come to a final project offer. This method is adopted in the decision making standard, presented in this chapter.

When an offshore structure owner decides to start with ”the road to decommissioning”, they inform the offshore contractors their intentions by opening a tender. In which substantial information is given to the offshore contractors. Offshore contractors like Ardent transform this information to a project proposal.

There are multiple routes of decision-making that leads to a final project offer. In the case of some of Ardent’s competition, owned assets determine the proposed method. For this competition the decision-making routes are limited. But, as described in chapter 1, Ardent does not own such assets. Therefore Ardent is free to chose any asset to operate , giving many options to chose from. Sorting out the best option one-by-one is a cumbersome operation. Therefore this model will support Ardent with selecting a suitable heavy lift vessel selection in their project proposal.

4.2. Model input

In this paragraph the decision making process is modelled though a process analysis. The method used for this analysis is the ”Black Box Approach”[37]. Here the decision making process is seen as a black box with input and output. This analysis requires no specific details on the transformation of input to output. Hence no specific project details are required, resulting in a generic process description for the decision making process in any decommissioning asset selection case. This generic description can therefore be referred to as the ”decision making standard” or ”the standard”. The in- and output used in the decision making standard is shown in figure 4.1.

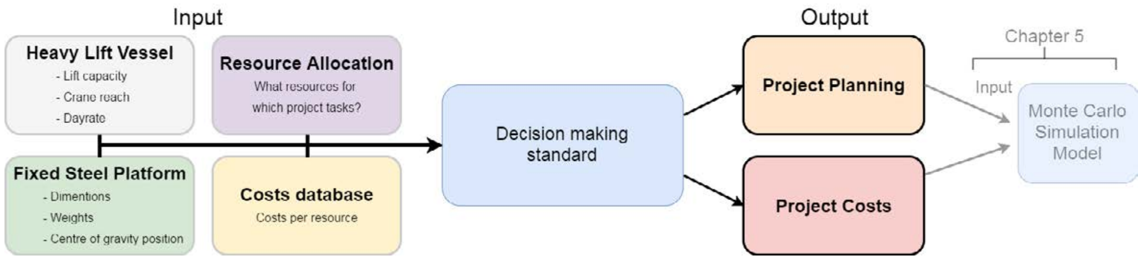


Figure 4.1: In- and output of the decision making standard

Section 4.2 deals with all the input of the model. Section 4.3 concerns the output of the model. The output of the decision making standard is part of the input for the Monte Carlo simulation model, which is described in chapter 5.

4.2.1. Heavy Lift Vessels Input

All HLV data are gathered in one ”heavy lift vessel database”. The main source of this database is the ”Offshore Magazine 2016 worldwide survey of heavy lift vessels”. Supplementary data, especially on the lift capacity, has been added as a result of internet research. These sources where mainly fact sheets found on the vessel owner’s website.

Properties	
Crane	Vessel
Lift Capacity	Positioning System
Crane reach	(Non-)Self-propelled
Rigging height	Distance Crane pivot point to stern/side

Table 4.1: Summary of HLV model input

The selection of a heavy lift vessel has a strong effect on the method-used and planning of the decommissioning project. These effects can be categorized by crane and vessel related properties. The properties are split-up to show their differences. The crane properties effect the capacity of the crane, where the vessel properties effect the project asset configuration. A summary of these properties are given in table 4.1. A detailed description of the HLV input and its effects is given in appendix C.

4.2.2. Resource allocation input

In order to calculate costs for a project it must be known which resources are required at what activity. As described in chapter 1, resources contain: people, assets and special service companies. However, the resources in this decision making standard are approached in a different manner. The resources in the standard contain: people, assets and fixed price resources. In this approach, special service companies are used in both assets and fixed price resources. In addition, the people resource is split onto Ardent’s own personnel and third party personnel.

People

At Ardent it is assumed that every decommissioning project will require the same quantity of its own personnel. This personnel is combined into one decommissioning team consisting of: an office team, one salvage master, one assistant salvage master, two project managers and one logistic coordinator. This team is allocated to every activity within the decommissioning project.

Third party personnel that is required for a decommissioning project concerns: a preparations team, lifting supervisors and potentially a Remote Operated Vehicle (ROV) crew. The preparations team consists of multiple welders, grinders, scaffolders and rope-access personnel. The preparations team size is estimated by a linear formula: $Y = \frac{X}{175} + 6$. In this formula, Y is the amount of persons in the prep team, and X is the topside weight. This means that here is a minimal prepteam size of 6 persons, and for every 175 ton topside weight a person is added to the team.

For the lifting supervisors it is estimated that two will be required for every lifting operation. Last of all the ROV crew will only be hired when a ROV is required during the pile cutting of a jacket. The model used for the decision making standard requires manual input to include the ROV within the project activities.

Assets
Most assets are selected as a result of the characteristics of the HLV. The assets used within a decommissioning project are: Anchor Handling Tugs, a flat top North Sea barge (300 x 90 ft), a HLV, an accommodation or preparation vessel, optionally a Diving Support Vessel including an ROV and cutting equipment.

- Anchor Handling Tugs are required for two purposes: for (de-)mobilizing non-self-propelled vessels, and for the positioning on site by anchors. It is assumed that two tugs are required for either of these two purposes. The maximum amount of tugs are used when an non-self-propelled HLV is used in the combination with a barge. In this case four tugs are utilized at the same time during mobilization and positioning. In addition an anchored vessel requires one tug to be on-site at all times. This is the case when an anchored HLV and/or a barge is used.
- A barge is used when the HLV has insufficient space to place the topside and jacket on deck. The jacket and topside are than loaded onto the barge.
- The HLV is the vessel that performs the actual lifting works during the decommissioning project. This makes the heavy lift vessel the key component in the project.
- The accommodation or preparation vessel is a vessel that is positioned next to the platform during preparation works. Since the preparation vessel does not influence any planning or method parameters, the prep vessel for every decommissioning project is set as the ”Seafox 1”, which is an accommodation jack-up vessel. This vessel can operate in a maximum water depth of 40 [m], which is the case for approximately 80% of the cases within the 1.400 [tons] topside weight constraint of this research[8].
- The Diving support vessel including ROV is required when subsea cutting is part of the project. This is the case when a jacket is removed using the Piece Medium method. Therefore this asset will not be required in every decommissioning project.
- Third party cutting equipment is hired by Ardent. This specialized equipment is used to cut the topside, and cut the jacket. A different set of tools is required for each job.

Fixed price resources
Any additional resources are captured in lump sum contracts. These consist of: Accomodation/hotelcosts, first survey, cutting topside and cutting jacket, consumables for prep. work, Rigging/Dunnage/Grillage, Pilotage/Harbour Fees/Tug Support and Fuel.

- Accommodation and hotel costs are the expenses coupled to the amount of personnel residing at sea. These costs are estimated at \$72.00 per person per day.
- First survey is also known as the ”as is” survey. This survey is done as a first check of the platform, to check for safety hazards, hazardous materials and structural integrity. The first survey is presumed to costs $\$25.000,-$ for the complete survey.
- Cutting topside and cutting jacket are additional costs that come with the hire of the cutting equipment.

- Consumables Preparation Work is considered as all steel and other materials that are added to the topside and jacket during the preparation phase. The consumables required for the preparation works are estimated at a fixed costs of $\$50.000,-$ per project.
- Rigging/Dunnage/Grillage are all steel and other materials that are required to lift and land the topside and jacket. Rigging is the required materials to connect the topside or jacket with the crane hook. Dunnage it the wood used on any support structure. Grillage is the steel frame which is specially built to support the topside and jacket on deck. The grillage costs is explained in section 4.6.
- Pilotage/Harbour Fees/Tug Support are all additional services to moor the utilized vessels in port. The pilotage/harbour fees and tug support are estimated at a fixed price of $\$12.500,-$ per mobilization or demobilization.
- Fuel is estimated based on the installed power of a vessel, their activity and the duration of a tasks. The estimated fuel is given in tons.

4.2.3. Platform information

The information about the offshore installation is distributed by the platform owner. The amount of information given varies per project. The model requires only basic platform information, such as dimensions and weights. The following platform information input is considered for the model.

- The most important feature of the offshore structure are its weights. The required weights are: topside weight, jacket weight. But in addition there are additional weights that should be added to the total jacket weight. These weights are: jacket pile weight, risers/conductor weights.
- A general feature of the offshore structure are its dimensions. The required dimensions are: topside length, topside width, topside height, jacket height.
- The location Center of Gravity (COG) is an important characteristic of a platform. Instead of the actual coordinates of the COG, only the minimum offset of the COG to the platform edge is required. This distance is shown in figure 4.2 under "C". It is herewith assumed that the crane will always lift the construction over this described edge.
- Another important estimate made is the rigging height, shown in figure 4.2 under "D". The rigging makes sure that lifting forces are spread through the platform or jacket and ensure a stable lift. Within Ardent the The Noble Denton rules by DNV-GL are applied, where the angle of rigging to the crane hook should be at least 60^o. Since the rigging height will be dependent on the unique lifting points of a platform, an assumption has to be made. Therefore it is assumed that the lifting poits will be at $\frac{1}{2}$ minimum distance from COG to platform side. This results in the following formula: $H_r = tan(\frac{1}{3}\pi) \times \frac{1}{2} COG_{min}$. Where H_r is the estimated rigging height and COG_{min} the minimum distance from COG to platform side.
- Number of wells on the platform. The amount of wells on the platform has an influence on the "Disconnect caissons/risers" activity in the preparation phase of a decommissioning project.
- A last parameter that had to be estimated for the platform is the distance between the platform and the HLV. Shown in figure 4.2 under "B". Based on expert estimates [2], this distance has be set as $8[m]$.

4.2.4. Costs sheet

The costs per asset are required to come up with a financial project estimate. The costs for this model are found through interviews and discussions within the commercial team at Ardent, IJmuiden. This information is joined in a "costs sheet". The cost sheet shows the exact same division of categories as shown in the "Resource allocation input". Within the costs sheet, two categories are presented: dayrates and lumpsum. For all personnel and equipment a price in dollars per day is specified. In case of the lump sum resources, a price in dollars for the total project use is given. This costs sheet is shown in appendix D.

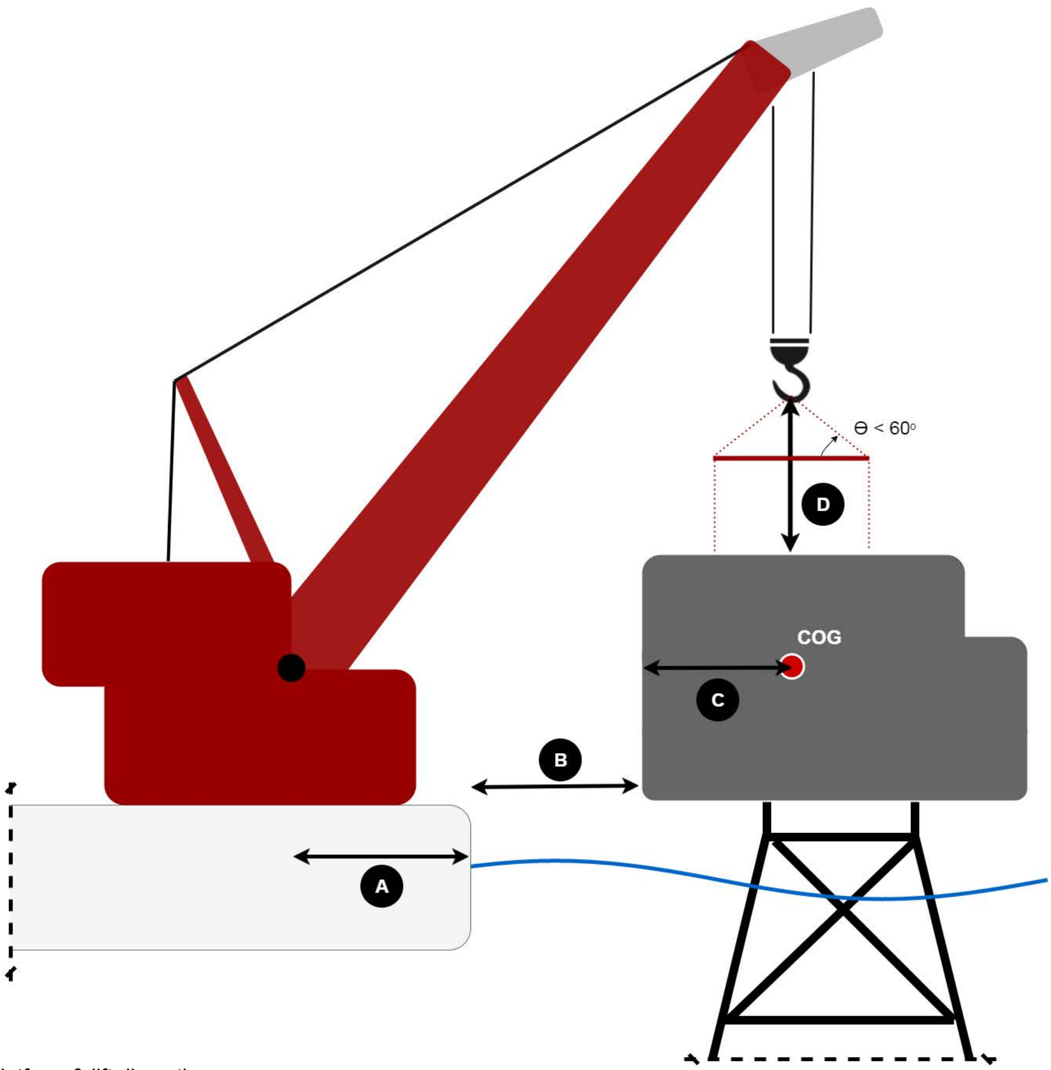


Figure 4.2: Platform & lift dimentions

4.3. Model output

The decision making standard results in two types of output: project planning and project costs. These two outputs are major parts of the tender proposal.

The planning output is given in a duration per activity. As the planning activities can occur in parallel, the sum of all activity durations will not result in the final project duration. This occurs mainly in the preparation phase.

In addition "loops" are used in the planning to simulate reoccurring activities. These activities can be found in: Topside module loop, Pile cutting loop and Jacket module loop. In the output planning the sum of the whole loop is shown. For example: the pile-cutting of one pile will take 3 days, and the platform will contain four piles, the displayed pile-cutting duration will be 12 days.

Planning output

Single Lift			
	Topside Chosen Method:	YES	
	Jacket chosen method:	YES	
1. Preparations			
1.1 Survey Platform		3	[days]
1.1.1	Mobilize Survey team	1	constant
1.1.2	Platform Survey	1	constant
1.1.3	Demob Survey team	1	constant
1.2 Mobilization		5	[days]
1.2.1	Load equipment	3	constant
1.2.2	Sail to site	1	constant
1.2.3	Positioning on site/DP trial	1	constant
1.3 Facilities making safe		10.4	[days]
1.3.1	Install lighting/Temp. powe	2	constant
1.3.2	Install navigational lighting	0.6	variable
1.3.3	Scaffolding	1.7	variable
1.3.4	De-energize platform's owr	2.8	constant
1.3.5	Flush clean and remove ha	2.8	variable
1.3.6	Secure loose items	2.8	variable
1.4 Topside preparations		11.1	[days]
1.4.1	Strenghtening works for cut	11.1	variable
1.4.2	Disconnect caissons/risers	3.6	variable
1.4.3	Disconnect pipework & ele	2.8	variable
1.4.4	Prepare as many cutting wo	4	constant
1.4.5	Prepare as many lifting pad	5	constant
1.5 Demob preparations		3	[days]
1.5.1	Sail to port	1	constant
1.5.2	Unload equipment to shore	2	constant

Costs output

Single Lift	Price [$]	
Topside Chosen Method:	YES	
Jacket chosen method:	YES	
1. Preparations		
1.1 Survey Platform	$	25,000.00
1.2 Mobilization	$	372,524.95
1.3 Facilities making safe	$	421,760.00
1.4 Topside preparations	$	1,687,598.00
1.5 Demob preparations	$	251,584.48
2. Topside removal		
2.1 Mobilization	$	1,085,167.03
2.2 Topside removal	$	512,366.00
3. Substructure removal		
3.1 Pile Cutting Loop	$	586,916.00
3.2 Jacket Lift	$	420,328.50
3.3 Demob	$	830,354.00
Total costs	$	6,193,598.95

Figure 4.3: Example model output

An overview of the total project duration is presented in a table. An example of a piece of this table is given in figure 4.3. An example of the complete planning table is given in Appendix E.

The costs results are shown in a table per element in the project. The costs of high expenses for the whole project such as the grillage for the topside and jacket are added to the corresponding element. In the case for grillage this has been added to the mobilization at the topside removal phase. An example of the costs table is shown in figure 4.3.

4.4. Decision making path

This section describes how the decision making standard transforms the input data into a model outcome. This "decision making path" is based on the method used by Ardent for two aforementioned tender proposals. This method is captured in figure 4.4. It is composed of seven steps, which are described in this section.

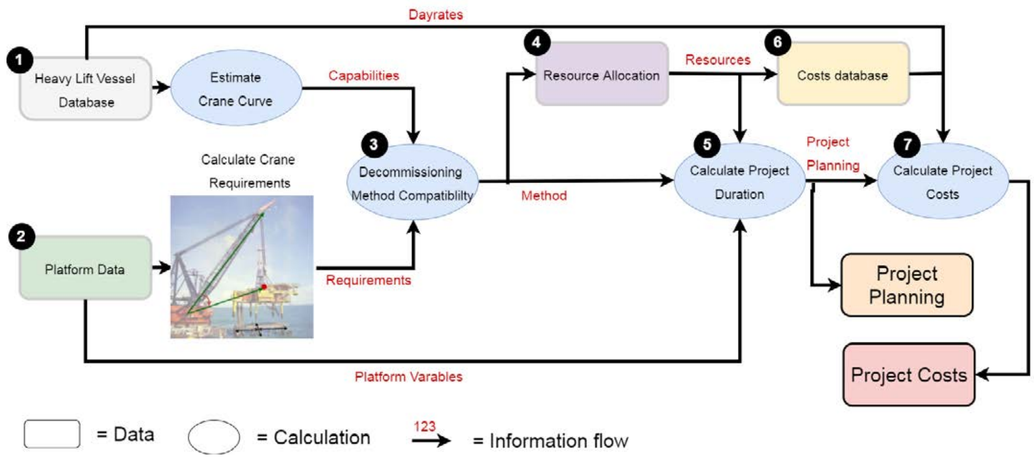


Figure 4.4: Methodology of static decision-making model

The model starts at step "1" with the selection of a heavy lift vessel from the database. When a HLV is selected, its capabilities are estimated by generating a crane curve from the available data in the HLV database. At "2", estimations based on the platform data result in the crane requirements for the project such as required crane reach and capacity.

At step "3" the model determines the method to use by comparing the capabilities of the crane with the requirements of the platform. This comparison result in three options.

- The crane vessel is not suitable for the project
- Platform to be decommissioned using Single Lift method
- Platform to be decommissioned using Piece Medium method

The selected method is used to address resources to all specified tasks at step "4". By combining the resources with the method and platform variables a project duration can be calculated at step "5". The specific variables and formulas for the calculations of the project planning are shown paragraph 4.5. This project planning is the first deliverable of the model. In figure 4.4 the resources are coupled to a price, either day-rate or lumb-sum. This is shown at step "6". These prices combined with the project planning and chosen Heavy Lift Vessel will result in the second and last deliverable of the model: the project costs at step "7".

This concludes the description of the decision making path within the standard. For this process the input, output and decision making path have been described. The next section will contain details about the calculation and variables used for the project planning estimation.

4.5. Data Table and Units

This section presents details on the planning calculation. The model concludes to one of the three results as shown in section 4.4. The two data tables cover all three conclusions. In case the Heavy Lift Vessel is not suitable for the project, no calculations are made.

Within the data-table, three types of activity durations are used:

- constant
- variable
- binairy

A constant activity duration hold the same value for every decommissioning project. Many of these constant durations are used in mobilizing and demobilizing activities, as the geographical size of the Southern North Sea will restrict the variance. Also the actual heavy lifting operations are shown in constant values. This is assumed, since the heavy lift operations itself is identical in every decommissioning project. The variation in heavy lifting concerns the preparations for the heavy lift work. For example: the strengthening works for the lift will not be similar in every decommissioning project.

The variable activity durations are calculated durations. These linear regressions, based on two tenders that Ardent made available during this thesis research. The variable activity duration has been used for activities that are dependant on the platform characteristics such as weight, or amount of piles.

The last variable used is the binary activity duration. Based on the asset configuration of the project these durations shift. For example the positioning method of the HLV will determine the positioning duration.

Two data tables on the next pages will show the variables and formulas used to calculate the single lift and piece medium method. One table for the single lift decommissioning methods, and one table for the piece medium method.

Table 4.2: Data table for Single Lift method

Single Lift				
No.	Activity	Type	Unit	Formula Value
1.1.1	Mobilize Survey team	constant	days	1
1.1.2	Platform survey	constant	days	1
1.1.3	Demob Survey team	constant	days	1
1.2.1	Load equipment	constant	days	3
1.2.2	Sail to site	constant	days	1
1.2.3	Positioning on site	constant	days	1
1.3.1	Installing lighting/temp. power supply	constant	days	2
1.3.2	Install navigational lighting	variable	days	$7.69 \times 10^{-4} \times topside\ weight$
1.3.3	Scaffolding	variable	days	$2.31 \times 10^{-3} \times topside\ weight$
1.3.4	De-energize platform	variable	days	$3.85 \times 10^{-3} \times topside\ weight$
1.3.5	Flush clean and remove hazardous materials	variable	days	$3.85 \times 10^{-3} \times topside\ weight$
1.3.6	Secure loose items	variable	days	$3.85 \times 10^{-3} \times topside\ weight$
1.4.1	Strengthening works	variable	days	$1.54 \times 10^{-2} \times topside\ weight$
1.4.2	Disconnect riser	variable	days	$7.14 \times 10^{1} \times amount\ of\ wells$
1.4.3	Disconnect pipework & electrical wiring jacket/topside	variable	days	$3.85 \times 10^{-3} \times topsideweight$
1.4.4	Prepare as many cutting works as possible	constant	days	4
1.4.5	Prepare lifting pad-eyes	constant	days	3
1.5.1	Sail to port	constant	days	1
1.5.2	Unload equipment	constant	days	2
2.1.1	Install grillage	variable	days	$Grillage\ weight/10$
2.1.2	Load equipment	constant	days	1
2.1.3	Sail to site	binairy	hours	[jack-up/non-self-propelled/self-propelled] [24/36/18]
2.1.4	Positioning on site	binairy	hours	[DP-system/Anchors/Jack-Up] [6/24/12]
2.2.1	Access topside	constant	hours	6
2.2.2	Rig topside	constant	days	1
2.2.3	Cut topside from jacket	constant	days	1
2.2.4	Lift topside	constant	hours	3
2.2.5	Load topside to barge/HLV	binary	hours	[grillage on barge/grillage on HLV] [12/3]
2.2.6	Sea-fast/de-rig topside	constant	hours	12
3.1.1	Dredging of pile	variable	hours	$9 \times number\ of\ piles$
3.1.2	Install cutting tool in pile	variable	hours	$2 \times number\ of\ piles$
3.1.3	Cut pile	variable	hours	$8 \times number\ of\ piles$
3.1.4	De-install cutting tool	variable	hours	$2 \times number\ of\ piles$
3.2.1	Install lifting pad-eyes	constant	days	2
3.2.2	Rig jacket	constant	hours	12
3.2.3	Lift jacket	constant	hours	3
3.2.4	Load jacket to barge/HLV	binary	hours	[grillage on barge/grillage on HLV] [12/3]
3.2.5	Sea-fast/de-rig jacket	constant	hours	12
3.3.1	Sail to dismantle yard	binary	hours	[jack-up/non-self-propelled/self-propelled] [24/36/18]
3.3.2	Lift jacket to shore	constant	days	1
3.3.3	Lift topside to shore	constant	days	1
3.3.4	Unload equipment	constant	days	3

Table 4.3: Data table for Piece Medium method

Piece Medium				
No.	Activity	Type	Unit	Formula Value
1.1.1	Mobilize Survey team	constant	days	1
1.1.2	Platform survey	constant	days	1
1.1.3	Demob Survey team	constant	days	1
1.2.1	Load equipment	constant	days	3
1.2.2	Sail to site	constant	days	1
1.2.3	Positioning on site	constant	days	1
1.3.1	Installing lighting/temp. power supply	constant	days	2
1.3.2	Install navigational lighting	variable	days	$7.69 \times 10^{-4} \times topside\ weight$
1.3.3	Scaffolding	variable	days	$2.31 \times 10^{-3} \times topside\ weight$
1.3.4	De-energize platform	variable	days	$3.85 \times 10^{-3} \times topside\ weight$
1.3.5	Flush clean and remove hazardous materials	variable	days	$3.85 \times 10^{-3} \times topside\ weight$
1.3.6	Secure loose items	variable	days	$3.85 \times 10^{-3} \times topside\ weight$
1.4.1	Strengthening works	variable	days	$1.54 \times 10^{-2} \times topside\ weight$
1.4.2	Disconnect riser	variable	days	$7.14 \times 10^{-1} \times amount\ of\ wells$
1.4.3	Disconnect pipework & electrical wiring jacket/topside	variable	days	$3.85 \times 10^{-3} \times topside\ weight$
1.4.4	Prepare as many cutting works as possible	variable	days	$4 \times amount\ of\ modules$
1.4.5	Prepare first lifting pad-eyes	constant	days	5
1.5.1	Sail to port	constant	days	1
1.5.2	Unload equipment	constant	days	2
2.1.1	Install grillage	variable	days	$Grillage\ weight/10$
2.1.2	Load equipment	constant	days	1
2.1.3	Sail to site	binairy	hours	[jack-up/non-self-propelled/self-propelled] [24/36/18]
2.1.4	Positioning on site	binairy	hours	[DP-system/Anchors/Jack-Up] [6/24/12]
2.2.1	Access topside	constant	hours	6
2.2.2	Install lifting pad-eyes	variable	days	$3 \times number\ of\ modules$
2.2.3	Rig module	constant	hours	$6 \times number\ of\ modules$
2.2.4	Cut module from topside	constant	days	$1 \times number\ of\ modules$
2.2.5	Lift module	variable	hours	$3 \times number\ of\ modules$
2.2.6	Load topside to barge/HLV	binary	hours	[grillage on barge/grillage on HLV] [12/3] $\times number\ of\ modules$
2.2.7	Sea-fast/de-rig topside	constant	hours	12
3.1.1	Dredging of pile	variable	hours	$9 \times number\ of\ piles$
3.1.2	Install cutting tool in pile	variable	hours	$2 \times number\ of\ piles$
3.1.3	Cut pile	variable	hours	$8 \times number\ of\ piles$
3.1.4	De-install cutting tool	variable	hours	$2 \times number\ of\ piles$
3.2.1	Install lifting pad-eyes	constant	days	$2 \times number\ of\ modules$
3.2.2	Rig jacket module	constant	hours	$12 \times number\ of\ modules$
3.2.3	Lift jacket module	constant	hours	$3 \times number\ of\ modules$
3.2.4	Load module to barge/HLV	binary	hours	[grillage on barge/grillage on HLV] [12/3] $\times number\ of\ modules$
3.2.5	Sea-fast/de-rig module	constant	hours	$12 \times number\ of\ modules$
3.3.1	Sail to dismantle yard	binary	hours	[jack-up/non-self-propelled/self-propelled] [24/36/18]
3.3.2	Lift jacket modules to shore	constant	hours	36
3.3.3	Lift topside modules to shore	constant	hours	36
3.3.4	Unload equipment	constant	days	3

4.6. Model assumptions

The decision making standard captures the decision-making process for a decommissioning project in one calculation. Without assumptions this would not be possible. This section describes the assumptions made in order simplify to this model. The assumptions will be explained per following category: main, financial, calculation and planning assumptions.

Main assumptions

- In the standard no risk or unexpected events such as weather downtime are considered.
- The estimated crane curve is not an accurate reproduction of crane performance. The estimated crane curve is based on a parabolic regression formula. The purpose of this crane curve is rather to support the heavy lift vessel selection for a project, not engineering purposes.

Financial assumptions

- All day rates of both Heavy Lift Vessels and other resources are estimated market prices on December 2016 [2].
- The first survey costs: NDT team, Hazardous materials, helicopter is assumed at $25.000,- for the whole survey (lump sum). In an actual project, it might be possible that a helicopter landing is not possible due to regulations/logistics, and costs will vary.
- Fuel consumption is based on the vessel's installed power. It is assumed that a vessel uses 75 per cent of the total power while sailing [39]. During operations the vessel uses 20 per cent of the total installed power. Based on Ardent archives two vessels where found with a fuel specification. From these specifications an consumption of 3 $\frac{ton}{day}/MW$ was assumed as average consumption. In addition a vessel on DP is assumed to consume 60 per cent of its calculated fuel consumption while sailing. The fuel price has a default value of $300,- per ton, based on the bunkerworld.com Heavy Fuel Oil prices in December 2016.
- the price for grillage construction is assumed at $5.000,- per ton of steel.

Calculation assumptions

- Both topside and jacket modules are cut based on the crane capacity without looking at individual module strength. In reality the modules should be cut in a manner where the structural integrity of the module is ensured.
- It is modeled that a self elevating vessel (preparation vessel and HLV) jacks-up to 5$[m]$ above sealevel. This is a positive adjustment for the crane height of the vessel.
- The grillage weight is calculated as follows: $grillage\ weight = \frac{topside\ weight + jacket\ weight}{deck\ capacity} \times grillage\ height \times 0.0222 \times 7.8 \frac{tons}{m^3}$ Where the grillage height is default at 2$[m]$. And a block coefficient is used of 2.22 %. This number has been based on one of the Ardent decommissioning tenders.

Planning assumptions

- 24 hours workdays
- Rigging a module, takes the same duration as rigging a whole topside
- All crane movements are assumed to be done by revolving cranes. Additional time for fixed or over-stern cranes is not included.

The main function of these mentioned assumptions is to simplify the complex reality of these projects. In general a decommissioning project is a "one-off" project. By implementing simplifications and assumptions the model becomes generic. In addition the details and requirements of input are limited, therefore the model can be used in an early stage of the tendering process.

4.7. Summary

This chapter presents the decision-making standard for the planning and costs calculations for a decommissioning project. The input of the model contains a heavy lift database, resource allocation, platform data and a costs database. Within the standard the input is transformed into a project planning and project costs.

The method of the decision-making standard is based on two decommissioning project proposals made available by Ardent at the time of this research. As Ardent is not restricted in selecting its own assets for decommissioning, many possible asset configurations for a proposal are feasible. Therefore this standard should help Ardent with selecting a suitable asset configuration for their project proposal.

Multiple assumptions were required to capture a decommissioning project in a standard. Most of the assumptions are simplifications from reality. These simplifications enable the model to come to conclusions without extensive details on any of the input.

5

Monte Carlo Simulation

This chapter the simulation model is explained. This model simulates decommissioning projects with use of the decision-making standard and risk adaptation methods. The reason for implementing risk in the model, the type of model and the input and output required for the model are all explained in this chapter.

The first part of this chapter describes why and how risk is to be implemented into a simulation model. Secondly the applied Monte Carlo simulation model is explained. As a third part the input of the Monte Carlo simulation model will be explained. The final part of this chapter describes the Monte Carlo simulation output.

5.1. Risk implementation

Risks in a project are uncertain events that have a negative influence on the results of the project. These risks are defined by a probability-of-happening and an impact on the project. This definition of risk is explained in section 3.4.

The decision making standard resulted in an estimated project planning and project costs. These results are useful at the first stages of a tender proposal for insight in the asset possibilities. But these results do not consider any risks. Therefore many uncertainties are included in the results.

With these uncertainties it is not possible to conclude an asset selecting strategy from these results. By incorporating the risks in a model, the uncertainty in the project can be quantified. Most of all, the model will show how the risks and corresponding uncertainties will scale with different heavy lift configurations. From this comparison a (sub-) optimal selection of heavy lift vessels can be made.

Therefore the goal of the model is to be able to calculate risks and uncertainty in decommissioning projects. With these calculations an evaluation of the effects of assets selection on project-risks is possible.

These measurements can be done by the use of two methods: monitoring real projects or a simulation model. These methods are also known as deterministic and non-deterministic modeling[22]. Since there is no data available based on decommissioning project experience, the remaining option is to calculate through a simulation model. Thus a non-deterministic model is used.

In a simulation model a reproduction of reality is attempted to be captured in a calculation model. This gives the model user the freedom to test any scenario, since the model does not require costly resources to test these scenarios. Nevertheless this is excepted since the assumptions do not influence the purpose of the model. Another feature of the simulation model is the speed at which results are generated. In case of a deterministic model for decommissioning projects, it would take years to gather the required input from project experience. With the simulation model this is not the case.

The downside of using a simulation model is that reality is complex to capture in a calculation model. Therefore multiple assumptions are required to ”fit” the reality into the simulation model. The more assumptions are used for the model, the further de results will deviate from reality. Therefore the model data should not be considered as an exact copy of real project measurements, and the simulation results will not be exact to real project results. The model will however give insights in possible heavy lift vessel configurations, as close to reality as possible. Also the cause and effect of different choices in the decommissioning project can be tested.

Risks in a non-deterministic simulation model can be implemented by a Monte Carlo simulation model (MC model). The definition and method of the MC model is explained in section 5.2.

5.2. Monte Carlo Simulation

The Monte Carlo simulation model simulates the behaviour of the risk uncertainty by creating statistic random samples based on a probability distribution, for each activity. All risks in the project are therewith included in the model-results as delay. For every activity in the project, a probability distribution represents the range of risks incorporated in that specific activity. The MC model, selects a value within this distribution with the use of a random number. This leads to a statistically varying, duration per activity. This is called the ”Monte Carlo duration”.

All found Monte Carlo durations result in a new total project duration. This is called a ”run”. One ”run” can be seen a the representation of one-time execution of a decommissioning project. By calculation multiple ”runs” a distribution of varying project durations , and thus costs, can be made. The variations in this distribution can than be analysed, resulting in insights of risks behaviour in the project.

The required input and resulting outcome of the MC model is shown in figure 5.1. In this diagram the corresponding sections and paragraphs are shown with every term.

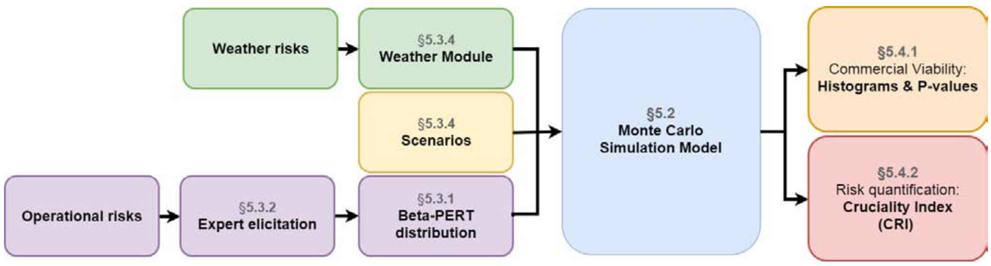


Figure 5.1: In- and Output for the Monte Carlo simulation model

The input for the MC model consist of three items:

- A probability distribution per activity (operational risks)
- Scenarios
- Weather module (weather risks)

All types of risks can be included in the probability distribution per activity. Within this research it is chosen to only included operational risks in the distributions and include weather risks through a separate weather module. This choice is further explained in section 5.3.3. The scenarios will define which variations in heavy lift selection will be tested in the model. This is explained in section 5.3.4.

The output of the MC model consists of two results:

- Histograms for commercial analysis
- Cruciality index (CRI) for risk analysis

The histograms are graphical presentations of the variance in the resulting Monte Carlo duration distributions. The histograms are further explained in section 5.4.1. The cruciality index is an index that identifies the portion of risks that is caused by a certain phase in the project. The cruciality index is further explained in section 5.4.2.

5.2.1. Implementation in Excel

This paragraph elaborates on how the Monte Carlo simulation model has been implemented in set of calculation sheet in Microsoft Excel. First the user interface and input is shown, secondly the calculation sheets are explained. As a third part an explanation is given on how the results are found in the model output. In figure 5.2, 5.3 and 5.4 three screen-shots capture these three steps in the excel sheet.

The required data for the scenarios are captured in a user-form sheet, as shown in figure 5.2. In this user-form several test criteria are to be specified. First of all, the heavy lift vessel is selected. By selecting the vessel, all properties influenced by the vessel are updated, for example: positioning method, crane capacity calculations and fuel consumption estimates. Secondly binary Yes/No questions are to be answered. These questions concern the offloading method for the scenario and optional extra assets that are required in the scenario such as an ”Diving Support Vessel”. The additional options are not used in the course of this research but are included for Ardent’s convenience only. Thirdly the starting month of the scenario is selected, with a default value of April. April is the default value since this will result in a decommissioning project planned in the summer, which is favourable considering the weather and weather risks. A systematic test of decommissioning starting dates and the effect on the projects is given in section 6.6.3. As a fourth and last part, the platform geometry and weight data is specified. Next to the user-form, the estimated crane curve is plotted.

From all input data, calculation are made in many sheets. One specific sheet calculates the durations in days, for the Monte Carlo simulation. This sheet is shown in figure 5.3. In this sheet the calculation of all new activity durations based on the probability distributions is done. Therefore this sheet should be considered as the calculation of one ”run”. In this sheet one excel function has an important role in the calculation. The Monte Carlo sheet uses the ”RAND()” function to select a duration in the probability distributions. Literature describes that this function in Excel does not guarantee true randomness as idealy would be assumed[25]. However it is presumed that the randomness of this function will be reliable enough to create the required variance in the model-results.

The result of the Monte Carlo simulation model are captured in a ”data table”, shown in figure 5.4. The data table enables the excell sheet to calculate multiple runs and safe all results from the individual runs in one table. The calculation of these runs takes approximately five minutes. From these results the histograms can be plotted. The calculation of the CRI values required another run to recalculate.

Heavy Lift Vessel (HLV) selection	
Select Crane Vessel	Seafox 5
Corresponding index number	57
Carry Topside+Jacket on HLV (YES/NO)	YES
Deck strenght (8 t/m2 = default)	8
Heavy lift vessel characteristics	
Type of Crane Vessel	Self Elevating Crane Vessel
Max Lift	1200
Max height	95
Estimated Dayrate	$ 70,000.00
Is the Heavy Lift Vessel self-propelled?	YES
Station keeping by:	Legs
Preparation works commence in month:	April
Accomodation vessel hire during Preparations?	YES
Is a Diving Support Vessel required?	NO
Amount of personel in prep. Team?	14
Platform Data	
Platform Name	**Tyne**
Dimensions [m]	
Topside length	20
Topside width	25
Topside height (LAT-highest point topside)	35
Number of Wells	5
Jacket	
Jacket height (sea-floor - cellar deck)	37.4
Number of piles	4
Weights [tons]	
Topside weight	721.3
Modular Support Frame weight (0 if not app.)	0
Jacket Weight (excl conductors)	734
Jacket Pile Weight	46
Riser/Conductor weights	196
COG offset [m]	
Minimum offset of COG to platform edge	10
Minimum mooring offset between platform and vessel	8
Crane rigging estimation [m]	
Estimated rigging height	8.7
Total Rigging height	43.7
Total required boom length	54.7

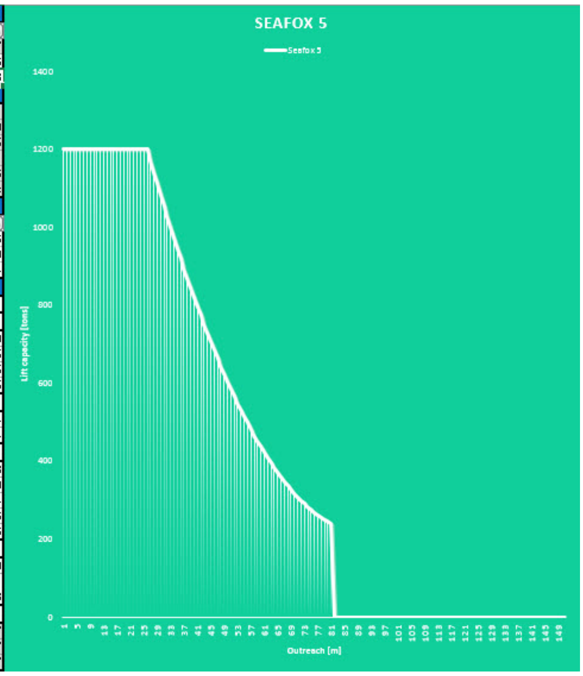


Figure 5.2: Screen shots of "Userform" sheet in Excel

			Optimistic Value (days) a	Most Likely Duration (days) m	Pessimistic Duration (day b	Start date ss start	Weather Module L1	L2	L3	L4	L5	L6	L7	μ	σ²	ss fin	α	β	MC start	MC duration	MC finish	Incl Weather
1. Preparations	1.1.1	Mobilize Survey team	0.6	1	1.83	1-4-2017	1	0	0	0	0	0	0	1.078	0.04	1.078	2.739	4.656	0.00	1.21	1.21	**2.21**
	1.1.2	Platform Survey	0.4	1	1.85	3-4-2017	0	0	0	0	0	0	0	1.042	0.058	1.042	3.488	4.393	2.21	0.89	3.10	**3.10**
	1.1.3	Demob Survey team	0.6	1	1.7	4-4-2017	0	0	0	0	0	0	0	1.056	0.032	1.056	3.012	4.597	3.10	1.06	4.17	**4.17**
	1.2.1	Load equipment	1.5	3	6.73	5-4-2017	0	0	0	0	0	0	0	3.372	0.761	3.372	2.601	4.67	4.17	3.61	7.78	**7.78**
	1.2.2	Sail to site	0.5	1	1.9	8-4-2017	0	0	0	0	0	0	0	1.072	0.052	1.072	2.996	4.602	7.78	0.93	8.71	**8.71**
	1.2.3	Positioning on site	0.6	1	2.73	9-4-2017	0	0	0	0	0	0	0	1.228	0.123	1.228	1.785	4.521	8.71	1.31	10.01	**10.01**
	1.3.1	Install lighting/Temp. power supply	1.3	2	2.8	11-4-2017	0	0	0	0	0	0	0	2.02	0.061	2.02	3.771	4.202	10.01	1.84	11.85	**11.85**
	1.3.2	Install navigational lighting	0.3	0.6	1	12-4-2017	0	0	0	0	0	0	0	0.622	0.012	0.622	3.417	4.432	11.85	0.88	12.73	**12.73**
	1.3.3	Scaffolding	0.9	1.7	3.21	12-4-2017	0	0	0	0	0	0	0	1.81	0.155	1.81	3.126	4.561	11.85	1.20	13.05	**13.05**
	1.3.4	De-energize platform's own electric system	1.6	2.8	5.44	13-4-2017	0	0	0	0	0	0	0	3.033	0.42	3.033	2.843	4.639	12.73	2.94	15.67	**15.67**
	1.3.5	Flush clean and remove hazardous materials	1.1	2.8	3.73	14-4-2017	0	0	0	0	0	0	0	2.67	0.194	2.67	4.577	3.077	13.05	3.22	16.28	**16.28**
	1.3.6	Secure loose items	2.1	2.8	5.32	14-4-2017	0	0	0	0	0	0	0	3.1	0.291	3.1	2.128	4.635	13.05	3.49	16.54	**16.54**
	1.4.1	Strenghtening works	5.6	11	35.2	17-4-2017	0	0	0	0	0	0	0	14.18	24.34	14.18	1.878	4.56	16.54	19.39	35.94	**35.94**
	1.4.2	Disconnect caissons/risers	1.8	3.6	11.4	17-4-2017	0	0	0	0	0	0	0	4.6	2.56	4.6	1.878	4.56	16.54	7.17	23.71	**23.71**
	1.4.3	Disconnect pipework & electrical wiring between	1.2	2.8	9.33	24-4-2017	0	0	0	0	0	0	0	3.617	1.853	3.617	1.968	4.592	23.71	3.66	27.38	**27.38**
	1.4.4	Prepare as many cutting works as possible	1.6	4	11.1	6-5-2017	0	0	0	0	0	0	0	4.778	2.536	4.778	2.376	4.67	35.94	7.09	43.03	**43.03**
	1.4.5	Prepare as many lifting pad-eyes as possible	1.7	5	9.17	17-4-2017	0	0	0	0	0	0	0	5.139	1.563	5.139	3.681	4.27	16.54	3.38	19.92	**19.92**
	1.5.1	Sail to port	0.5	1	1.9	14-5-2017	0	0	0	0	0	0	0	1.072	0.052	1.072	2.996	4.602	43.03	1.27	44.31	**44.31**
	1.5.2	Unload equipment to shore	1	2	4.33	15-5-2017	0	0	0	0	0	0	0	2.222	0.309	2.222	2.699	4.661	44.31	2.38	46.68	**46.68**

Figure 5.3: Screen shots of "MonteCarloSim" sheet in Excel

RUN		Total Project duration [days]	$(SPD - \overline{SPD})^2$	Total Project costs [$]	$(SAC - \overline{SAC})^2$	Top.+Jack. Duration [days]
1		72.4	1.2	$ 5,855,509.95	$ 33,006,444,251.99	33.8
2		82.1	74.6	$ 6,737,130.95	$ 488,484,652,692.10	43.4
3		67.8	32.4	$ 5,879,724.95	$ 25,124,920,690.26	34.6
4		59.5	194.7	$ 5,156,443.95	$ 777,347,175,714.21	29.4
5		77.2	13.9	$ 6,202,642.95	$ 27,073,609,750.45	32.8

Figure 5.4: Screen shots of "RUNS" sheet in Excel

5.2.2. Validation: number of runs

The number of runs required for a "correct distribution" varies per simulation model. Literature decribes that any number of runs for the Monte Carlo Simulation will result in a true distribution of results [19]. Another approach is stated by Mooney (1997): "The best practical advice on how many trials are needed for a given experiments is "lots!" Most simulations published recently report upward from 1.000 trials, and simulations of 10.000 to 25.000 trials are common". Due to calculation durations of the simulation model, a minimal amount of runs is preferable.

Therefore a test has been performed to find the minimal amount of runs without influencing the outcome of the simulation model. In this test the amount of runs have been tested from a range of 25.000 to 100. By calculating the standard deviation of all runs an estimation of the variation can be done. It is expected that an increase in standard deviation can be found in a decreasing amount of runs. In this test the standard deviation is calculated over the total project duration results from the MC model. The results of these calculations are shown in table 5.1.

Runs	**Standard deviation of total project duration [days]**
25.000	9.7
15.000	9.7
12.500	9.7
10.000	9.7
7.500	9.7
5.000	9.8

Runs	**Standard deviation of total project duration [days]**
2.500	9.8
2.000	9.9
1.500	9.9
1.000	10.0
500	10.1
100	10.8

Table 5.1: Standard deviation test for the amount of runs for the MC model

From the results it is found that 25.000 to 2.500 runs result in a similar standard deviation. By decreasing the runs bellow 2.500 runs, the standard deviation will tend to increase. From these results it can be concluded that 2.500 runs would be the minimum amount of runs to ensure a sound distribution for the Monte Carlo simulation model.

Based on the practical advice in the literature, a larger amount of runs have been used in this research than the absolute minimum. Therefore 7.500 runs have been selected as the amount of runs for the Monte Carlo simulation calculations. This amount of runs will ensure an acceptable distribution for the results, but will require more calculation time than strictly necessary.

5.3. Model Input

In this section the required input for the Monte Carlo simulation is explained in detail. First the selected type of probability distribution is explained. Second the source for the initial values for the distribution is given in the expert elicitation paragraph. The third part describes the weather module which calculates the weather caused delays. In the last paragraph of this section the scenarios and their selection in explained.

These paragraphs are divided to two parts. In the first part the theoretical or ideal method is explained. In the second part describes the practical implementation of the method used in this research.

5.3.1. Probability distribution: Beta-PERT

The probability distribution of activity duration can be calculated through multiple distributions. The goal of the distribution is to give the operational risks a scale for chance of happening and impact, as close to reality as possible. The options considered in this research are the triangular distribution and Beta-PERT distribution. These distributions are selected since they both share the required input of a optimistic, most likely and pessimistic value. In this research project, these values are defined as a, b and c respectively. A visualisation of the Beta-PERT and triangular distributions is given in figure 5.5.

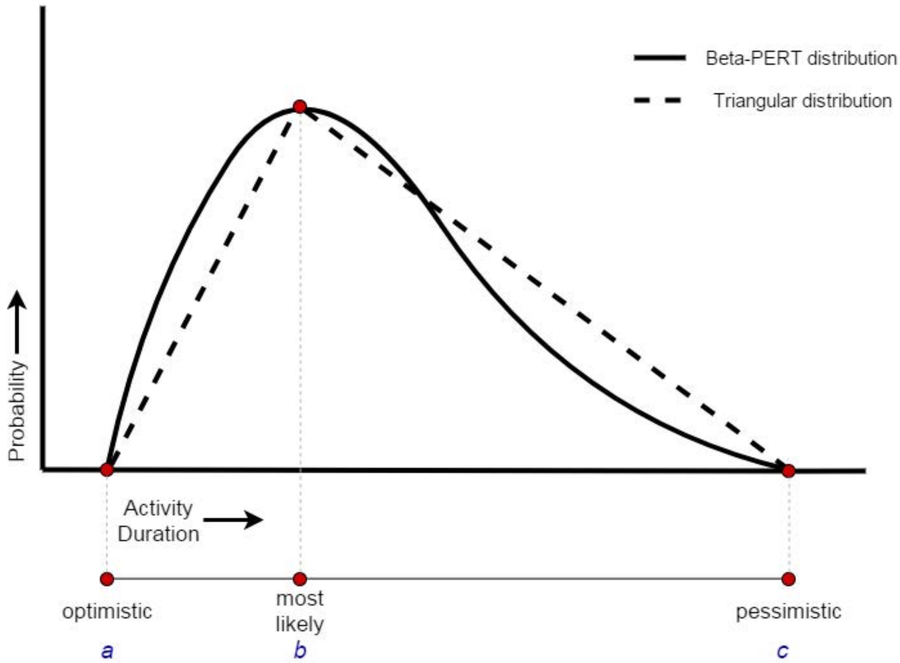


Figure 5.5: Pessimistic, most likely and optimistic distribution in survey

The main difference between the Beta-PERT and triangular distribution is the "consentration" on the most likely value. With the triangular distribution the optimistic and pessimistic values are more accented. Where in the Beta-PERT distribution the most likely value is more accented [29]. As a result the triangular distribution will cause more extreme values in the Monte Carlo simulation results. For this research the Beta-PERT distribution is chosen as distribution for the Monte Carlo simulation.

The PERT distribution defined as follows:

$$PERT(a,b,c) = Beta(\alpha,\beta) \times (c-a) + a$$

The density probability function is defined as [12]:

$$f_y(y) = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} \frac{(y-a)^{\alpha-1}(c-y)^{\beta-1}}{(c-a)^{\alpha+\beta-1}} \quad for \quad a < y < b \; and \; \alpha,\beta > 0$$

But in this research the optimistic and pessimistic values are known, the following linear transformation is applicable:

$$X = \frac{Y-a}{c-a}$$

This gives a more standard for to the density probability function:

$$f_x(x) = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} x^{\alpha-1}(1-x)^{\beta-1} \quad for \quad 0 < x < 1 \; and \; \alpha,\beta > 0$$

Here the shape parameters α and β are defined as:

$$\alpha = \frac{(\mu-a)\times(2b-a-c)}{(b-\mu)\times(c-a)}$$
$$\beta = \frac{a\times(c-\mu}{(\mu-a)}$$

The mean, standard deviation and variance of the distribution is [21]:

$$\text{Mean duration for activity i: } \mu_i = \frac{a_i+4b_i+c_i}{6}$$
$$\text{Standard deviation of activity i: } \sigma_i = \frac{c_i-a_i}{6}$$
$$\text{Variance of activity i: } \sigma_i^2 = \frac{c_i-a_i}{6}^2$$

Within these formulas the values a b c are the optimistic, most likely and pessimistic values, respectively. These values are required to create the distribution per activity. These values are found through expert elicitation or a PERT survey. This is explained in paragraph 5.3.2.

5.3.2. Expert elicitation: pessimistic, most likely and optimistic values

The required activity duration distribution for the simulation model is collected though expert elicitation. A structured approach [5] has been used to gather expert estimations of pessimistic, most likely and optimistic values of activity durations. The experts estimated operational risks with these values. Within this expert elicitation two decommissioning methods and three platform sizes have been surveyed.

These values have been estimated by the total of four experts. In total three of these experts have been working on the tender proposals as explained in section 3.3. The one remaining expert has been selected due to salvage and wreck-removal project experience. Preferably the survey would be done by more experts, as more experts would decrease the error margin in the survey. However, no more experts were available at Ardent's at the time.

5.3.3. Weather module

The weather is an important cause of risks in a decommissioning project. Multiple weather constraints are set to ensure safe operations, for every activity. The sensitivity to the weather varies per activity. Hence some activities will have a higher chance of weather delay than the other. The selection of heavy lift vessel also influences the weather sensitivity of an activity. For example a self elevating crane vessel will jack-up alongside the platform and will not be bothered by wave disturbance while lifting.

Therefore three constraints are used to set the weather sensitivity. These contraints are given in two numbers: the maximum allowable significant wave height (Max. sign wave height) and maximum allowable wind speed. Where the significant wave height is defined as the mean wave height of the highest one third of the waves. These constraints are given in table 5.2.

Constraint	Max. sign. wave height [m]	Max. wind speed [knots]
Lifting operations	1	17 (5 Beaufort)
Platform operations	3	34 (8 Beaufort)
Mobilization	2	28 (7 Beaufort)

Table 5.2: Weather constraints for operations

The lifting constraint is the most narrow constraint of the three. This constraint is set for every activity where lifting occurs. An exemption is made for self elevating platforms where the Max. sign wave height during lifting is set at 3 [m], instead of 1 [m]. The platform operations constraint is the most forgiving constrain. This constraint is set for all activities performed on the platform itself. The third constraint is the mobilization constraint, and is set for every mobilization and de-mobilization activities.

These weather risks are not incorporated in the Beta-PERT distribution since the weather can not be estimated by selecting a random value in a probability distribution. Since the weather is seasonal and is more consistent than "every day random", a separate module is used.

The weather data for the weather constraints comes from North Sea weather data by Fugro[15]. The weather data contains wave and wind frequency distributions from multiple locations on the North Sea. The data is produced using: "hindcast wind and wave time series data from the NEXT model, for the combined periods January 1977 to December 1979 and January 1989 to December 1994"[15]. The Fugro source contained multiple data points in the North Sea. One data point in the Southern North Sea has been selected for the simulation model. This location has been selected to be close to the range of platforms selected for this research. The location of the weather data-point is shown in figure 5.6.

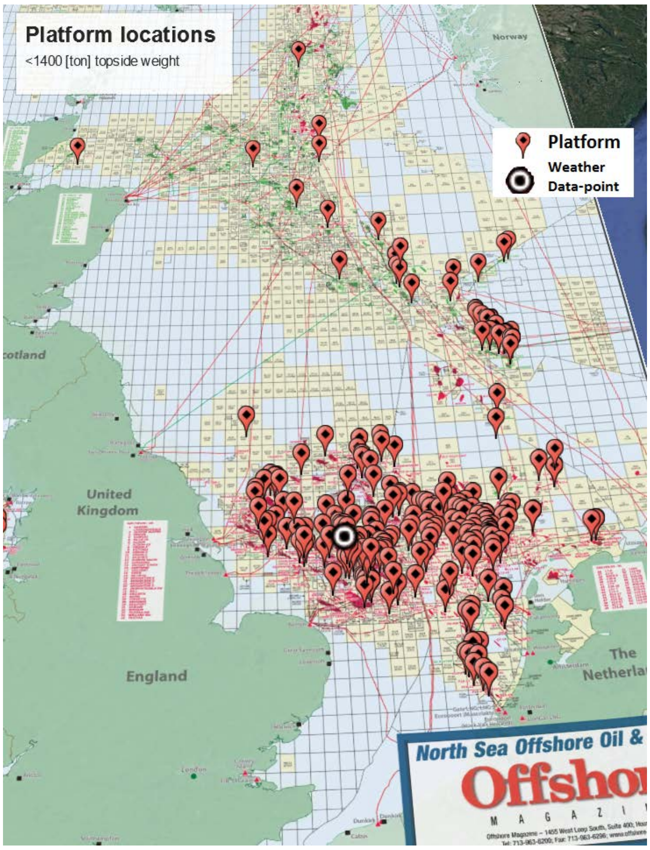


Figure 5.6: Location Weather data-point (53.480^{o}N,2.405^{o}E)

The weather data are used to calculate one year of weather for each of the three constraints. These calculations are performed using a binary method where a number one represent a "bad weather day" and a number zero represents a "good weather day". Thus three binary years, each representing one constraint.

These binary values are calculated in two steps.

- (1) The first day of the month is assumed to be a good or bad weather day, with the use of a random number
- (2) All consecutive days of the month are calculated with method called a "Markov Chain"

The weather data gives the probability of exceeding a certain wind speed or significant wave height for every month. The first day is checked with the value of the random number ranging from zero to one. If this number is higher than the probability of exceeding for that constraint, the day is considered a good weather day. Otherwise the day is set as a bad weather day.

The consecutive days of the month are calculated using the Markov Chain method. The Markov chain is a statistic method where a previous state (or previous day) is evaluated to remain stationary (weather remains) or change (weather changes). Thus the previous day is checked for a good or bad weather day, based on this value, the probability of exceedance from the weather data and a random number is used to calculate the state change. As a result of these calculations, every day will get a binary value, based on a random number and the previous day.

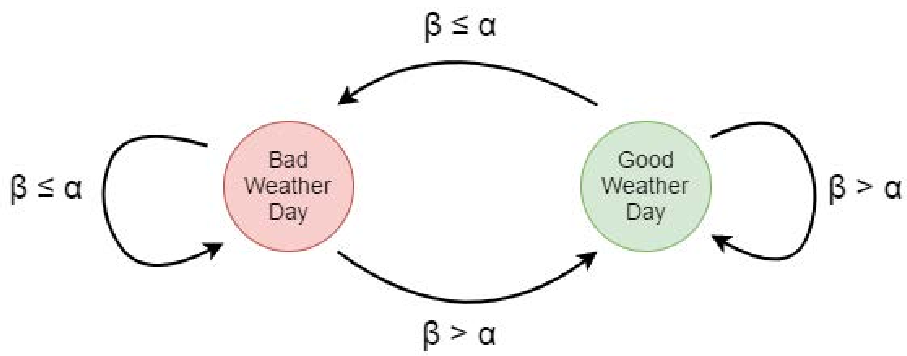
An example of the Markov chain calculation:

The goal is to calculate the weather on 2 April.

Given:

$$Probability\ of\ constraint\ exceedance\ for\ April = \alpha = 63\% \text{ (Fugro Data)}$$
$$Random\ number\ assigned\ to\ 2\ April = \beta = 0.7546 = 75.46\%$$
$$Weather\ value\ on\ previous\ day = \gamma = 1 \text{ (Bad weather day)}$$

The general Markov Chain is given as:



In this example the previous day is a bad weather day, from this point a comparison of α and β is made to calculate the weather on 2 April. In this example:

$$\beta > \alpha \text{ or } 75.46\% > 63\%$$
Results in: April 2 is a Good Weather Day

The Monte Carlo Simulation model will start its simulation on a given date. Every activity is assigned to one of the three constraints. Per activity the start date and the Monte Carlo duration is used to check the binary weather year for bad weather. When bad weather day is found in any of those specific days, the duration of the activity is extended. This extension is done with a loop that is limited to loop seven times. When weather delay passes this loop, the Monte Carlo run is not recorded. This happens on average once per 7.500 runs.

An example of the weather delay loop:

The following binary values are given:

Date	Weather value 1 = Bad 0 = Good
1-apr	0
2-apr	0
3-apr	1
4-apr	1
5-apr	0
6-apr	1
7-apr	1
8-apr	1
9-apr	0

Loop 1	
Loop 2	
Loop 3	
Loop 4	
Loop 5	

In this example the Monte Carlo simulation model plans an activity with the start-date 1 April and a Monte Carlo Duration of 4 [$days$]. The loops will make the following steps:

- **loop 1** will analyse if the 4 first days (1 - 4 April) can be used to complete the activity
- **Loop 1** finds 2 $Bad\ Weather\ Days$ in the binary dates
- 2 days are added as delay in the model
- **loop 2** will analyse if the 2 consecutive days (5 and 6 April) can be used to finish the activity
- **loop 2** finds 1 $Bad\ Weather\ Day$ in the binary dates
- 1 day is added as delay in the model
- **loop 3** will analyse if the 1 consecutive day (7 April) can be used to finish the activity
- **loop 3** finds 1 $Bad\ Weather\ Day$ in the binary dates
- 1 day is added as delay in the model
- **loop 4** will analyse if the 1 consecutive day (8 April) can be used to finish the activity
- **loop 4** finds 1 $Bad\ Weather\ Day$ in the binary dates
- 1 day is added as delay in the model
- **loop 5** will analyse if the 1 consecutive day (9 April) can be used to finish the activity
- **loop 5** plans the final day of the activity

Result: The activity requires 9 [$days$] duration due to weather delay, instead of the original 5 [$days$] Monte Carlo Duration.

5.3.4. Scenarios: selection of possible asset configurations

The purpose of the scenarios is to capture all essential variations possible in asset configurations. If all 139 HLV's in the database were to be modelled, the amount of scenarios required would be hundreds. Therefore the essential asset configuration have to be captured in scenarios. These scenarios have been selected through multiple steps. These steps are:

- Platform size
- Decommissioning method
- Heavy Lift vessel category
- Positioning method
- Offload to HLV own deck or barge

These steps are chosen since they show the strongest influence on the decision making standard results. These variations with the steps is shown in figure 5.7. In the following paragraphs, each step well be explained in detail.

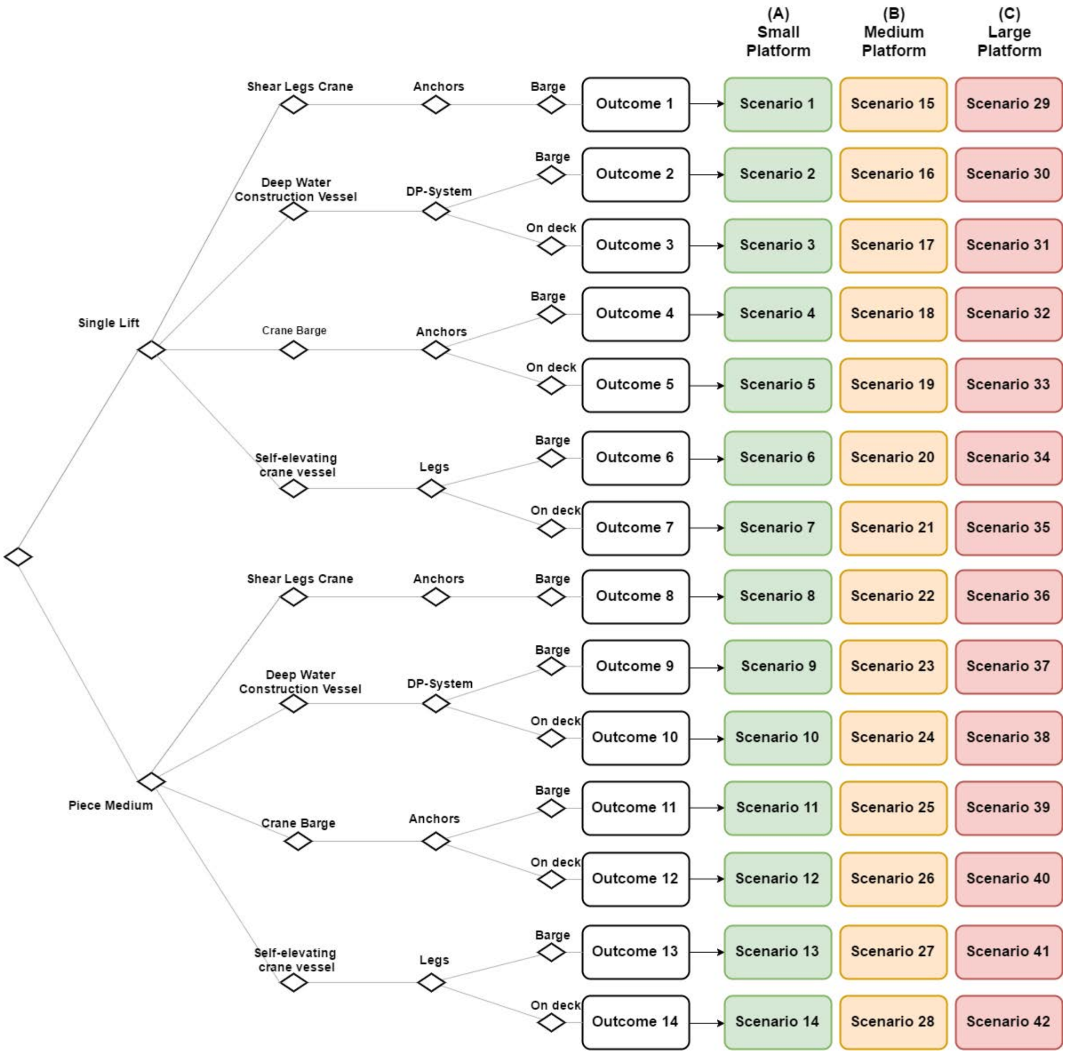


Figure 5.7: Overview of selected scenarios

Platform Size

Within this research all North Sea platforms with a topside weight of less than 1400[*tons*] are considered. In total 280 platforms in the North Sea, including 140 platforms that are 25 years or older. Although this is a limited selection of all North Sea platforms there are still different sizes of platform within this range. The platform information requirements for the simulation model, contain detailed information such as centre of gravity location. This is not commonly shared by platform operators. Therefore the platform information within Ardent is the only data available. Three platforms that fall within the 1400 [*tons*] constraint have been found Ardent's database.

According to these three known platforms, the platform database (section 2.4) has been analysed. As shown in figure 5.8 the platforms within the 1400 [*tons*] constraint do not cluster, but shown an equal spread over the range. Therefore no categories could be assigned within the range of platforms. As a result the three known platforms will be used in the scenarios. Although these platforms do not represent a certain category of platform, they do represent a different size of platform.

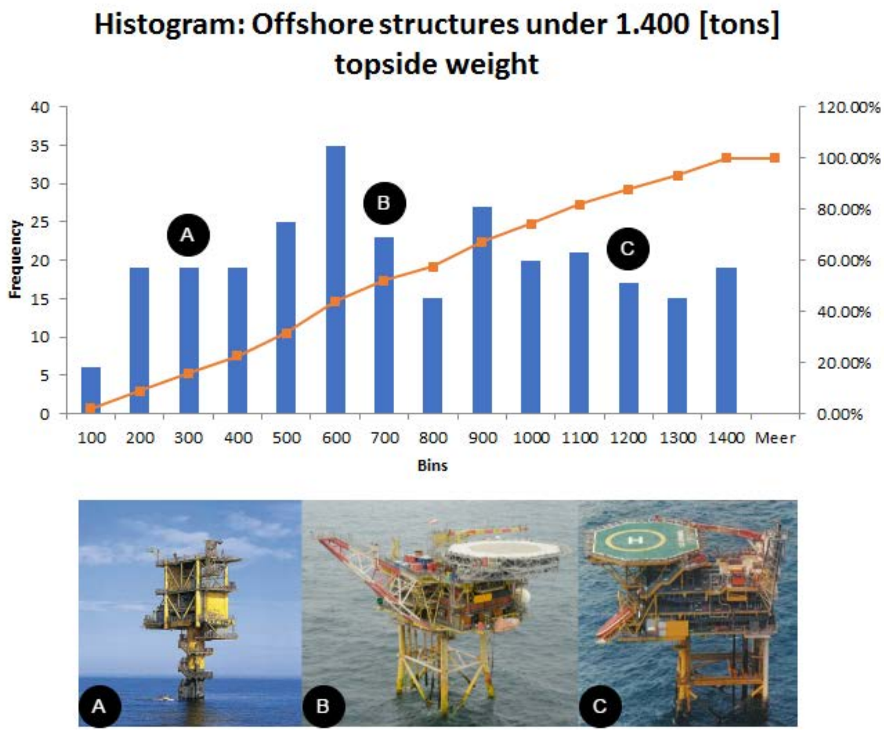


Figure 5.8: Overview of selected selected platforms for the scenarios

	(A)Small	(B)Medium	(C)Large
Topside weight [tons]	290	725	1250
Jacket weight [tons]	550	750	900

Table 5.3: Summary of weights of platforms used in the scenarios

Decommissioning methods

The second step in the scenario selection is the decommissioning method. In this research two decommissioning methods remain: Single Lift and Piece Medium. The piece small methods has been eliminated due to safety hazards, identified in the Risk register in section 3.4.

In the Single Lift method, the topside and jacket of the platform are removed through one single lift. In the piece medium method the topside and jacket are removed separately in two lifts. Compared to the single lift method, the piece medium method requires less crane capacity, but more time.

Heavy Lift Category

In the heavy lift database six heavy lift vessel categories are specified. From these categories a selection is made to run through the scenario model. The categories that are not included in the scenarios are: "Semi-Submersible Crane Vessels" and "Side Mounted Crane Vessels".

The Semi-Submersible Crane Vessels are excluded due to their lift capacity and draft. Most of the selected platforms are positioned in the southern, shallow part of the North Sea. Average minimal operating depth of these vessels is 20 [$meter$][26]. The average lifting capacity of all Semi-Submersible Crane Vessels is 7900 [$tons$][26]. Therefore this category of crane vessel is considered over-dimensioned for the range of platforms selected in this research. The Side Mounted Crane Vessels are excluded since their reach simply is not sufficient to position the crane hook above the platform.

The four selected heavy lift vessel categories are: Shear Legs Crane, Deep Water Construction Vessel, Crane Barge and Self-elevating Crane Vessel. For every scenario the best suitable HLV from the Heavy Lift Database is selected. This selection is based on minimizing crane capacity and day-rate. For the Piece Medium method the crane capacity is selected in such manner that both topside and jacket are removed in two pieces, for a minimal dayrate and minimum lift capacity.

Positioning Method

Within this research three positioning methods are used: anchors, DP-system or jack-up system. The Jack-up system is only used on the ”Self Elevation Crane Vessels”. For the other HLV categories, both anchors and DP-system is used, but the first is more commonly used than the other. Therefore the ”Shear Legs Crane” and ”Crane Barge” is simulated with anchors only. The ”Deep Water Construction Vessel” is simulated with DP-system only.

However, the regarding positioning system exceptions can be found in the HLV database. For example, a ”Deep Water Construction Vessel” that works with anchors can be found in the database. This it is assumed that exceptions like these are represented by other scenario. In this case it is presumed that the ”Deep Water Construction Vessel” on anchors will behave similarly in the model as a ”Crane Barge” on anchors.

Offloading of topside and jacket

No every HLV category can carry a topside and jacket on its own deck. In this case a barge is required to offload the topside and jacket. For the Shear Legs Crane category, the only offload possibility for the jacket and topside is a barge. This is because the movement of these cranes does not enable them to unload cargo to their own deck. For all other selected HLV categories both options for offloading are used in the simulation. It is not guaranteed that the HLV has sufficient deck space to store the topside an jacket on its own deck. The option to carry the topside and jacket on the HLV in the scenarios is therefore only to capture the differences in risks and costs. For an actual project further engineering will be required to in- or exclude the deck carrying option.

Summary of scenarios

With all steps considered a total of 42 scenarios are set. This is the result of 14 scenarios per platform. These 14 scenarios are set through: decommissioning method, heavy lift category, positioning method and topside/jacket offload option. The scenarios are numbered in figure 5.7. This numbering will also be refereed to in the ”Results” chapter, chapter 6.

5.3.5. Validation: extreme value variability test

In this paragraph extreme values of the input variables in the Monte Carlo simulation model are tested. The purpose of this test is to do a sanity check of the model behaviour . By systematicly adjusting extreme values in the model input, the model output is checked to be conform to expected values [31].

For every input of the Monte Carlo simulation model shown in figure 5.1, two tests are performed. One will test the lower model constraint by setting an input zero, the second test will set a extreme high value for that input. Before all test were run, the expected test results have been estimated. The test description and estimated results are shown in table 5.4.
The test results are summarized bellow:

Test 1

Of all runs, 40 % of the runs resulted in a total project duration of less than one day. Another 40 % of the runs resulted in a total project duration between 1 and 10 days. The remaining 20 % of the runs showed many varying results with a maximum project duration of 41 days. This 20% is caused a consecutive range of bad weather days, where the strict binary regime of the weather module disables any planning in that period.

Test 2

Results showed extreme variations with a minimum and maximum project duration of 3500 and 5200 days respectively. The extreme variance was the expected result.

Test 3

A decreased variability and decrease of risk resulted in a concentrated distribution. This is equal to the expected results.

Test	Extreme constraint	Test description	Expected results
1.1	Beta-PERT to minumum	Set each activity duration to 0.00001 $[days]$	Total project duration of 1-10 [days] due to weather delays
1.2	Beta-PERT to maximum	Set each activity to a pessimistic, most likely and optimistic value of: $1 - 100 - 200$ $[days]$	Too much variations in total project duration, inconclusive results
2.1	Weather module to minimum	Set weather constraints to high values, no weather delays	Less variance to be found in model results, since only operational risks are incorporated
2.2	Weather module to maximum	Set weather constraints to low values, every day weather delay	Model cannot plan days, resulting in an error
3.1	Scenarios to minimum	Select a heavy lift vessel with insufficient reach to execute a project	No results are calculated, resulting in an error
3.2	Scenarios to maximum	Set all platform weights to 1 $[ton]$	Project contains activities with extreme short duration

Table 5.4: Extrme value variability test description and expected results

Test 4
The weather module did not result in an error. The results showed a high variability and a random character. This is caused by the weather module planning loop that is limited to seven loops.

Test 5
Model showed user that Heavy Lift Vessel was not capable for the project.

Test 6
Model resulted in an error as the Monte Carlo simulation model was required to divide by and activity duration of zero. This is caused by the regression formulas in the activity duration calculation. These regression formulas reach a value of zero in the origin $(0;0)$. By adjusting the regressions values to a minimal value higher than zero at the origin this unexpected behaviour is solved. The adjusted value will have minor influences on the actual regression values, thus no results are effected.

In conclusion the only non-expected result was the Weather Module that is able to produce results in test 4, even though no days are available to plan activities. This is caused by the constant exceeding of the planning loop in the weather module. For the purpose of this model this is not a problem, since exceeding the loop occurs on average once every 7500 runs for each scenarios tested in this thesis. But this does show the sensitivity for errors concerning the exceeding of the weather planning loop, and should be taken into consideration for future model iterations. All other tests resulted in the expected model behaviour.

5.4. Model Output

In this section the output of the MC model is explained. The results are split in two parts: Histograms & P-values for commercial analysis and a Cruciality index (CRI) for risk analysis. Both are explained in the following paragraph.

5.4.1. Commercial viability: Histrograms of duration and costs

For each of the three platform sizes, 14 scenarios are ran through the simulation model. The costs and durations of the scenarios are visualised in a histogram. A histogram is a graphic representation of statistical data by displaying the frequency of value appearances. A cumulative percentage is added by a line running through the histogram, showing the percentage of values in the dataset that is lower than that specific value. An example of a histogram is given in figure 5.9.

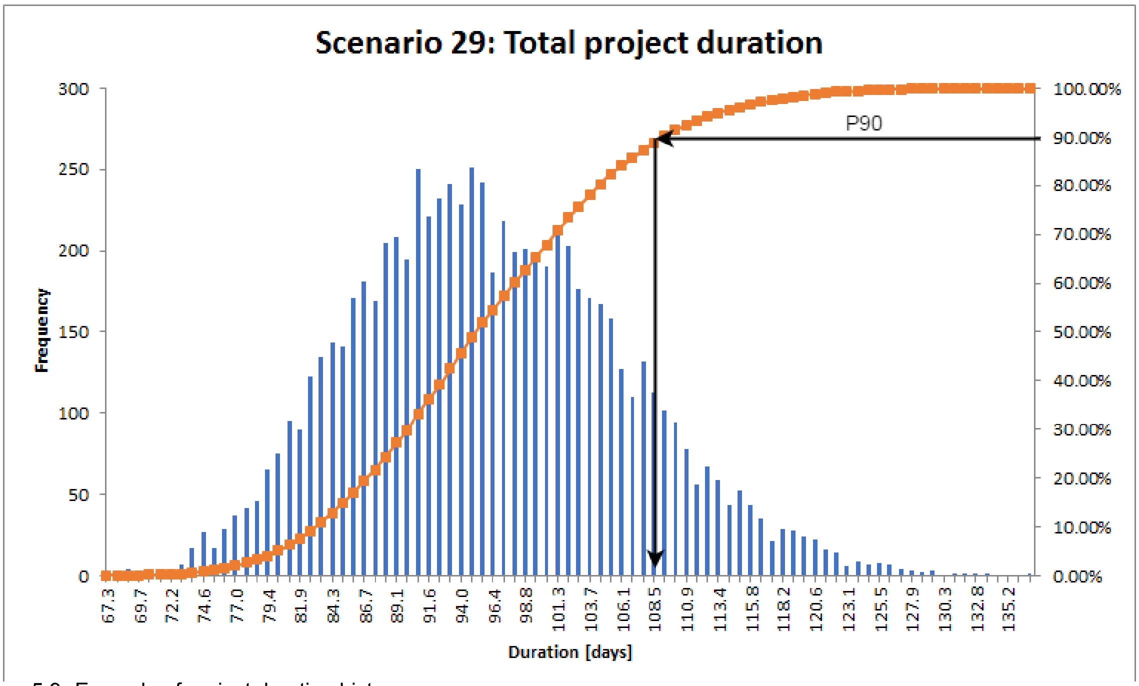


Figure 5.9: Example of project duration histrogram

These cumulative values can be used as guidelines for the chance to come to that certain value. For example the 90% chance to complete a project in X $[days]$. These chances are refereed to as ”P” values. From figure 5.9: the $P90$ duration of the project is 108.5 $[days]$.

Six histograms are created for every scenario. The following information in captured in these histograms:

- Total project duration
- Total project costs
- Lifting phase duration
- Lifting phase costs
- Preparation phase duration
- Preparation phase costs

The results are presented as total project, lifting phase and preparation phase because of the asset requirements. The reason for this categorization is caused by the asset requirements. Less costly assets are required for the preparation phase of a decommissioning project. On the other hand, the Lifting phase containing the topside removal plus jacket removal combined, requires the costly heavy lift vessel. The Cruciality Index also requires this categorization in the model outcome, this is further explained in paragraph 5.4.2.

From these histograms the cheapest or "most commercially viable" solution for the project can be found. When the multiple P-values are compared, for example $P60$ and $P70$, the increase in costs can give an idea of the financial uncertainty of the scenario.

5.4.2. Risk quantification: Cruciality Index

The second output from the MC model is Pearson's Cruciality Index (CRI). This index is described as: "This measure reflects the relative importance of an activity in a more intuitive way and calculates the portion of total project duration uncertainty that can be explained by the uncertainty of an activity"[36]. The CRI outcome is within the range of 0 to 1, where 1 corresponds to complete uncertainty caused by the activity, and 0 corresponds to no uncertainty is caused by the activity.

The Cruciality Index for durations is defined as [36]

$$CRI(r) = \left| \frac{\sum(SAD-\overline{SAD})\times(SPD-\overline{SPD})}{\sqrt{\sum(SAD-\overline{SAD})^2\times(SPD-\overline{SPD})^2}} \right|$$

With:
$r = simulation\ runs$
$SAD = Simulated\ Activity\ Duration$
$\overline{SAD} = average\ Simulated\ Activity\ Duration\ over\ all\ runs$
$SPD = Simulated\ Project\ Duration$
$\overline{SPD} = average\ Simulated\ Project\ Duration\ over\ all\ runs$

The Cruciality Index for costs is defined as:

$$CRI(r) = \left| \frac{\sum(SAC-\overline{SAC})\times(SPC-\overline{SPC})}{\sqrt{\sum(SAC-\overline{SAC})^2\times(SPC-\overline{SPC})^2}} \right|$$

With:
$r = simulation\ runs$
$SAC = Simulated\ Activity\ Costs$
$\overline{SAC} = average\ Simulated\ Activity\ Costs\ over\ all\ runs$
$SPC = Simulated\ Project\ Costs$
$\overline{SPC} = average\ Simulated\ Project\ Costs\ over\ all\ runs$

In general the CRI is "Key Performance Indicator" (KPI), that can be used for an multi activity project. For each activity the CRI will give a value between 0 and 1 that represents the portion of duration or costs risks for that specific activity. In this research the CRI is used as if the decommissioning project contains two activities: a preparation activity, and a lifting activity. These two activities correspond to the preparation phase and lifting phase division as explained in the previous paragraph, paragraph 5.4.1.

Ideally the majority of the risks in a decommissioning project would occur during the preparation phase. Within this phase, the least costly assets are used, and operational errors have a lower impact on the operation safety then during the lifting operations. This can be quantified with the two activity approach, where the CRI values are calculated for the preparation phase and lifting phase individually.

Since the risks in the project are calculated in the MC model as delay, the appropriate value to measure risks is duration and not costs. Therefore the CRI duration values are used for risk analysis of the scenarios.

With the CRI duration values, a maximal preparation phase CRI value, and a minimal lifting phase value, defines an risk optimal scenario. Thus based on the CRI values the scenarios are ranked on their maximal preparation phase CRI and minimal lifting phase CRI.

The Pearson's CRI is not the only possible KPI to measure the portion of risk per activity. The alternatives are: Kendall's Tau CRI and Spearman's CRI [36]. The difference with the Pearson's CRI and the alternative CRI's is that Pearson's method assumes a linear relationship between variables, where the alternatives assume a non-linear relationship between variables. Since the CRI value is applied in a non-complex two activity approach, it is unlikely to expect non-linear relation ships between the variables. In projects with multiple activities occurring in parallel to each other, a non-linear approach would be more appropriate. Therefore it is presumed that the Pearson's linear CRI method will be sufficient in this research.

5.5. Summary

In this chapter project risks and uncertainty have been included in a Monte Carlo simulation model. By including uncertainty a realistic estimation of project duration and costs can be made. Most of all, the simulation model will show how the risks and corresponding uncertainties will influence the duration and costs of a project.

The Monte Carlo simulation model simulates the behaviour of the risk uncertainty by creating statistic random samples based on a probability distribution, for each activity. This leads to a statistically calculated duration of an activity, called the ”Monte Carlo Duration”. All these durations results in new project duration called a ”run”. The model creates 7.500 runs per scenario to come to a distribution of project duration and costs. From this distribution commercial viability and risks can be quantified.

The input required for the Monte Carlo simulation are: a probability distribution per activity, and scenarios. In addition weather risks are included through a separate weather module. The probability distribution per activity is calculated using the Beta-PERT distribution. The optimistic, most likely and optimistic values for this distribution are found through expert elicitation. The scenarios for the Monte Carlo simulation model are selected step-by-step, resulting in 42 scenarios overall.

The Monte Carlo simulation model generates two outputs: Commercial information captured in histograms, and risk related values through Pearson's Cruciality Index. The histograms show the project costs and duration for multiple P-values. Pearson's Cruciality Index represents the portion of risks that is caused in the preparation and lifting phase in the project. A minimized risk during the lifting phase is ideal, since the most expensive assets are selected in the lifting phase, hence delay is most costly.

6

Results

This chapter presents the results of the model and scenarios as explained in chapter 5. The first part of this section will summarize how the model development contributes to the heavy lift vessel selection for decommissioning projects in the North Sea. Secondly the results of the expert elicitation are given. Here the resulted pessimistic, most likely and optimistic values for the probability distribution in the Monte Carlo simulation model are presented. The third part presents the scenario histograms containing the commercial results from the Monte Carlo simulation model. A fourth part presents the Cruciality Index values for each scenario. In the fifth and last part, multiple validation tests are presented.

6.1. Research contribution to decision making

Within this research a model is developed to support the decision making process of asset selection for decommissioning of fixed steel platforms in the North Sea. This development is visualised in figure 6.1. Based on the basic work-breakdown structure for decommissioning projects[8], a detailed work breakdown structure is formulated that can be applied to any decommissioning project for fixed steel platforms in the North Sea. From tender experiences [2] a decision making standard was made. This standard contains a generic calculation method that results in a project planning and costs estimate. These estimates do not include any risks, but do formulate an first estimate for asset selection early in the tender proposal.

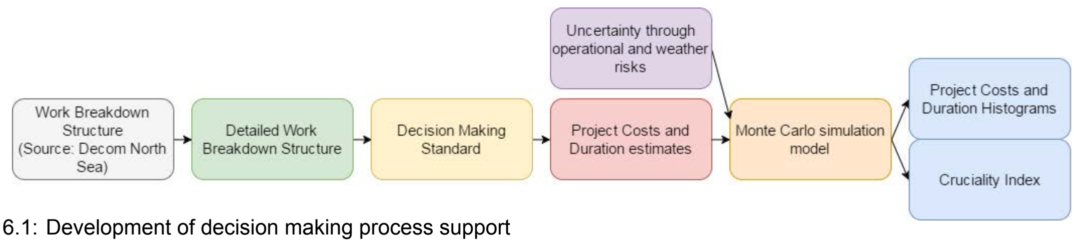


Figure 6.1: Development of decision making process support

In order to calculate the risks and uncertainties caused by the asset selection, a Monte Carlo simulation model has been developed. This model includes operational risks and weather delay to the project costs and duration estimations from the decision making standard. The simulation model simulates a project through multiple runs to create a statistically sound probability for project duration and costs. In addition a Cruciality Index is calculated for the preparation and heavy lift part of a project. From this cruciality index it can be concluded how the risks and uncertainties of a project are distributed thought preparation and lifting phase.

This model is a first development and is based on all available information. Once new activity durations or risks quantifications are available, both the decision making standard as the Monte Carlo simulation model can be enhanced with this information. It is expected that more information, especially based on true decommissioning experience will have a positive result on the model outcome reliability.

With the data available during this research a first run of scenario simulations have been performed. An example of the raw data from the scenario simulation, is given in appendix F. The results of all scenarios will be analysed in section 6.4 and 6.5.

6.2. Expert Elicitation: PERT survey

The Monte Carlo simulation model requires a probability distribution per activity as input. For the chosen Beta-PERT distribution, experts have estimated a pessimistic, most likely and optimistic value though a PERT-survey. This is explained in detail in section 5.3.2.

In the PERT survey many variation in the activity duration estimations where found. An ideal expert elicitation would result in consensus for most of the estimated values. Unfortunately this is not the case with the provided estimations.

In order to prove the variation in the survey, a graphical representation is made in a bar-chart. This chart is shown in figure 6.3. A horizontal bar in this figure represent the normalized results of one of the activities in the survey. An ideal survey with 100% consensus is shown in figure 6.2 where every survey represent the same value or width. The true survey results are taken from the most likely value estimated for the medium size platform, referred to as platform (B) in figure 5.3 in section 5.

From these estimated values it can be concluded that no collective knowledge on project durations is reached within Ardent. With these uncertainty in the estimated values, the duration estimates are therefore not used in the Monte Carlo simulation model. In consultation with the experts an other method was found to use the PERT survey values.

The pessimistic and optimistic estimates are analyses as percentages of the estimated most likely value. For example: the pessimistic, most likely and optimistic durations are $1 - 2 - 4$ [days] respectively. Than the estimations can also be transformed to $50\% - 100\% - 200\%$ of these values.

When these optimistic and pessimistic percentages from the PERT survey are compared less variation is found in the results. These results are shown in figure 6.4. In this figure the average percentages are shown per activity, per platform size. Also the standard deviation per activity estimate is given.

In conclusion the use of these percentages decrease the uncertainty in the probability distribution per activity, compared to the estimated durations. The downside of this method is that only the pessimistic and optimistic values are now estimated, based on the most likely value. No consensus can be found in the most likely durations in the survey, as shown in figure 6.3. Therefore the decision making standard is used to calculate the most likely value. The decision making standard in explained in chapter 4.

Figure 6.2: Theoretical survey result with 100% consensus

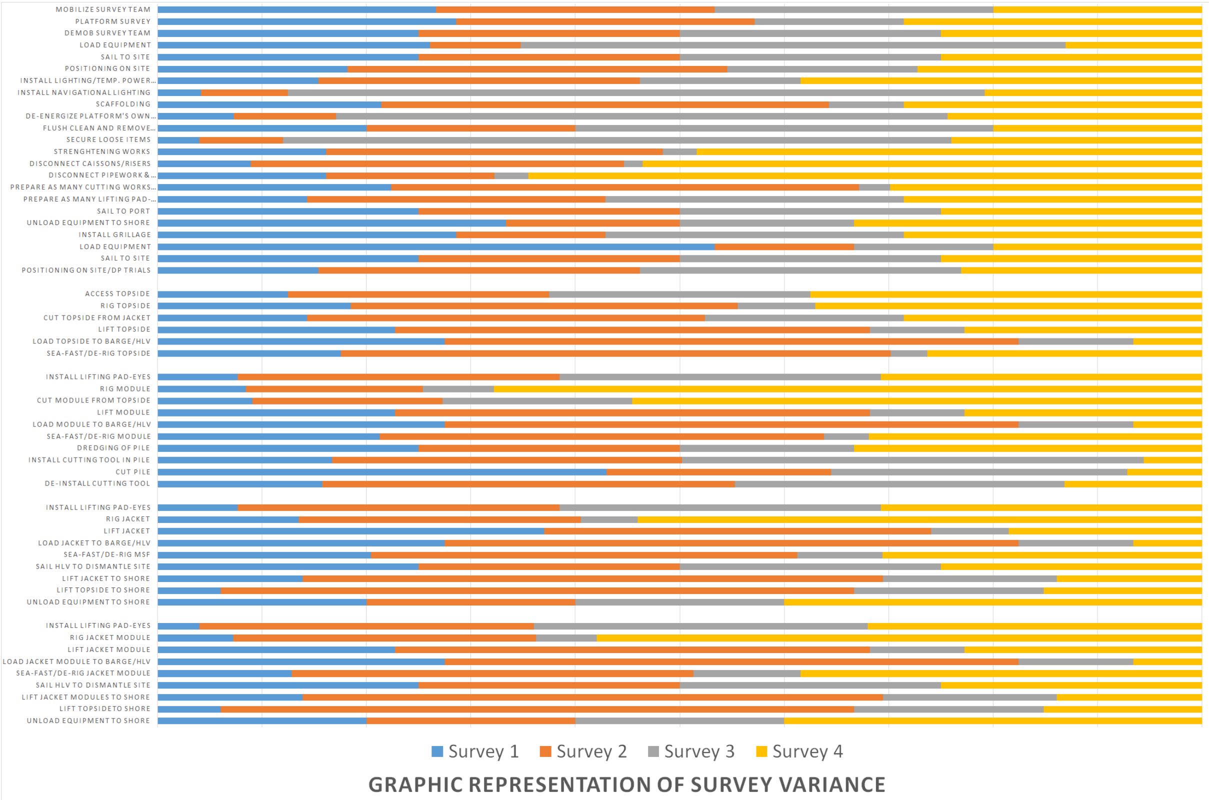


Figure 6.3: Sample to show variance in expert survey

			Small platform						Medium platform						Large platform					
			Optimistic		Mean		Pessimistic		Optimistic		Mean		Pessimistic		Optimistic		Mean		Pessimistic	
			Average	Stand. Dev.	Average	Stand. Dev.	Average	Stand. Dev.	Average	Stand. Dev.	Average	Stand. Dev.	Average	Stand. Dev.	Average	Stand. Dev.	Average	Stand. Dev.	Average	Stand. Dev.
1. Preparations	1.1.1	Mobilize Survey team	64%	16%	100%	0%	171%	30%	64%	16%	100%	0%	171%	30%	64%	16%	100%	0%	171%	30%
	1.1.2	Platform Survey	71%	21%	100%	0%	188%	22%	49%	18%	100%	0%	164%	40%	50%	16%	100%	0%	148%	33%
	1.1.3	Demob Survey team	71%	21%	100%	0%	154%	46%	71%	21%	100%	0%	154%	46%	71%	21%	100%	0%	176%	41%
	1.2.1	Load equipment	54%	14%	100%	0%	158%	28%	54%	14%	100%	0%	177%	74%	54%	14%	100%	0%	204%	114%
	1.2.2	Sail to site	57%	7%	100%	0%	168%	34%	59%	10%	100%	0%	155%	29%	59%	10%	100%	0%	155%	29%
	1.2.3	Positioning on site	64%	16%	100%	0%	163%	37%	64%	16%	100%	0%	163%	37%	64%	16%	100%	0%	183%	29%
	1.3.1	Install lighting/Temp. power supply	61%	17%	100%	0%	200%	0%	65%	20%	100%	0%	145%	15%	63%	16%	100%	0%	170%	33%
	1.3.2	Install navigational lighting	60%	15%	100%	0%	163%	22%	56%	13%	100%	0%	155%	29%	56%	13%	100%	0%	155%	29%
	1.3.3	Scaffolding	60%	11%	100%	0%	177%	40%	56%	16%	100%	0%	183%	29%	61%	21%	100%	0%	179%	37%
	1.3.4	De-energize platform's own electric system	50%	18%	100%	0%	143%	13%	57%	7%	100%	0%	148%	10%	58%	8%	100%	0%	163%	25%
	1.3.5	Flush clean and remove hazardous materials	60%	11%	100%	0%	158%	25%	46%	14%	100%	0%	142%	28%	48%	17%	100%	0%	167%	20%
	1.3.6	Secure loose items	54%	19%	100%	0%	147%	17%	72%	17%	100%	0%	151%	30%	67%	12%	100%	0%	163%	51%
	1.4.1	Strenghtening works	46%	7%	100%	0%	233%	154%	54%	7%	100%	0%	275%	130%	50%	12%	100%	0%	275%	130%
	1.4.2	Disconnect caissons/risers	58%	8%	100%	0%	258%	142%	54%	7%	100%	0%	252%	145%	52%	10%	100%	0%	258%	142%
	1.4.3	Disconnect pipework & electrical wiring	54%	7%	100%	0%	254%	143%	50%	18%	100%	0%	263%	139%	56%	11%	100%	0%	250%	146%
	1.4.4	Prepare as many cutting works as possible	59%	16%	100%	0%	240%	153%	51%	22%	100%	0%	238%	152%	50%	12%	100%	0%	246%	149%
	1.4.5	Prepare as many lifting pad-eyes as possible	53%	22%	100%	0%	190%	71%	47%	26%	100%	0%	175%	25%	51%	27%	100%	0%	183%	46%
	1.5.1	Sail to port	57%	7%	100%	0%	168%	34%	59%	10%	100%	0%	155%	29%	59%	10%	100%	0%	155%	29%
	1.5.2	Unload equipment to shore	56%	11%	100%	0%	165%	38%	56%	11%	100%	0%	175%	25%	54%	7%	100%	0%	171%	30%
2. Topside removal	2.1.1	Install grillage	54%	7%	100%	0%	160%	42%	50%	0%	100%	0%	151%	34%	52%	15%	100%	0%	173%	31%
	2.1.2	Load equipment	54%	7%	100%	0%	171%	30%	65%	18%	100%	0%	185%	75%	58%	8%	100%	0%	179%	70%
	2.1.3	Sail to site	64%	14%	100%	0%	155%	29%	64%	14%	100%	0%	155%	29%	64%	14%	100%	0%	155%	29%
	2.1.4	Positioning on site/DP trials	54%	7%	100%	0%	151%	30%	54%	7%	100%	0%	151%	30%	54%	7%	100%	0%	151%	30%
	SINGLE LIFT																			
	2.2.1	Access Topside	60%	23%	100%	0%	193%	47%	52%	10%	100%	0%	192%	14%	54%	13%	100%	0%	200%	0%
	2.2.2	Rig Topside	60%	23%	100%	0%	218%	109%	50%	18%	100%	0%	143%	13%	56%	22%	100%	0%	154%	27%
	2.2.3	Cut Topside from Jacket	52%	15%	100%	0%	171%	30%	63%	14%	100%	0%	171%	30%	60%	11%	100%	0%	183%	46%
	2.2.4	Lift Topside	54%	13%	100%	0%	200%	0%	52%	10%	100%	0%	192%	14%	52%	10%	100%	0%	192%	14%
	2.2.5	Load topside to barge/HLV	56%	16%	100%	0%	179%	36%	56%	16%	100%	0%	179%	36%	58%	14%	100%	0%	159%	41%
	2.2.6	Sea-fast/de-rig Topside	58%	14%	100%	0%	175%	43%	50%	12%	100%	0%	200%	0%	44%	11%	100%	0%	188%	41%
	PIECE MEDIUM																			
	2.2.1	Install lifting pad-eyes	48%	18%	100%	0%	193%	68%	49%	26%	100%	0%	188%	22%	62%	27%	100%	0%	176%	55%
	2.2.2	Rig module	54%	13%	100%	0%	155%	29%	54%	13%	100%	0%	225%	103%	56%	11%	100%	0%	188%	22%
	2.2.3	Cut module from topside	56%	11%	100%	0%	168%	34%	58%	14%	100%	0%	179%	22%	56%	11%	100%	0%	181%	21%
	2.2.4	Lift module	54%	13%	100%	0%	180%	35%	52%	10%	100%	0%	192%	14%	52%	10%	100%	0%	192%	14%
	2.2.5	Load module to barge/HLV	56%	16%	100%	0%	179%	36%	56%	16%	100%	0%	179%	36%	56%	16%	100%	0%	179%	36%
	2.2.6	Sea-fast/de-rig module	58%	14%	100%	0%	180%	35%	48%	15%	100%	0%	200%	0%	46%	7%	100%	0%	188%	22%
3. Substructure removal	3.1.1	Dredging of pile	33%	18%	100%	0%	163%	37%	46%	26%	100%	0%	177%	40%	45%	29%	100%	0%	181%	48%
	3.1.2	Install cutting tool in pile	48%	4%	100%	0%	205%	113%	48%	4%	100%	0%	225%	103%	50%	0%	100%	0%	263%	96%
	3.1.3	Cut pile	49%	2%	100%	0%	193%	121%	50%	0%	100%	0%	225%	160%	50%	0%	100%	0%	250%	203%
	3.1.4	De-install cutting tool	68%	24%	100%	0%	330%	273%	64%	20%	100%	0%	404%	268%	51%	14%	100%	0%	329%	273%
	SINGLE LIFT																			
	3.2.1	Install lifting pad-eyes	53%	26%	100%	0%	251%	110%	54%	33%	100%	0%	188%	53%	60%	26%	100%	0%	184%	49%
	3.2.2	Rig jacket	59%	21%	100%	0%	144%	36%	54%	28%	100%	0%	163%	41%	66%	19%	100%	0%	146%	35%
	3.2.3	Lift jacket	54%	13%	100%	0%	200%	0%	47%	17%	100%	0%	172%	33%	47%	17%	100%	0%	192%	14%
	3.2.4	Load jacket to barge/HLV	56%	16%	100%	0%	179%	36%	56%	16%	100%	0%	229%	104%	58%	14%	100%	0%	159%	41%
	3.2.5	Sea-fast/de-rig MSF	56%	16%	100%	0%	188%	22%	47%	17%	100%	0%	200%	35%	50%	0%	100%	0%	200%	61%
	3.3.1	Sail HLV to dismantle site	64%	14%	100%	0%	155%	29%	64%	14%	100%	0%	155%	29%	64%	14%	100%	0%	155%	29%
	3.3.2	Lift jacket to shore	53%	13%	100%	0%	180%	34%	52%	10%	100%	0%	175%	28%	47%	17%	100%	0%	175%	28%
	3.3.3	Lift topside to shore	66%	17%	100%	0%	196%	41%	64%	16%	100%	0%	250%	146%	47%	17%	100%	0%	175%	28%
	3.3.4	Unload equipment to shore	56%	11%	100%	0%	160%	40%	56%	11%	100%	0%	155%	46%	60%	11%	100%	0%	151%	30%
	PIECE MEDIUM																			
	3.2.1	Install lifting pad-eyes	48%	18%	100%	0%	263%	96%	54%	22%	100%	0%	238%	96%	56%	21%	100%	0%	200%	35%
	3.2.2	Rig jacket module	54%	13%	100%	0%	159%	29%	54%	13%	100%	0%	179%	22%	56%	11%	100%	0%	179%	22%
	3.2.3	Lift jacket module	54%	13%	100%	0%	180%	35%	52%	10%	100%	0%	192%	14%	52%	10%	100%	0%	192%	14%
	3.2.4	Load jacket module to barge/HLV	56%	16%	100%	0%	179%	36%	56%	16%	100%	0%	179%	36%	56%	16%	100%	0%	179%	36%
	3.2.5	Sea-fast/de-rig Jacket module	56%	16%	100%	0%	191%	15%	48%	13%	100%	0%	241%	93%	48%	4%	100%	0%	179%	22%
	3.3.1	Sail HLV to dismantle site	64%	14%	100%	0%	155%	29%	64%	14%	100%	0%	155%	29%	64%	14%	100%	0%	155%	29%
	3.3.2	Lift jacket modules to shore	53%	13%	100%	0%	180%	34%	52%	10%	100%	0%	175%	28%	47%	17%	100%	0%	175%	28%
	3.3.3	Lift topsideto shore	66%	17%	100%	0%	196%	41%	64%	16%	100%	0%	250%	146%	52%	10%	100%	0%	225%	104%

Figure 6.4: Calculated percentages based on PERT surveys

6.3. Scenarios: Selected heavy lift vessels and exclusions

This section will provide an overview of the selected Heavy Lift vessels for the scenarios. The selected heavy lift vessel are shown in figure 6.5. As explained in section 5.3.4, these heavy lift vessels have been selected through two criterion's: minimum lift capacity to full fill decommissioning method at a minimum day rate.
For scenario 8, no suitable HLV could be selected. In the database, the "Shear Legs" category does not contain a vessel suitable for the piece medium removal of a small platform. The "Shear Legs" are therefore considered over-dimensioned for scenario 8.

Scenario	Chosen Heavy Lift Vessel	Max. Lift capacity [tons]
1	HLV Ulgen	719
2	Saipem FDS 2	1000
3	Saipem FDS 2	1000
4	PML 15000 E	680
5	PML 15000 E	680
6	Apollo	800
7	Apollo	800
8	n/a	n/a
9	Saipem FDS	1000
10	Saipem FDS	1000
11	Jascon 2	300
12	Jascon 2	300
13	JB 114	114
14	JB 114	114
15	Rambiz	3300
16	Global 1200	1200
17	Global 1200	1200
18	Conquest MB1	1400
19	Conquest MB1	1400
20	Seafox 5	1200
21	Seafox 5	1200
22	Matador 3	1700
23	Saipem FDS	1000
24	Saipem FDS	1000
25	PML 15000 E	680
26	PML 15000 E	680
27	Neptune	500
28	Neptune	500
29	Rambiz	3300
30	Oleg Strashnov	5000
31	Oleg Strashnov	5000
32	Castoro Otto	2177
33	Castoro Otto	2177
34	Innovation	1500
35	Innovation	1500
36	Taklift 4	2200
37	Global 1200	1200
38	Global 1200	1200
39	Conquest MB1	1400
40	Conquest MB1	1400
41	Seafox 5	1200
42	Seafox 5	1200

Figure 6.5: Selected HLV vessels for scenarios

6.4. Commercial values: Histrograms and P-values

The histogram output of the Monte Carlo simulation is presented in this section. The histograms give a graphic representation of statistical data by displaying the frequency of value appearances. From these values a cumulative percentage can be calculated, resulting in P-values. Detailed information on the histograms an P-values is given in section 5.3.2.

The results of the total project costs histograms are presented in this section. This his done with the use of P-values. The P-values that have been selected are the P-60-,P-70-,P-80 and P90 values. These values capture the project costs with an acceptable amount of (un)-certainty.

The goal of analysing these "total project costs P-values", is to find the cheapest decommissioning solution for the selected platforms. Therefore a ranking has been made for the three cheapest scenarios per platform type. These results are shown in figure 6.6.

From figure 6.6, it can be concluded that the "Deep Water Construction Vessels" are the most expensive solution for all platforms. Also the "Shear Legs" crane vessels are never selected to be in the top tree cheapest solutions. It can therefore be concluded than from a commercial perspective, the use of "Deep Water Construction Vessels" and "Shear Legs", are not a commercial viable solution.

The remaining "Crane Barge" and "Self Elevating Crane Vessel" category vessels show appearances in the top three of all modelled platforms. An overview of the top three commercially most viable scenarios per platform are shown in figure 6.7. From these results the crane barge "Conquest MB1" has been the most selected vessel in the top three cheapest options.

Scenario	Single Lift/ Piece Medium	HLV Category	Positioning System	Offload to:	P60	P70	P80	P90
1	Single Lift	Shear Legs	Anchors	Barge	$ 5,337,579.91	$ 5,467,847.62	$ 5,641,537.90	$ 5,902,073.32
2	Single Lift	DWCV	DP	Barge	$ 6,892,652.32	$ 7,074,142.00	$ 7,316,128.23	$ 7,679,107.58
3	Single Lift	DWCV	DP	Deck	$ 5,827,930.55	$ 5,977,589.11	$ 6,177,133.86	$ 6,476,450.97
4 (3)	Single Lift	Crane Barge	Anchors	Barge	**$ 4,965,839.07**	**$ 5,068,771.37**	**$ 5,206,014.44**	**$ 5,377,568.28**
5 **(1)**	Single Lift	Crane Barge	Anchors	Deck	**$ 4,059,802.16**	**$ 4,136,730.04**	**$ 4,239,300.56**	**$ 4,393,156.32**
6	Single Lift	SECV	Legs	Barge	$ 6,154,425.08	$ 6,350,022.70	$ 6,545,620.33	$ 6,790,117.37
7	Single Lift	SECV	Legs	Deck	$ 5,229,034.48	$ 5,389,304.02	$ 5,549,573.55	$ 5,749,910.47
8	Piece Medium	Shear Legs	Anchors	Barge	n/a	n/a	n/a	n/a
9	Piece Medium	DWCV	DP	Barge	$ 11,091,713.18	$ 11,496,524.62	$ 11,901,336.06	$ 12,508,553.22
10	Piece Medium	DWCV	DP	Deck	$ 9,712,076.44	$ 9,979,612.25	$ 10,336,326.67	$ 10,871,398.30
11	Piece Medium	Crane Barge	Anchors	Barge	$ 6,404,144.75	$ 6,573,364.19	$ 6,700,278.77	$ 6,954,107.94
12 **(2)**	Piece Medium	Crane Barge	Anchors	Deck	**$ 4,779,126.97**	**$ 4,870,618.88**	**$ 4,992,608.09**	**$ 5,145,094.60**
13	Piece Medium	SECV	Legs	Barge	$ 6,665,245.49	$ 6,792,703.70	$ 7,005,134.05	$ 7,260,050.46
14	Piece Medium	SECV	Legs	Deck	$ 5,411,925.37	$ 5,518,005.13	$ 5,659,444.80	$ 5,871,604.31
15	Single Lift	Shear Legs	Anchors	Barge	$ 9,935,746.19	$ 10,273,788.33	$ 10,611,830.47	$ 11,118,893.68
16	Single Lift	DWCV	DP	Barge	$ 11,188,596.36	$ 11,569,161.90	$ 11,949,727.43	$ 12,520,575.73
17	Single Lift	DWCV	DP	Deck	$ 9,979,919.18	$ 10,306,547.55	$ 10,633,175.92	$ 11,204,775.57
18	Single Lift	Crane Barge	Anchors	Barge	$ 7,212,335.47	$ 7,419,978.59	$ 7,627,621.71	$ 7,939,086.38
19 **(1)**	Single Lift	Crane Barge	Anchors	Deck	**$ 6,029,007.39**	**$ 6,198,182.98**	**$ 6,367,358.56**	**$ 6,621,121.93**
20	Single Lift	SECV	Legs	Barge	$ 7,113,672.61	$ 7,254,412.48	$ 7,442,065.64	$ 7,723,545.38
21 **(2)**	Single Lift	SECV	Legs	Deck	**$ 6,130,014.37**	**$ 6,249,726.16**	**$ 6,449,245.82**	**$ 6,648,765.47**
22	Piece Medium	Shear Legs	Anchors	Barge	$ 14,464,141.58	$ 14,801,720.21	$ 15,251,825.05	$ 15,926,982.30
23	Piece Medium	DWCV	DP	Barge	$ 15,808,111.28	$ 16,181,152.46	$ 16,678,540.69	$ 17,424,623.04
24	Piece Medium	DWCV	DP	Deck	$ 13,876,879.51	$ 14,256,659.80	$ 14,636,440.09	$ 15,269,407.25
25	Piece Medium	Crane Barge	Anchors	Barge	$ 7,735,154.16	$ 7,932,832.20	$ 8,130,510.25	$ 8,377,607.81
26 **(3)**	Piece Medium	Crane Barge	Anchors	Deck	**$ 6,291,115.97**	**$ 6,465,615.46**	**$ 6,596,490.07**	**$ 6,814,614.43**
27	Piece Medium	SECV	Legs	Barge	$ 8,326,891.79	$ 8,476,493.70	$ 8,675,962.91	$ 9,025,034.02
28	Piece Medium	SECV	Legs	Deck	$ 6,853,360.90	$ 7,032,258.66	$ 7,211,156.43	$ 7,434,778.64
29	Single Lift	Shear Legs	Anchors	Barge	$ 11,261,037.72	$ 11,516,923.91	$ 11,943,400.89	$ 12,369,877.86
30	Single Lift	DWCV	DP	Barge	$ 18,046,574.80	$ 18,715,402.14	$ 19,217,022.66	$ 20,220,263.68
31	Single Lift	DWCV	DP	Deck	$ 16,633,967.17	$ 17,226,220.93	$ 17,818,474.70	$ 18,558,791.91
32	Single Lift	Crane Barge	Anchors	Barge	$ 9,417,107.31	$ 9,643,511.72	$ 9,945,384.28	$ 10,398,193.12
33 **(2)**	Single Lift	Crane Barge	Anchors	Deck	**$ 8,230,137.55**	**$ 8,487,553.64**	**$ 8,744,969.74**	**$ 9,131,093.88**
34	Single Lift	SECV	Legs	Barge	$ 13,405,520.86	$ 13,728,983.52	$ 14,160,267.05	$ 14,807,192.35
35	Single Lift	SECV	Legs	Deck	$ 12,319,408.22	$ 12,610,025.24	$ 12,997,514.59	$ 13,481,876.27
36	Piece Medium	Shear Legs	Anchors	Barge	$ 13,601,798.41	$ 13,952,341.96	$ 14,302,885.50	$ 14,887,124.75
37	Piece Medium	DWCV	DP	Barge	$ 16,856,526.30	$ 17,391,968.99	$ 17,793,551.02	$ 18,596,715.06
38	Piece Medium	DWCV	DP	Deck	$ 14,980,376.36	$ 15,369,082.25	$ 15,757,788.13	$ 16,405,631.27
39 **(3)**	Piece Medium	Crane Barge	Anchors	Barge	**$ 8,981,153.78**	**$ 9,186,587.11**	**$ 9,460,498.23**	**$ 9,802,887.13**
40 **(1)**	Piece Medium	Crane Barge	Anchors	Deck	**$ 7,523,451.69**	**$ 7,707,359.33**	**$ 7,952,569.51**	**$ 8,320,384.79**
41	Piece Medium	SECV	Legs	Barge	$ 10,561,835.79	$ 10,765,951.54	$ 11,038,105.86	$ 11,514,375.93
42	Piece Medium	SECV	Legs	Deck	$ 9,074,518.59	$ 9,272,568.71	$ 9,536,635.55	$ 9,866,719.10

Figure 6.6: Resulting Total Project costs for all scenarios

A notable similarity in the best results, is the amount of assets required for the project. Since the crane barges selected for the scenarios do not have their own propulsion system, Anchor Handling Tugs are required to mobilize the vessels. When the use of a barge for the offloading of the topside and jacket are included, additional Anchor Handling Thugs are required. This brings the amount of assets present at the offshore site to five vessels. The risks caused by these additional assets have not been included in the operational risks. Therefore it is questionable weather the commercial advantages weigh up to the additional risks and complexity in the operations. Guidelines on the balance in offering a commercially viable solutions versus the operational complexity and risks should be discussed within Ardent.

Small Platform							
Ranking	**HLV vessel**	**Scenario**	**Single Lift/ Piece Medium**	**HLV Category**	**Positioning System**	**Offload to:**	**P60**
1	PML 15000 E	5	Single Lift	Crane Barge	Anchors	Deck	$ 4,059,802.16
2	Jascon 2	12	Piece Medium	Crane Barge	Anchors	Deck	$ 4,779,126.97
3	PML 15000 E	4	Single Lift	Crane Barge	Anchors	Barge	$ 4,965,839.07
Medium Platform							
Ranking	**HLV vessel**	**Scenario**	**Single Lift/ Piece Medium**	**HLV Category**	**Positioning System**	**Offload to:**	**P60**
1	Conquest MB1	19	Single Lift	Crane Barge	Anchors	Deck	$ 6,029,007.39
2	Seafox 5	21	Single Lift	SECV	Legs	Deck	$ 6,130,014.37
3	PML 15000 E	26	Piece Medium	Crane Barge	Anchors	Deck	$ 6,291,115.97
Large Platform							
Ranking		**Scenario**	**Single Lift/ Piece Medium**	**HLV Category**	**Positioning System**	**Offload to:**	**P60**
1	Conquest MB1	40	Piece Medium	Crane Barge	Anchors	Deck	$ 7,523,451.69
2	Castoro Otto	33	Single Lift	Crane Barge	Anchors	Deck	$ 8,230,137.55
3	Conquest MB1	39	Piece Medium	Crane Barge	Anchors	Barge	$ 8,981,153.78

Figure 6.7: Summary of top 3 scenarios

6.5. Risk values: Cruciality Index

The Cruciality Index output of the Monte Carlo simulation is presented in this section. This CRI ”calculates the portion of total project duration uncertainty that can be explained by the uncertainty of an activity”[36]. From these values the scenarios can be analysed on the risks emphasis in either the preparation phase or the lifting phase. Ideally the risks would mainly occur during the preparation phase where cheaper assets are used. This is further explained in section 5.4.2.

The durations Cruciality Index for every scenario is given in figure 6.8. The goal of analysing these CRI values is to find which scenarios are favourable in terms of risks. The analysis is done per heavy lift vessel catagory.

From these results it can be concluded that the ”Self Elevating Crane Vessel” has the best risk ratio in the scenarios. For all platforms in the scenarios, the ”Self Elevating Crane Vessel” is the best option in terms of risks emphasis. This is caused by the ”Jack-Up” positioning system on these vessels. By elevating the crane vessel above sealevel, motions of the vessel induced by waves is cancelled out. This enables the vessel to be less sensitive to weather delay, resulting in the best risk scores.

In addition to the type of Heavy Lift Vessel, the results also converge to a preference for the Single Lift method. The single lift method, requires less days offshore, resulting in a better risk score.

The worst performing HLV category in terms of risks is the ”Shear Legs” crane. The remaining ”Deep Water Construction Vessel” and ”Crane Barge” category are considered to have an equal performance in terms of risks.

Scenario	Single Lift/ Piece Medium	HLV Category	Positioning System	Offload to:	Preparation Phase	Lifting Phase
1	Single Lift	Shear Legs	Anchors	Barge	0.43	0.88
2	Single Lift	DWCV	DP	Barge	0.44	0.88
3	Single Lift	DWCV	DP	Deck	0.43	0.88
4	Single Lift	Crane Barge	Anchors	Barge	0.37	0.91
5	Single Lift	Crane Barge	Anchors	Deck	0.39	0.90
6	Single Lift	SECV	Legs	Barge	0.53	0.82
7	Single Lift	SECV	Legs	Deck	0.54	0.82
8	Piece Medium	Shear Legs	Anchors	Barge	n/a	n/a
9	Piece Medium	DWCV	DP	Barge	0.38	0.90
10	Piece Medium	DWCV	DP	Deck	0.40	0.90
11	Piece Medium	Crane Barge	Anchors	Barge	0.43	0.87
12	Piece Medium	Crane Barge	Anchors	Deck	0.44	0.87
13	Piece Medium	SECV	Legs	Barge	0.47	0.85
14	Piece Medium	SECV	Legs	Deck	0.46	0.85
15	Single Lift	Shear Legs	Anchors	Barge	0.66	0.69
16	Single Lift	DWCV	DP	Barge	0.67	0.70
17	Single Lift	DWCV	DP	Deck	0.68	0.72
18	Single Lift	Crane Barge	Anchors	Barge	0.66	0.70
19	Single Lift	Crane Barge	Anchors	Deck	0.66	0.69
20	Single Lift	SECV	Legs	Barge	0.76	0.54
21	Single Lift	SECV	Legs	Deck	0.77	0.54
22	Piece Medium	Shear Legs	Anchors	Barge	0.61	0.76
23	Piece Medium	DWCV	DP	Barge	0.61	0.75
24	Piece Medium	DWCV	DP	Deck	0.61	0.76
25	Piece Medium	Crane Barge	Anchors	Barge	0.72	0.65
26	Piece Medium	Crane Barge	Anchors	Deck	0.72	0.64
27	Piece Medium	SECV	Legs	Barge	0.71	0.64
28	Piece Medium	SECV	Legs	Deck	0.73	0.63
29	Single Lift	Shear Legs	Anchors	Barge	0.83	0.52
30	Single Lift	DWCV	DP	Barge	0.83	0.51
31	Single Lift	DWCV	DP	Deck	0.83	0.52
32	Single Lift	Crane Barge	Anchors	Barge	0.82	0.51
33	Single Lift	Crane Barge	Anchors	Deck	0.83	0.52
34	Single Lift	SECV	Legs	Barge	0.90	0.40
35	Single Lift	SECV	Legs	Deck	0.90	0.40
36	Piece Medium	Shear Legs	Anchors	Barge	0.77	0.61
37	Piece Medium	DWCV	DP	Barge	0.78	0.60
38	Piece Medium	DWCV	DP	Deck	0.78	0.59
39	Piece Medium	Crane Barge	Anchors	Barge	0.79	0.57
40	Piece Medium	Crane Barge	Anchors	Deck	0.79	0.57
41	Piece Medium	SECV	Legs	Barge	0.83	0.52
42	Piece Medium	SECV	Legs	Deck	0.86	0.52

Figure 6.8: Overview of CRI duration values per scenario

6.6. Multi stage Validation

In order to calculate the scenario results presented in this chapter, multiple assumptions were required. Through multi stage validation these assumptions will validated in this section. Theory describes the multi stage validation as: "This validation method consists of (1) developing the model's assumptions on theory, observations, and general knowledge, (2) validating the model's assumptions where possible by empirically testing them, and (3) comparing (testing) the input-output relationships of the model to the real system. Operational" [31]. This paragraph describes step (2) of this method. It is presumed that step (1) is described sufficiently through chapter 3,4 and 5. For step (3) future project experience might be used to further validate these assumptions.

This section contains three validations tests. First of all the assumptions required to come to the Monte Carlo simulation output is justified. Secondly a parameter variability test examines the sensitivity of the risk results. A third and last test presents the effects of seasonal variation in the project.

6.6.1. Assumption justification

The purpose of this validation is to compare the theoretical optimal or ideal result calculation compared to the actual research results with assumptions. A diagram was made, that maps the input for the Monte Carlo simulation model and the constraints applied to is input. In this diagram the ideal theoretical input of the Monte Carlo simulation model. All red coloured spaces are excluded from the research. The blue spaces show the source of that specific data. The diagram is shown in figure 6.9.

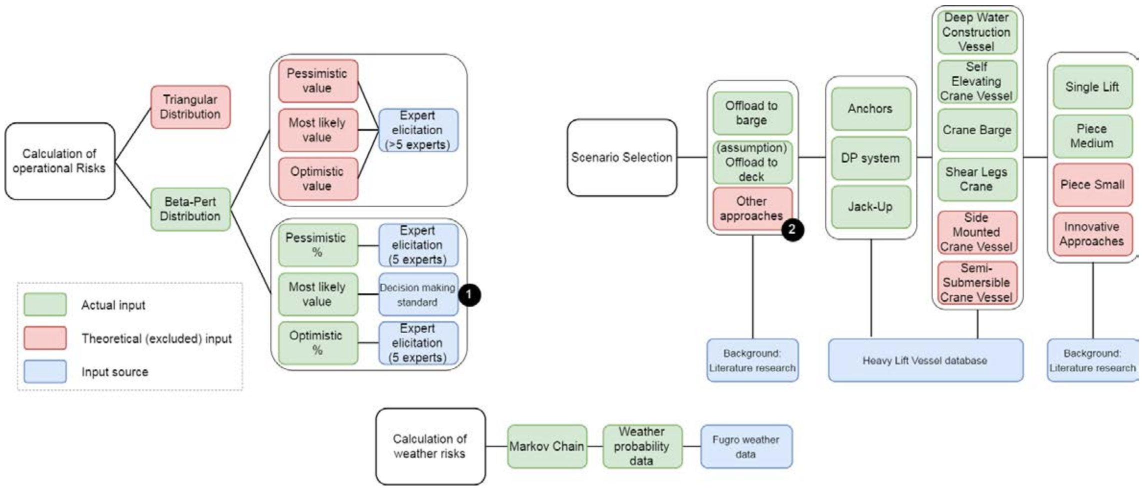


Figure 6.9: Overview of theoretical and actual simulation model input

In figure 6.9, two points have been accented that show two frail assumptions that might shift the results of the tested scenarios.

The first assumption is the use of the decision making standard in the PERT distribution. Since the decision making standard is a calculation method based on tender proposals, this standard also contains assumptions. These assumptions are explained in section 4. These assumptions are therewith included in the Monte Carlo simulation model. This is an unintended consequence of the attempt to decrease the variance in the survey. Ideally beta-PERT distribution would be purely based on a expert survey that shows mostly consensus between the experts. Unfortunately this was not the case and a compromise has been made with this available alternative.

The second assumption in the fact that the capacity of the heavy lift vessel deck space and deck strength have not be incorporated in the scenarios. Therefore a scenario where the topside and jacket are to be carried on the deck of the HLV might not be executable in reality. Ideally the deck space and deck strength of the HLVs would be available and incorporated in the scenario selection. In reality additional engineering will be required to find weather a HLV can carry a specific topside and jacket on deck.

In the second phase of the multi phase validation, two assumptions have been identified as unfavourable. A comparison has been made between the theoretical ideal model input, and the true model input as presented in this research. From this comparison two assumptions showed to have an unfavourable influence on the outcome of the model. These assumptions are the use of the Decision Making Standard for the most likely value in the beta-PERT distribution and the assumptions that every HLV can carry topside and jacket on deck.

6.6.2. Parameter variability: Result sensitivity

In this paragraph the sensitivity of the model output is validated. This validation is done through a parameter variability test. The purpose of this test is to gain insight in the sensitivity of the Cruciality Index values for both preparation and lifting phase. Therefore systematic adjustment to activity duration variability are made. In these systematic adjustments the pessimistic and optimistic estimates for the probability distribution function are manipulated.

In this parameter variability test scenario 37 is randomly selected as a starting point for these calculations. In the test the preparation phase an lifting phase are evaluated for risk sensitivity. Multiple calculations are made in which the risks of one phase are manipulated to be constant, as the risk in the other phase is systematically increased. If both phases were to share an equal cruciality in the project, both CRI values result in 0.7. The goal of this test is to find the ratio at which this balance point is found.

The systematic manipulation of the pessimistic and optimistic values are specified by the formulas bellow plus table 6.1.

$$most\ likely\ value = ml$$

Values for activities the preparation phase:

$$optimistic\ activity\ duration = ml - (ml * \alpha)$$
$$pessimistic\ activity\ duration = ml + (ml * \alpha)$$

Values for activities the lifting phase:

$$optimistic\ activity\ duration = ml - (ml * \beta)$$
$$pessimistic\ activity\ duration = ml + (ml * \beta)$$

Test	1	2	3	4	5	6	7	8	9	10	11	12	13
α	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.05	0.1	0.25	0.5	0.75	0.99
β	0.99	0.75	0.5	0.25	0.1	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Table 6.1: Risk ratios for parameter variability test

The CRI values resulting from the tests are presented in figure 6.10. From these results, test 10 showed results where equal cruciality in the project is reached for both the preparation and lifting phase. From these results it is concluded that the preparation phase requires 25 times more risk variability to reach the same cruciality as the lifting phase.

The results do not imply any quantifications of the amount of risks. They indicate the sensitivity to risks for the two phases in the project. For the lifting phase, slight variations in the activity duration result in a dominating risk portion in the project. In terms of sensitivity caused by activity duration variations, the preparation phase is 25 times less sensitive compared to the lifting phase.

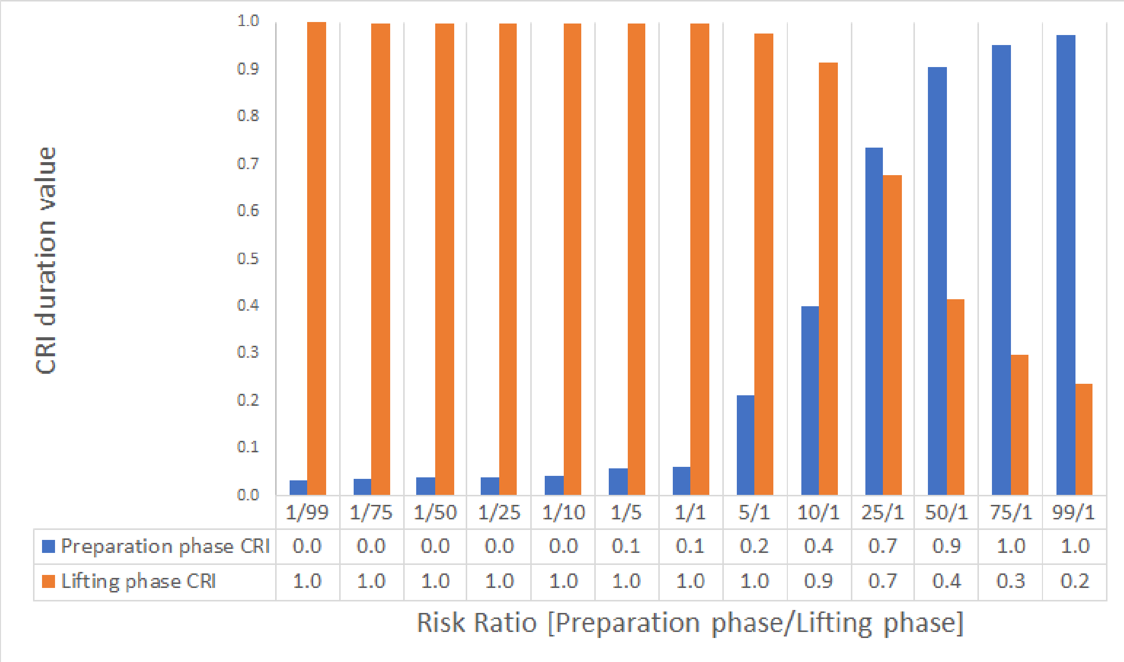


Figure 6.10: CRI scores for different risk ratios

6.6.3. Seasonal variation test

As explained in section 5.2.1, all scenarios are simulated from the default starting month April. This is a preferred month to start a decommissioning project due to preferable weather in the summer months. In this paragraph a systematic adjustment of the starting month of the project will be tested on two scenarios. These tests will identify the weather effects in the project in less than ideal weather conditions.

Two scenarios are used in this test: scenario 40 due to its commercial characteristics and scenario 35 due to its risks characteristics. In this systematic test the ”P60” total projects costs are calculated for every consecutive month. These total project costs are analysed on costs increase compared to the ideal situation in April.

All calculated total project costs are visualized in figure 6.11. In this figure the x-axis represents the starting month of the project, and the y-axis represents the P60 total project costs.

The results show that no break-even-point can be found for scenario 35 and 40. The optimal starting month versus the worst starting shows an project increase of approximately 46% for scenario 40 and 61% for scenario 35. The difference in percentage is caused by the difference in heavy lift vessel day-rates.

In this test three assumptions have been made that should be considered with the result analysis. First of all a fixed day-rate has been used in the simulation. Heavy lift vessels are commonly chartered in summer. To become more attractive for operations in the rest of the year, the day-rates of the HLVs might be adjusted accordingly. There is no information available on variation of these day-rates. Additional research will be required to implement the influences of day-rate changes ”off-season”.

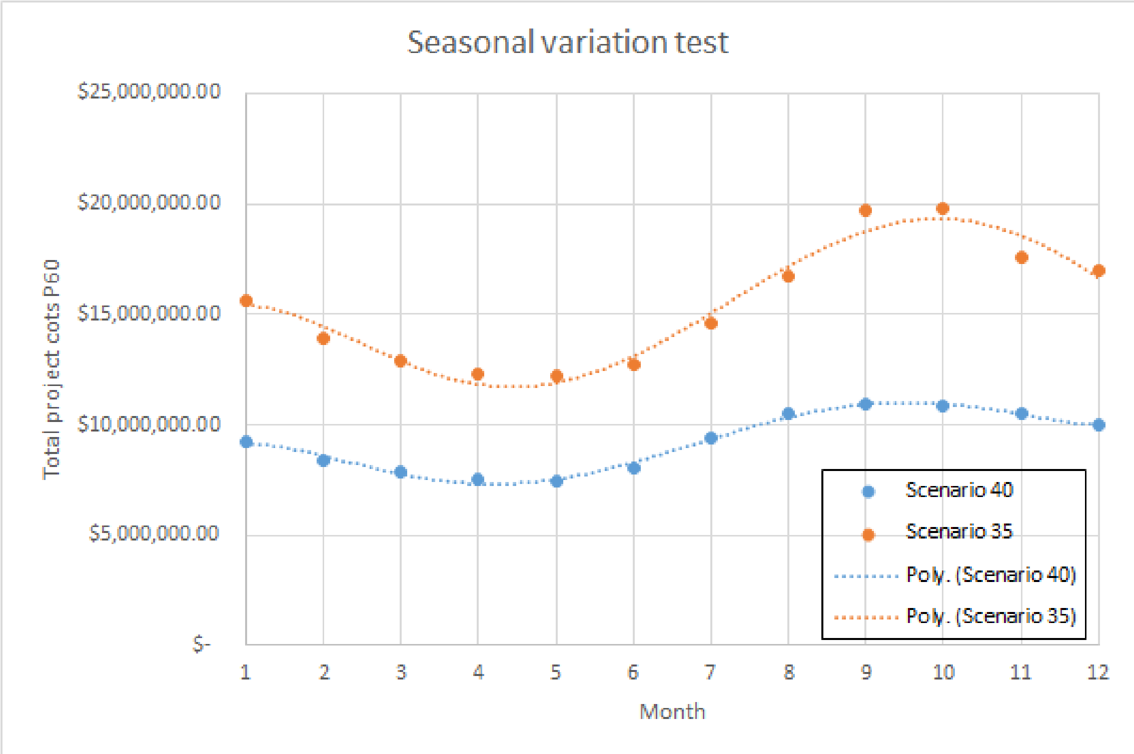


Figure 6.11: Seasonal variation test

Secondly the weather module in the Monte Carlo simulation model has been created with 7 loops. These loops are sufficient to result in a loop exceeding error once every 7500 runs. This is equal to 0.001% error occurrence. Unfortunately these errors increase when more extreme weather is tested, with a maximum error of approximately 10% can be found when September is the starting month of the project. This high error occurrence will influence the results of this test. Therefore an additional iteration of the weather module development is required for more reliable results.

Thirdly the operation risks may vary through-out the season. Current the operational risks are estimated as static value. Weather these values also apply to less favourable seasons is to be researched.

From this seasonal variation test, it is concluded that no break-even point can be found in a commercially and risk favorable selected scenarios. These results should be implemented as first estimates, considering the assumptions that were required to come to the test results. With additional information on the off-season HLV dayrate changes, an updated weather module and off-season operational risks more reliable results can be expected. To accomplish this, extra research will be required.

6.7. Summary

In this chapter the research results have been presented. First of all a summary is given how this model development contributes to the heavy lift vessel selection for decommissioning projects in the North Sea.

Secondly the results for the Monte Carlo simulation model are presented for all scenarios. From these results the following conclusion can be draw:

- From the variance in the expert elicitation, it was found that no collective knowledge on decommissioning activity duration is shared within Ardent. As a solution a percentage of the pessimistc and optimistic values is used combined with the decision making standard to come to a probability distribution for the MC model.
- From the histograms and P-values of the scenarios, a top three ranking is made for the most commercially viable options per platform. From these result the crane barge ”Conquest MB1” is most successful vessel in the scenarios.
- From the duration Cruciality Index values, the ”Self Elevating Crane Vessel” category showed the best risk ratio for all types of platforms.

As a third part Multi Stage validation is performed to validate the assumptions required to come the the model results. In this Multi Stage validation three tests have been performed.

- First the assumptions justification, where two assumptions were found that showed a unfavourable influence on the results. Ideally these assumptions would not be required, but the variance in the expert surveys and lack of information on deck strength and space of Heavy Lift Vessels forced the assumptions to be made. These assumptions are the use of the Decision Making Standard for the most likely value in the beta-PERT distribution and the assumptions that every HLV can carry topside and jacket on deck.
- Secondly a parameter variability test presented the risk sensitivity of the preparation and lifting phase. The test concludes a highly sensitive lifting phase compared to the preparation phase.
- All scenarios have been modelled in the summertime, which is the favourable seasons in terms of weather, and thus weather related risks. Therefore a test has been performed to compare a ”Crane Barge Vessel” with a ”Self Elevating Crane Vessel” throughout the less favourable seasons. The test results presents the ”Crane Barge” as the cheapest scenario throughout the seasons. These results are based on a test without varying dayrates, a high error occurrence in weather delay calculations, and static operational risk estimations. Hence a additional iteration of the test with extra data is required for more accurate results.

7 Conclusions and Recommendations

The purpose of this thesis research as presented in the Introduction chapter, section 1.4:

The purpose of this thesis is to develop a model to identify an optimal heavy lift vessel configuration for North Sea decommissioning projects, concerning platforms with a topside weight of less than 1.400 [tons].

Ardent Global (Ardent) wants to become a contractor in the North Sea decommissioning market. In contrast with their competitors, Ardent does not own any large assets to perform these decommissioning projects. This is known within Ardent as the "asset light" strategy. The asset light strategy enables Ardent to propose tailored solutions for the removal of a platform, by cooperating with asset owning companies called "strategic partners". The most expensive asset required during the platform removal is the "Heavy Lift Vessel". In this thesis research a model is developed to aid Ardent in the selection of this heavy lift vessel and corresponding strategic partner.

In chapter 2 and 3 multiple sub-questions are answered concerning the constraints and the background of this research. In section 2.1, the definition of decommissioning has been defined as the final phase of an offshore structure's life-cycle. The relevant influencing factors to this decommisioning phase are identified as Laws/regulations, public opinion and decommissioning costs, in section 2.2. From these influencing factors, mainly decommissioning costs are considered in this research. In section 2.4, the size of the North Sea decommissioning market has been quantified as 157 structures facing decommissioning. In total 1355 offshore structures can be found on the North Sea. For these decommissioning projects the legislation can be identified as Global (IMO) , Regional (OSPAR), Local regulations, as explained in section 2.7. The methods considered for decommissioning fixed steel platforms are shown in section 3.2 and contain: Single Lift, Piece Medium, Piece Small and Innovative Approaches. Single Lift and Piece Medium considered in this research.

In chapter 3 and 4 sub-questions are answered concerning the development of a generic decommissioning project. In chapter 3, all activities required to perform a decommissioning project are identified. These activities are identified in a general and a detailed work breakdown structure. In the detailed work breakdown structure the activities are divided in preparation phase, topside removal phase and jacket removal phase. In section 4.2.2 the required resources for a decommissioning project are explained. The main resource required is a Heavy Lift Vessel. Secondly people, assets and fixed price resources are required. The Heavy Lift Vessel properties that show influences on the project, have been identified in section 4.2.1. These are the vessel properties, which determine the positioning and mobilization in the project, and the crane properties, which influence the capabilities of the vessel and required decommissioning method. A method to estimate project costs and duration is found in section 4.4. By implementing data from tender proposals, regression formulas could be set up to create a decision making standard for estimates of costs and project duration. Within these estimation no risk is considered.

In chapter 5 sub-questions are answered concerning the risk implementation and the simulation model. First of all a method to implement operational risks in the project duration and cost estimation is defined in section 5.1. With the use of a Monte Carlo simulation model the operational risks can be simulated. The probability distributions for the activity duration have been found through a combination of an expert survey and the decision making standard estimates. In section 5.3.3, weather delay has been quantified for a project. Weather delay is quantified by incorporating bad weather in the planning of the simulation model. This is achieved with Fugro weather probability data, and a weather module using a Markov-Chain. The required simulation model outcome is explained in section 5.4. First a commercial analysis is made based simulation model output. Secondly a risk analysis is made with the use of Person's Cruciality Index. The final sub-question concerning the scenario selection for the simulation model is explained in section 5.3.4. Here, 42 scenarios have been set-up to test 3 platforms, four Heavy Lift Vessel categories, three positioning methods and two offloading methods.

7.1. Conclusions

(i) This thesis has analysed and described the decision making process for the selection of a Heavy Lift Vessel for North Sea platform decommissioning projects. Based on recent decommissioning tenders, the selection process was modelled through a decision making standard and Monte Carlo Simulation model. The decision making standard results are both estimated costs and duration of a project. These values can be used to make first estimates for a new tender proposal. The output of the Monte Carlo simulation model can be used to compare commercial viable options and compare the effects of risks per Heavy Lift Vessel selection. These tools are made available to Ardent Global.

(ii) From the scenarios tested in the Monte Carlo simulation model the costs results converged to a HLV preference for the ”Crane Barge” category. These vessels are positioned alongside the platform using anchors. Offloading the topside and jacket on deck or barge both show to be a cheap option. Whether the selected Heavy Lift Vessel is able to carry the topside plus jacket or not requires additional research and engineering.

(iii) For the scenarios tested in the Monte Carlo simulation model the risk effects of heavy lift vessels selection converged to a preference for the the ”Self Elevating Crane Vessel” category. These vessels have the ability to ”jack-up” above sea-level alongside the platform. This enables the vessel to perform lifting operations without interference of wave educed motions. This ability reduces the risks encountered in the lifting phase, where delay shows a bigger impact on the project costs compared to the preparation phase.

(iv) All scenarios have been modelled in the summertime, which is the favourable seasons in terms of weather, and thus weather related risks. Therefore a test has been performed to compare a ”Crane Barge Vessel” with a ”Self Elevating Crane Vessel” throughout the less favourable seasons. The test results presents the ”Crane Barge” as the cheapest scenario throughout the seasons. These results are based on a test without varying dayrates, a high error occurrence in weather delay calculations, and static operational risk estimations. Hence a additional iteration of the test with extra data is required for more accurate results.

(v) In the activity duration estimates variations were noticed in the expert elicitations. This indicates that no collective knowledge on decommissioning project durations is shared within Ardent.

7.2. Recommendations

(i) With the use of the decision making standard and the Monte Carlo simulation model Ardent is able to quantify decisions about the Heavy Lift Vessel for a decommissioning project. These models can be improved by including data about:

- Heavy Lift Vessel day-rates
- Activity durations
- Operational risks in a project
- Additional activities required in the project

The source of this data could be either from wreck-removal/salvage projects with similarities to decommissioning or experiences gained in the decommissioning market.

(ii) From the tested scenarios, the "Crane Barge" showed to be the cheapest option to perform decommissioning projects. The first recommendation for this conclusion concerns its operability. The "Crane Barge" is strongly dependant on additional assets both for positioning and (de-)mobilization. Whether this option is executable in terms of operational complexity or not is a decision Ardent has to make. Secondly the "Crane barge" owners supplying the HLV for the cheapest project solutions are:

- Conquest Offshore Operations BV
- HAPO International Barges

Hence, it is advised that Ardent researches the opportunities with these companies for potential "Strategic Partnership".

(iii) From the tested scenarios, the "Self Elevating Crane Vessel" showed to be preferred in terms of risks sensitivity in the lifting phase. Owners of these "Self Elevating Crane Vessels" are:

- GeoSea n.v
- Seafox
- Jack-Up Barge
- MPI Offshore B.V.
- A2SEA A/

Hence, it is advised that Ardent researches the opportunities with these companies for potential "Strategic Partnership".

(iv) Comparing the cheapest HLV option versus most risk averse HLV option might result in a commercial break-even-point in varying seasons; this requires additional research. First of all varying day-rates of HLVs throughout the seasons should be quantified. Secondly an additional iteration for the "Weather Module" in the Monte Carlo simulation is required to ensure less errors in the results. The third and last recommendation is to review the operational risks in terms of seasons. In this review any variations in operational risks per season are to be added to both risk register and estimated activity durations.

(v) The discussion of views and sharing of data and experiences in meetings for colleagues, would help to define a set of parameters for decommissioning operations.

7.3. Discussion

In this paragraph the usage of the model now and in the future is discussed. Secondly the role of Ardent in the decommissioning market is discussed. As a third an final part, new research is discussed that might lead to legislation reform in the North Sea decommissioning market.

Implementation and future use of the model

This research has focussed on the North Sea decommissioning market, considering fixed steel platforms with a topside weight of less than 1.400 [tons]. A model has been developed to support the selection of heavy lift vessel for these projects. It is considered as a first iteration of the model development. The use of this model will gain insights in heavy lift vessel selection process, but does not result in a direct results for a tender proposal.

The current model is to be used as a first assumption tool to estimate the project risks, costs and duration. Therewith the model is able to generate knowledge that would take weeks to create using the traditional step-by-step method in previous tender proposals. However, the model produces these results using multiple assumptions. An understanding of these assumptions is important for proper implementation of the results. Also the possibilities to further configure a project with for example the amount of personnel used or the use of an ROV during the project, has to be known for proper usage of the model. Guidelines for the usage of the model along with the calculation model itself will is handed over to Ardent in confidentiality.

In the future multiple iteration of the model could result to more reliable outcome, to a degree that it can be used for a tender proposal directly. Then, the estimates of activity duration should be based on more data than currently available. Also the weather model would either require an update or a plug-in to use the ”ABPMER” software that Ardent has started using lately for their weather delay estimations.

Ardent's role in the decommissioning market

In this research a market has been analysed with approximately 280 platforms. From these platforms 140 are 25 years or older. Considering the water depth and the use of a Jack-Up preparation vessel, the remaining platforms will be 110 platforms that could be decommissioning using the method described in this research project. Assumed that these 110 platforms will be decommissioned over the next 10 years, an amount of 11 platforms are to be dealt with per year. This is a considerable amount.

For some decommissioning tenders, up to 20 companies have offered a tender proposal. Assuming a same amount of offers for all 11 yearly projects, the market becomes quite shallow. At the 2017 Kivi symposium ”Gracefull demolition”, Allseas founder Edward Heerema explained how their huge vessel the ”Poineering Spirit” was positioned in the market. He explained that their vessel was specialized in a decommissioning market where they were the only player. He continued jokingly: ”These are million euro projects, but with many mouths to feed, nobody is going to get rich”.

Positioning Ardent in a potentially big, and also really competitive market will require thorough strategic planning. The model presented in this research project will not yet help to that extend. But, with the use of carefully selected strategic partners and a further developed model, Ardent will have the ability to create tender proposals with less effort. Resulting in less costs before any project is awarded to Ardent, and therefore less risks in competing in the decommissioning market.

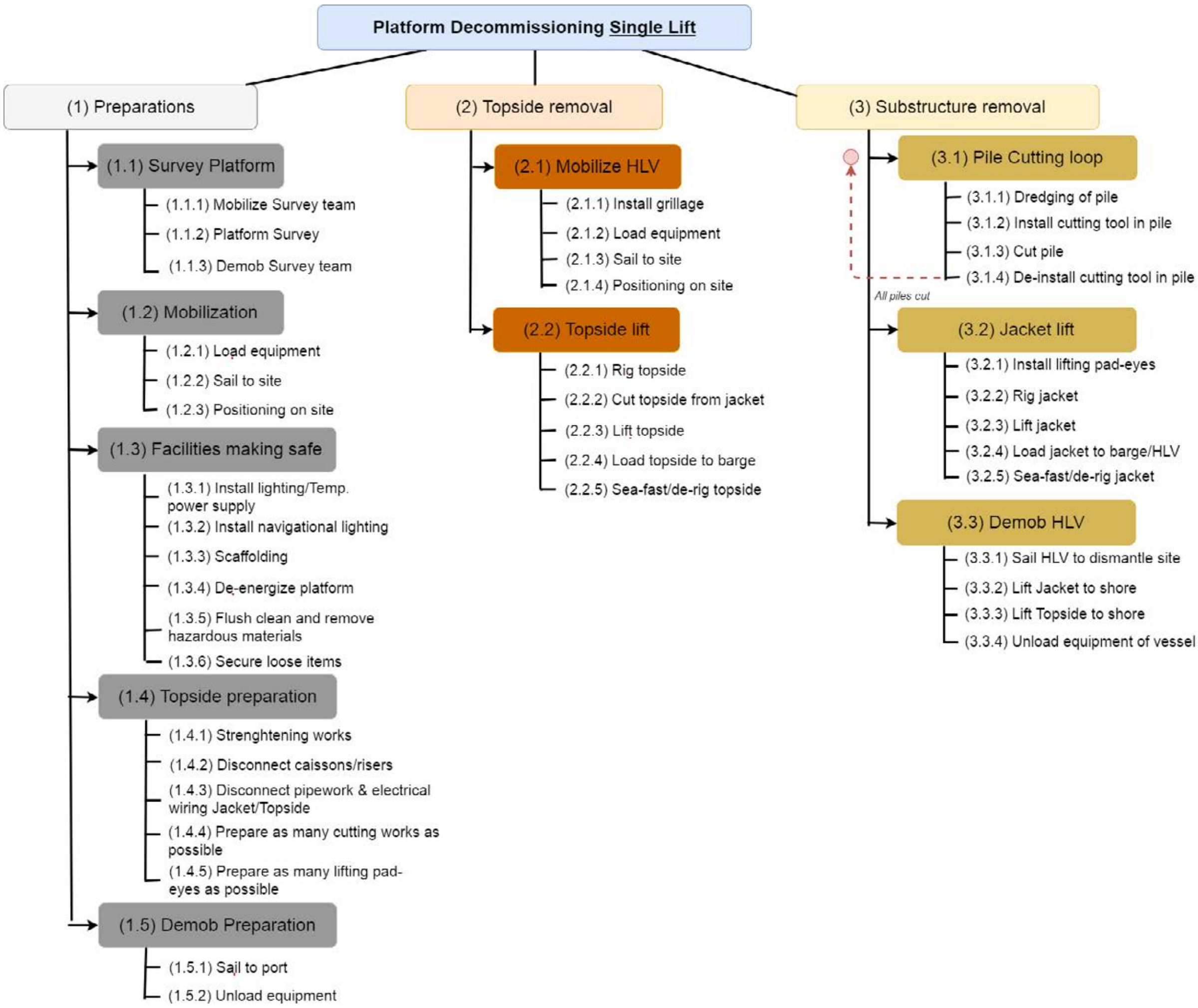
New research and potential legislation changes

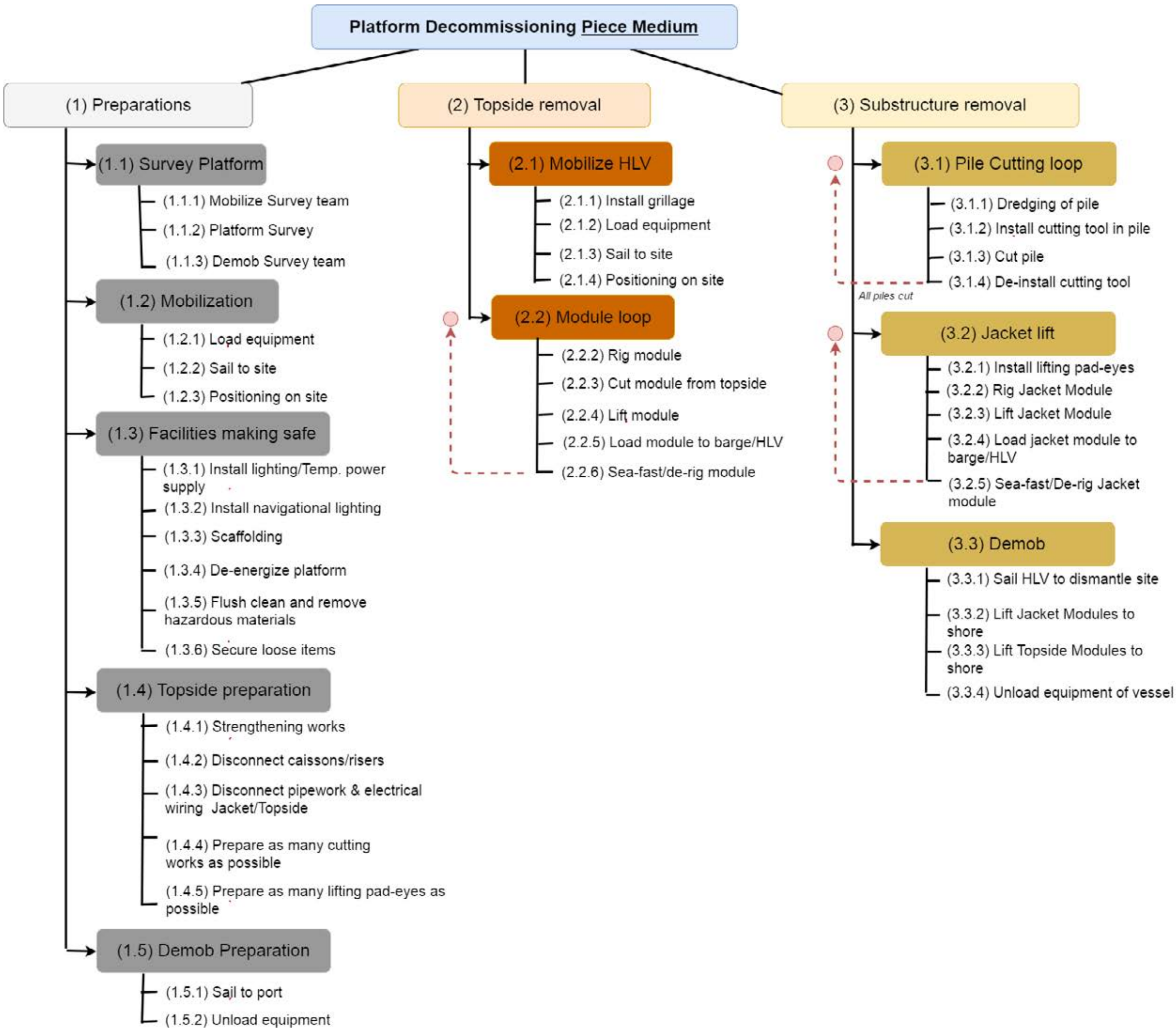
During this research project, a PhD research on the ecological values of offshore structures on the North Sea has been published by J. Coolen. From his research he concluded that leaving parts of the jacket on-site will have a positive influence on the North Sea biodiversity [6]. These finding are quite revolutionary compared to the tendency to completely decommission every North Sea structure since the Brent Spar incident. These findings might lead to new insights in decommissioning legislation for the North Sea.

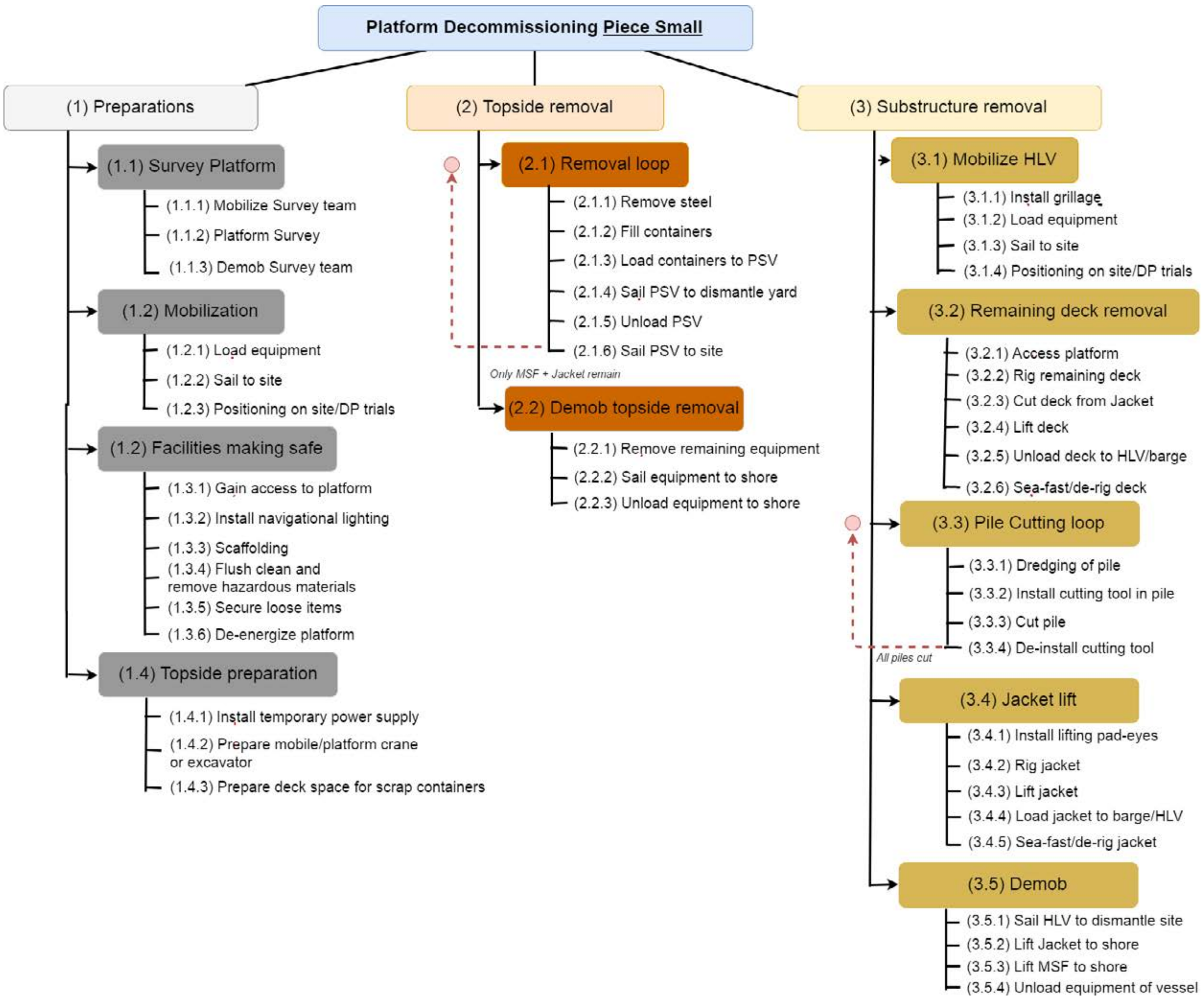
If a change of legislation on the removal of jackets is imminent, the model could still be used with two changes. The first change concerns the balance of the topside and the jacket weights. Currently the topside and jacket require an equal amount of lifting capacity from the heavy lift vessel. Through a new set of scenarios the effects of this change can be evaluated. Secondly, the activities currently planned in the jacket removal will not be the same when only half a jacket is removed. Mainly the dredging and cutting of piles will change to making subsea cuts at multiple positions on the jacket. This will create a shift in use of personnel and equipment, and therefore costs and activity durations. Implementing these changes in assets, costs and durations will require additional research.

A

Appendix A: Detailed WBS per method


Platform Decommissioning Single Lift
(1) Preparations
(1.1) Survey Platform
(1.1.1) Mobilize Survey team
(1.1.2) Platform Survey
(1.1.3) Demob Survey team
(1.2) Mobilization
(1.2.1) Load equipment
(1.2.2) Sail to site
(1.2.3) Positioning on site
(1.3) Facilities making safe
(1.3.1) Install lighting/Temp. power supply
(1.3.2) Install navigational lighting
(1.3.3) Scaffolding
(1.3.4) De-energize platform
(1.3.5) Flush clean and remove hazardous materials
(1.3.6) Secure loose items
(1.4) Topside preparation
(1.4.1) Strenghtening works
(1.4.2) Disconnect caissons/risers
(1.4.3) Disconnect pipework & electrical wiring Jacket/Topside
(1.4.4) Prepare as many cutting works as possible
(1.4.5) Prepare as many lifting pad-eyes as possible
(1.5) Demob Preparation
(1.5.1) Sail to port
(1.5.2) Unload equipment
(2) Topside removal
(2.1) Mobilize HLV
(2.1.1) Install grillage
(2.1.2) Load equipment
(2.1.3) Sail to site
(2.1.4) Positioning on site
(2.2) Topside lift
(2.2.1) Rig topside
(2.2.2) Cut topside from jacket
(2.2.3) Lift topside
(2.2.4) Load topside to barge
(2.2.5) Sea-fast/de-rig topside
(3) Substructure removal
(3.1) Pile Cutting loop
(3.1.1) Dredging of pile
(3.1.2) Install cutting tool in pile
(3.1.3) Cut pile
(3.1.4) De-install cutting tool in pile
All piles cut
(3.2) Jacket lift
(3.2.1) Install lifting pad-eyes
(3.2.2) Rig jacket
(3.2.3) Lift jacket
(3.2.4) Load jacket to barge/HLV
(3.2.5) Sea-fast/de-rig jacket
(3.3) Demob HLV
(3.3.1) Sail HLV to dismantle site
(3.3.2) Lift Jacket to shore
(3.3.3) Lift Topside to shore
(3.3.4) Unload equipment of vessel


Platform Decommissioning Piece Medium
(1) Preparations
(1.1) Survey Platform
(1.1.1) Mobilize Survey team
(1.1.2) Platform Survey
(1.1.3) Demob Survey team
(1.2) Mobilization
(1.2.1) Load equipment
(1.2.2) Sail to site
(1.2.3) Positioning on site
(1.3) Facilities making safe
(1.3.1) Install lighting/Temp. power supply
(1.3.2) Install navigational lighting
(1.3.3) Scaffolding
(1.3.4) De-energize platform
(1.3.5) Flush clean and remove hazardous materials
(1.3.6) Secure loose items
(1.4) Topside preparation
(1.4.1) Strengthening works
(1.4.2) Disconnect caissons/risers
(1.4.3) Disconnect pipework & electrical wiring Jacket/Topside
(1.4.4) Prepare as many cutting works as possible
(1.4.5) Prepare as many lifting pad-eyes as possible
(1.5) Demob Preparation
(1.5.1) Sail to port
(1.5.2) Unload equipment
(2) Topside removal
(2.1) Mobilize HLV
(2.1.1) Install grillage
(2.1.2) Load equipment
(2.1.3) Sail to site
(2.1.4) Positioning on site
(2.2) Module loop
(2.2.2) Rig module
(2.2.3) Cut module from topside
(2.2.4) Lift module
(2.2.5) Load module to barge/HLV
(2.2.6) Sea-fast/de-rig module
(3) Substructure removal
(3.1) Pile Cutting loop
(3.1.1) Dredging of pile
(3.1.2) Install cutting tool in pile
(3.1.3) Cut pile
(3.1.4) De-install cutting tool
All piles cut
(3.2) Jacket lift
(3.2.1) Install lifting pad-eyes
(3.2.2) Rig Jacket Module
(3.2.3) Lift Jacket Module
(3.2.4) Load jacket module to barge/HLV
(3.2.5) Sea-fast/De-rig Jacket module
(3.3) Demob
(3.3.1) Sail HLV to dismantle site
(3.3.2) Lift Jacket Modules to shore
(3.3.3) Lift Topside Modules to shore
(3.3.4) Unload equipment of vessel


Platform Decommissioning Piece Small
(1) Preparations
(1.1) Survey Platform
(1.1.1) Mobilize Survey team
(1.1.2) Platform Survey
(1.1.3) Demob Survey team
(1.2) Mobilization
(1.2.1) Load equipment
(1.2.2) Sail to site
(1.2.3) Positioning on site/DP trials
(1.2) Facilities making safe
(1.3.1) Gain access to platform
(1.3.2) Install navigational lighting
(1.3.3) Scaffolding
(1.3.4) Flush clean and remove hazardous materials
(1.3.5) Secure loose items
(1.3.6) De-energize platform
(1.4) Topside preparation
(1.4.1) Install temporary power supply
(1.4.2) Prepare mobile/platform crane or excavator
(1.4.3) Prepare deck space for scrap containers
(2) Topside removal
(2.1) Removal loop
(2.1.1) Remove steel
(2.1.2) Fill containers
(2.1.3) Load containers to PSV
(2.1.4) Sail PSV to dismantle yard
(2.1.5) Unload PSV
(2.1.6) Sail PSV to site
Only MSF + Jacket remain
(2.2) Demob topside removal
(2.2.1) Remove remaining equipment
(2.2.2) Sail equipment to shore
(2.2.3) Unload equipment to shore
(3) Substructure removal
(3.1) Mobilize HLV
(3.1.1) Install grillage
(3.1.2) Load equipment
(3.1.3) Sail to site
(3.1.4) Positioning on site/DP trials
(3.2) Remaining deck removal
(3.2.1) Access platform
(3.2.2) Rig remaining deck
(3.2.3) Cut deck from Jacket
(3.2.4) Lift deck
(3.2.5) Unload deck to HLV/barge
(3.2.6) Sea-fast/de-rig deck
(3.3) Pile Cutting loop
(3.3.1) Dredging of pile
(3.3.2) Install cutting tool in pile
(3.3.3) Cut pile
(3.3.4) De-install cutting tool
All piles cut
(3.4) Jacket lift
(3.4.1) Install lifting pad-eyes
(3.4.2) Rig jacket
(3.4.3) Lift jacket
(3.4.4) Load jacket to barge/HLV
(3.4.5) Sea-fast/de-rig jacket
(3.5) Demob
(3.5.1) Sail HLV to dismantle site
(3.5.2) Lift Jacket to shore
(3.5.3) Lift MSF to shore
(3.5.4) Unload equipment of vessel

B

Appendix B: Risk Register

Category	Sub-category	Risk ID	Risk Description	Maximum likely impact	Probability Score (1-5)			Impact Score (1-5)			Risk Score			Risk response measure	Probability score after risk			Impact Score after response			Risk Score after response		
					Single Lift	Reverse Inst.	Piece Small	Single Lift	Reverse Inst.	Piece Small	Single Lift	Reverse Inst.	Piece Small		Single Lift	Reverse Inst.	Piece Small	Single Lift	Reverse Inst.	Piece Small	Single Lift	Reverse Inst.	Piece Small
General		1A	Personnel transfer (small boat,heli, enz)	LTI / Man overboard	2	2	4	4	4	4	8	8	16	Transfer only per agreed procedure / Communication	1	1	2	4	4	4	4	4	8
		1B	Alongside operations (grillage on HLV)	Collision / damage / personnel injury	1	1	4	3	3	3	3	3	12	Agreed procedures between captains, detailed mooring plan.	1	1	3	3	3	3	3	3	9
		1C	Alongside operations (grillage on barge)	Collision / damage / personnel injury	2	2	4	3	3	3	6	6	12	Agreed procedures between captains, detailed mooring plan.	2	2	3	3	3	3	6	6	9
		1D	Lack of consumables	Delay	2	2	2	2	2	2	4	4	4	Proper planning	1	1	1	2	2	2	2	2	2
		1E	Stop due to non-conformity of procedures	Delay	5	5	5	2	2	2	10	10	10	Share existance for procedures / Communication	3	3	3	2	2	2	6	6	6
		1F	Delay due to lack of "permit of work"	Delay	5	5	5	2	2	2	10	10	10	Share existance for "permits of work" / Communication	3	3	3	2	2	2	6	6	6
		1G	Small hoist rigging mistakes	LTI / Fatality	2	2	4	3	3	3	6	6	12	Always double check connection before hoisting	1	1	3	3	3	3	3	3	9
		1H	Small hoist hits object	LTI / Delay / Injury	2	2	5	3	3	3	6	6	15	Set weather window for crane oparations / Communication / Procedures	1	1	4	3	3	3	3	3	12
		1I	Maintenance works	Delay	2	2	3	2	2	2	4	4	6	Agree upon maintenance times in contacts	1	1	2	2	2	2	2	2	4
		1J	Man overboard	LTI / Fatality	1	1	2	5	5	5	5	5	10	Standby procedures / Detailed scaffolding plan / Communication	1	1	1	4	4	4	4	4	4
		1K	Waiting on Weather	Delay	4	4	4	4	4	4	16	16	16	**Include weather downtime in planning**	4	4	4	3	3	3	12	12	12
		1L	Slips and trips during operations	Personnel injury / medevac	2	2	4	4	4	4	8	8	16	Procedures / Detailed scaffolding plan / Communication	1	1	4	4	4	4	4	4	16
		1M	Fire/explosion onboard	LTI / Delay / Injury	2	2	5	5	5	5	10	10	25	Flushing platform first stand alone task once safe access is reached	1	1	4	2	2	5	2	2	20
		1N	Personnel injury resulting in government/press involvement	Government involvement/delay/injury	2	2	5	3	3	3	6	6	15	Check Government Involvement / Safety Officers	1	1	5	3	3	3	3	3	15
		1O	Collapse of structure during lift	LTI / Delay / Injury	1	1	1	5	5	5	5	5	5	Inspection with NDT testing	1	1	1	4	4	4	4	4	4
		1P	Offshore operations not excecuatble at night	HVL on standby, waiting for dawn	2	2	3	2	2	2	4	4	6	Planning conform day and night work standards	1	1	2	2	2	2	2	2	4
Preparation phase	Survey	2A	Inspection equipment configuration faults	Wrong conclusion resulting from inspection/structural collapse	1	1	0	4	4	0	4	4	0	Contract with survey company should include accuracy	1	1	0	4	4	0	4	4	0
		2B	Platform integrity worse than described in docs.	Additional engineering and workshop activities	3	3	3	2	2	2	6	6	6	Change of contract / re-engineering	3	3	3	2	2	2	6	6	6
	Acco-modation vessel	2C	Prep works equipment not ready for loading	delay in mobilization	2	2	2	2	2	2	4	4	4	Proper planning, Prepare equipment prior to arrival of vessel	1	1	1	2	2	2	2	2	2
		2D	Vessel not ready for mobilization	Delay	1	1	1	2	2	2	2	2	2	Contracting with vessel owner	1	1	1	2	2	2	2	2	2
		2E	Deck layout insuficcient to store equipment	Delay	2	2	2	3	3	3	6	6	6	Deck-layout plan / Proper planning	1	1	1	2	2	2	2	2	2
		2F	Prep works equipment sea fastening failure	damage to equipment or vessels	1	1	1	4	4	4	4	4	4	Proper planning, Prepare deck layout including lashing points	1	1	1	3	3	3	3	3	3
	Topside	2G	Power failure	Delay	2	2	4	3	3	3	6	6	12	Make sure supplied power is conform equipment used	1	1	3	2	2	2	2	2	6
		2H	working on heights	LTI / Fatality	1	1	3	5	5	5	5	5	15	Procedures / Detailed scaffolding plan / Communication	1	1	2	5	5	5	5	5	10
		2I	Cutting tool incompatible with platform structure	No cutting can be performed	1	1	1	4	4	4	4	4	4	Proper design and planning	1	1	1	4	4	4	4	4	4
		2J	Prep works equipment not functional	delay in preparation phase	2	2	2	1	1	1	2	2	2	Proper design and planning	1	1	1	4	4	4	4	4	4
		2K	Incomplete cut	Obstruction of planned tasks, delay in lifting phase	2	2	2	4	4	4	8	8	8	Confirm testing of cutting device on replica	1	1	1	4	4	4	4	4	4
		2L	Loss of structural integrity due to cutting	Topside slides off Jacket	1	1	1	5	5	5	5	5	5	Design proper, executable castellated cut	1	1	1	5	5	5	5	5	5
		2M	Small movements in topside due to cutting	Causing tension in temporary reinforcements	2	2	3	5	5	5	10	10	15	Install motion/tension sensor systems	1	1	2	5	5	5	5	5	10
		2N	No access to topside temp reinforment areas	improper/ no installation of reinforcements	2	2	2	4	4	4	8	8	8	Proper design with respect to limitations of working area	1	1	1	4	4	4	4	4	4
		2O	Difficuilt access for topside scafolding	delay in scafolding activities	2	2	2	4	4	4	8	8	8	proper design and testing of design	1	1	1	4	4	4	4	4	4
	Jacket	2P	No access to jacket temp reinforcement areas	improper/ no installation of reinforcements	2	2	2	4	4	4	8	8	8	Proper design with respect to limitations of working area	1	1	1	4	4	4	4	4	4
		2Q	Difficuilt access for scafolding	delay in topside cutting activities	3	3	3	4	4	4	12	12	12	Proper design with respect to limitations of working area	1	1	1	4	4	4	4	4	4

Category	Sub-category	Risk ID	Risk Description	Maximum likely impact	Probability Score (1-5)			Impact Score (1-5)			Risk Score			Risk response measure	Probability score after			Impact Score after			Risk Score after		
					Single Lift	Reverse Inst.	Piece Small	Single Lift	Reverse Inst.	Piece Small	Single Lift	Reverse Inst.	Piece Small		Single Lift	Reverse Inst.	Piece Small	Single Lift	Reverse Inst.	Piece Small	Single Lift	Reverse Inst.	Piece Small
Topside removal	HVL mob.	3A	Grating or grillage not-ready/wrong	delay in mobilization	1	1	1	4	4	4	4	4	4	Grating Preparation and design Incl review	1	1	1	2	2	2	2	2	2
		3B	Required equipment and slings not ready	delay in mobilization	2	2	2	4	4	4	8	8	8	Proper planning, Prepare equipment prior to arrival of vessel	1	1	1	4	4	4	4	4	4
		3C	Pile dredging equipment not ready for loading	delay in mobilization	2	2	2	4	4	4	8	8	8	Proper planning, Prepare equipment prior to arrival of vessel	1	1	1	4	4	4	4	4	4
		3D	Piledredging/cutting equipment seafastening failure	damaged equipent/HLV	1	1	1	4	4	4	4	4	4	Proper planning, Prepare deck layout; including lashing points, Arrange welding team	1	1	1	3	3	3	3	3	3
	Positioning	3E	(If Jack-Up is used) Jack-up punch through	Mobilization of additional equipment	1	1	1	5	5	5	5	5	5	Execute core sampling	1	1	1	5	5	5	5	5	5
		3F	(If Jack-Up is used)Presence of footprints from jack-up	Requiring alternative execution methodologies	2	2	2	2	2	2	4	4	4	assess bottom profile survey	1	1	1	2	2	2	2	2	2
		3G	(If Jack-Up is used) Presence of unknown obstacles at seabed	Requiring alternative execution methodologies	2	2	2	2	2	2	4	4	4	assess bottom profile survey	1	1	1	2	2	2	2	2	2
		3H	Vessel DP system fails	jacket/topside collapse	1	1	1	5	5	5	5	5	5	DP trails before operations	1	1	1	5	5	5	5	5	5
		3I	Vessel Anchor system fails	jacket/topside collapse	1	1	1	5	5	5	5	5	5	Prepare detailed mooring plan	1	1	1	5	5	5	5	5	5
	Topside lift	3J	CoG not as per design due to modifications	Load spread in lifting slings incorrect/delay of jacket lift	3	3	3	5	5	5	15	15	15	Prepare detailed lift plans. Check for modifications	3	3	3	4	4	4	12	12	12
		3K	Tension in crane wire not correct	Shock loads when cutting	1	1	1	5	5	5	5	5	5	Prepare detailed lift plans	1	1	1	4	4	4	4	4	4
		3L	Cables/Pipes/Other not disconnected	No lift possible	2	2	1	5	5	5	10	10	5	Prepare detailed lift plans. Check for modifications. Prepare checklist for separation	1	1	1	4	4	4	4	4	4
		3M	Grillage not suitable	Cannot land topside onto grillage	1	1	1	4	4	4	4	4	4	Proper design	1	1	1	2	2	2	2	2	2
Substructure removal	Pile dredging	4A	Pile dredging equipment failure	Delay in pile dredging	2	2	2	3	3	3	6	6	6	Proper planning, Deliver Equipment with Sufficient spares	1	1	1	3	3	3	3	3	3
		4B	Pile dreding equipment sea fastening failure	damage to equipment or vessels	1	1	1	4	4	4	4	4	4	Proper planning / Prepare deck layout	1	1	1	4	4	4	4	4	4
		4C	Failure to install dredging tool, inside pile	Mobilization of additional equipment	1	1	1	4	4	4	4	4	4	Proper design and planning, verify diameters, consider guiding	1	1	1	4	4	4	4	4	4
		4D	To much soil resistance to clean out	Mobilization of additional equipment	3	3	3	4	4	4	12	12	12	Proper selection of tool, Inspection of Seabed condition	1	1	1	4	4	4	4	4	4
		4E	Soil migration into dredged areas	Impossible to install cutting tool in removal phase	1	1	1	3	3	3	3	3	3	Cap off dredged piles	1	1	1	3	3	3	3	3	3
	Jacket lift	4F	Unforeseen tension in temporary reinforcements	Shock loads when cutting	2	2	2	5	5	5	10	10	10	Check motion sensor logs. Install tension sensors	1	1	1	3	3	3	3	3	3
		4G	Tension in crane wire not correct	Shock loads when cutting	1	1	1	5	5	5	5	5	5	Prepare detailed lift plans.	1	1	1	4	4	4	4	4	4
		4H	CoG not as per design due to modifications	Load spread in lifting slings incorrect/delay of jacket lift	3	3	3	5	5	5	15	15	15	Prepare detailed lift plans. Check for modifications	3	3	3	4	4	4	12	12	12
		4I	Pile still attached to jacket	Cannot lift jacket	2	2	2	5	5	5	10	10	10	Prepare detailed lift plans. Check for modifications. Prepare checklist for separation	1	1	1	3	3	3	3	3	3
		4J	Jacket heavier, marine growth	Insuficient lifting capacity	4	4	4	5	5	5	20	20	20	Used addittional factor for heavy lift vessel selection	2	2	2	4	4	4	8	8	8
		4K	Grating not suitable	Cannot land Jacket	1	1	1	4	4	4	4	4	4	Proper design	1	1	1	2	2	2	2	2	2
	Demob	4L	Unsufficient waterdepth for HVL to reach quayside	Crane barge can't come alongside	1	1	1	3	3	3	3	3	3	Proper planning / Organize harbor tugs	1	1	1	3	3	3	3	3	3
		4M	Loss of tow wire	Grounding of barge/HLV	2	2	2	5	5	5	10	10	10	Ardent personel onboard one of each tug	2	2	2	3	3	3	6	6	6
		4N	Insufficient stability	Capsizing of barge/HLV	1	1	1	5	5	5	5	5	5	Calculate stablility with payload	1	1	1	4	4	4	4	4	4
		4O	Failure of seafastings	Loss of cargo	2	2	2	5	5	5	10	10	10	Proper planning / Prepare deck layout including lashing points	1	1	1	4	4	4	4	4	4
		4P	(If Jack-UP is used) Seabed Puncture at quayside	Damage to HLV/cargo	1	1	1	5	5	5	5	5	5	Check allowable seabed loads	1	1	1	4	4	4	4	4	4

C

Appendix C: Heavy Lift input variables

Crane influences

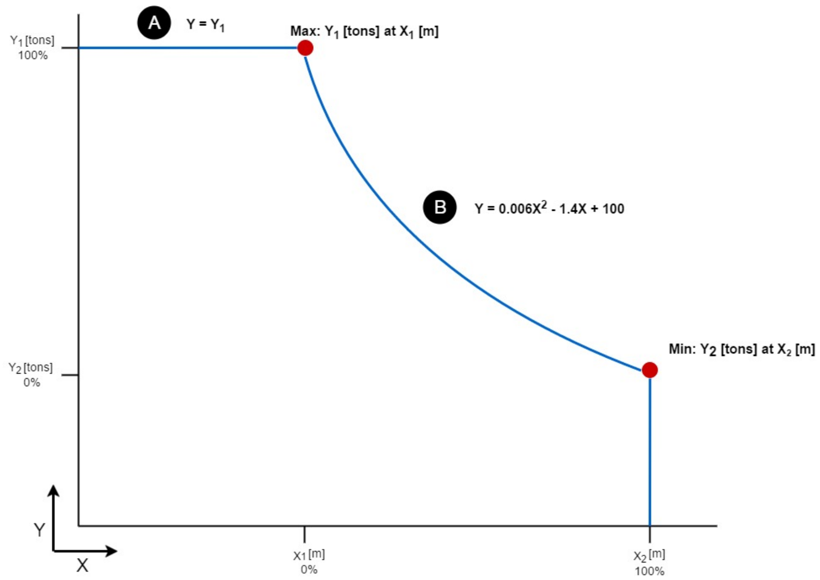


Figure C.1: Estimation of crane curve

Lift capacity

Lift capacity determines whether the offshore structure can be lifted by single lift, or in modules using piece medium. The crane capacity is given in a certain amount of tons at a maximal reach, such as 800 [tons] at 40 [m]. Also a maximal reach of a crane is given. Based on these two variables a crane curve has been estimated as shown in figure C.1. Within the figure the first part of the crane curve shown as "A", is the constant maximum crane capacity. Part "B" estimates the decrease in crane capacity with the formula $Y = 0,006X^2 - 1,4X + 100$. In this formula Y represents the percentage of the maximum lifting capacity Y_1 remaining at a certain reach. The variable X is the percentage of crane reach, where 0% is given at maximum capacity X_1.

The crane curve estimate formula is a regression formula based on five crane vessels. The crane vessels where each in a different category of crane vessel category, and had varying crane capacities.

An important note to this crane curve estimation is its simplicity. In reaction to this estimation, TU Delft lecturer of "Design of Transport Equipment" Ir. W. van den Bos stated: "A crane curve is dependent on the crane type. Most of the times there is a maximum momentum that limits the total lifting force. In addition there might be certain parts within the crane that cannot exceed load limits. Last of all a crane will have a minimum lifting radius."

From this feedback, only the mentioned maximal lift force is used in the estimate. In conclusions the estimated crane curve can be described as scientifically inaccurate. When the crane curve estimation is analyzed from a more broad perspective, the function of the estimate is to be able to select a HLV in an early phase of the decommissioning project. In this early phase the emphasis should be on the decommissioning method selection and planning. If the contract is won, further detailed engineering will be required to calculate the actual limits for the offshore lifting operations. Therefore the limitations of this crane estimate are noted and excepted within this research.

Crane Reach

The reach of the crane determines whether the crane hook can actually move into position above the platform. For a stable lift the crane hook should be positioned above the center of gravity of the platform. If the crane is not able to reach above the platform, the crane is not suited for that specific decommissioning project. Also the lifting of the jacket is dependant on the crane reach. When the reach of the crane is insufficient to lift the whole jacket above sea-level, the crane will not be able to lay down the jacket on a barge. In that case, the jacket will have to be decommissioned piece medium.

Vessel influences

Positioning System

The type of positioning system that an HLV uses determines the duration of the positioning at the offshore structure. The positioning systems identified in this research are: anchors, DP system and jack-up legs.

(non-)Self-propelled

A HLV can be self-propelled or non-self propelled. In case of a non-self-propelled HLV, additional tugs are required during the project to maneuver the HLV. Therefore this parameter influences the (de-)mobilization durations.

Crane pivot point to stern or side

The distance of the crane pivot point to the stern/side of the vessel influences the distance between platform and crane pivot point. This results in a reduction of crane reach. The distance from pivot point to stern/side is visualized in section! in figure! under ”A”.

D

Appendix D: Costs sheet

			Price [$]	
Dayrate	People	Office Team & Logistical Support	$ 2,875.00	DEFAULT
		Salvage Master	$ 2,100.00	DEFAULT
		Assistant Salvage Master	$ 1,725.00	DEFAULT
		Project Manager	$ 1,725.00	DEFAULT
		Naval Architect	$ 1,725.00	DEFAULT
		Logistics Coordinator	$ 1,150.00	DEFAULT
		Warehouse Personnel	$ 800.00	DEFAULT
		Prep. Team	$ 718.00	DEFAULT
		Lifting Supervisor	$ 750.00	DEFAULT
		Piece Small Team	$ 718.00	DEFAULT
		ROV Crew	$ 1,050.00	DEFAULT
	Equipment	(Anchor Handling) Tug	$ 9,000.00	DEFAULT
		Barge	$ 5,000.00	DEFAULT
		Crane Vessel	$ 275,000.00	
		Accomodation Vessel	$ 19,000.00	DEFAULT
		Platform Supply Vessel	$ 10,000.00	DEFAULT
		Diving Support Vessel	$ 25,000.00	DEFAULT
		ROV	$ 1,200.00	DEFAULT
		Cutting Equipment Topside	$ 9,250.00	DEFAULT
		Cutting Equipment Jacket	$ 9,000.00	DEFAULT
Fixed price		Accomdation Costs per person	$ 72.00	
		First Survey, incl. helicopter	$ 25,000.00	
		Cutting Equipment Topside	$ 48,000.00	
		Cutting Equipment Jacket	$ 110,000.00	
		Consumables Prep. Work	$ 50,000.00	
		Rigging/Dunnage/Grillage	$ 479,523.33	
		Pilotage/Harbor Fees/Tug Support	$ 12,500.00	
		Fuel Costs per ton	$ 300.00	DEFAULT

E

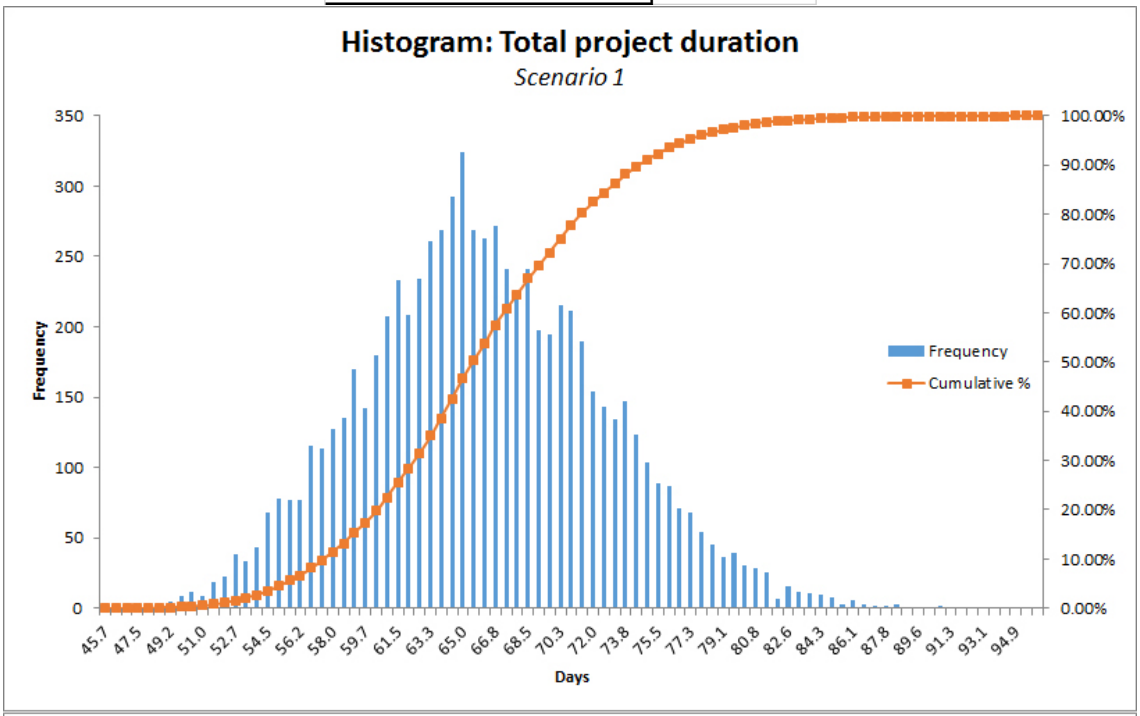
Appendix E: Example of planning table

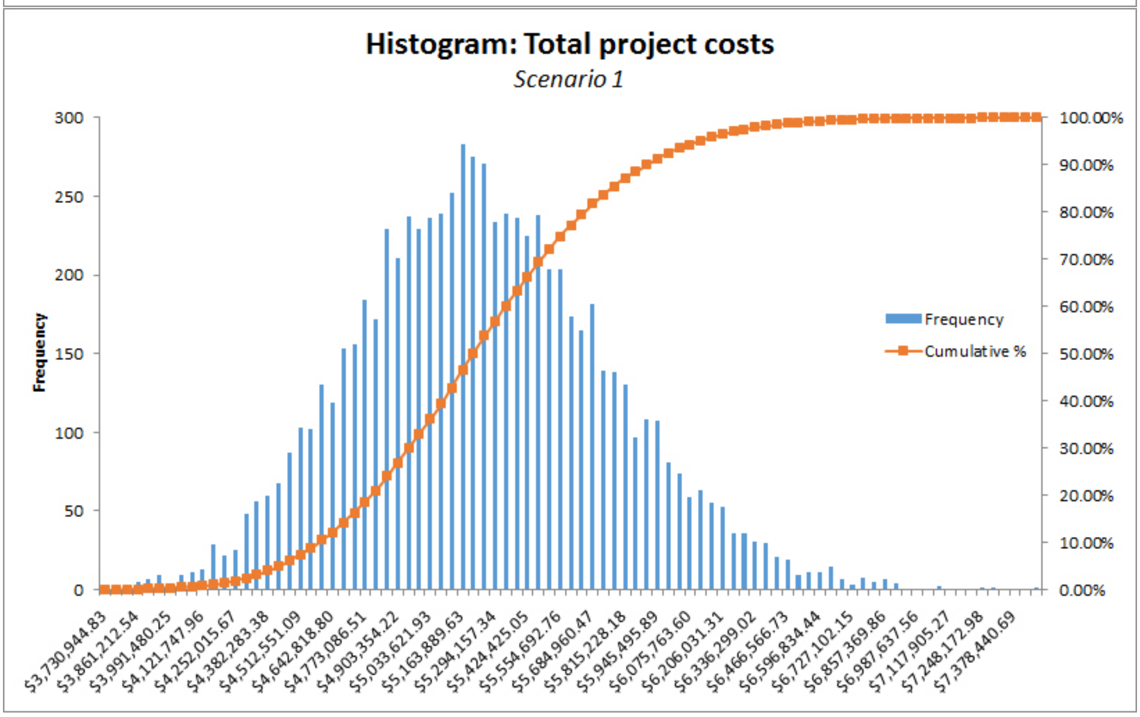
Single Lift			
	Topside Chosen Method:	YES	
	Jacket chosen method:	YES	
1. Preparations			
1.1 Survey Platform		3	[days]
1.1.1	Mobilize Survey team	1	constant
1.1.2	Platform Survey	1	constant
1.1.3	Demob Survey team	1	constant
1.2 Mobilization		5	[days]
1.2.1	Load equipment	3	constant
1.2.2	Sail to site	1	constant
1.2.3	Positioning on site/DP trials	1	constant
1.3 Facilities making safe		10.4	[days]
1.3.1	Install lighting/Temp. power	2	constant
1.3.2	Install navigational lighting	0.6	variable
1.3.3	Scaffolding	1.7	variable
1.3.4	De-energize platform's own	2.8	constant
1.3.5	Flush clean and remove haza	2.8	variable
1.3.6	Secure loose items	2.8	variable
1.4 Topside preparations		11.1	[days]
1.4.1	Strenghtening works for cutt	11.1	variable
1.4.2	Disconnect caissons/risers	3.6	variable
1.4.3	Disconnect pipework & elect	2.8	variable
1.4.4	Prepare as many cutting wor	4	constant
1.4.5	Prepare as many lifting pad-e	5	constant
1.5 Demob preparations		3	[days]
1.5.1	Sail to port	1	constant
1.5.2	Unload equipment to shore	2	constant
2. Topside removal			
2.1 Mobilization		8.5	[days]
2.1.1	Install grillage	7	variable
2.1.2	Load equipment	1	constant
2.1.3	Sail to site	1	binary
2.1.4	Positioning on site/DP trials	0.5	binary
2.2 Topside removal		2	[days]
2.2.1	Access Topside	0.25	constant
2.2.2	Rig Topside	1	constant
2.2.3	Cut Topside from Jacket	1	constant
2.2.4	Lift Topside	0.125	constant
2.2.5	Load topside to barge/HLV	0.125	binary
2.2.6	Sea-fast/de-rig Topside	0.5	constant
3. Substructure removal			
3.1 Pile Cutting Loop		3.4	[days]
3.1.1	Dredging of pile	1.5	variable
3.1.2	Install cutting tool in pile	0.3	variable
3.1.3	Cut pile	1.3	variable
3.1.4	De-install cutting tool	0.3	variable
3.2 Jacket Lift		3.25	[days]
3.2.1	Install lifting pad-eyes	2	constant
3.2.2	Rig jacket	0.5	constant
3.2.3	Lift jacket	0.125	constant
3.2.4	Load jacket to barge/HLV	0.125	binary
3.2.5	Sea-fast/de-rig MSF	0.5	constant
3.3 Demob		6	[days]
3.3.1	Sail HLV to dismantle site	1	constant
3.3.2	Lift jacket to shore	1	constant
3.3.3	Lift topside to shore	1	constant
3.3.4	Unload equipment to shore	3	constant
	Total Duration	59	[days]

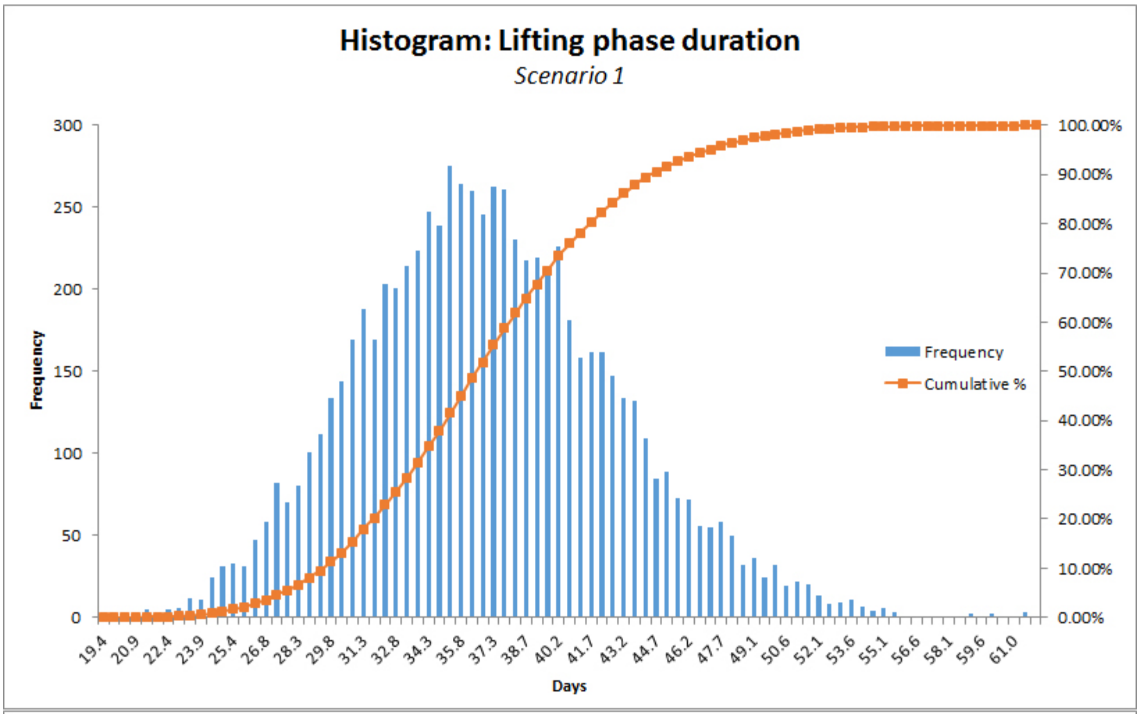
F

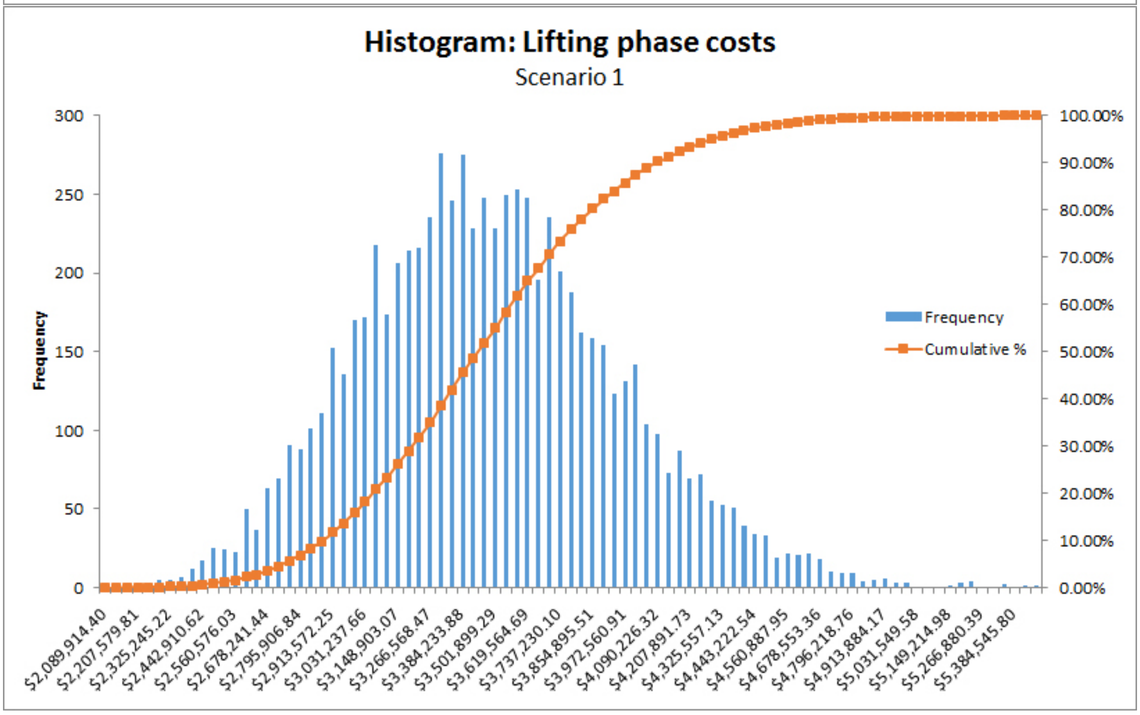
Appendix F: Example scenario results

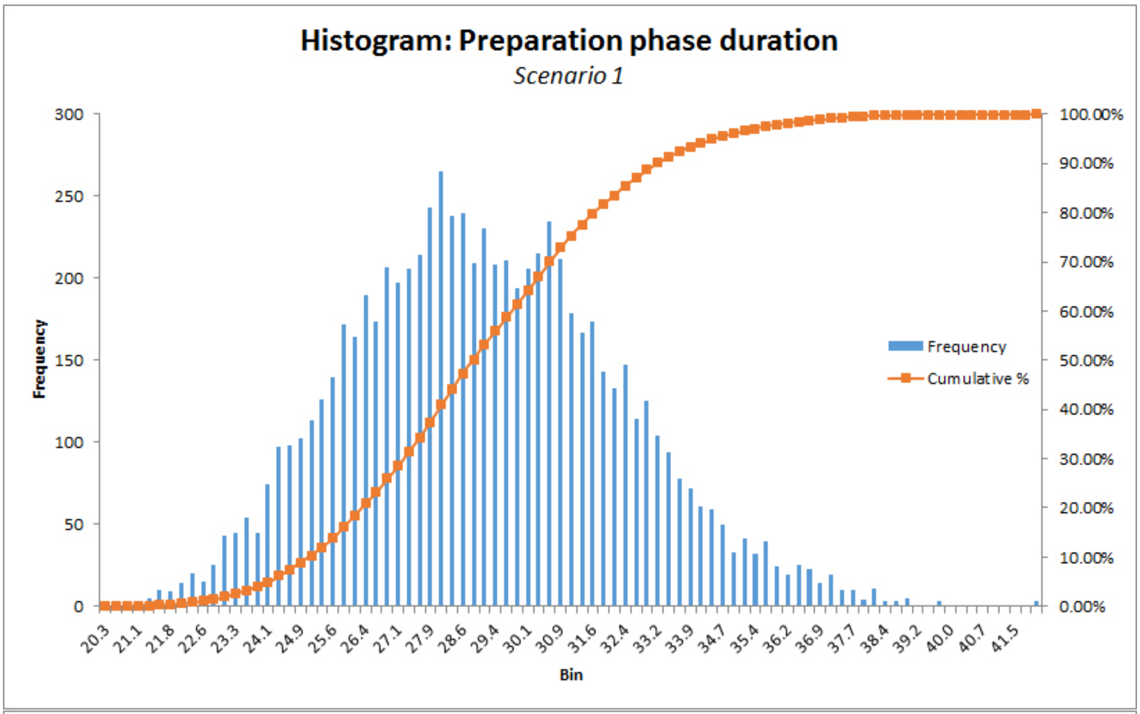
No Risks Durations [days]:		
Total project	Top.+Jack.	Prep.
44	22	22
average price per day:		
Top.+Jack.	Prep.	
$ 83,050.00	$ 58,352.00	
CRI (Duration HeavyLift)		
0.8782220		
CRI (Duration Preparations)		
0.4304055		
CRI (Costs HeavyLift)		
0.9369542		
CRI (Costs Preparations)		
0.3085441		

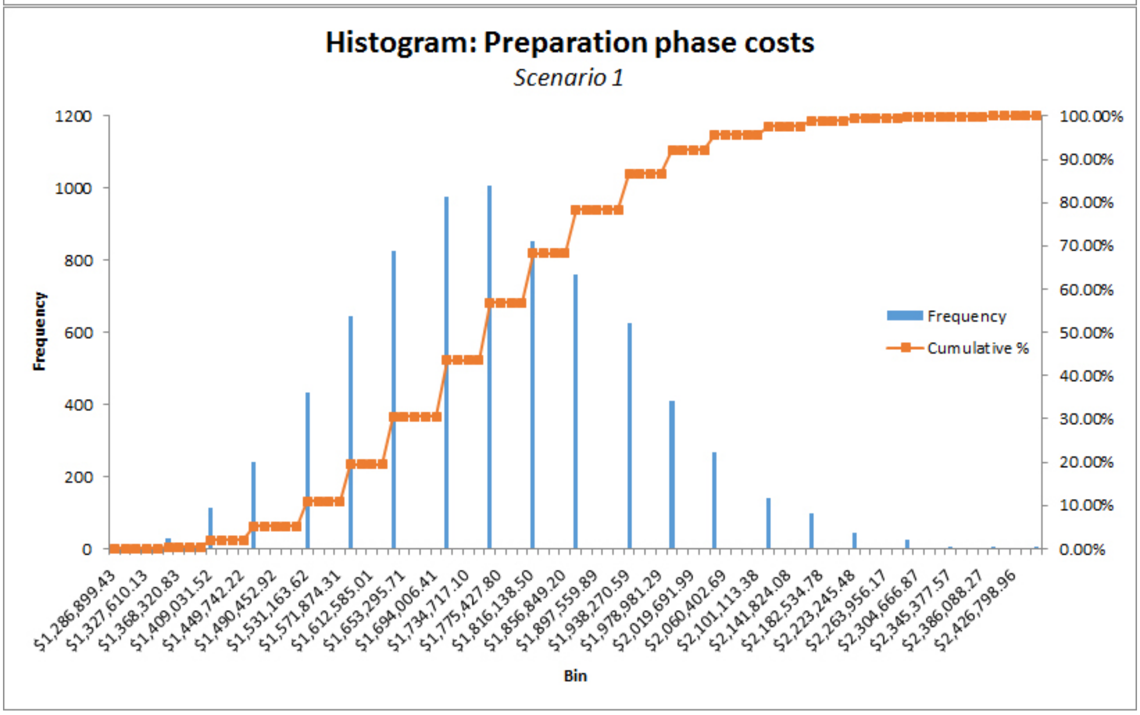





Histogram: Lifting phase duration
Scenario 1
Frequency
Cumulative %
Days
Frequency


Histogram: Lifting phase costs
Scenario 1
Frequency
Cumulative %
Frequency


Histogram: Preparation phase duration
Scenario 1
Frequency
300
250
200
150
100
50
0
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
Frequency
Cumulative %
20.3 21.1 21.8 22.6 23.3 24.1 24.9 25.6 26.4 27.1 27.9 28.6 29.4 30.1 30.9 31.6 32.4 33.2 33.9 34.7 35.4 36.2 36.9 37.7 38.4 39.2 40.0 40.7 41.5
Bin


Histogram: Preparation phase costs
Scenario 1
Frequency
1200
1000
800
600
400
200
0
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
Frequency
Cumulative %
$1,286,899.43 $1,327,610.13 $1,368,320.83 $1,409,031.52 $1,449,742.22 $1,490,452.92 $1,531,163.62 $1,571,874.31 $1,612,585.01 $1,653,295.71 $1,694,006.41 $1,734,717.10 $1,775,427.80 $1,816,138.50 $1,856,849.20 $1,897,559.89 $1,938,270.59 $1,978,981.29 $2,019,691.99 $2,060,402.69 $2,101,113.38 $2,141,824.08 $2,182,534.78 $2,223,245.48 $2,263,956.17 $2,304,666.87 $2,345,377.57 $2,386,088.27 $2,426,798.96
Bin

Bibliography

[1] N R Anthony, B F Ronalds, and E Fakas. Platform Decommissioning Trends. *SPE Asia Pacific Oil and Gas Conference*, pages 1–8, 2000.

[2] Ardent Global. Ardent internal documents.

[3] British Petroleum. North West Hutton Decommissioning Close-Out Report. (February): 0–278, 2005.

[4] Climate and Pollution Agency Norway. Decommissioning of offshore installations. pages 4–10, 2011. ISSN 00222410.

[5] R M Cooke and L H J Goossens. Procedures Guide for Structural Expert Judgement in Accident Consequence Modelling. *Radiation Protection Dosimetry*, 90(3):303–309, 2000. ISSN 01448420. doi: 10.1093/oxfordjournals.rpd.a033152. URL `http://rpd.oxfordjournals.org/content/90/3/303.abstract`.

[6] Joop W P Coolen. North Sea Reefs. Benthic biodiversity of artificial and rocky reefs in the southern North Sea. 2017.

[7] Decom North Sea. *Decommissioning in the North Sea*. Number 1. 2014. ISBN 9780874216561. doi: 10.1007/s13398-014-0173-7.2.

[8] Decom North Sea. Norh Sea Installations Database, 2014.

[9] Department of Energy & Climate Change. Decommissioning of Offshore Oil and Gas Installations and Pipelines under the Petroleum Act 1998. *Offshore Decommissioning*, 6 (March), 2011.

[10] EBN. Focus on Dutch Oil and Gas 2015. 2015.

[11] Energy Resource Technology Ltd. Camelot Decommissioning Close-Out Report. pages 1–39, 2012. URL `https://www.gov.uk/government/uploads/system/uploads/attachment{_}data/file/255075/Camelot{_}dp.pdf`.

[12] Nicholas R.; Farnum and Laverne W. Stanton. Some Results Concerning the Estimation of Beta Distribution Parameters in PERT. *The Journal of the Operational Research Society*, 38(3).

[13] Fornyeleses Fonden. A Danish Field Platforms and Pipelines Decommissioning Programmes, 2013.

[14] A. M. Fowler, P. I. Macreadie, D. O B Jones, and D. J. Booth. A multi-criteria decision approach to decommissioning of offshore oil and gas infrastructure. *Ocean and Coastal Management*, 87:20–29, 2014. ISSN 09645691. doi: 10.1016/j.ocecoaman.2013.10.019. URL `http://dx.doi.org/10.1016/j.ocecoaman.2013.10.019`.

[15] Fugro GEOS. Wind and wave frequency distributions for sites around the British Isles. Technical report, 2001.

[16] J. Grolin. Corporate legitimacy in risk society: the case of Brent Spar. *Business Strategy and the Environment*, 7(4):213–222, 1998. ISSN 09644733. doi: 10.1002/(SICI)1099-0836(199809)7:4<213::AID-BSE158>3.0.CO;2-I.

[17] Haitham K. M. Mokhtar. Decommissioning of Offshore Platforms, 2014. URL `www.pceuae.com/d/96{_}wYew4a.pdf`.

[18] David Hillson. Existing Approaches to Risk Management. *Effective Opportunity Management for Projects: Exploiting Positive Risk*, 2003.

[19] Adery C Aca Hope. A simplified Monte Carlo significance test procedure, 1968. ISSN 00359246. URL http://www.jstor.org/stable/2984263.

[20] Dolly Jørgensen. OSPAR's exclusion of rigs-to-reefs in the North Sea. *Ocean and Coastal Management*, 58:57–61, 2012. ISSN 09645691. doi: 10.1016/j.ocecoaman.2011.12.012. URL http://dx.doi.org/10.1016/j.ocecoaman.2011.12.012.

[21] J. Kamburowski. New validations of PERT times. *Omega*, 25(3):323–328, 1997. ISSN 03050483. doi: 10.1016/S0305-0483(97)00002-9.

[22] Russell Kenley and Olli Seppänen. *Location-Based Management for Construction*. 2010. ISBN 978-0-415-37050-9.

[23] Salem Y. Lakhal, M. I. Khan, and M. Rafiqul Islam. An "Olympic" framework for a green decommissioning of an offshore oil platform. *Ocean and Coastal Management*, 52(2):113–123, 2009. ISSN 09645691. doi: 10.1016/j.ocecoaman.2008.10.007. URL http://dx.doi.org/10.1016/j.ocecoaman.2008.10.007.

[24] D Liversidge, Shell, S Taoutaou, and S Agarwal. Permanent Plug and Abandonment Solution for the North Sea. *SPE Oil and Gas*, pages 1–5, 2010. doi: 10.2118/100771-MS.

[25] Guy Mélard. On the accuracy of statistical procedures in Microsoft Excel 2010. 2014. doi: 10.1007/s00180-014-0482-5.

[26] Offshore Magazine. Worldwide survey of heavy lift vessels. 2016.

[27] Oil & Gas UK. 2013 Decommissioning Insight UK. page 6, 2013.

[28] OSPAR. GUIDELINES AND STANDARDS FOR THE REMOVAL OF OFFSHORE INSTALLATIONS AND STRUCTURES ON THE CONTINENTAL SHELF AND IN THE EXCLUSIVE ECONOMIC ZONE. 1998.

[29] Terry Berends Robert B. Stewart Ovidiu Cretu. *Risk Management for Design and Construction*. 2011.

[30] John Preedy. Subsea Engineering (Lecture Notes), 2015.

[31] Robert G. Sargent. Vefication and Validation of Simulation Models. *Proceedings of the 2011 Winter Simulation Conference, 11-14 Dec*, pages 2194–2205, 2011. ISSN 08917736. doi: 10.1109/WSC.2011.6148117.

[32] Silverstone Energy Limited. Tristan NW Field Close-Out Report, 2010.

[33] Rob Sparreboom and Herman Zant. Indefatigable Field Platforms and Pipelines Decommissioning Programme Close Out Report. 2014.

[34] Staatstoezicht op de Mijnen. Dutch Mining Law Sect.4, 2002.

[35] Total E&P Norge AS. Frigg Field Cessation Plan Close Out Report, 2011. URL https://www.gov.uk/government/uploads/system/uploads/attachment{_}data/file/43409/4204-frigg-close-out-report.pdf.

[36] Mario Vanhoucke. *Integrated Project Management Source Book*. 2016. ISBN 0071466266. doi: 10.4043/10830-MS. URL https://www.fgould.com/uk-europe/articles/integrated-project-management/.

[37] H.P.M. Veeke, J.A. Ottjes, and G. Lodewijks. *The Delft Systems Approach*, volume 1. 2008. ISBN 978-1-84800-176-3. doi: 10.1007/978-1-84800-177-0.

[38] Venture Production plc. Kittiwake SAL Decommissioning Close-Out Report, 2009. URL https://www.gov.uk/government/uploads/system/uploads/attachment{_}data/file/43401/kittiwake-sal-export-dp.pdf.

[39] Doug Woodyard. *Pounder's Marine Diesel Engines and Gas Turbines*. 2009. doi: 10.1016/B978-0-7506-8984-7.00005-9.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