Optimization of the lift point design decision-making process for offshore jacket decommissioning

Thesis

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MSc Thesis

Optimization of the lift point design decision-making process for offshore jacket decommissioning

by

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to obtain the degree of Master of Science
at the Delft University of Technology,
to be defended publicly on Tuesday the 13rd of December, 2022 at 14:00.

Student number:	4305639	
Project duration:	October 18, 2021 – December 13, 2022	
Thesis committee:	Prof. dr. Ir. A. Metrikine	TU Delft, Chair
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Abstract

All over the world, many offshore structures have been built in the last decades, both by the oil and gas industry and by the renewable industry. When these structures reach their end of life, they have to be removed. The removal is done in decommissioning projects. Many of those offshore structures are bottom founded. Of that amount, a big part has steel space frame substructures called jackets. Jackets are often removed with a heavy lift vessel. The crane hook of such a vessel is connected to the structure to be lifted by means of lift points. These lift points are the connection point of the rigging with the structure.

The structures removed in decommissioning projects are often more than 30 years old. Because of that, there are a lot of uncertainties encountered by the industry in decommissioning projects that can lead to issues, such as loss of information or unknown material strength. The result is that all aspects of a decommissioning project have to be reconsidered each time. This makes the preparation phase costly and time-consuming. An aspect of the preparation is the selection of the lift point type, while it is unclear how and whether an optimum solution is chosen. Therefore the question arises, if the decision making process can be optimized by improving the selection of the lift point type in the preparation phase. One way to optimize such a decision-making process is by means of artificial intelligence. AI is able to compare data where humans see no connection, it can analyze large pieces of data in a much shorter time than humans can, it makes unbiased decisions and it can significantly reduce errors and increase accuracy and precision. This thesis will therefore focus on the optimization of the decision-making process of the lift point design of jackets by means of artificial intelligence.

To answer the overall research question, first an analysis is made of various decommissioning projects of the past years. These projects were carried out by Boskalis. In this analysis, an attempt is made to visualize which steps are taken in the lift point selection process. By means of these steps it can be investigated whether there is a repetition or trend in the selection process of the lift points. In addition, the analysis aims to find the criteria the decisions are based on.

Secondly, the analysis shows that certain steps are taken by Boskalis in the decision-making process of the lift point design in decommissioning projects. A trend was clearly visible in the way the lift points were selected. The relatively simple options are examined first, after which the more difficult options are investigated if the others prove impossible. In addition, the analysis found clear criteria that are used in the selection of the lift points. These criteria were reflected in the selection process of the execution strategy and in the selection process of the lift points. In addition to the total costs, among others ease of installation and the total duration also play a major role in the decision-making process. For example, an option was chosen that was more expensive than its alternative, but had a much shorter duration. This information made it possible to determine whether AI could be used in decommissioning projects in the future, to accelerate the preparation phase.

Thirdly, it is investigated whether AI can improve the decision-making process of the lift point design. Therefore, three AI applications are examined and compared with the previous findings. The AI applications are: machine learning, genetic algorithms and single variable optimization. All three turned out not to be a good solution to the problem. For machine learning there is too little data available. Genetic algorithms do not seem to give the desired output with the given inputs. And single variable optimization is too limited in its solution. The final conclusion is therefore that the three investigated AI applications in this way will not improve the decision-making process of the lift point design.

If the data set were to be expanded, machine learning could eventually be applied in the future. In addition, it could be investigated in future research whether genetic algorithms can be used if the input is changed. This thesis only briefly discusses what GA entails and whether the method has the desired output with the data found. Also, only a limited number of AI applications have been investigated in this thesis. But there are many today. For example, multi variable optimization could be a starting point for further research. Because there, the optimization function can have two variables, so that, for example, time and cost can be entered in different units.

Preface

This thesis has been written in order to obtain my masters degree in Offshore & Dredging Engineering, a multidisciplinary cooperation between Civil Engineering, Mechanical Engineering and Marine Technology of the Delft University of Technology.

This project was realized in collaboration with Boskalis, one of the largest offshore contractors and dredging companies in the world. Together with Boskalis, a subject was found that corresponds with my personal interests. I am grateful that I was able to write this thesis at Boskalis. With this I also got to know the company well and eventually found results that can be used in further research.

I would like to take this opportunity to thank Mark ten Klooster for his excellent guidance within Boskalis throughout the project, which gave me insight into the actual course of affairs within Boskalis. He was always open to my questions and had a clear answer that allowed me to move on.

From TU Delft I would like to thank Bart Ummels for his huge support, his way of guiding my research, but especially his guidance in writing it down. I really enjoyed working with you.

Of Boskalis I would also like to thank Rik van Mierlo, Diogo Tavares, Alex de Leur, Jack Spaan, Job Valstar and Harmen Boersma for the interviews, time for questions and support. Thanks to them I obtained information to do my research.

In terms of AI, I want to thank Gilbert Kruimer, Harold van Heukelum and Rogier Wolfert for helping me in an area I knew nothing about. Thanks to them I gained new insights and knowledge concerning artificial intelligence.

Finally, I would like to thank my girlfriend, family and friends for their support and mental support to make this research a success. And for the welcome distraction every now and then.

D.W. Tetteroo
Delft, December 2022

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Chapter 1

Introduction

This chapter will give an introduction to the thesis topic that focuses on the optimization of the decision-making process of the lift point design of offshore jacket decommissioning projects. First, some information about the current amount of offshore structures and what a decommissioning project is, is given in section 1.1. Second, the different substructures and vessel types will be treated in 1.2 and 1.3. Then, some common equipment that is being used in decommissioning projects is discussed in 1.4, followed by the impact the weather can have on offshore operations in 1.5. In section 1.6, the way Boskalis approaches projects and risks will be set out. The link to artificial intelligence will be made in 1.7. Finally, the problem will be formulated together with the research objective and research questions in 1.8 and the approach is defined in section 1.9.

1.1 Background

In the last decades a lot of offshore structures have been built around the globe. At first it were mainly oil & gas platforms consisting of a topside to accommodate the facilities and equipment and a substructure to support the topside. In 2018 there were already 1332 offshore oil rigs throughout the world. Some examples are the North Sea with 184 rigs, the Gulf of Mexico with 175 and East Asia with 155 rigs [1].
Then, with the increasing demand for clean energy, wind farms are being constructed offshore. At present, Europe alone has already a total installed offshore wind capacity of 22,072 MW.[2]. And in addition, for example, China has also build a lot of offshore wind turbines and is still expanding, see Figure 1.1. Therefore, both the oil industry and the renewable energy industry have a large number of structures offshore.

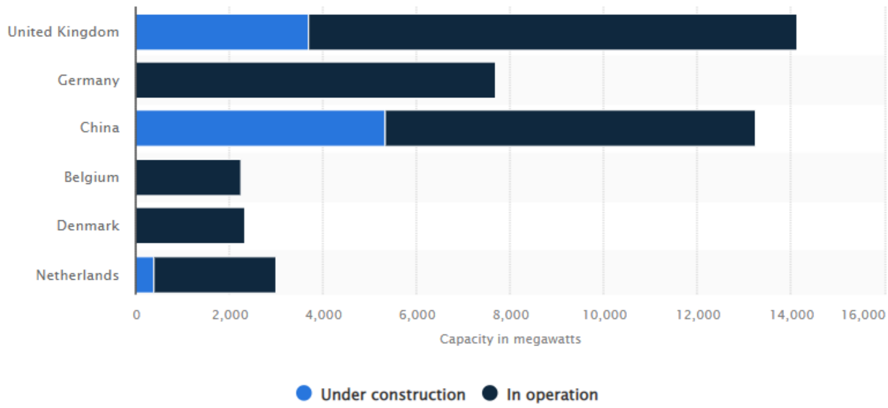


Figure 1.1: Wind Capacity in 2021[3]

According to the regulations set by the International Maritime Organization(IMO), owners should remove offshore installations in order to protect the environment when such facilities reach their end of life and are thus abandoned or no longer used [4]. This removal operation is done in a decommissioning project.

In decommissioning projects, the company that owns the structure can no longer make a profit. These kinds of projects only cost money as value is no longer generated by the structure. There is only a downside for the company as it costs money and the project entails some risk: If the decommissioning fails, it can lead to major costs and environmental damage. Also, decommissioning failure can lead to reputation damage. This happened, for example, at

Shell in 1995 during the decommissioning of the Brend Spar. Shell decided to sink the Brent Spar at the North Feni Ridge in the Atlantic Ocean. This decision met with a lot of resistance from society. As a result, European consumers and politicians turned against Shell. In Germany, the resistance became so great that several service stations of Shell were damaged. Eventually Shell abandoned this plan and came up with another solution to reuse the steel in the construction of a harbour in Norway. However, the reputational damage for Shell had already been done and became such that the business operations of the multinational came under pressure: it had an extremely negative effect on business operations [5].

That is why the owner wants to transfer the risks associated with the removal as much as possible to the contractor to prevent PR-damage and to carry out these types of projects as cheaply and quickly as possible. Because the longer it takes, the more it will cost. This therefore requires an efficient approach by the contractor that executes the project to meet those demands. The company that owns the structure will issue a tender for the removal of the structure. In the tender, the company indicates whether, for example, it wants a lump sum or day rate contract. A lump sum contract means that a fixed amount of money is asked for the whole execution. A lump sum is often requested because the risk then lies with the contractor: if the costs are higher than expected due to, for example, setbacks, these costs are for the contractor. But on the other hand, the contractor can earn a lot from such a contract if it can estimate the costs well in advance: if the contractor can estimate his costs well, he can either bid lower than the competitors to increase its probability to win the tender, or he can still bid more or the same as the competitors and thereby make more profit than if the costs cannot be estimated correctly and as a result his expenditures can be higher than predicted.
The contractors that compete for the tender must determine and present the methodology of the execution to the client and indicate for which price they want to do it. It is possible that the client wants a lump sum, but that the contractor does not agree due to for instance uncertainties and risks, so that the contractor still offers a day rate as price. If the contractor chooses or agrees to offer a lump sum, it is crucial, as mentioned, that the costs for the execution are properly estimated. This can be a real challenge to achieve as the structure has been around for over 30 years and in that time information may have been lost and thus become unavailable to the contractor. Such information may be (unreadable) construction drawings, dimensions of structural members, additions or removals made to the platform, weight control reports, or inspection reports. Due to this type of contract and the lack of information, most of the risks lie with the contractor. For example, if something is not as was documented, the contractor has to deal with it and if this takes more time or increases the costs the contractor will not get extra money in compensation. In such a case it would have been better for the contractor to have a day rate contract so that this risk was borne by the client. Some other risks are the condition of the structure and its strength, which can be unclear. Because of these risks, these uncertainties, the costs for decommissioning can become high for the contractor. If a vessel is needed longer, this can cost a few tons per day extra. The vessels that are used for these operations will be discussed later on.

1.2 Offshore substructures

Each offshore location has its own environmental conditions such as soil type, wave conditions and water depth. These conditions determine what kind of substructure is necessary, that is why there are several types of substructures. The type of substructure is mainly determined by the water depth and the corresponding cost: if two types of substructures could be used, the one with the least cost would be chosen. See Figure 1.2 for a rough estimate of the costs per water depth for some substructure types. For a water depth of 1000m the tension leg platform (TLP) will be preferred over the compliant tower (CT).
About 95% of all offshore substructures world-wide are bottom founded structures, that means they are connected to the seabed [6]. This connection can be permanent (jacket) or temporary (jack-up), stiff (jacket) or compliant (compliant tower) and piled or gravity based. Of these bottom founded structures [6]:

- About 35% are Steel Space Frame structures (ca. 4600),
- Almost 64% are Monopile or Caisson structures (ca. 8400), and
- Less than 1% are Gravity Based Structures (51).

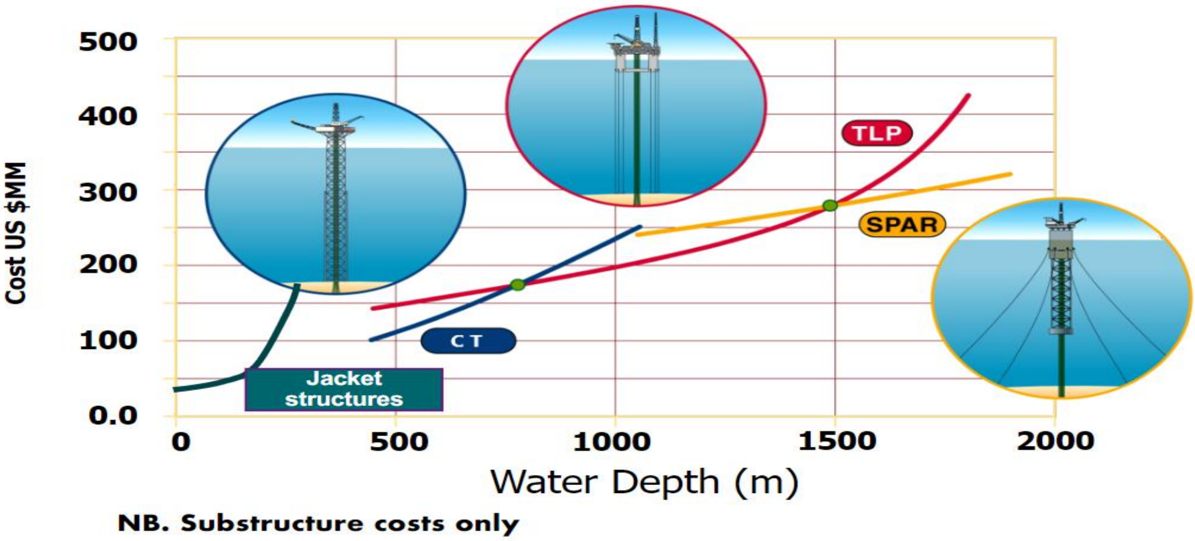
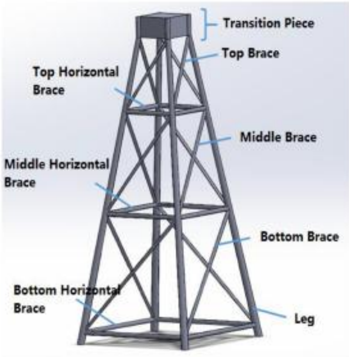


Figure 1.2: Cost per water depth [7]

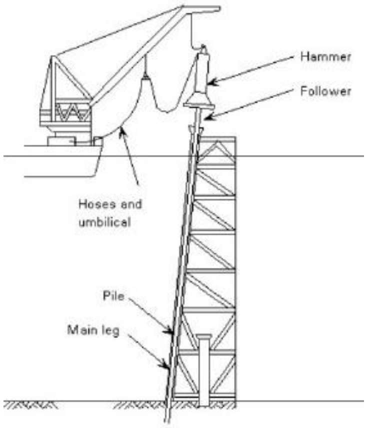
Monopiles and caisson structures are the largest part, followed by steel space frame structures. Monopiles and caisson structures are mostly used as substructure for offshore wind turbines. And because this industry is relatively new, many of these structures are still in operation and not yet at their end-of-life. With some exceptions.
The structures that are reaching their end-of-life are mostly oil & gas platforms, which are for the most part build on space frame substructures such as jackets. Thus, most structures that are being decommissioned or going to be decommissioned are jacket structures. In addition, some wind farms were also being built on jackets, so jackets will still need to be removed in the future. Also, the removal of bottom founded structures is more difficult than that of floating structures as floating structures do not have to be lifted out of the water, but can be stabilized, cut loose and towed to the disassemble area. This makes the decommissioning process easier than that of bottom founded structures. Therefore the focus will be put on the decommissioning of jacket substructures.

1.2.1 Jackets

A jacket is a steel space frame consisting of multiple legs and braces, see Figure 1.3a. The legs are connected to the seabed by means of a pile. This pile can be hammered into the ground with a hydraulic hammer placed on top of the pile, or it can be vibrated into the ground with a vibrating device. Both machines work under water. The advantage of a vibration device is that it produces much less noise than a hammer, which is beneficial for marine life and therefore requires less noise mitigation. However, these machines are generally a factor of 10 heavier than a hammer according to experts. As a result, the crane can lift a less heavy construction for the same radius than when using a hammer. In addition, a hammer requires less energy than a vibrating device, because the hammer uses the kinetic energy of the anvil and because the energy to get the pile into the ground is used more efficiently: the energy in the hammer is used to crumble and move the ground and to give the pile a speed so that it goes into the ground: the energy is converted into a force pointing towards the ground. Whereas the energy of a vibrating device vibrates the entire pile so that that energy cannot be used to drive the pile into the ground: there is no great force pointing towards the ground like with the hammer. For these reasons, the hydraulic hammer is generally used to install such piles.
Piles can be put through the leg, see Figure 1.3b, or through a sleeve of the leg built at the base of the structure, see Figure 1.3c. The latter is also called a tower instead of jacket. To obtain a rigid and strong connection between the pile and leg/sleeve, grout is used. In the case of jackets, the grout is poured over the entire length between the leg and pile and the top of the pile is also welded to the jacket. With towers, grout is poured between the pile and sleeve and ridges are welded on the inside of the sleeve and on the outside of the pile to generate more friction resulting in a stronger connection.
Jackets come in all shapes and sizes and are commonly used for water depths in the range of 20 to 150 meters, but can be used up to a depth of 450 meter [7].



(a) A conventional Jacket [8]



(b) Installation of a jacket [9]

(c) A tower [10]

Figure 1.3: Jacket and tower

1.2.2 Cutting tools

In order to be able to remove the jacket, all piles have to be cut through. Nothing should remain after the jacket has been removed, the site should be returned to the state it was found in before the installation of the jacket. However, there is an exception for the piles as they run very deep into the seabed. The piles can be cut some meters below the mudline, how much meter depends on local legislation [11]. There are multiple tools to cut a pipe such as external cutting tools like a (diamond) wire cutter and internal cutting tools like an abrasive water jet cutter (AWJC) [12]. Internal cutting tools are initially used to cut the piles under the mudline due to accessibility: the seabed gets in the way with external tools. Only dents and deformations in the pile can prevent or complicate the lowering of the internal cutting tool.
External cutting tools are also used to cut the pile at other locations. Wire cutters can cut above or under water and are often used to cut the pile at the top so that for example an ILT can be installed. An example of such a cut is the top of the grey pile of Figure 1.6a.

1.3 Vessels

Offshore structures are installed and removed by vessels offshore. The choice of size and capacity of the vessel depends on the method used to lift and move the cargo and on the size and mostly the mass of the cargo. A method that is commonly used is the use of a heavy lift vessel (HLV) such as the Bokalift 1 in Figure 1.5b or the use of a float-over vessel like the White Marlin in Figure 1.4a. Float-over vessels can sail under the cargo and sink and rise in the water allowing them to pick up and drop the cargo, see Figure 1.4b. This is only not possible with most old jackets as it is a fairly new method and those (old) jackets do not allow for this method. Therefore this thesis will treat the case where a heavy lift vessel is used.

(a) Float-over vessel White Marlin[13]

(b) Float-over vessels in action[14]

Figure 1.4: Float-over

1.3.1 Heavy lift vessel

Heavy lift vessels are vessels with a large crane to lift and move the cargo. There are several types of heavy lift vessels as environmental conditions and other constraints such as needed lift capacity may vary. Depending on the environmental conditions and constraints, one vessel will be better than the other for the specific task. In this way, the best cost-effective type of vessel can be chosen for every project. Some common types are: a jack-up such as in Figure 1.5a, which can lift itself out of the water by extending its legs onto the seabed, eliminating the influence of the waves on the motion of the vessel. A Sheerleg vessel, see Figure 1.5c, that are used principally in shipbuilding, cargo management and salvage operations. Semi-submersibles such as the Sleipnir in Figure 1.5d, that can lower or rise their working deck for loading and offloading cargo by partially submerging itself. And at last mono-hull vessels such as the Bokalift 1 in Figure 1.5b. The Bokalift 1 and the Bokalift 2 are the heavy lift vessels of Boskalis that will be worked out in more detail because these vessels are almost always used by Boskalis for decommissioning projects.

(a) Jack-up NG-20000X [15]

(b) Monohull vessel Bokalift1 [16]

(c) Sheerleg vessel Taklift4 [17]

(d) Semi-submersible Sleipnir [18]

Figure 1.5: Some heavy lift crane vessels

Bokalift 1

The Bokalift 1 is one of the two heavy lift vessels of Boskalis. It is a mono-hull vessel with a revolving crane which has a main block capacity of 3000 metric ton up to 28 meter radius and 800 tonnes up to 72 m radius. The crane also has an auxiliary block with a lift capacity of 1,200 tonnes up to 50 m radius and 600 tonnes up to 81 m radius. And a whip hoist with either a double fall of 200 tonnes up to 92 m radius or a single fall of 80 tonnes up to 94 m radius. The choice of which hoist block to use depends on the weight of the structure that has to be lifted and the reach that is needed. The smaller the block capacity, the less often the cable is reeved, so the faster the hook can move up and down. It is a choice between speed and capacity. This HLV is, just like any other floating vessel, not limited by water depth and uses the dynamic positioning (DP) system DP-2 for station keeping and stability. Due to its DP-2 capabilities there is no loss of time for anchor spread deployment. The vessel can handle more than 60 knots of wind on the bow and winds of force 6 to 7 on the beam, and the vessel can maintain its position in strong currents [19]. Furthermore, the shape of the hull is more streamlined, allowing the vessel to sail faster and operate in a rougher marine environment than any other non-streamlined vessel. In addition, mono-hull vessels can weather vane continuously in order to reduce the motion. This improves the workability of the vessel.
With the given crane capacity, the Bokalift 1 has the ability to lift structures up to approximately 3000 tonnes. As an HLV the vessel is used for installation and removal operations for both the oil & gas industry and the renewable industry. In the oil & gas industry this comes down to the installation and removal of relatively small to medium-sized jackets and topsides when compared to, for instance, the bottom founded Ringhorne platform in the North Sea with a topside of 11520 tonnes and a jacket of 7200 tonnes [6]. In the offshore renewable industry these small to medium-sized jackets are commonly used for wind turbines. Therefore the Bokalift 1 also regularly installs these types of jackets for the renewable industry, as can be seen on Figure 1.5b.

Bokalift 2

After the success of the Bokalift 1, Boskalis decided to convert another hull to create the Bokalift 2, which would be ready in 2021. This vessel also has a DP-2 system for station keeping and a revolving crane of 4,000 tonnes capacity capable of lifting structures more than 100 meters high, up to a range of 28 m radius. Or the crane block is moved where it can lift 2,400 tonnes up to 25.5 m radius. The auxiliary block can lift 800 tonnes at 63 m radius. The vessel has 7,500 m2 of free deck space and is able to accommodate 150 persons.

Just like the Bokalift 1, the Bokalift 2 is used for installation and removal operations for both the oil & gas industry and the renewable industry. Which of the two vessels is used for a project depends on the required crane capacity. And the type of project chosen, be it installation or decommissioning, depends on the market and the available projects: if there are many projects available on the market to do, then the contractor can choose between projects and thus chooses a project with less risk than the alternatives. In such a case, the contractor will then, for example, go for installation rather than decommissioning, since there are more uncertainties involved with decommissioning, which can lead to more risks. But on the other hand, if few projects are available, the contractor is more likely to take more risk and therefore accept a project with more risk, because income must continue to be generated.

1.4 Lift Points

When using a crane vessel, the rigging to lift the structure must be connected from the hook to the structure. There are several ways to do this. Equipment could be used to connect the rigging to the structure or a fixed connection could be made between the structure and the rigging. The point where the rigging is connected to the structure is called a lift point. Usually 3 or 4 lift points are used while lifting an offshore structure, but this could be more. Four common techniques to make a lift point for the decommissioning of jackets will be discussed followed by spreader bars & frames.

1.4.1 Shackles

Shackles are one the most simple forms to create a lift point as it is not a complicated configuration and it does not take a lot of time to install: first two holes are made, then a shackle is attached to each hole, and finally the shackles are connected to a sling of the rigging. See Figure 1.6a for an example of such a situation. Only the cutting of the holes can take some notable time: the holes must be perfectly round which requires a sophisticated device. And sometimes scaffolding or another form of access is required in order to install the cutting machine. In addition, it may be the case that the pile is not strong enough to resist the load in the shackle, so that reinforcement is needed. This reinforcement can be the application of cheekplates where the holes should be to increase the thickness. Shackles are standardized to certain standards, usually by fabricator; a Crosby standard or a Green Pin standard, for example. These standards define how much force you can put on the shackle and what the respective dimensions should be. In this way the risk of failure is reduced and it makes finding the right size of shackle for the applied load easy. A downside is that shackles usually cannot be pre-installed on jackets because the pile often has to be cut in order to install them.

1.4.2 Trunnion

A trunnion consists of a tube with two endcaps, see Figure 1.6b. One way is to make two holes in the structure where the trunnion must be placed. The diameter of the holes depends on the diameter of the trunnion, which depends on the load it must carry and on the curve the sling's noose at least needs to have to run smoothly. When the holes are made the tube is pushed through and finally the endcaps are attached. Then a sling can be put around the trunnion after which it can be lifted. This method takes more preparation time than the shackle, because the trunnion needs to be fabricated and the two holes that need to be made must be on exactly the same line in order for the trunnion to fit. As with shackles, sometimes scaffolding or another form of access is required to be able to make the holes. A disadvantage of this method is that the trunnion will block the access to the inside of the pile, so that, for example, an internal cutting tool can no longer enter the pile. Therefore this type of trunnion cannot be pre-installed to a jacket, that is in a phase prior to the removal operation.

The other way to install a trunnion is to weld the two endcaps of the trunnion to the structure instead of putting the trunnion as a tube trough two holes. This connection is weaker than the other trunnion configuration. And it will take a lot of welding, which is not preferred as it takes a lot of time. The advantage is that this type of trunnion can be pre-installed to a jacket.

1.4.3 Internal Lifting Tool

The internal lifting tool (ILT) is used to lift and upend structures and piles. This connection is also quite simple: The ILT is placed inside the pile and then the lifting contact teeth or spacer blocks around the gripping circumference expand and make contact with the pile inner wall which results in a fail-safe and quick lift. This can be reversed for a quick release. Therefore the ILT is easily installed and removed.

Each ILT has a certain range of diameter in which it can be used, often a range of around 40 to 50 centimeters. This is accomplished by shortening or lengthening the spacer blocks: the spacer blocks are not one solid part but consist of multiple smaller parts which can be removed or added while staying in the range of the ILT. The outer contact teeth are removed, then the spacer block can be altered and finally the contact teeth are put back on. As a result, 1 ILT can be used to lift, for example, piles from 36 inch to 54 inch by only adjusting the spacer blocks. See Figure 1.6c for an ILT, the grey blocks are the spacer blocks. There are several sizes of ILTs available for the various type of dimensions and loads. There also exists a special decommissioning ILT that has a larger capacity. This is to account for the extra material added during the structure its operational life and the unknown weight additions due to environmental factors [22].

1.4.4 Padeye

A padeye is a connection point between an object and a shackle to facilitate lifting and/or fastening of the object, see Figure 1.6d. Padeyes are typically dimensioned for the specific situation according to the required Safe Working Load (SWL) of the specific padeye. Because of this the (peak) stresses will be brought to a minimum. But still a padeye uses less area than a trunnion to withstand the forces, so a trunnion will often introduce even less stress peaks in the material. Another downside of padeyes is that they have to be welded to the structure if they are not already there. This therefore creates extra work prior to lifting, which entails additional costs. An advantage is that pad-eyes usually can be pre-installed.
The Roark's equations for stress and strain can be used to obtain a quick but conservative solution for the load capacity using a two-dimensional model. Besides that a three-dimensional FEM model can be used to get a very detailed solution of the load capacity, but FEM requires a lot of computation time [23].

(a) Shackle connection (b) A trunnion[24] (c) An internal lifting tool[22] (d) A padeye[25]

Figure 1.6: Four common lift points

The discussed types of lift points can be compared with regard to their installation. Only the situation in which the lift point must be installed is considered: the situation in which the lift point is already present is not taken into account. This comparison is depicted in Table 1.1. The configuration involves the complexity of the lift point. Please note that this is a general assessment and that this may differ per project.

Lift point type	Can be pre-installed	Configuration	Installation duration	Ease of installation
Shackle	-	++	++	+
Trunnion	-	+	+	+
Trunnion - welded	+	-	-	-
ILT	-	+	++	++
Padeye	+	++	-	-

Table 1.1: Lift point type comparison

From the table can be concluded that the ILT and shackle connections are the fastest and easiest lift points to install. The lifting points that need to be welded are not and will take the most time to install. This problem can be solved by pre-installing them, if possible.

1.4.5 Spreader bars & frames

Spreader bars and lift frames are applied to divert the compressive and bending forces into the frame instead of the section that is lifted. Therefore the use of a lift frame or spreader bar is particularly favourable for the lift of a section that has been cut loose or has low compressive resistance. Or for situations where the force needs to act in a certain direction, as with pad-eyes and ILTs. The spreader bar then ensures that that direction is maintained. Figure 1.7a shows an example of a spreader frame. The difference between a spreader bar and a spreader frame is the layout. A spreader bar diverts the forces over one axis and a spreader frame is able to divert the compressive forces in two directions [27].

Besides spreader bars & frames there are also spacer frames. Spacer frames are used to position equipment while suspended form the crane hook, such as ILTs. These frames do not divert compressive and bending moments but only hold equipment in position. In Figure 1.7b a spacer frame is shown that is used to install four ILTs simultaneously in a jacket. The difference in purpose of the two frames is clearly visible when the two images are compared: it can be seen that the main rigging (the thick slings) through which the load passes is attached to the frame in Figure 1.7a, while that is not the case in Figure 1.7b. There the main rigging is attached to the four ILTs instead of the frame and there are additional slings to hold the frame in place.

(a) A spreader frame (b) A spacer frame in combination with four ILTs suspended from the crane hook

Figure 1.7: Spreader & spacer frame

1.5 Weather window & Workability

Weather conditions are an important factor in the planning and execution of marine operations as they determine whether a vessel can perform an offshore operation or not. Furthermore, during the execution of the operation the weather has to be monitored continuously to successfully perform the operation. Therefore, marine operations can be classified as weather restricted or as weather unrestricted. This depends on the duration of the marine operation, the operation reference period, T_R according to the DNV-GL code[21]. The operation reference period consists of two parts, the planned operation period T_{POP} and the estimated maximum contingency time T_C, and is defined as:

$$T_R = T_{POP} + T_C \tag{1.1}$$

The planned operation period, T_{POP}, shall as far as possible be based on a detailed schedule for the operation. The time estimated for each task in the schedule should be based on an assessment of experience with same or similar tasks. The contingency time, T_C, will cover the uncertainties in the planned operation. This includes general uncertainties, unproductive time during the operation due to unforeseen problems and possible contingency situations that require additional time to complete the operation.
Marine operations with a reference period less than 96 hours and a planned operation time less than 72 hours may be defined as weather restricted. If the operation cannot be defined as weather restricted the operation shall be defined as weather unrestricted. The starting point of a weather restricted operation is the point where the last weather forecast is published. A weather restricted operation shall be planned to be executed within a reliable weather window. In Figure 1.8 the operation periods with the required weather window is depicted. This weather window is, together with weather forecasts, established by defining a forecasted operational criteria OP_{WF}, defined as:

$$OP_{WF} = \alpha \times OP_{LIM} \tag{1.2}$$

OP_{LIM} is the limiting operational environmental criteria and is described in the operational manual. The α factor is to account for uncertainties in both the monitoring and the forecasting of the environmental conditions. The DNV-GL guideline has more details of how to obtain this α factor, but T_{POP} is the basis for selecting the α factor.

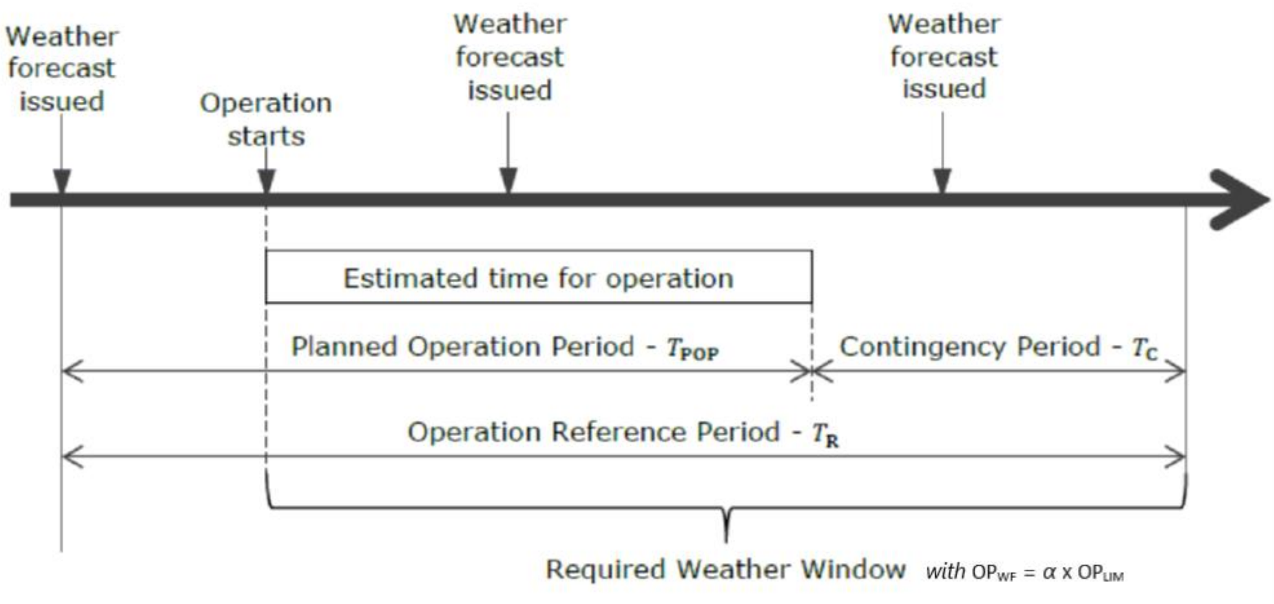


Figure 1.8: Operation periods [21]

1.5.1 Weather forecasts & sensitivity

Weather forecasts are needed to obtain a reliable weather window and to successfully perform the operation. Therefore, arrangements should be made to receive weather forecasts at regular intervals before and during marine operations. Such weather forecasts must be obtained from recognized sources and should be project and area specific.

There are different types of marine operations and each operation has its own sensitivity to weather conditions. That is why there are three levels of weather forecasts, level A, B and C according to chapter 2.7.2 of the DNVGL code [21]. The required weather forecast level is based on the sensitivity of the type of operation to the weather conditions and the operation reference period, T_R.

The weather forecast levels are as follows:

- Level A: This level applies to major marine operations that are sensitive to environmental conditions, such as mating operations and float-over operations.
- Level B: This level applies to operations of significant importance with regard to value and consequences that are sensitive to environmental conditions. Examples of such operations are tow-out operations and heavy lift operations.
- Level C: This level applies to conventional marine operations less sensitive to weather conditions that are carried out on a regular basis. Examples are onshore/inshore lifting operations and load-out operations.

Public domain weather forecasts are acceptable as Level C forecasting, but the inherent increased uncertainty should be considered. For operations that require a Level A weather forecast, thorough consideration should be given to have the dedicated meteorologist on site to monitor the forecasts continuously. In the case of installation and decommissioning with an HLV, generally a level B forecast is needed as these projects entail mainly heavy lifts.

1.5.2 Workability

Every method and equipment has a certain weather sensitivity and therefore a limit to where it can be applied or used. This can be the lift of a structure or the transit with the structure onboard. In the case of a lift, several situations are considered such as, for example, when the construction is still in the water, in the splash zone, in the air and when lowered on deck. For each of these situations a certain limit applies in which the operation can be executed. And if the operation is weather restricted, a weather window is required for the time needed for the operation. The required weather window together with this limit translates into downtime, which determines the workability of the operation: the more downtime there is, the lower the workability will be.
The downtime is the amount of time that the operation cannot be executed, in days. It is calculated by means of the maximum significant wave heights that are allowed for the operation and the weather data of the specific location from the past 20 years. The weather data is given either by the client, is from Boskalis itself, or from another institute.

The full calculation is explained in Appendix A. When compared to the data of the last 20 years, this downtime can be expressed in a P-value. Often the P50 and P80 value are determined. P50 means that there is a 50% chance that the downtime will be less than the downtime value given for the P50 value. This determines the workability.
The workability and downtime are then used to make decisions with respect to, for instance, the start date of the execution phase. If the downtime is less when the execution phase is started in June instead of August, it would be wise to start in June. It can also influence the choice of lift point type: suppose there are two options for the lift point. The first option is weather restricted and needs a weather window with certain weather conditions to be able to install the lift point. The second option is not weather restricted and can thus be installed anytime without a weather window. Then the second options has a higher workability as it is not dependent on the weather, as option 1 is.
Another example of how workability can influence the choice of lift point type is with respect to the installation duration. Again, suppose there are two options for the lift point. The first option can be installed in a preparatory phase, but the second option can only be installed when the HLV is on site. Such a situation is, for example, when the lift point can only be installed when the HLV lifts the topside away. If this is the case, the HLV must wait for the lift point to be established before it can continue its work. And because the HLV is performing heavy lifts, a weather window is required in which the work must be done: this time period is also called a critical time path. So the lift point has to be installed in this critical time. This is not desirable because then there is less room for errors or setbacks due to the weather window. The workability of the second option is in this situation therefore less than that of the first option.

1.6 Boskalis Way of Working

Boskalis has incorporated a general approach to projects and risks in their own Way of Working (WoW), a consistent approach in initiating, planning, executing and completing projects [28]. In designing this system, Boskalis observed the principles and guidelines of the ISO 31000 standard for risk management. The WoW is a quality system and the aim is to enable employees to excel together in what Boskalis does, with a clear focus on safety, sustainable solutions and customer focus, more than just systems and procedures. At the same time, the system encourages diversity in the teams and facilitates innovation. This with an eye for people and the environment and based on a way of acting in which respect and integrity are central. The overall process is depicted in Figure 1.9 and an extended version can be found in Appendix B.
With WoW, the projects are made visual already in the preparation phase. Therefore the entire team and the client know what they are working towards. Projects are visualized in modules and these are literally hung on the wall. This way everyone can see at a glance how each part will eventually be delivered. In addition, it makes the team more flexible. The team can adjust or leave out separate modules where necessary without completely changing the planning of the project.

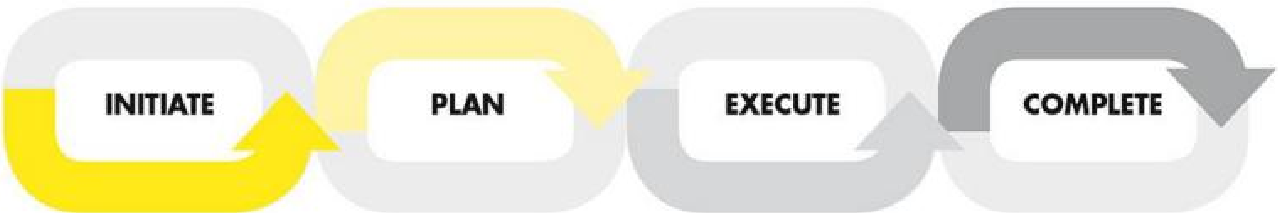


Figure 1.9: WoW flowchart.

This way of working corresponds to the general structure of a project: projects always consist of different stages [41]. These are the Tender phase, Early preparation phase, Preparation phase, Execution phase and Close out [42]. Compared to Boskalis' WoW, the Tender phase and Early preparation phase belong to Initiate, the Preparation phase to Plan, the Execution phase to Execute and Close out to Complete. All these phases will be elaborated in subsection 2.3.1.

1.6.1 One language

WoW, which was devised by Boskalis' own people, ensures that people speak the same language within Boskalis. The project team jointly decides what the layout plan will look like. This makes the goal tangible for the entire team. An example of when the WoW first proved its worth was with a large-scale dredging project on the Nieuwe Waterweg and the Botlekhaven where five million cubic meters of dredging was removed in 26 weeks. The team discussed the approach ahead of time using WoW-visuals to accomplish the goals. By visualising the plans in this manner, possible discussions can start at an early stage. A joint agreement is already made in advance about the method of delivery.

This immediately forms a solid basis for the smooth running of the project.
This approach can also be found in decommissioning projects. Interviews with engineers of Boskalis and after viewing documents from the decommissioning projects show that in such projects discussions with the client and project team members are started as early as possible to make an inventory of what information is available and what is missing, and to define the deliverables so that everyone knows what needs to be done.

1.6.2 Safety

The Health, Safety Environment and Quality section (HSEQ) is responsible for implementing health and safety legislation for offshore operations. Health and safety is about stopping workers getting (lethally) hurt at work or ill through work. All workers have a right to work in places where risks to their health and safety are properly controlled and brought to a minimum. The major aspects of offshore safety include ensuring that employees wear protective clothes whenever they are working. This is of the utmost importance because it protects the employees from accidents. Another aspect is to insure that all the machines and tool are in good conditions. This means that the machines should be repaired and maintained regularly. And that the machines are operated by people who are properly trained. This is to make sure that everything goes well with the machines being operated properly. It is also paramount to ensure that the buildings and other structures are in good condition, this is achieved through having regular inspections to make sure that everything is in order [29].

Safety is a core value and a top priority at Boskalis. The No Injuries No Accidents (NINA) safety program reflects the objective of ensuring that employees return from work safely each day. NINA embeds the desired safety culture in the organization and makes safety a fully integrated part of working behavior. Personnel safety shall be duly considered throughout the marine operations. This subject shall be managed by the client or his nominated contractor in accordance with local jurisdiction, as well as appropriate guidelines and specifications regarding health, safety and the environment [21]. In this report, therefore, the assumption is made that every action or choice guarantees this safety.

1.6.3 Lessons learned

After each project Boskalis does a session of 'Lessons Learned'. The project will be evaluated to find points such as decisions or actions that went well or could have been done better. This way the overall work output, the deliverables, can be improved in the future. It is checked whether accidents have happened and, if so, how to prevent them next time. Or if the chosen lift point was eventually the best choice. Or if the mobility of vessels was done efficient. For example, trying to 'quickly' use another vessel because the planned vessel is not available yet is something that will only make it worse and will not work. It has proven that it is better to stick to the original plan.

1.6.4 Findings

Thus, the WoW is a means to steer the execution of a project in the right direction. In this way, the team makes an overview at the beginning with all deliverables that need to be done after which they are worked out and eventually the project can be executed. Documents and interviews show that this is applied and going well in the decommissioning projects. And in the end the team reviews its performance by means of Lessons Learned sessions to improve the work output in the future. It is not clear, however, whether these lessons are actually carried over to other projects. In one case a lesson was to keep track of the decision-making process, but this was not applied in the next project. And in addition, all documents with deliverables are lumped together with no clear structure which makes retrieving documents very difficult. There is room for improvement here.
With decommissioning, part of the deliverables is determining the method to remove the structure. This means, among other things, that the type of lift point must be selected. Because there are many uncertainties surrounding decommissioning due to, for example, information that is missing or the condition of the steel and the strength of the construction that are unclear, several options for lift points are generally worked out. After elaboration, the options are compared with each other on the basis of certain criteria and the best option is chosen. Such criteria are, for example, cost, time required, safety, accessibility and applicability. This process can take a lot of time and it will therefore be investigated whether this decision-making process can be improved. One way to improve such a process is by means of Artificial Intelligence.

1.7 Artificial intelligence

McKinsey Global Institute, alongside other researchers, believe AI to have a revolutionary impact on the man-made decision-making process. The issue with leaving every decision to a human is that our emotions creep in, we get stressed, and our cognitive biases (there are over 180 of them) guide our decisions as much as the data sets do [35]. Dr Jim Taylor, a psychology expert at the University of San Francisco, says that these cognitive biases are simply bad for business [36]. It's important to understand, though, that it does not have to be this black and white. It's not a case of deciding who is going to make every decision in a business, machines or humans – they both have their strengths and they both have their weaknesses. AI is great at dealing with noise and complexity, looking at data sets and spotting trends instantly. Therefore AI can be helpful to improve the decision process of the lift point design. Humans are fantastic at understanding certain external factors and making more creative-led decisions. In most cases, it is therefore the best solution if AI and humans work together, which is illustrated in Figure 1.10: The AI will process the data such as the different types of lift points and will give a suggestion as output to the engineer. This suggestion can be the type of lift point. The engineer can then in turn decide if it really is a good solution or not.

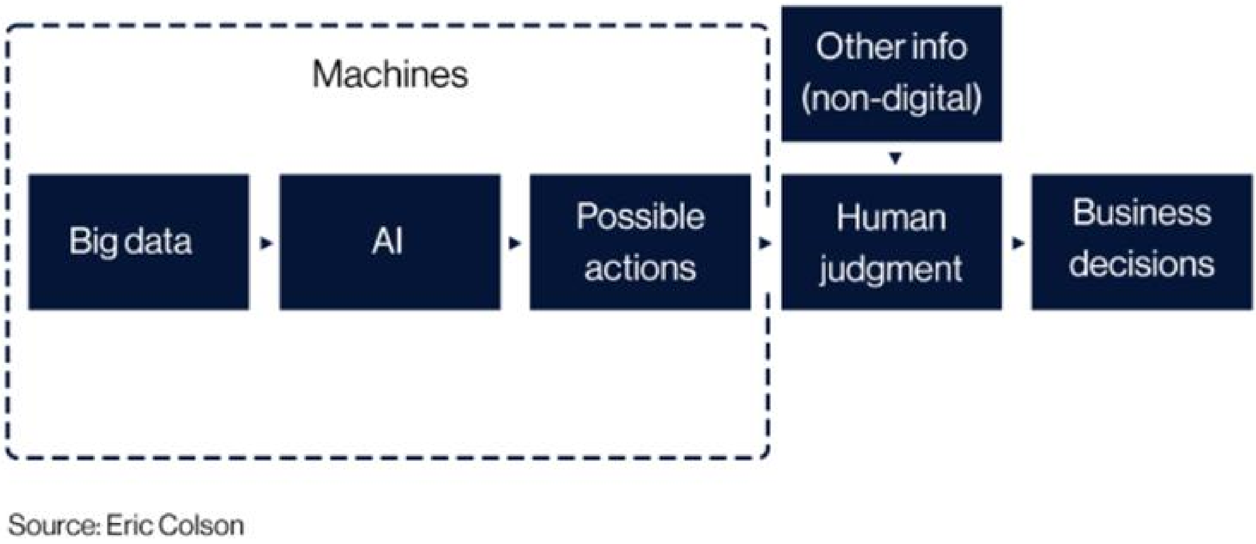


Figure 1.10: Illustration of cooperation of AI and humans

1.8 Problem formulation & Research objective

In decommissioning projects a lot of uncertainties are encountered by the industry that can lead to issues. The main uncertainties are:

- Lack of information available
- Unknown Platform Condition
- Unknown Platform Strength
- Unknown Platform Weight
- Uncertain Breakaway Weight

The result of these issues is that all aspects of a decommissioning project have to be investigated per project (i.e. what information/data is available, how strong is the material after its lifetime, how will the structure be lifted, which lift points can be used, is strengthening needed or not, etc.). Since everything has to be reconsidered each time, the preparation phase is costly and time-consuming. Boskalis is a company with a profit motive, so it wants to do this as fast as possible while maintaining safety and quality. If the engineers have to spend less time on the preparation, they can be redeployed to other tasks more quickly. In this way more work can be done in the same amount of time, which in turn can lead to more profit.

The aim of this thesis is to improve the decision-making process of the lifting design process for decommissioning projects. As most decommissioning projects consist of the same aspects or 'building blocks' (i.e. the same actions and the same moments where a decision is made), but only the inputs are different; an Artificial intelligence (AI) software could be used to assess the inputs by means of defined criteria. It will be investigated whether a generalization can be made such that it could be implemented in AI software and that the software could make the optimal decision for the engineer or could help the engineer to make the optimal decision. This would then improve the decision-making process by making it faster. In other words:

Can Artificial Intelligence software be used to improve the decision-making process of the lift point design process for offshore decommissioning projects?

To be able to answer this question, the following research questions are formulated:

- What steps are taken by Boskalis in the lift point design process for offshore decommissioning projects?
- Which criteria are used in the decision-making process for decommissioning projects?
- How can existing AI models be used in the optimization of the decision-making process of the lift point design process?

1.9 Scope & Approach

This thesis focuses on the lift point design of decommissioning projects and investigates whether the associated selection process can be improved through AI. As mentioned, AI software needs criteria to be able to assess the inputs it receives. These criteria are determined by commercial, strategic, safety and structural requirements. Through interviews with the involved engineers and by looking at previous decommissioning projects it is examined how these criteria influence the decision-making process. Then it will be checked whether the decision-making process can be generalized. If so, it is investigated how it can be implemented in AI such that the process is optimized. This will be a concept and the AI implementation will thus not be done in this thesis.

The structure of the report is as follows: In chapter 1 an introduction is given to decommissioning, it briefly introduces how Boskalis approaches decommissioning projects and it states the problem. Chapter 2 describes the planning of a project, explains existing removal methods and highlights the uncertainties often encountered in a decommissioning project. Then, in chapter 3 three decommissioning projects that have been executed by Boskalis are analysed and an attempt is made to find a global procedure. Chapter 4 attempts to apply the results of the previous chapter to AI in order to obtain a concept to improve the decision-making process of the lift point design of decommissioning projects. Finally, conclusions and recommendations are presented in chapter 5.

Chapter 2

Overview of Offshore Structure Removal

This chapter discusses the uncertainties, general removal methods and general project planning. First, the structures that Boskalis has removed and the uncertainties associated with each part are discussed. Then, some commonly used removal methods are explained. After that the general planning of a decommissioning project is treated, together with the main uncertainties encountered by the industry. And finally, two approaches to do the lift point design are elaborated.

2.1 Removed Offshore Structures

In the last couple of years Boskalis has carried out a number of decommissioning projects. In these projects Boskalis was asked to remove, transport and dispose offshore structures, such as topsides, jackets, bridges and subsea templates. When removing such parts, there are uncertainties as described in section 1.8, such as an unknown platform strength and unknown platform weight. However, some parts will have more uncertainties than other parts. For example, there is a greater chance that the jacket is more deteriorated than the topside, because the jacket is in direct contact with the sea. As a result, the condition of the jacket may be worse than the topside, which can lead to more uncertainties. Or it may deviate more from what has been documented. This can then influence the removal of such a part and therefore also the lift point design: if there is more uncertainty, there will be more risks that must be taken into account and for which mitigations must be devised. There is also a greater chance that there will be oversizing in order to be able to deal with the uncertainties related to forces and moments, i.e. more safety factors. This results in more weight and bigger rigging equipment.
In Table 2.1, Table 2.2 and Table 2.3 are the components listed that Boskalis has removed in three decommissioning projects: the Viking & Vulcan 2019 and 2020 campaign, and the L10 project in 2020. It were 14 platforms in total: 7 platforms in the Viking & Vulcan 2019 campaign, 4 platforms in the Viking & Vulcan 2020 campaign and 3 platforms in the L10 project. In all these projects the Bokalift 1 was used for the execution and in some cases an Offshore Support Vessel (OSV) was also chartered. Jackets and topsides are the main parts, so each will be briefly covered, along with their interfaces.

2.1.1 Topsides

For topsides, Boskalis used the reverse-installation method to reduce the risk when lifting by limiting the uncertainties. With this method, one can look at smaller modules and therefore deal better with the risks per module: the structural integrity between the individual modules no longer needs to be taken into account, where reinforcements might have been necessary if the topside were to be lifted in its entirety. And the reduction in weight also means that fewer safety factors will be needed as the weight uncertainty will be limited. The lift points have to withstand less forces, thus can have a smaller capacity. For jackets this method is not applicable, because a jacket does not consist of multiple modules such as a topside. Therefore this risk reduction is not present with the lift of a jacket and it will have to be dealt with in a different way.

2.1.2 Jackets

Tables 2.1, 2.2 and 2.3 show that the jackets are the heaviest part of the offshore structures. In most cases the weight was much less than the lift capacity of 3000 tonnes of the Bokalift 1 and the geometry was not that large and complex so those jackets could be lifted out of the water in one go, with the single-lift approach. This method reduces uncertainties and risks with regard to safety because only 1 heavy lift is required per jacket and thus also less preparatory work is required, but the risks related to forces will be greater due to the greater weight. The lift points need to have a greater capacity than for the modules in the topside. This risk was reduced by, among other things, using ILTs with a greater capacity than was necessary in terms of strength to account for any uncertainties in strengths and forces.

The CD jacket in the V&V 2019 campaign was different than the other jackets. The geometry of that jacket was more complex and lifting it in one go would entail too many uncertainties with respect to strength, weight and center of gravity leading to too many risks, therefore the piece-small method was chosen, which means that the structure is split in multiple parts: the jacket was split in three pieces; 'Tower 1 & 2' and 'main jacket', see Figure 2.1. The scissors in the figure represent the cutting lines. Because the jacket was cut in three parts, the geometry became less complex, which reduced the uncertainties in weight and mass point. But it did mean that three lifts were needed, which in turn creates more uncertainty regarding safety. In addition there is the uncertainty of the method of cutting: will the part be entirely cut through and can the device work without problems or breakage. In the end, these uncertainties weighed less than the uncertainties that would have existed if the jacket had been lifted with single-lift.

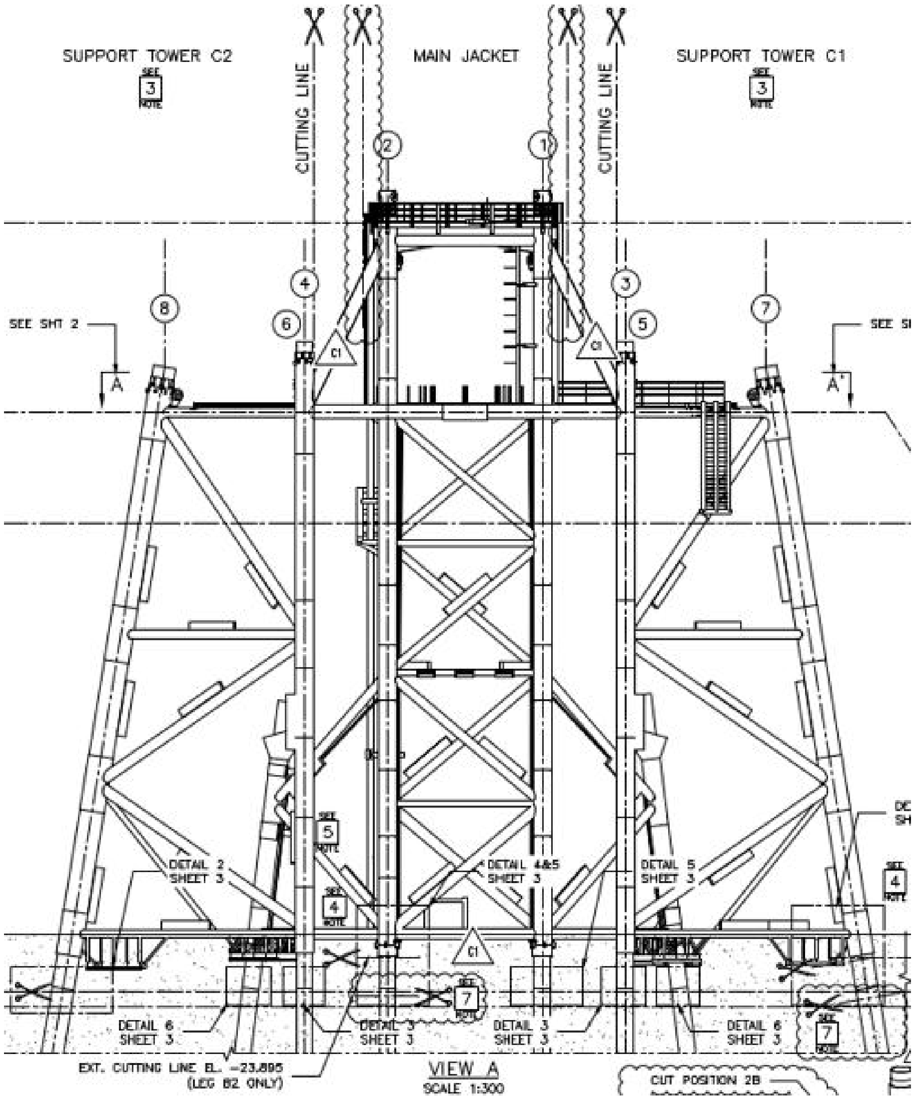


Figure 2.1: CD Jacket of V&V 2019 campaign

2.1.3 Interfaces

A point of interest is the difference in the interface between the topside and jacket and between the jacket and seabed. In general it is often easier to detach and lift the topside from the jacket than to have to cut the jacket off the seabed and lift it out of the water. This is because the interface between topside and jacket is much easier to reach, is not in the water and has often better structural conditions. This reduces uncertainties and risks associated with the detachment. The piles that connect the topside and jacket can often be cut with an external cutter and because the location is above the splash zone and out of the water it can be easily applied. In addition, the cut can also be checked more easily this

way.
It will be different for the jacket-seabed interface. First, the location to cut is under water, a couple of meters under the seabed. This location is not easily accessible and internal cutters need to be used, which involves the uncertainty that there will be deformations or blockages in the pile, creating a risk that the cutter will get stuck or blocked when it is lowered through the pile. An alternative is to cut the piles above the mudline requiring an extra trip to remove the last parts, which entails more cost. Or to excavate the soil around the pile up to the designated depth and then to apply an external cutter, but this option is not preferable as it costs more than an internal cutter and it is more complex. The underwater cut cannot be checked as easily as with the topside-jacket cut, which also gives more uncertainty.

Secondly, the jacket has to be pulled out of the seabed, so it will experience forces due to the soil. With surveys and other tests the soil type and condition can be determined with a certain certainty. Then that data can be used to calculate the soil forces onto the pile, but the uncertainty will work through in this calculation besides the fact that the calculation itself also has a certain accuracy and thus uncertainty. That it can be very difficult to determine these forces is apparent from the V&V 2020 project. The actual hook loads while pulling the jacket out of the seabed were significantly less then the hook loads calculated. This was because the actual weight was 23% less than the calculated weight, which shows that determining the weight is also very difficult. And because the suction force and friction force were significantly lower than expected. In this case it was not that big a problem because the lift could go on. But if it had been the other way around, that the force was significantly higher than calculated, things could have gone seriously wrong. The capacity of elements could be exceeded such that it fails and brakes. Or the vessel could have been damaged. This shows that there are more uncertainties involved when removing a jacket from the sea than removing a topside from a jacket.

Structure	Actual weight in air (metric ton)
Vulcan UR Topside	855
Vulcan UR Jacket	1332
Viking ED Topside	425
Viking ED Jacket	807
Viking HD Jacket	870
Viking CD Support Tower 1	350
Viking CD Support Tower 2	350
Viking CD Main Jacket	730
Victor JD Topside	680
Victor JD Jacket	1240
Victor JD Helideck	89
Victor JD Template	30
Viking GD Jacket	660
Viking DD Jacket	825

Table 2.1: Removed structures in the 2019 Viking & Vulcan campaign

Structure	Actual weight in air (metric ton)
Caister CM Jacket	1310
Caister CM Template	67
Caister CM Topside	992
Ganymede ZD Jacket	1082
Ganymede ZD Topside	976
Viking Bravo BA Jacket	1048
Viking Bravo BA Topside	1433
Viking Bravo BP Jacket	867
Viking Bravo BP Topside	1542
Viking Bravo Bridge BA-BC	191
Viking Bravo Bridge BC-BP	139
Viking Bravo Bridge BP-BD	104
Viking Bravo PLQ	735

Table 2.2: Removed structures in the 2020 Viking & Vulcan campaign

Structure	Actual weight in air (metric ton)
L10-C Helideck	106
L10-C Generator	25
L10-C Topsides	459
L10-C Jacket	583
L10-D Helideck	104
L10-D Generator	25
L10-D Topsides	434
L10-D Jacket	679
L10-G Topsides	465
L10-G Jacket	610

Table 2.3: Removed structures in the 2020 L10 campaign

2.1.4 Q8 project

In addition to the three decommissioning projects stated above, Boskalis already did a removal project in 2012. In that project the Q8-A & Q8-B platforms and their jackets were removed from the Dutch sector of the Southern North Sea. These were three legged and four legged jackets. In order to maintain safety and to reduce accompanying uncertainties the Ampelmann gangway was used to get on and off the platforms. The preparation for removal works consisted of: erection of scaffolding at cutting and inspection positions, inspection of lifting points by Rope Access Technology, installation of bracings to the Q8-B jacket for skimmers left in-place, the cutting of two risers, one J-tube, two skimmers and various other piping, the installation of rigging for lifting operations and replacement of lifting pins, and gauging, airlifting & internal pile cutting 4 times 30 inch skirt piles of the Q8-B jacket prior lift off. These preparations were necessary to be able to lift, but also to make sure nothing goes wrong, to reduce the risks related to the uncertainties. The Taklift 4 lifted the Q8-B platform and its jacket in one go. There is no data available of the weight of the topside and jacket, but this vessel has a maximum lift capacity of 2200 tonnes so the topside and jacket together had to weight less than that.
The Taklift 7 first lifted the Q8-A platform and after that the jacket. To facilitate the internal cutting of the four 36" jacket foundation piles over 6 m below average surrounding seabed level, the soil was removed by airlift technique. An Abrasive Water Jet Cutting (AWJC) tool was used to cut all four legs and shackle pin holes were made to connect the lifting gear. Again there is no weight data, but the Taklift 7 has a maximum lift capacity of 1226 tonnes so the topside and jacket each had to weight less.

When looking at the data of the three tables, it can be seen that the jackets weigh an average of approximately 400 tonnes more than the topsides, with the Bravo BA and Bravo BP platforms as exception. Since the Q8-B topside and jacket together had to weigh less than 2200 tonnes, it can be assumed that the jacket would weigh a maximum of approximately 1300 tonnes and the topside a maximum of 900 tonnes. The real weight may therefore be lower. And the weight of the Q8-A topside and jacket should each be less than 1226 tonnes. If these masses are compared with those of the V&V and L10 projects, it can be seen that the weights of all the structures are approximately in the same range. So in a span of 8 years the weight class has not increased significantly.
The Q8-A & Q8-B platforms were build in 1986 and 1994, respectively [26]. Many other platforms of the same size were also built during that time. It is therefore plausible that in the next 10 years those platforms will reach their end of life and have to be removed, and that they will fall in the same weight class and thus can be removed by Boskalis with the Bokalift 1 or 2.

2.2 Existing Removal Methods

In the previous section, several different removal methods were already mentioned that Boskalis has applied to remove offshore structures. This section explains these methods in more detail.

2.2.1 Classification of lifts

According to the Norwegian University of Science and Technology there are two different kind of lifts, light lifts and heavy lifts [38]. A light lift is defined as a lift where the mass of the load is very small compared to the installation vessel and therefore it is assumed that the motion characteristics of the vessel are not affected by the load. A heavy lift is defined as a lift where the weight of the cargo will have significant influence on the motion of the vessel and thus the coupled dynamics have to be considered. These lifts need to be properly designed to maximize safety and minimize costs.
Lifts during decommissioning are mainly heavy lifts, so a decommissioning project that uses a crane vessel requires a lot of engineering work beforehand. These lifts are therefore called engineered lifts. Engineered lifts are those which are planned, designed and executed in a detailed manner, with thorough supporting documentation [21]. These lifts are often simulated to train the workforce.
The previous section already briefly mentioned the different removal methods that are used when using a crane vessel such as single lift where the structure is lifted out of the water in one go, piece-small which entails multiple lifts with smaller sections [39], and reverse-installation [21][40].The option with the least costs is chosen and this is thus project specific. Each of them will be treated next:

2.2.2 Reverse-installation

Reverse-installation means that the structure will be decommissioned in the reverse installation sequence. This method can be applied to topsides, because it is common for topsides to consist of several modules that are connected together in a certain sequence during the construction of the entire topside. And even more modules could be installed during its lifetime. These modules can be disconnected again. By using reverse-installation the topside will be removed in modules rather as a whole. The removal of the sections will be carried out in such a way that the removal of one section will not cause other sections to get unstable [41]. An example of a project where it was applied is the Sable Project [44]. This means that the required crane capacity is less than when lifting the topside as a whole, which means that a smaller ship is needed that has a lower daily rate than a bigger one. The downside of this procedure is that it consists of multiple heavy lifts, so more engineering preparatory work is needed beforehand. And the operational time will be longer, which in turn entails more costs. A balance has to be found between costs and the number of lifts.

2.2.3 Piece-small

Piece-small means that the structure is cut and disassembled into multiple sections and each segment is lifted separately. The difference with reverse-installation is that these sections can be a part of the structure and do not necessarily be loose modules. The cuts are done in-situ and when loose the section can be lifted with the available lift vessel. The focus is put on optimizing the cutting strategy to ensure a cost effective decommissioning solution so that the heavy lift vessel time is minimized, because this is one of the main expenses. This method is particularly handy for large structures (>4000Mt) where reverse installation is no longer practicable [27]. Figure 2.2 shows the difference between piece-small and single lift for a jacket. Piece-small can be applied to topsides and substructures.

2.2.4 Single lift

Single lift means that the structure will be lifted in one piece without disassembling the structure into smaller pieces. This can be the topside or the substructure. Thus, the single lift method consists of one heavy lift per activity, be it topside or substructure. Therefore HLVs with a larger crane capacity are needed than with piece-small or reverse-installation, which cost more. But single lift topside and single lift substructure removal has clear advantages [45]:

- Maximum safety to personnel due to minimised offshore work
- Maximum protection of the environment by containment and taking all decomposing parts to shore
- Minimum offshore preparatory work
- Minimum subsea cutting operations, especially when clearing to the seabed in a single lift is feasible

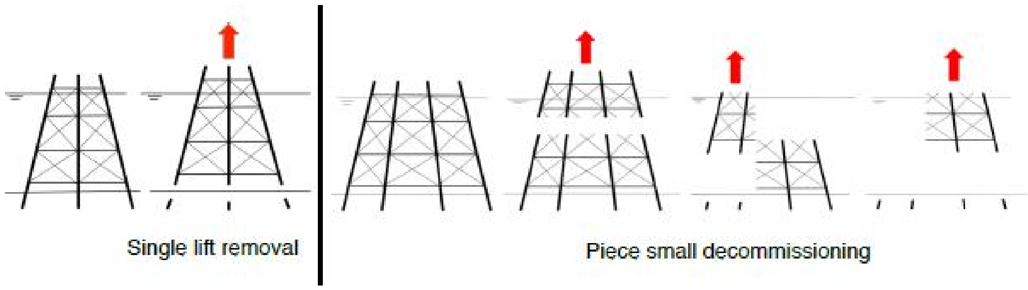


Figure 2.2: Difference single lift and piece-small [27]

2.2.5 Other Concepts

Buoyancy tanks

Sometimes buoyancy tanks are used when lifting the substructure to reduce the load on the crane by attaching them to the substructure. This was done during the removal of a jacket at the Frigg field [41]. The substructure can then be transported to shore while floating due to the tanks [27]. Or it can be put on a vessel or barge. This method means that a vessel with smaller crane capacity is required. But the downside is that extra preparatory work has to be performed both in and above the water which increases the costs. Nowadays there are ships with much more crane capacity available that can lift such a jacket without buoyancy tanks. This will be preferred as it often costs less than with buoyancy tanks and it can still be quite a challenge to connect the tanks to the substructure.

Twin Marine lifter

There is a new Single Lift technology for medium to larger platform removals offshore, to compete with the old heavy lift vessel (HLV) method [46]. Once a few successful operations are completed there will be reason to believe that the Single Lift systems represent a reduced risk level technically, operationally and commercially. The new single lift system is not a system that can lift all and everything easier than a traditional HLV. It has its pro's and con's. Traditional lift methods with HLVs will in many cases still be most effective, especially with regard to lower lift weight requirements. In most cases Single Lift advantages have been focused mainly on platform topsides and jackets weighing more than 5.000 tonnes. The intended capacity for Single Lift vessels is much higher than that of a traditional HLV, ranging from 12000 to 40000 tonnes. In many cases the cost for the preparatory work will be higher than the cost for the actual marine lift operation. The main activities prior to using existing HLVs are cleaning of vessels and pipes, disconnection of electrical and instrumentation cables, removal of items crossing from one module to the other, installation of lifting points on each module and do necessary strengthening of each object to be lifted if required. These are expensive, time consuming and manning intensive activities. Using Single Lift technology, most of these activities can be carried out onshore at a much lower cost. The main preparatory activity for single lift would be structural to ensure the distribution of the lift point loads is going well.
The new single lift vessel does not need the rigging that a HLV needs, reducing these costs for the single lift vessel. As mentioned previously, no heavy lift system can lift all platforms cost effectively and safely. Therefore some platforms will suit one system over the other. This again will have a cost impact caused by the requirements to modify the platform before lifting, which will have to be assessed on a case by case basis. A HLV needs a significant amount of continuous maintenance work to avoid mechanical breakdown and subsystem failures. The new single lift vessel has fewer rotating and other mechanical components, thus needs less maintenance.

So this new single lift technology is called the Twin Marine lifter(TML) single lift system, see Figure 2.3. The basic principle of the system is that the dynamics of the buoyancy tank is equalised by the opposite acting dynamics of the ballast tanks, giving a close to zero vertical interface force between the TML arm and the platform. This simple principle is the key to the unique performance of the TML system, and is now subject to world patenting. Having the TML arms rigged for both topside and jacket lifting, the TML system can remove a topside and jacket within a few days of operation, giving it a strong competitive advantage over the other marine lifting systems.

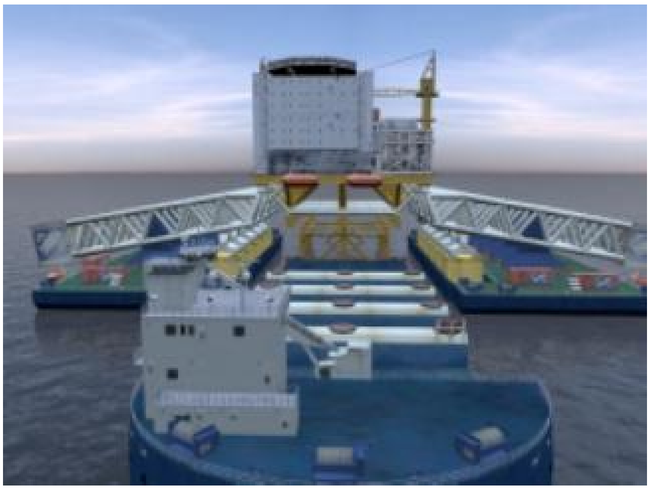


Figure 2.3: The Twin Marine lifter single lift system

2.3 Planning of a Decommissioning Project

2.3.1 Project Phases

Projects always consist of different stages [41]. These are the Tender phase, Early preparation phase, Preparation phase, Execution phase and Close out [42]. This also accounts for decommissioning projects. Each phase will be briefly explained:

Tender phase

The tender is the basis of the project. The owner of a platform asks for instance Boskalis whether and for what price the platform can be removed. Then Boskalis will prepare a tender. According to the experts of Boskalis you always need

a strategy and working methodology and this is being established in the tender: How will the platform be removed, what is needed for that and how much will it cost. This is dominated by: what does the jacket look like, is it safe to work without an additional work platform or not, and how strong is the structure. It is also looked at which lift points will be used and which equipment. The price is then based on that. But even then you sometimes run into problems that lead to a completely different situation. Because it is so project and situation specific and there are many uncertainties, there is almost no standardization possible.
Tenders are usually made before the platform actually stops producing. How far in advance this is done is up to the contractor, but they are often made 2 to 3 years before they are executed. The tender phase must be won by the company in order to do the rest of the project. There, it is worked out and implemented what was devised in the tender phase. Sometimes it is adjusted what has been devised in the tender because it is not possible or there is a better idea. And sometimes it is simply not detailed enough in the tender and it has to be worked out anyway. With decommissioning the devil is in the details. They often do not match what is stated on paper. How detailed the tender is made depends on the tender manager and the time that can be made available.

Early preparation

In the early preparation phase the preliminary discussions will be started where all options are screened and data is retrieved, either by documents or by surveys. And by reviewing what was done in the tender phase. It could be that parts of what was devised in the tender turns out to be unusable, so another solution has to be found. Again look at the different working methods and analyse and discuss what would be the best option. This is then developed into a working concept and applied. It must be operationally, technically and security feasible. The preliminary discussions are with the involved parties and a regulatory institute to ensure the decommissioning is well understood at the beginning. Operators should focus on gathering data and preliminary identification of the different options for decommissioning [42]. List all the deliverables, processes and analysis that needs to be done: all the work that you need to do or think that you need to do. These can change throughout the project, but often 80 to 90 percentage is correct.
With those lists a Master Document Register (MDR) can be build. It includes all documents of the work that needs to be done and what is related to each document. Then a rough estimate can be made of how many hours of engineering each document needs, so the operators can outline the likely timetable/schedule of the future events to form a basis for the detailed discussions. If all events are known they can be ordered by workload and a rough estimate can be made of how many persons are needed per event: How many structural engineers, marine engineers, etc. When possible use a planner to make an efficient time schedule. This is mainly the task for the Lead Project Engineer. If more effort is done in this beginning stage it will pay out in a later stage. If less effort is put in it, it will become less accurate and that will produce issues in a later stage [43]. With the MDR it can be checked whether the progress is on track or not. Or that the team size might be reduced when possible.

Preparation phase

In the preparation phase a safe working environment is established together with preparations for cutting and lifting. Non-critical cuts such as cutting wires can also be done in this phase. The make safe operations are done to ensure that it is safe to dismantle the platform. This ensures safe passage on the platform by establishing and marking escape routes and securing the walkways, carrying out weight control and rigging temporary systems. Also the topside and jacket will be inspected for hazards or structural damage [41]. It depends on the specifics of the project whats needs close attention. Old lift points are investigated and if necessary repaired and/or new lift points are installed. A rough estimate of where the lift points can approximately be placed can be made rather easily. But the engineering phase, the actual designing of the lifting point, can take a lot of time. It is often good to look at multiple concepts and to evaluate which one fits best in the situation. Bring the preferred one to the structural engineers for calculation. Welding large or thick materials is something to avoid because it takes a long time. Rather use already existing material in place. But on the other hand some welds could be done with smaller vessels. It could happen that the structure itself also needs some reinforcement to withstand the loads during lifting. This accounts for topside and substructure. It is determined in the first phase whether the jacket will be removed in one or in multiple pieces. And thus if strengthening is needed or not.
The Decommissioning programme (DP) is designed produced and eventually submitted[42] in this phase. It includes the planning, the assessment of options and the final conclusion. This is accomplished by having detailed discussions with the involved parties and by doing a comparative assessment or similar. This includes the assessment of risks, the development & submission of the consultation DP and an environmental appraisal to the regulatory institute. And lastly it is accomplished through consultation with other interested parties or public for consideration. The assessment of options will lead to a preferred decommissioning solution that will be described in detail in the DP. Decisions must be transparent and the operator should consult on proposals with the interested parties. Section 29(3) of the

Petroleum 1998 Act gives a minimum for these consultations. Under the same act the final DP must be approved in order to be executed.

Often, but not always, the engineer that does the preparation work will also be working at the execution after the preparation. This reduces the risk of losing information. The engineer that does the execution needs to have some insight in how the contract is drafted, the risks and opportunities.

Execution

The execution phase, the execution of the decommissioning programme. In this phase the main works will commence. The executive costs are much greater than the engineering costs, so good preparatory work in the engineering phase will keep the execution phase as efficient and short as possible to minimize the cost. The DP will specify the arrangements by which regular progress reports must be drafted and send to the regulatory institute such that they will be kept informed of the progress. Potential DP revisions should be identified and discussed. At the end of this stage the operator is required to report to the regulatory institute to satisfy them that the approved programme has been implemented in the manner described in the DP. The so called Close-Out Report[42].

Close Out

The last phase is Close Out. Having executed the decommissioning programme, the completion of the work needs to be reported in a close out report. In addition, the operator should implement arrangements to monitor & remediate the site as required and to implement arrangements for maintenance and management of any remains of installations or pipelines that may exist. The scope and duration of the monitoring requirements will be discussed with the interested parties and the regulatory institute. The close out report also contains the details of all post DP surveys within one year of full completion. The regulatory institute must be updated with amendments to the post DP monitoring plan[42].

2.3.2 Uncertainties for Removal

There are a lot of uncertainties surrounding offshore jackets that stood in place more than 30 years. Already mentioned were the loss of information and the condition of the platform itself. These are main uncertainties that always occur. In addition, the weight of the jacket and the center of gravity are often a major uncertainty, as is the breakaway weight. That is the force required to pull the jacket out of the seabed.

Worldwide there are many bottom founded offshore structures. And about a third of them have a jacket substructure, as mentioned in section 1.2. These platforms are often more than 30 years old and after all those years a lot has happened. One example is that the owner could have changed in the lifetime of the structure that led to loss of information. This information can be, for example, construction drawings or dimensions of structural members. Due to this lack of information, the biggest and most common problem is that in reality it almost always differs from what is documented on paper. As a result, this often leads to other minor problems such as wrong sizes or drawings that are not readable. Therefore drawings cannot be trusted blindly without a visual check/survey of the structure. Even if a client has everything well documented, which is unlikely to happen in practice, problems are still encountered.
It is also possible that the production could have stopped years before the decommissioning campaign and no one has maintained it since. Therefore, the structure could have been deteriorated in such a way that it is no longer safe to access. After all those years there is, for instance, uncertainty around the integrity of the jacket steel thickness. The structural condition is hard to assess after a lifetime at sea. If the wall thickness decreases, the tool length will have to increase so it covers a greater area [37].
These are some of the reasons why there are many uncertainties in decommissioning projects, a lot of unknowns. It is confirmed by experts that besides the known uncertainties new problems are encountered all the time and that it is important for the project team to understand that it is an unknown structure. A way to deal with uncertainty is to make use of safety factors. But this can lead to complications.

Old Lift Points

Due to the uncertainties and the related problems, a lot of engineering work is needed upfront. But even then it remains a difficult job. For each decommissioning project, it must be determined which type of lift point is the best and the most cost effective choice. There are various ways to make a lift point. But before making new lift points it is first checked if old lift points can be reused, as reuse is the easiest and cheapest option. Over the years, the platform

may have been modified in such a way that the overall mass may have changed. The capacity of the old lift points may therefore not be sufficient anymore. Or the center of gravity has moved to a point that the old lift point is useless. Also, parts could have been removed, like braces, such that the construction can no longer handle the loads when lifting at that lift point. If the old lift point meets all these criteria its integrity is checked by means of Non Destructive Testing (NDT) according to the DNVGL-OS-C401. It is a testing and analysis technique used to evaluate the properties of a material, component, structure or system for characteristic differences or welding defects and discontinuities without causing damage to the original part.
If the old lift points are not suitable anymore new ones need to be installed. This can take some time, especially when welding is needed. Therefore, lift points that require welding are the least preferable option if the welding has to be done in the critical time path in the execution fase. If the welding can be done a preparatory fase, so not in the critical time, this disadvantage does not apply. Installing lift points on a topside is often not that difficult, because everything is still easy to access. But for substructures where most of the working platforms are corroded away, new working platforms/areas need to be designed and installed before the lift points can be installed. This can lead to even more engineering time and preparatory work.

Lack of Information

The lack of information is mostly due to changes in owner. Information can be lost during transfer between owners because parts of the information may have been forgotten or because it was already lost. Or documents may have become unreadable after all these years. In addition, it is common for the client to provide a pile of such documents at the start of the decommissioning project that the contractor has to dig through. A period of 2 weeks is normally given for this. But after 30 years, the pile of documents has become very large. Often so large that the contractor will have to spend an enormous amount of time going through everything to see if all required and needed data is present and available. If in those two weeks the contractor does not indicate that information is missing, but that it is only discovered after the deadline, the client points out that it has given all documents it has and the contractor has to look for that information himself. Whether the client has actually given everything is then still to be doubted. The consequence of the lack of information is that the contractor who has to remove the structure eventually has to plan his project based on incorrect or incomplete data, therefore the uncertainty increases. Many times an inspection of the platform is needed because of this.

Unknown Platform Condition

The platform condition is the state of the platform. It relates to the condition of the system and subsystems like walkways and their associated deterioration. Over the life time of the platform the salty seawater and other environmental conditions will affect the systems. Therefore these have to be maintained like new paint and maybe replacement of equipment. This will be done mostly for the topside as people need to work there safely in the life time of the platform. But the jacket does not have to be entered during production, reducing the need to maintain the walkways and other components needed when the jacket is removed again. Thus, often the condition of the jacket is worse than the condition of the topside. On top of that, it regularly happens that platforms are removed a few years after production has stopped. In the time between the stop of production and the start of the actual removing operation the platforms will deteriorate even further because there will be no or minimal maintenance, making the condition even worse. This creates a great deal of uncertainty. Often repairs are needed prior to decommissioning in order to work safely. It will be investigated with a survey what is needed. And the choice of execution plan will also determine what needs to be repaired. For example, when a jacket can be lifted without the need of employers to connect the rigging to the structure, the repair of the walkways of the jacket would not be needed. Besides the deterioration of the systems, there could also be changes or deviations to the system that are not documented and discovered with a survey. These could be dimensions that have changed or deformed over the years like pile diameters, damage such as dents in the steel or the removal or addition of systems to the platform. For example, a dent in the pile makes it difficult for the abrasive water jet cutter to be lowered into the pile. These kind of problems also increase the uncertainty, which can be reduced again by means of a survey, by quantifying what is actually there.

Unknown Platform Strength

In addition to the condition of the platform, the strength or capacity must also be checked. Many platforms were installed without taking decommissioning into account. And during the lifetime of the platform there could have been changes to the system, like removing or adding braces. Therefore the capacity of the platform to withstand removal loads could have changed. The deterioration of the steel will also reduce the strength of the components. This is why the capacity of old lift points needs to be checked to see if they are still strong enough or that they need to be strengthened if possible. When it is not possible, new lift points need to be installed.

Unknown Platform Weight

Determining the present-day weight of the jacket together with its center of gravity (CoG) is very difficult. Over the years, as mentioned, there could have been changes to the platform. These changes like adding something will change the weight of the structure. But also during the life time of the jacket the weight could have changed due to deterioration and marine growth. The latter is nowadays still uncertain. Therefore the increase in weight due to marine growth is estimated. Because the jacket cannot just be weighed, the weight and CoG are determined with software. This is a tedious and precise process as the whole system needs to be implemented as detailed as possible to make a good approximation of the weight and CoG. There are some alternatives like the use of strain gauges but software is mainly used as it has proven itself to give estimates that are reliable enough.

Uncertain Breakaway Weight

The breakaway weight is determined by a couple of things. As a start this pull-out force is determined by the weight of the whole structure that has to be lifted including the marine growth. Then the soil type and the soil condition will influence the frictional force on the remaining pile length that has to be pulled out of the seabed after cutting, which influences the pull-out force. And finally the success of the cutting tool. There is a chance that the pile is not entirely cut through at some parts by the cutting machine. When this happens the structure will still be connected to the remaining pile in the seabed. This connection has to break in order for the structure to come loose and to be lifted. The pull-out force has to compensate for the extra load, increasing it. Since there is an uncertainty regarding the weight and cutting tool, the breakaway weight will also be affected by this uncertainty.

Safety Factors

Safety factors can be used to deal with uncertainty. For instance, if a calculated load has a certain deviation and it is therefore uncertain whether the strength of a member is sufficient to resist the load, a safety factor can be used: the member will be overdimensioned in order to withstand the force and to make it safe. Due to this the weight and thus the load increases. A problem that could arise, according to Boskalis, is that the structure fails under lifting because safety factors are added upon safety factors. This increases the weight even more, which calls for bigger cranes and rigging equipment and sometimes strengthening of the structure. For decommissioning it is therefore sufficient to use less safety factors but enough so that the structure can withstand two lifts: one to lift the structure out of the water and one to lift the structure onto the shore. After that the structure is at its end of life. This means that the mindset has to be different for installation and for removal.

2.3.3 Planning & Risk Management

The design and planning of marine operations shall as far as feasible be based on well proven principles, techniques, systems and equipment [21]. The design calculations/analysis shall be documented by design reports and drawings. The condition of all involved equipment, structures and vessels shall be documented as acceptable by means of certificates and test, survey and Non Destructive Testing (NDT) reports. All relevant documentation shall be available and accessible on site or on board during execution of the operation.

Risk management shall be applied to the project to reduce the overall risk. Risk is equal to the probability of occurrence times the corresponding consequence or damage. The preferred approach is to address the following:

- Identification of potential hazards
- Preventative measures to avoid hazards wherever possible
- Controls to reduce the potential consequences of unavoidable hazards
- Mitigation of the consequences, should hazards occur.

The overall responsibility for risk management shall be clearly defined when planning marine operations [21].
If a risk matrix is made and the severity of the risks can be subdivided into three categories; green = low risk, orange = medium risk and red = high risk, the orange ones would be the Key Risks. These key risks often are[27]:

- The structural integrity of the platform(s) differs from (or is worse than) the information obtained from client survey.
- Not possible to enter pile legs with pumps, hydro cutting tool or internal lifting tools.

- Waiting on weather beyond the anticipated normal weather uncertainty for cutting of the jacket (braces, anodes, etc).
- No safe access/working area and walkways to/on the platform.
- Overestimated workability of heavy lift vessel.
- A fire or explosion.

2.4 Engineering Methods

Often the same steps are taken to do the lift point design. But determining the lift points remains difficult. With every project it is again a discussion of how it is going to be done, weighing up concepts. It needs to be sorted out what the best option is. At the start of a decommissioning project, so in the preparation phase, the work done during the tender phase is reviewed and evaluated. Often you have to investigate further. The tender is already a good start, but not always reliable. It needs to be determined how to structure is going to be removed, with which method as stated in section 2.2; reverse-installation, piece-small or single lift. This depends mainly on the mass of the structure and the available crane capacity: what will give the best economical option. When the method is determined, it is known whether to break the structure into smaller parts or not and if necessary where to cut and how to cut. The weights of the sections are then defined together with the Center of Gravity (CoG) of each section to be lifted. According to Boskalis this is the most difficult part of the lift point design, as it is a very critical part that drives everything and the situation is often not the same in reality as what is documented. Or it has been adjusted after the tender phase and therefore no longer corresponds with what is in the tender plan when it will be executed. What also makes it difficult is that everything with a (small) uncertainty always works through in the following steps: the uncertainty in the mass point affects, for example, the load definition and so on. When the weights and CoGs are known there can be looked at lifting points and the amount of lifts that are going to be needed to remove the structure. Either reuse existing ones and/or design and install new lifting points. When the lift points are chosen structural engineers need to check whether the chosen option is viable, so a motion analyses is done. The duration depends on the state of the system. If everything is still in good condition, it makes the process easier, reducing the time needed. But often the condition is not so good, which is why the structural integrity check takes the most time.

When the old lift points cannot be used new ones are needed. There is no standard procedure to design and install new lift points. You only have a certain number of methods to lift something and not everything can be applied to all situations. In a brainstorm session a lot of ideas are devised, but according to the experts of Boskalis you often end up with these three solutions: or use shackles or use ILTs or use trunnions. There is hardly ever time available to figure everything out. So in general the same type of lift points to use are looked at because people know that it works and how much time it takes.

2.4.1 Engineered Approach

It starts with the definition of the load: with the mass and CoG you can determine the distribution of the force over the lift points. How will be lifted, what occurs and in what circumstances. There is a table/flowchart in the DNVGL-ST-N001 code how to merge that and the corresponding inaccuracy. There are also guidelines such as how far you should cut your pile under the mudline. There are certain standards to deal with inaccuracy. Often uncertainty margins have to be added for e.g. the weight, because marine growth has grown over the years. Under water it weighs nothing, but above water it does weigh a lot. Therefore a prescribed uncertainty margin is applied.
The dynamics must also be taken into account when determining the lift point, the transfer of the force to the lift point and the fluctuation therein. If the construction is still fixed, the dynamics come from the movements of the ship, but as soon as it comes loose and hangs in the water, you have to deal with added mass and the movements of the medium, which also contribute to the dynamics. According to Boskalis, a topside is relatively easy to remove, because the mass can be measured with a hydraulic system and the dimensions are known or can be measured. This is not the case for substructures. Once the load definition is known the lift points can be determined.

The type and size of the lift point that is going to be used depends on the size and orientation of the noose of the sling that will be attached to the lift point. The size of the sling and its noose depends on the load it has to carry. The orientation of the noose gives the orientation of e.g. the trunnion and that in turn gives the location of where the holes should come. It is a logical consequence according to Boskalis. Then, when designing a new lift point, start with the easiest method that can be used. If this cannot be applied move to a more difficult one, with the most difficult method as last option. If you have a leg for example, the easiest way would be to drill two holes and put a shackle through it. And then connect the shackles with a sling. ILTs are very handy but very expensive and require a lot of maintenance, but can you save a lot of time. On the other hand, the plugging of multiple ILTs at the same time is very difficult. A frame could be designed that makes this easier. But then the frame should be made in such a way that it can be used for more projects than just a specific situation. Otherwise it is not economically attractive.

When the lift points have been worked out, the loads needs to be optimised to to get as little load as possible on a lift point, the in-plane and out-of-plane forces. For example, ILTs are susceptible to out-of-plane forces and can only operate within an angle of 2 degrees in that direction. Also the skew loads need to be determined: the dimensional tolerances on your rigging. Skew loads are additional loading caused by rigging fabrication tolerances, fabrication tolerances of the lifted structure and other uncertainties with respect to asymmetry and associated force distribution in the rigging arrangement. According to the DNV code a skew load safety factor of 25% needs to be applied to account for the skew loads. Boskalis often wants to work towards a three-point lift. That reduces the skew load, because the rigging can be compensated so that the system can find the center of gravity so that it hangs well and all lifting points are loaded equally

2.4.2 Dynamic Curve Approach

Besides the engineered lift procedure as explained above which is mainly used, there also exist another procedure: the Dynamic Curve Approach. It prescribes how much load you can lift at which boom angle and weather conditions. It includes safety margins so the working window is smaller than with an engineered lift. Then the motions of the ship and the load can be inspected and with that an accurate estimate can be made of the dynamics. With this the load on the total system can been devised. From there it can be worked out what the load distribution is throughout the system. Then it can be seen which members get the greatest load. The location of the lift points influences the distribution of forces, as does the stiffness of the element that is being lifted and the configuration of the lift system. A thick sling will take more load than a thinner sling because it is stiffer. This influences the lift point design. The more you know for sure, the more accurately you know the lift point load and the better you can optimize it.

2.5 Summary

There are several methods used with an HLV to remove an offshore structure. Based on the uncertainties and circumstances associated with each project, the best option can be selected to eliminate most uncertainties. The structure with phases of the project must ensure that the risks arising from the uncertainties are mitigated as much as possible. And because there are so many uncertainties, the preparation is mainly done via the engineering approach instead of the dynamic curve approach, to be more flexible.

Chapter 3

Analysis of Decommissioning Projects

This chapter discusses three decommissioning projects that Boskalis has carried out. Each project will be analysed with respect to the decision-making process of the lift point design and that of the execution strategy. In this way, an attempt is made to gain an overview of the Boskalis selection process and to discover a trend in it.

3.1 Viking & Vulcan

In 2015, the client Chrysaor Production (U.K.) Limited awarded the contractors Boskalis and Scaldis, an offshore heavy lift contractor, the engineering, preparation, removal, transportation and disposal services for the decommissioning of in total 20 platforms in the Viking, Loggs and Murdoch areas in the Southern North Sea of the United Kingdom. Boskalis & Scaldis carried out the project in a joint venture (JV), named BOSC. In the period 2015 - 2018 various preparation activities were carried out on all the satellite, processing and accommodation platforms by the JV. The project was executed in two phases, the offshore removal campaign 1 in 2019 and the offshore removal campaign 2 in 2020. The two companies divided the work to be done, i.e. the number of platforms to be removed: Scaldis would remove 9 platforms and Boskalis would remove 11 platforms. Of those eleven platforms Boskalis would decommission 7 platforms in the first campaign in 2019. The other 4 would be removed in the 2020 campaign. Besides the platforms Boskalis also removed some bridges, a subsea template and living quarters. The way in which Boskalis has done the decommissioning of these structures will be further analysed, starting with the removal campaign 1 of 2019.

3.2 Viking & Vulcan 2019 campaign

3.2.1 Execution Strategy

In order for the execution to go smoothly and with as little delay as possible, the strategy must be determined. This requires choosing the best start date, determining the number of trips required, and deciding whether an additional vessel is needed. Such vessels are mainly Offshore Support Vessels (OSV), as depicted in Figure 3.1. These vessels are used, among other things, to transport people and materials and to help with preparatory work such as lifting operations with the onboard crane.

Figure 3.1: The OSV Constructor of Boskalis

Start Date & Additional Vessel

The goal of choosing the start date is to complete the work in as little time as possible in order to do more work in the same amount of time to maximize profit. Thus, the choice of start date mainly depends on the weather and the associated downtime. Weather conditions are known to be rougher in winter, which results in more downtime. That is why it is preferred not to start the execution in winter. For this project the downtime was determined with the use of P50 and P90 values. These values were put together in a graph, shown in Figure 3.2. The graph reflects the yearly weather conditions well because is shows that there will be less downtime in the summer and more in the winter.

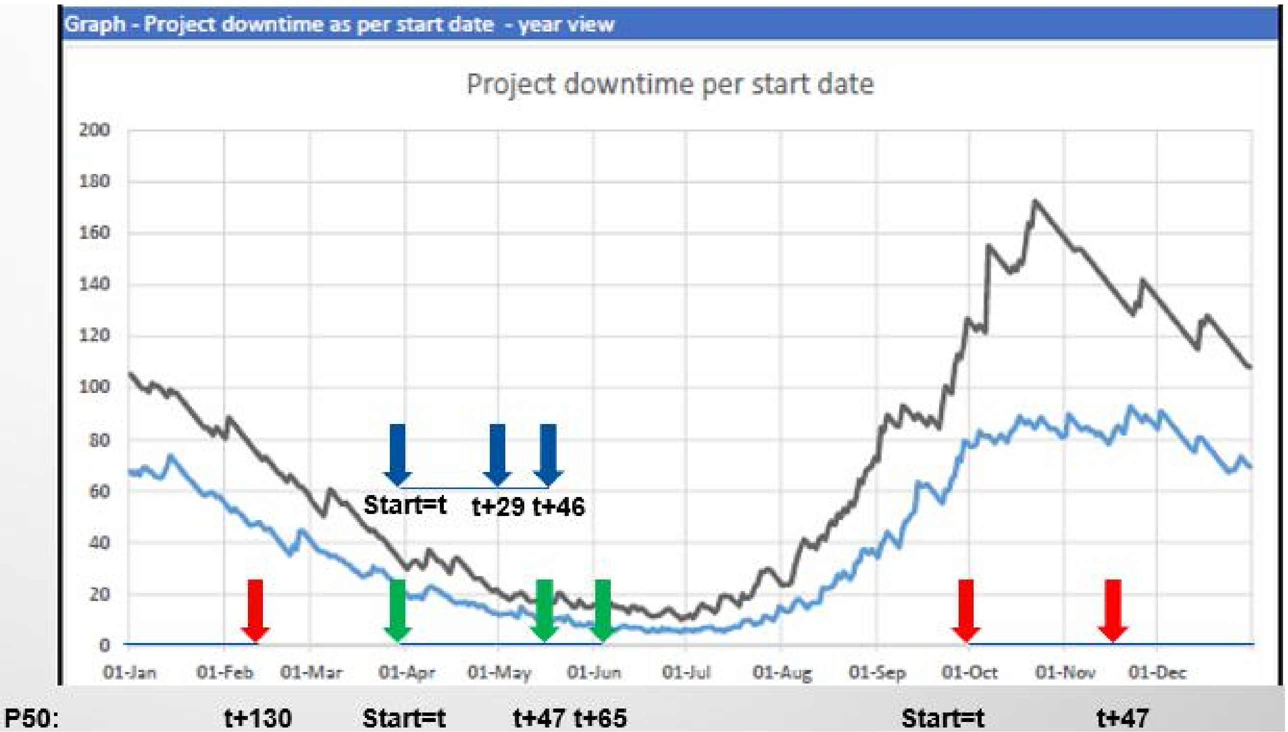


Figure 3.2: Project downtime per start date of the V&V 2019 campaign

In the figure the three options that Boskalis had devised to start the execution of the 2019 campaign are also depicted. These options are:

1. Starting in October 2018 without the use of an OSV. (red)
2. Starting in April 2019 without the use of an OSV. (green)
3. Starting in April 2019 with the use of an OSV. (blue)

The figure shows how much time is needed per start date. The first option will take 47 days of operation and the rough weather will increase the downtime resulting in 83 days of waiting on weather (WOW), making a total of 130 days. The second option will also last 47 days, but because the weather is better around this time of year, the downtime is less than option 1 resulting in 18 days of WOW with a total duration of 65 days. The third option will start at the same time as the second option but in this case an additional OSV is used. Because of this the total amount of time needed is reduced: 46 days, consisting of 29 days of operation and 17 days of WOW. Due to the same starting date as the second option the difference in WOW is very small.
In addition to the figure with the downtime depicted, a cost overview has been made for each option, see Figure 3.3. Because option 1 would take a very long time with only the Bokalift1, it was also investigated what the difference would be if an OSV was used for option 1.

Option 1

BL1 & OSV 2018-Oct	Bokalift	OSV
Oper. Days	29,50	29,42
WoW	49,10	20,20
Total	78,60	49,62
Total costs	17.000.000	

BL1 only 2018-Oct	Bokalift	OSV
Oper. Days	47,20	-
WoW	83,00	-
Total	130,20	-
Total costs	20.000.000	

Option 3

BL1 & OSV 2019-Apr	Bokalift	OSV
Oper. Days	29,00	29,43
WoW	17,00	11,90
Total	46,00	41,33
Total costs	13.500.000	

Option 2

BL1 only 2019-Apr	Bokalift	OSV
Oper. Days	47,20	-
WoW	18,00	-
Total	65,20	-
Total costs	13.000.000	

Figure 3.3: V&V 2019 execution cost overview

It can be seen that option 1 takes the longest time and is the most expensive option. And although the OSV reduces the total amount of days needed and reduces the total cost for option 1, option 2 and 3 still remain a better option. When comparing the latter two, the table shows that option 3 would be more expensive than option 2. But option 3 required less days to complete the project. In the end, the difference in costs did not outweigh the difference in days, because as the project takes more time, winter approaches and the chance of downtime increases as the weather gets rough. The difference in costs was too small to take that risk. Therefore Boskalis chose to start the execution in April 2019 with the use of an OSV, option 3.
After this decision, an opportunity arose: Boskalis was able to lease the Bokalift 1 to a client who needed the vessel. The problem was that the client needed the vessel in April to June which interfered with committed schedule. Boskalis decided not to miss out on that income and rented out the vessel which resulted in a delay in the schedule. The new start date became July 2019.

Amount of trips

In addition to the start date, the number of trips must also be determined. This depends on a couple of things such as the type of HLV that is being used and the method to transport the structures. At first, Boskalis had chosen to use the Taklift 4 and the Bokalift 1 for this project. By using both vessels the project could be completed faster. Apart from the lifting capacity, the difference between these vessels is that the Bokalift 1 has a revolving crane which can place the structures from the water onto the deck, whereas the Taklift 4 has a shearleg crane which cannot rotate and does not have deckspace to place the structures on. Therefore the Taklift 4 needs a barge to put the structure on or it sails with the structure hanging in its hook to the disposal site allowing it to transport only 1 structure per trip. This choice of vessels influenced the removal sequence of the V&V 2019 campaign: it was decided that the Taklift would sail with the structure suspended in it hook to the disposal site. That way no grillages and sea fastenings had to be engineered and made for the Taklift 4 which would be more complex than using the hook, saving time and money. The Bokalift could use its deck for storage, therefore the Bokalift 1 would remove the ED topside, UR topside and all three parts of the CD jacket in its first trip, the ED jacket in the second trip and the UR jacket in the last thus third trip. But in the end this plan changed. In some cases a greater lift capacity was required than expected and Boskalis had another opportunity to make extra profit by leasing the Taklift 4 for another well-fitting long-term job. Therefore it was decided to use the Bokalift 1 for all heavy lifts. However, this opportunity came quite late in the preparations, so there was no time left to build additional grillages. It was therefore decided to adopt the removal method of the Taklift 4 for the Bokalift1: part of the constructions would be transported while suspended in the hook. Due to this method the amount of trips and the deck layout of the Bokalift 1 changed. Instead of 3 trips, the vessel would need 9 trips, which are depicted in Figure 3.4.

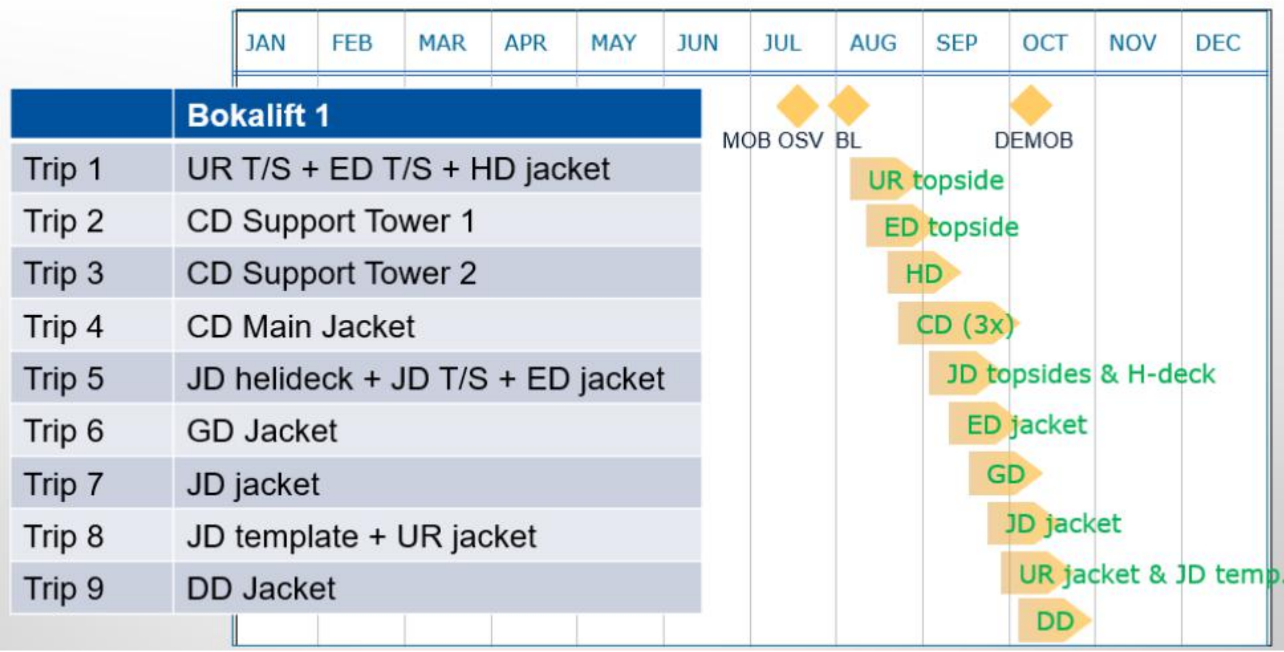


Figure 3.4: Amount of trips of the Bokalift 1 in the V&V 2019 campaign

In trip 1 the HD jacket did not come loose, so an extra trip was needed to remove it. In the end there were 10 trips.

3.2.2 Lift point

In order to get a good overview of the decision-making process of the type of lifting points that were used in the removal of the seven platforms, each platform will be treated individually. This is because they could not be removed in the same way. And prior to the decommissioning in 2019, the client had to do some work on the platforms that required a jack-up. This created a unique situation in which Boskalis could make cheap use of this jack-up for its own preparatory work. It was therefore decided to conduct a separate preparation campaign which enabled some options that were previously not feasible in terms of time and/or cost, such as welding.

Viking CD Jacket

For the Viking CD Jacket, the initial plan was to lift the jacket in its entirety out of the water. In the preparation campaign the old lift points were investigated, but they turned out to be no longer usable as they were found to be in poor condition or had disappeared. Therefore new lift points had to be designed and installed. First the options of the shackle-hole combination and trunnions were investigated but the legs turned out to be too thin and/or too short to apply them. Due to this a new lift point was devised: prefabricated pieces of leg with two reinforced holes each, see Figure 3.5. These pieces could then be welded onto the existing legs. Afterward two shackles are attached to these holes. The downside of this option is that the prefabricated piece of leg had to be welded onto the existing leg which would take a lot of time. But due to the unique situation this was not problematic since the work could be done in the preparatory campaign with no risk of idle time for the HLV. Without the preparation campaign Boskalis would have opted for ILTs and a spreader frame because then the welding scope of the prefabricated pieces of leg would become problematic as it had to be done in the critical time path of the execution. And there were multiple platforms that had the same dimensions and laying diameter such as the GD jacket, the DD jacket and the HD jacket, making the ILT option economically attractive.
After this type of lift point was chosen, the entire lift operation of the CD jacket was calculated. It turned out that the jacket could not be lifted in its entirety without failing. Unfortunately, Boskalis found out so late that the preparatory phase was already over. As a result, it was no longer possible to make adjustments to the CD jacket without incurring extra large costs in order to lift the jacket as a whole. Therefore it was decided to cut the jacket into three parts, as in the piece-small method, resulting in one main jacket and two support towers. Figure 2.1 shows the CD jacket with the cutting lines indicated as scissors.

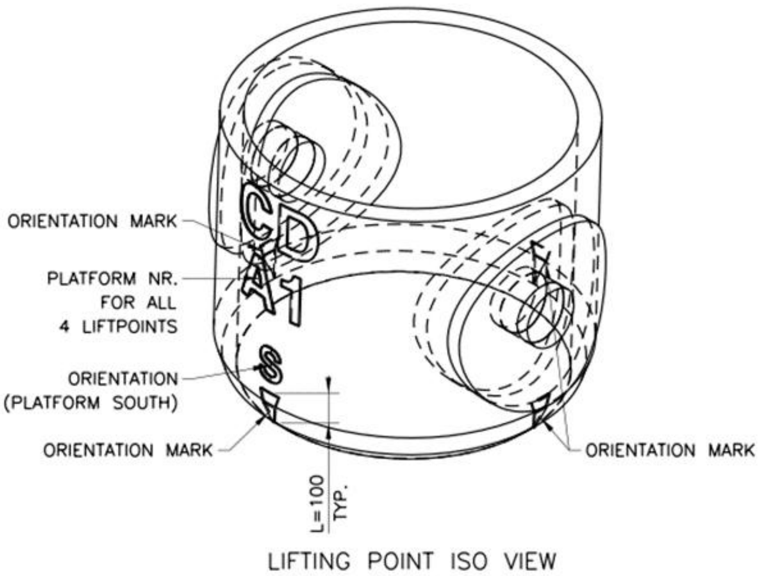
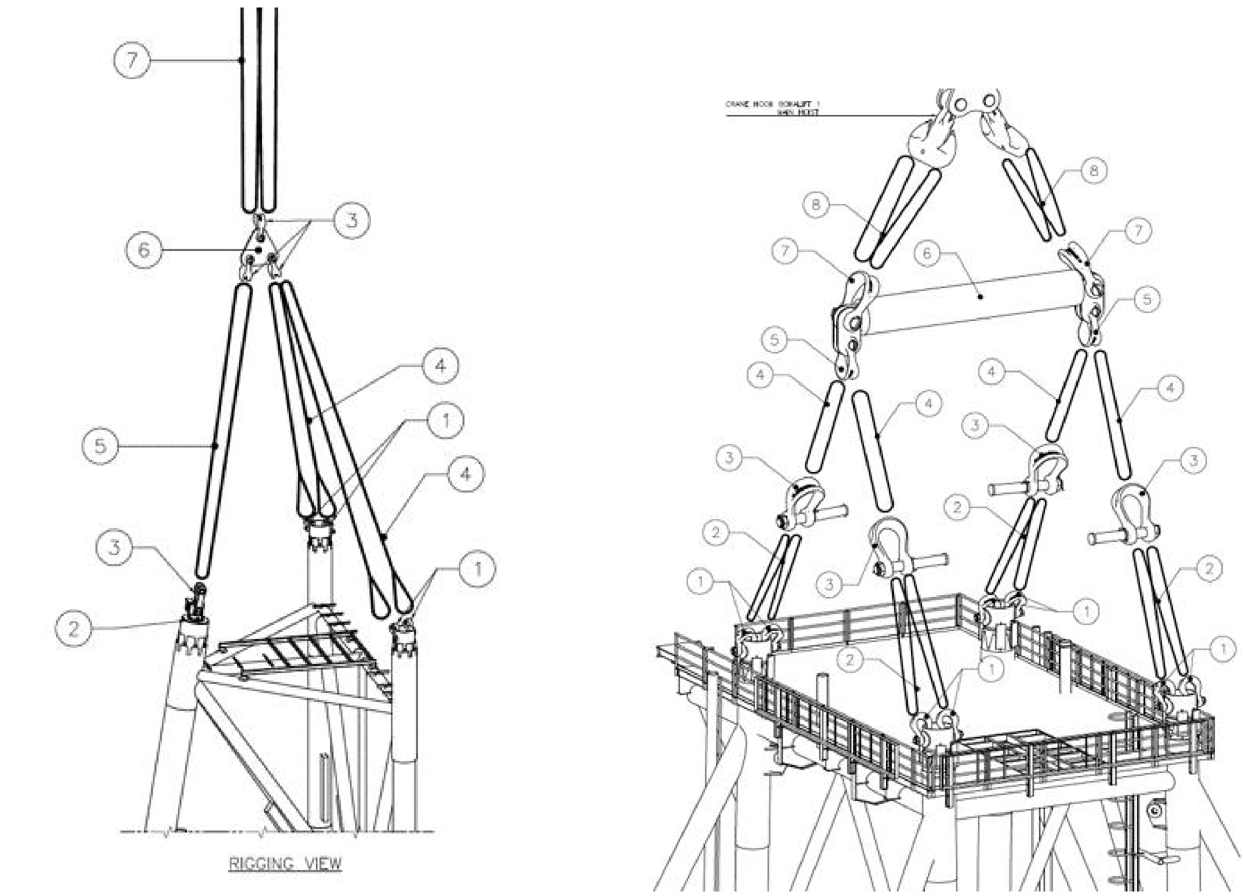


Figure 3.5: Prefabricated piece of leg with two reinforced holes.

The towers each have two vertical legs and one inclined one to which a lift point can be made. Because it was only decided after the preparatory phase to split the jacket into three parts, the existing lift points of the towers were not inspected. Therefore, the use of the old lift points of the towers was not considered as it involved too many risks: if the old lift points were not strong enough and it is only discovered offshore, it would create a huge problem. That is why new lift points had to be made.
As a first option the combination of holes and shackles was investigated for all legs. But after calculations and modelling it became apparent that the loads in the inclined leg would be too high. Therefore another type of lift point had to be found for the inclined legs and the use of an ILT or a trunnion was considered. Both options proved to be structurally possible and were further investigated.
The trunnion needed extra preparatory work where the ILT did not. For example, an access platform had to be installed in order to safely make the holes in the leg and to install the trunnion. At first this looked like a real challenge, but after investigation it became clear that it was not that difficult to realize.
On the other hand, the downside of the ILT was that the rental costs of the ILT were high and that the ILT would only be used for these two towers. Even though making the platform and holes for the trunnion takes time and money, the rental cost turned out to be much higher than the costs for installing the trunnion.
Because the prefabricated legs were already designed for the main jacket, it was also investigated whether this type would be a good solution for the inclined legs of the towers. It appeared that this option was also more expensive than the trunnion. See Figure 3.6 for a cost overview of the different options. The values are representative but not the actual costs. Due to the late decision to cut the jacket into three parts, the lift points for the towers could no longer be installed in the preparatory phase, but the installation had to be done in the critical time path of the execution phase. That is why it would take too much time to install this option while in the critical path of the project which is not preferable.
In the end, the new trunnion was chosen as the lift point for the inclined legs of the towers because it involved less risk and because it was the cheapest option of all three. The vertical legs of the towers however where thick and strong enough to install holes for shackles as lift point without additional cheek plates. So the holes in combination with shackles were chosen as lift point for the four vertical legs as this was the fastest and cheapest option for this situation. This lift point configuration of the towers is depicted in Figure 3.7a. Note that in the figure the inclined leg has an ILT, while it should be a trunnion.
The main jacket was lifted at four prefabricated pieces of leg as lift points, because two other easier options were structurally not possible and because the welding scope did not pose any problems due to the preparatory phase. This final configuration is shown in Figure 3.7b.

Summary						Qualitative	Risks
Option A	ILT						
A1	Offshore ops (vessel days + man hours)	€ 900.000				engineering resources	L10 uses ILT
A2	Mobilization	€ 25.000				agreement with COP + possible impact on cost IHC	
A3	Engineering	€ 10.000				spread on TL4 to be mob and demob	
			Total	€	935.000	Umbilical in A-frame	depending on operations (crewchange) longer duration
						L10 needs ILTs and alternative for L10 is to install lift points a 9 days Bokalift	
			Total	€	1.857.500	no operational concerns	
Option B	New trunnion						
B1	Offshore ops (vessel days + man hours)	€ -				lift point design resources	
B2	Fabrication and mobilization	€ 60.000				was no go -> access low. Eventually a go	
B3	Engineering	€ 80.000				ops challenges when designing lp with shackles	
			Total	€	140.000		
			Total	€	280.000		
Option C	Existing trunnion						
						no go to use existing trunnion	
	Not possible - padeye calculation fails						
			Total	€	-		
			Total	€	-		
Option D	New lift point						
	Offshore ops			€	120.000	engineering resources	
	Fabrication and mobilization			€	9.000	opportunity to engineer smart lift point	
	Engineering			€	30.000	no additional access required	
			Total	€	159.000	No clash with L10	
			Total	€	318.000		

Figure 3.6: Overview of the costs



(a) Rigging and lift point configuration of CD towers (b) Rigging and lift point configuration of CD main jacket

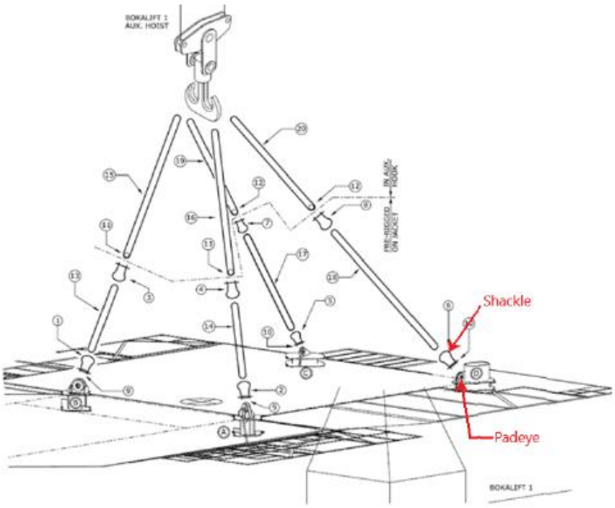
Figure 3.7: CD jacket lift point configuration

Viking GD, DD & HD jackets

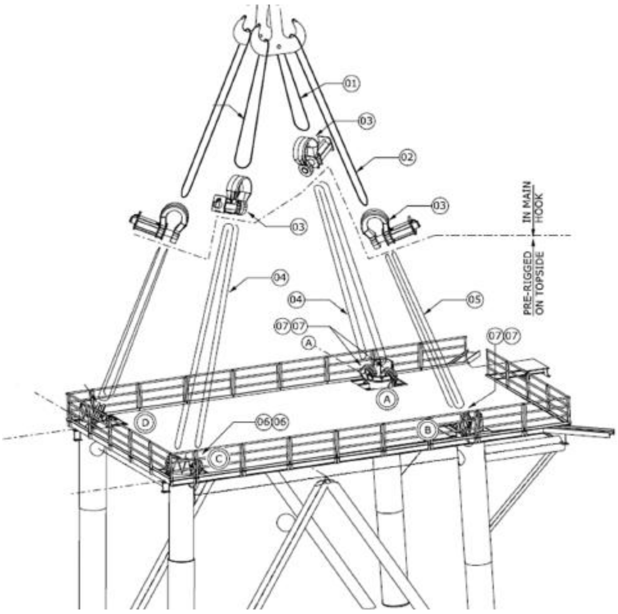
With the Viking GD jacket, the Viking DD jacket and the Viking HD jacket the same problems as with the CD jacket were experienced by Boskalis. First the old lifting points were examined, but they were missing or in bad condition. Then other options were investigated but again the legs where too thin and/or too short to apply trunnions or shackle-holes. That is why Boskalis has decided to use the same option as with the CD jacket, the use of the prefabricated piece of leg. For these jackets the prefabricated pieces of leg would also be welded onto the existing legs in the preparatory campaign, see Figure 3.7b for the final configuration. And if the welding had not been possible in a preparatory campaign, Boskalis would have chosen the ILTs and spreader frame as stated with the CD jacket.

Viking ED platform

Boskalis had to remove the topside and the jacket of the Viking ED platform. First the old lift points were investigated: the existing lifting points of the topside were strong enough to lift the topside, but the existing lifting points on the jacket were not or were missing. That is why a different option as lift point had to be chosen for the jacket.
The topside would be removed first in the removal campaign and due to this the lift points of the jacket could only be made in the removal campaign and not in the preparation campaign. Therefore the use of the prefabricated pieces of leg to lift the jacket would not be efficient as it would take too much time to install in the critical path after the topside was removed. Therefore the option to install holes in the legs in combination with shackles was investigated first as alternative. The problem was that the legs had a too small thickness, so they had to be reinforced with cheek plates. But these cheek plates to strengthen the holes could be welded on the outside of the leg in the preparation phase, making it a viable option. However, the holes for the shackles could not be made until the topside was removed, so this work had to be done in the execution phase. In addition, part of the legs had to be removed so that the shackle would fit, which also had to be done in the removal campaign.
The ED topside was eventually removed by means of its existing old padeyes together with shackles as depicted in Figure 3.8a and the ED jacket was removed using reinforced holes & shackle connections for each of the four legs, shown in Figure 3.8b. Afterwards it turned out that the use of trunnions such as on the CD side towers would probably have been better for the jacket, but at the moment of decision there was still too little experience with that possibility making it a risky option at that time.



(a) Rigging and lift point configuration of ED topside



(b) Rigging and lift point configuration of ED jacket

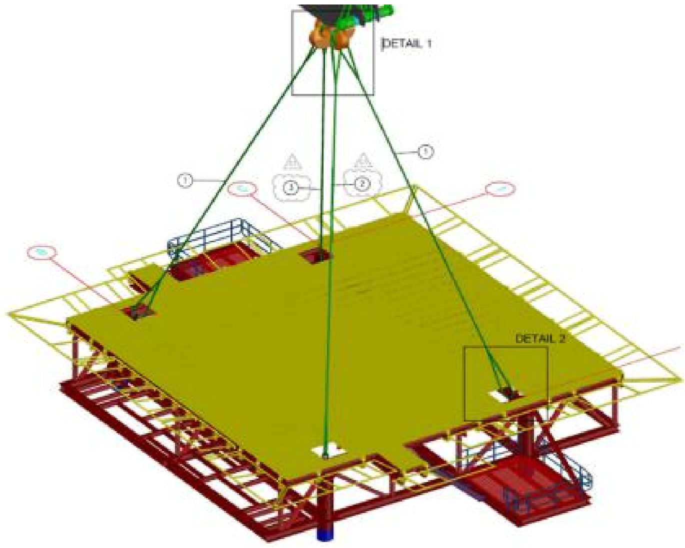
Figure 3.8: ED platform lift point configuration

Victor JD platform

The decommissioning of the Victor JD platform involved the removal of the topside, helideck, template and jacket. First the old lift points were investigated. It turned out that some of the existing lift points of the JD topside and helideck needed some remedial works. After further recertification they proved to be in good shape and sufficiently strong to be used.
But for the jacket this was again not the case. The old lift points were gone or in too bad shape. And because the topside had to be removed before the jacket in the removal campaign, the prefabricated pieces of leg were not a viable option. The first option that was investigated was to install reinforced holes in combination with shackles such as with the ED jacket. But during the installation of the cheek plates it became clear that it would not work because in this case it turned out to be impossible to correctly calculate the connection: it was not possible to make the calculations

to show that sufficient load could be transferred via the shackle-hole combination.
As a second option, the use of ILTs was investigated. Boskalis had some ILTs available, but it turned out that the capacity of the ILTs was insufficient for the applied load. And Boskalis discovered in a survey that there were still pieces of half-cut steel on the inside of the legs that would hinder the ILT. That is why another option had to be found.
As a third option, the trunnion was evaluated. After calculation it turned out that the trunnion was structurally possible. It was therefore decided to install separate trunnions, because the other options were not possible. The installation would be done during the removal campaign after the topside was removed, as it would only then become possible to install.
The helideck was lifted at its existing four padeyes in combination with shackles. The lift point is depicted in Figure 3.9a and the rigging configuration in Figure 3.9b. The topside was lifted at its old existing trunnions, shown in Figure 3.10a. The rigging configuration is depicted in Figure 3.10b. Afterwards, the jacket was lifted at four newly installed trunnions. And at last the template could be removed. It was a relatively light-weight lift of 30 tonnes. The rigging was attached to the template with the use of a Remotely Operated Vehicle (ROV) and a spacer frame. The slings were put around the braces of the template, see Figure 3.11.

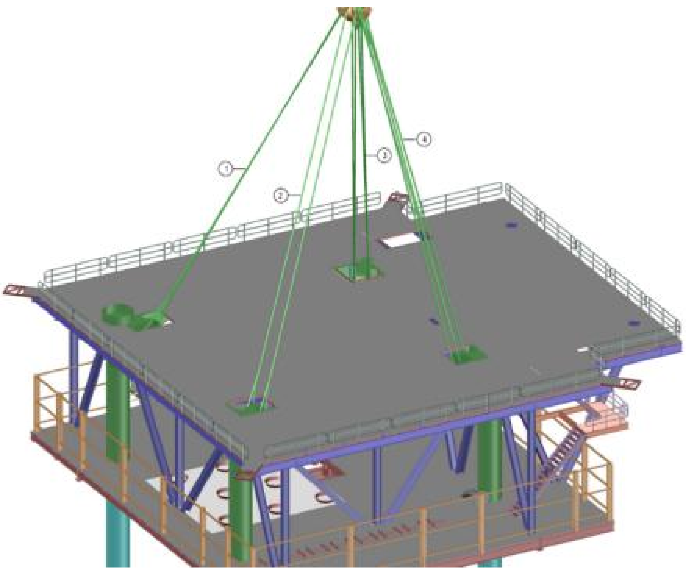
(a) Old padeye of JD helideck



(b) Rigging and lift point configuration of JD helideck

Figure 3.9: JD helideck lift point & configuration

(a) Old trunnion of JD topside



(b) Rigging and lift point configuration of JD topside

Figure 3.10: JD topside lift point & configuration

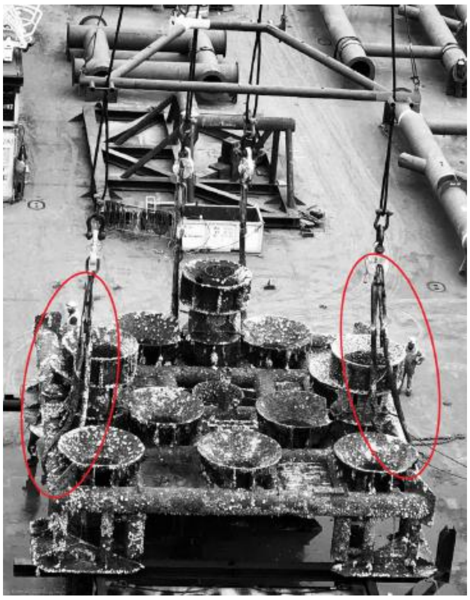
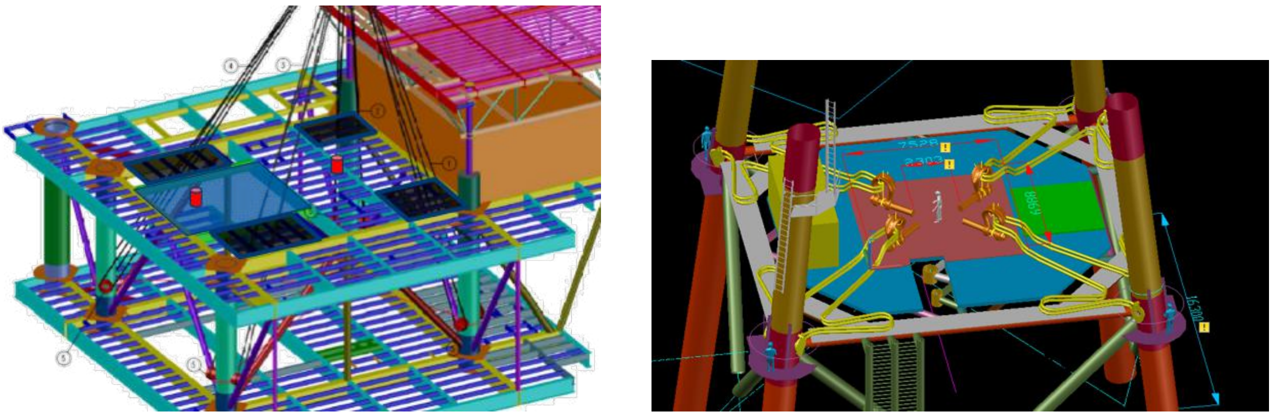


Figure 3.11: JD template

Viking UR platform

Of the Viking UR platform, both the topside and jacket had to be removed by Boskalis. After investigation it became apparent that all the old lift points were no longer suitable and could not be used for the lifting operations. Thus, new lift points had to be devised for both the topside and the jacket.
The first option that was investigated were trunnions. This proved to be a viable option, so trunnions were designed for the topside because they could be installed in the preparation campaign. In that way the time required for welding was not a problem. What turned out to be a problem was the position of the trunnions: they were installed in the middle of the leg between the lower and upper deck instead of at the top of the leg underneath the top deck, see Figure 3.12a. Due to this position, a significant sling path clearance scope had to be done in the removal campaign in order to connect the rigging to these trunnions. This was a lot of work and took a lot of time, which costed more money than anticipated. In hindsight, it was a wrong choice due to lack of experience.
The UR jacket had the same problems as the JD jacket. At first it was investigated whether a shackle-hole connection could be made, but it turned out to be impossible to calculate the connection correctly, ruling out the use of reinforced holes in the legs. The capacity of the available ILTs was also too small for this jacket and pieces of steel were in the way on the inside of the leg to install the ILT. That is why Boskalis opted to install individual trunnions during the removal campaign at all legs, see Figure 3.12b. In order to do this a rigging platform and some access platforms around the legs were installed.



(a) Rigging and lift point configuration of UR topside

(b) Rigging and lift point configuration of UR jacket

Figure 3.12: UR lift point configuration

3.2.3 Result and Evaluation

With this amount of manhours (1.500.000) it is a very good achievement that there are no Lost Time Injuries. It proves that Boskalis has safety as a core value and that they make sure that it is maintained. Some decisions were made in order to accomplish this, such as to take the time for a proper HazID (Hazard Identification Document). To ensure that the workers are aware of the content. And to ensure that the open atmosphere is preached and maintained by SHE representatives on site. The latter means that anyone, regardless of their function, is able to address against someone in their way of working with regard to safety and can instruct them to stop working until the situation is safe again.
In addition, lessons learned meetings were being held with the joint venture, including partners and client, project team and subcontractors. In this way everybody was involved and knew what was expected from them. Uncertainties and mistakes could already be discussed. This reduces the risk that something will go wrong and that it cannot be resolved in time.

To get a good overview of the decision-making process of the lift point design of all platforms removed in the 2019 campaign, the following tables are made, see Table 3.1 and Table 3.2. In these tables an attempt has been made to present all considerations as accurately as possible with the associated advantages and disadvantages as discussed in subsection 3.2.2.

			Old lift points	Holes + shackles	ILT	(New) trunnion	Prefabricated piece of leg
CD main jacket		Pro	Structurally not possible	Structurally not possible	Applicable to multiple platforms	Structurally not possible	Welding can be done in preparation campaign
		Con			Spreader frame needed		Extended welding scope
CD Tower	Inclined leg	Pro	Not considered,	Structurally not possible	No additional platform needed	Cheapest option	Cheaper than ILT
		Con	too many risk		Very high rental cost	Additional access platform and preparations needed	A lot of time in critical path needed to install
	Vertical leg	Pro	Not considered,	Fastest and cheapest option	Not considered	Not considered	Not considered
		Con	too many risk	-			
GD, DD, HD jacket		Pro	Structurally not possible	Structurally not possible	Applicable to multiple platforms	Structurally not possible	Welding can be done in preparation campaign
		Con			Spreader frame needed		Extended welding scope

Table 3.1: Overview lift point trade-off of the CD, GD, DD & HD jackets

			Old lift points	Holes + shackles	ILT	(New) trunnion	Prefabricated piece of leg
ED platform	Topside	Pro	Suitable for reuse	Not considered due to reuse old lift points	Not considered due to reuse old lift points	Not considered due to reuse old lift points	Not possible
		Con	-				
	Jacket	Pro	Structurally not possible	Reinforcement can be done in preparation campaign	Not considered	Not considered due to lack of experience	Structurally possible
		Con		- Holes need to be made and legs partly cut after topside removal - Reinforcement needed			- Extended welding scope - Installation in critical path after topside removal
JD platform	Topside	Pro	Suitable for reuse	Not considered due to reuse old lift points	Not considered due to reuse old lift points	Not considered due to reuse old lift points	Not possible
		Con	-				
	Jacket	Pro	Structurally not possible	Calculation could not be done	-	- Proved to work at CD jacket - Not expensive	Structurally possible
		Con			- Insufficient capacity of ILT - Pieces of steel interfering ILT	Installation in critical path after topside removal	- Extended welding scope - Installation in critical path after topside removal
UR platform	Topside	Pro	Structurally not possible	Not considered	Not considered	Can be installed in preparation campaign	Not possible
		Con				-	
	Jacket	Pro	Structurally not possible	Calculation could not be done	-	- Proved to work at CD jacket - Not expensive	Structurally possible
		Con			- Insufficient capacity of ILT - Pieces of steel interfering ILT	Installation in critical path after topside removal	- Extended welding scope - Installation in critical path after topside removal

Table 3.2: Overview lift point trade-off of the ED, JD and UR platforms

For every topside and jacket the process of deciding which lift point to use, as described in subsection 3.2.2, is indicated with colours in the table. Each option that is stated in the upper row of the table is coloured lime if that option was not possible due to some reason. The option that was eventually chosen is coloured bright green. If a trade-off has taken place, it will be displayed in multiple shades of green, with the lightest being the worst option.

Then, when looking at the table, a process can be discovered that goes from the most left option to the most right. It is striking that if the old lift points can be used, they are used and other possible options are no longer investigated. This can be seen at the ED & JD topside. In addition, it is striking that if that option is not possible, the 'hole-shackle' combination is almost always looked at first. Because it can be seen from the process of the CD towers and the ED jacket that other options will no longer be explored if this option is possible.
If the old lift points and the 'hole-shackle' combination are not possible, either the ILT or the trunnion or both are examined. The best option is then chosen by means of a trade-off.
Sometimes another option is devised that is not one of the main options as described in section 1.4, such as the prefabricated piece of leg in this project. Such an option is devised when the other options are not possible or do not seem optimal. For example, in the case of the CD jacket, the situation was that the old lift points, the hole-shackle combination and the trunnions were not possible. The ILT was possible, but this option required additional prep work for a spreader frame that also comes at a cost. This frame would allow the necessary ILTs to be installed simultaneously in the execution campaign, but that would be in the critical time frame. And installing multiple ILTs at the same time can be difficult and time consuming. Therefore a new alternative, the prefabricated pieces of leg, was investigated to see if it would be a better option. Due to the unique situation with the preparation campaign, this option turned out to be a better choice than the ILT. In this case it was therefore more favorable to come up with a new lift point.
Also in the case of the GD, DD and HD jacket, the ED jacket, the JD jacket and the UR jacket, only one of the standard options was available. Therefore, in those situations, the available option was again compared with the newly devised lift point to see which of the two would be the best choice. Only with the GD, DD and HD jacket did the prefabricated piece of leg turn out to be the better choice.

Based on the whole decision-making process of the V&V2019 campaign, the following final decisions were made with respect to each platform:

Viking CD jacket

The Viking CD jacket is split in three parts because it was too complicated to lift it out of the water in its entirety, resulting in one main jacket an two towers. The center main jacket is lifted by means of 4 prefabricated pieces of leg with two reinforced holes each that will be welded onto the existing legs, after which shackles will be installed in the holes. This option was chosen because most options were structurally not possible and these prefabricated pieces of leg could be welded onto the existing legs outside the critical time path of the removal campaign.
The support towers are lifted by means of 3 lift points. The two vertical legs will have shackle-hole connections because those are the fastest and cheapest to install. The inclined leg will have a trunnion connection as it was the cheapest of the available options. In the end, all three parts were removed and transported while suspended from the hook in their own trip (trip 2, 3 and 4).

Viking GD, DD jacket & HD jackets

The GD, DD and HD jackets can be removed by means of the same method. It was structurally not possible to reuse the old lift points and to install trunnions or padeyes. Therefore the same option was chosen as for the CD jacket: to use the prefabricated pieces of leg. The installation of these pieces could be done in the preparation campaign so no additional time was needed. All three jackets are removed and transported in a separate trip because they have to hang in the crane hook during transit.

Viking ED platform

First the topside is cut loose from the jacket and lifted at its existing old lift points as they were suitable for reuse and reuse is the cheapest and fastest option. Then the ED jacket is lifted at 4 reinforced hole & shackle connections. This option was chosen because the reinforcement of the holes could be done outside the removal campaign whereas the alternative had to be installed in the removal campaign. The ED topside is transported in trip 1 and the ED jacket is transported in trip 5. Both could be placed on grillages on deck of the Bokalift 1 as they were already made for the initial execution strategy.

Victor JD helideck, topside, jacket and template

First the helideck of the JD platform is removed by means of its old lift points as they were in good condition. Then the topside will also be lifted and removed at its old lift points for the same reason. The jacket however needs other lift points. It was decided that trunnions would be used to lift the jacket, because this option together with the alternative could only be installed after the topside was removed and the trunnions needed less time to install. The template is lifted as last at some slings wrapped around the template. The helideck and topside can be transported in one trip together with the ED jacket in trip 5, the JD jacket in trip 7 while suspended in the hook and the template can be transported together with the UR jacket in trip 8.

Viking UR platform

For the Viking UR platform, the topside must also be cut loose first just as with the ED platform. After the topside has been cut loose from the jacket, the topside is lifted at 4 trunnion connections because the trunnions could be installed in the preparation campaign. These trunnions are located at the cellar deck which is the lower deck of the topside. Due to this some holes need to be made in the upper deck such that the rigging could pass through the upper deck to the trunnions at the cellar deck.
For the UR jacket a rigging platform needs to be build together with another platform around the jacket legs for the crew to be able to connect the rigging safely. The jacket is also lifted at 4 trunnion connections as this method proved to work at the CD jacket and it was not an expensive option. The UR topside is transported in trip 1 together with the ED topside and the UR jacket is transported onto grillages on the Bokalift 1 in trip 8.

The execution of the project started in July 2019 with the mobilisation of the vessels. The first platform was removed in August. All heavy lift were executed by the Bokalift 1 and to shorten the duration of the project the OSV Da Vinci was also used.

3.2.4 Conclusion

From the foregoing information the following can be concluded.
The start date selection process has shown that an important aspect is the total duration of the execution: the longer the execution will take the more money it will cost and the less likely that option is chosen. For example, option 1 lasted 130 days and cost 17 million while option 3 lasted 46 days with a cost of 13.5 million. The latter was chosen. In addition, the selection process shows that downtime and the risk of it (weather that gets worse in winter) plays an important role in choosing the final start date. Because in some cases a more expensive option is chosen if this reduces the risk of downtime, such as with option 3 where the additional cost to the OSV outweighed the risk of downtime that came with option 2.
The importance of the total duration is also reflected in the decision for the number of trips: the Bokalift 1 and Taklift 4 were both chosen because they allowed the project to be completed faster with less trips than when one vessel was used. In addition, the Bokalift 1 could also place multiple objects on its deck, so that several objects could be transported per trip, which accelerated the process and reduced the number of trips even further.
The opportunities that Boskalis received with regard to the rental of the Bokalift 1 and the Taklift 4 are not taken into account, because this concerns a unique situation and because both opportunities were only identified at the end of the selection process, thus had no influence on the course of the selection process.

The importance of the total duration and the risk of downtime in the selection process of the execution strategy is also reflected in the choice for the type of lift point: often the option is chosen that takes the least time/effort, has less risk or uncertainty, costs the least money, or is an optimum of such a combination. For example, it is first checked whether the old lift points are usable, because this is the cheapest and fastest/easiest option. If that is not possible, the shackle-hole combination is often considered as a second option, because this option is easy to implement, does not take much time to install and does not cost a lot of money. After that, the trunnion and ILT are generally looked at and compared. The ILT often has a high rent, but is fairly easy to use. The trunnion is more difficult to realise than the shackle-hole combination, but still not difficult to do. It also costs more money and takes more time to install than the shackle-hole combination. So it can be seen that there is a process in choosing a lift point that goes from the easiest and often cheapest option towards more expensive and complicated options. This process seems to be applied to every platform.

3.3 Viking & Vulcan 2020 campaign

3.3.1 Execution Strategy

In order to execute the decommissioning of the structures properly and in a cost-effective way, the execution strategy must be devised. For the second campaign of the Viking & Vulcan project, 2 options were suggested as starting date of the execution phase. These are placed under 'option 1'. And 4 options were created that concern the number of trips required and whether an additional Offshore Support Vessel (OSV) is needed. This can be summed up to the following options:

1. Starting 1-Jan or 1-Apr.
2. 4 trips. Aim: least amount of trips.
3. 5 trips (+OSV). Aim: OSV to do all prepwork to shorten Bokalift 1 duration.
4. 6 trips (+OSV). Aim: optimize OSV efficiency & separate jacket and topside scope, so efficient equipment usage.

Option 1

The choice of start date for the execution phase depends on the time needed for the execution and the number of days that work cannot be done, the downtime. This again strongly depends on the weather conditions. In Figure 3.13 the two scenarios are compared for options 2, 3 and 4. It shows the net duration, the downtime with a P50-value, the idle time and the total duration in days per starting date. The figure shows that the downtime of the vessels will be less when the execution starts on the first of April. Therefore the total duration is also less, which is preferred because the vessels can then be deployed elsewhere faster.

Bokalift P50 (Execution date = 1-jan)	Vessel startdate	Nett. Duration [days]	Downtime P50 [days]	Ilde time [days]	Total duration P50 [days]	Completion date P50
4 trips	1-jan	49,5	40,6		90,1	1-4-2019
5 trips	1-jan	51,8	42,3		94,1	5-4-2019
5 trips + OSV	12-jan	33,9	28,4	4	66,3	19-3-2019
6 trips	1-jan	49,3	41,0		90,3	1-4-2019
6 trips + OSV	12-jan	33,4	29,5		62,9	15-3-2019

OSV P50	Vessel startdate	Nett. Duration [days]	Downtime P50 [days]	Ilde time [days]	Total duration P50 [days]	Completion date P50
OSV 5 trips	1-jan	23,5	19,9	18	61,4	3-3-2019
OSV 6 trips	1-jan	18,5	18,8		37,3	7-2-2019

Bokalift P50 (Execution date = 1-apr)	Vessel startdate	Nett. Duration [days]	Downtime P50 [days]	Ilde time [days]	Total duration P50 [days]	Completion date P50
4 trips	1-apr	49,5	12,7		62,2	2-6-2019
5 trips	1-apr	51,8	12,2		64,0	4-6-2019
5 trips + OSV	13-apr	33,9	7,5	4	45,4	28-5-2019
6 trips	1-apr	49,3	12,4		61,7	1-6-2019
6 trips + OSV	13-apr	33,4	7,9		41,3	24-5-2019

OSV P50	Vessel startdate	Nett. Duration [days]	Downtime P50 [days]	Ilde time [days]	Total duration P50 [days]	Completion date P50
OSV 5 trips	1-apr	23,5	7,5	18	48,9	19-5-2019
OSV 6 trips	1-apr	18,5	7,1	2	27,6	28-4-2019

Figure 3.13: Starting date scenario comparison for the V&V 2020 campaign

Option 2

To have 4 trips with the Bokalift 1 without an OSV because it would not be very efficient to use one according to Boskalis. The advantages of having four trips is that it has the least amount of trips, i.e. port calls & transit. And that the ILT mode is optimal, namely first 3 times a diameter of 54 inch, then 1 of 48 inch and at last 1 of 36 inch. In this way the spacer blocks only need to be removed and not added to accomplish the change in diameter of the ILT. The disadvantages are that there is very little flexibility in the sequence and that the CM & ZD platforms are not on the same grillage location on the vessel. The grillage is a means to connect the structure to the vessel in compliance with the standards established by the relevant marine insurance company such that the vessel can transport the structure safely. The grillage is directly connected to the vessel, often with a weld. Then the structure or module can be lifted onto the grillage such that the structure is locked and cannot move. Important is that the structure is not directly connected to the grillage as the grillage is to the vessel. Grillages can be combined with sea fastening when the center of gravity of the structure is relatively high such that grillages alone are not sufficient anymore to hold the structure in place during transport.

Option 3a

Five trips without the use of an OSV. The advantage of this option is that the extra trip gives some flexibility in the sequence with a minimal impact on the schedule. But there are several disadvantages. Just like the second option the CM & ZD platforms are not on the same grillage location. Additionally the ILT mode is not optimal anymore, namely first 1 time a diameter of 48 inch, then 3 times of 54 inch and at last 1 diameter of 36 inch. In this mode the spacer blocks need to be added and at the end removed again. Finally the extra trip requires more port calls and more transit. Therefore it makes more sense to do 4 trips if the OSV is not used.

Option 3b

Five trips with the use of an OSV. The advantage of having 5 trips is again that there will be a little more flexibility in the sequence with minimal impact on schedule than with 4 trips. Another advantage is that using an OSV will reduce the duration that the Bokalift 1 is required. In the end an OSV costs less per day than the Bokalift 1. But this option has several disadvantages. The first one is that the Bokalift 1 is idle for 4 days which must be prevented because it costs a lot of money unnecessarily. The second one is that the OSV also has some idle time, which is 18 days. So the use of an OSV is not very efficient. Another disadvantage is that more preparation of grillages is required. And that the OSV requires extra crew, equipment and SIMOPS, that is a Simultaneous Operations Risk Assessment needed when two or more work activities are carried out within the same location at the same time. SIMOPS activities can significantly increase the risk level, with serious and sometimes disastrous consequences. And just like option 3a this option also does not have an optimal ILT mode: first 1 of 48 inch, then 3 of 54 inch and finally 1 of 36 inch. The last disadvantages are that it requires more port calls and transit and that the CM & ZD platforms are not on the same grillage location.

Option 4a

Six trips without the use of an OSV. Because no OSV is required, the advantage is that no additional crew, equipment and SIMOPS are needed. There is reduced idle time for dedicated jacket & topside equipment, such as DECO, ILTs and ROVs. Other advantages are that there is more flexibility in the sequence with minimal impact on the schedule, that the preparation of grillages is optimal and that the CM & ZD platforms have the same grillage location on the vessel. And the last advantage is that the ILT mode is descending, which is optimal: 3 times a diameter of 54 inch, then 1 of 48 inch and at last 1 of 36 inch. Two disadvantages of this option are that it requires more port calls and more transit.

Option 4b

Six trips with the use of an OSV. Advantages of this option are the reduced Bokalift 1 duration due to the OSV and that the use of the OSV is optimal. The reduced idle time for dedicated jacket & topside equipment and that there is more flexibility in the sequence with minimal impact on the schedule. Also optimal preparation of the grillages and that the CM & ZD platforms have the same grillage location. The disadvantages are that the ILT mode is not optimal just like option 3b, that the OSV requires additional crew, equipment and SIMOPS and that more port calls and transit are needed.

Trade-off

In order to make it easier to compare all the options and to draw a conclusion, a table has been made. See Figure 3.14. The values in the table are representative but not the actual costs.

Jan-20	**Scenario 1** *(All BL1, 4 trips) (start 1 Jan 20)*	**Scenario 2** *(All BL1, 5 trips) (start 1 Jan 20)*	**Scenario 3** *(Incl. OSV, 5 trips) (start 12 Jan 20)*	**Scenario 4** *(All BL1, 6 trips) (start 1 Jan 20)*	**Scenario 5** *(Incl. OSV, 6 trips) (start 12 Jan 20)*
Duration *	98	102	74 (+74)	99	71 (+51)
Completion date	**9 April**	**13 April**	**27 March**	**10 April**	**24 March**
Total cost (mi €)	**27**	**28**	**30**	**27**	**27**
Apr-20	**Scenario 6** *(All BL1, 4 trips) (start 1 Apr 20)*	**Scenario 7** *(All BL1, 5 trips) (start 1 Apr 20)*	**Scenario 8** *(Incl. OSV, 5 trips) (start 1 Apr 20 **)*	**Scenario 9** *(All BL1, 6 trips) (start 1 Apr 20)*	**Scenario 10** *(Incl. OSV, 6 trips) (start 1 Apr 20 **)*
Duration	70	72	54 (+61)	70	50 (+40)
Completion date	**10 June**	**12 June**	**25 May**	**10 June**	**21 May**
Total cost (mi €)	**22**	**23**	**25**	**22**	**23**
Remarks	• No flexibility • Lift jacket over topside		• OSV = more complex prep & ops → risk • Some idle time	• Optimal flexibility • Most efficient use of equipment	• OSV = more complex prep & ops → risk

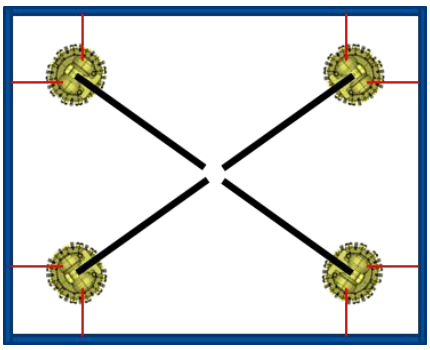
* incl. mob/ demob
** OSV start date 19 Mar 20

Figure 3.14: V&V 2020 Execution Strategy Comparison Table

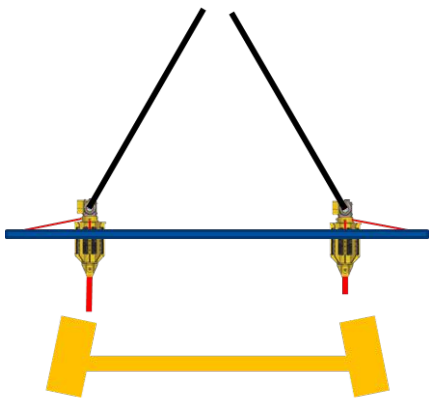
When looking at the comparison table it can be seen that options 3b & 4b have the shortest duration, but that in the worst case the duration can be extended such that it will take the longest time of all options. In addition, the OSV needs more complex preparation and operation which entails more risks, such as the SIMOPS. And the use of the OSV also has additional costs.
Options 2 and 4a have the shortest duration after options 3b and 4b. The durations are almost the same and they are also one of the cheapest options. But because option 2 has no flexibility in the planning and option 4a does have flexibility, option 4a is preferred over option 2. On top of that, option 4a has the most efficient use of equipment.
Option 3a has a long duration and costs more than most of the other options so it will not be considered.
The execution will start in April 2020 instead of January because it results in less costs and takes less time to complete.

3.3.2 Lift point

The lift point type selection process for the 4 platforms of the 2020 campaign is discussed here. The first option that is considered is the use of ILTs, as it proved to be a good and reliable option in a previous campaign and because this concept could be applied to multiple structures with no modification to the concept. But in order for the client to accept this method some conditions must be met with respect to the structural integrity of the internal lifting tool. According to the client statement, the proposed lift arrangement utilising ILTs for the previous removed KD & LD platforms is accepted but the following conditions must be met: The original lift trunnion at each leg (3 in total) need to be removed. And the friction factors established from IHC (company) its test data need to be verified and used in the engineering assessment. This is to reduce uncertainties and therefore the risk of failures. When these actions are done the lifting method must be approved by the client and MWS, that is the Marine Warranty Surveys. A problem that occurs is that using ILTs in complex joints currently has no DAD (Design Appraisal Declaration). With DAD critical areas for construction and through-life maintenance are identified. It is done by Lloyd's register. Therefore an ongoing item is that Lloyd's register is preparing a quotation and schedule to make lift specific DADs. Lloyd's Register is an organization founded in 1760 for the purpose of assessing and classifying ships of the merchant fleet. This assessment enables insurers to better oversee and manage their risks.
When using internal lifting tools the handling, installation and retrieval method of the ILTs needs to be investigated. Usually the structure is lifted at more than one lift point, therefore multiple ILTs are needed. In order to be able to install and remove these ILTs in a safe and preferably quick way, a method must be devised to achieve this. Therefore the use of a non-load bearing spacer frame was designed in this project, see Figure 3.15 for clarification. This is because there was high confidence that the ILTs could be installed remotely in a safe and efficient way with the proposed concept, although careful detailed engineering is required. During the project the handling was investigated and verified by the Bokalift simulator and an Orcaflex motion analysis.



(a) Spacer frame top view



(b) Spacer frame side view

Figure 3.15: The spacer frame

In addition to the ILT, two alternatives are investigated: a trunnion and a shackle connection, both fixed lift point connections. These are proven concepts that have been engineered for multiple projects such as the Viking & Vulcan 2019 campaign and the L10 project, meaning that the uncertainty surrounding the use of such a lift point and thus the risk of failure will be less when using these fixed connections. But the downside of these methods is that it requires additional design, fabrication and subcontractors.
The following two tables provide an overview of these different types of lift points. Table 3.3 depicts the pros and cons of each of the methods whereas Table 3.4 gives the costs related to each method. The values in the table are not actual costs, but they are representative.

	ILT	Fixed lifting points
Pros	· No personnel required on the unsecured jacket to connect and disconnect rigging – **safety / time** · No rigging platforms required - **cost** · Reduced vessel duration - **cost**	· Proven concept - **opportunity**
Cons	· JV owns four (4) ILTs – Currently no back up (5th) ILT available – **risk / cost** · Availability not guaranteed as JV partner Scaldis can claim the ILTs as well. (Scaldis plans to mobilize for their 2020 removal campaign in June) - **risk** · A New Lloyds design appraisal for using ILTs in non-bare pipes is required – **cost / time** · Stabbing 4 ILTs remotely in one lift is unproven and needs detailed design & functional testing – **risk / cost** · Use of ILTs currently not yet approved by Client - **risk**	· Requires rigging platform and mobile crane on jacket to install installation aids – **cost / time** · Requires substantial more critical preparation and installation & removal time when compared with ILTs – **cost / time** · Lifting points to be engineered, fabricated and installed – **cost / time** · Personnel required on the unsecured jackets to connect the shackles – **safety / time** · At disposal yard: separate crane plus work basket required to disconnect the shackles / trunnions - **cost / time** · More expensive; additional vessel time – **cost**

Table 3.3: Pros and cons of lift point types for the V&V 2020 campaign

	ILT		Fixed lifting points	
Engineering	IHC Lloyds	100.000€	+5000 hrs. conv. Lifting point	350.000€
			+1000 rigging platform	
Procurement	Spacer frame	100.000€	Rigging platform	300.000€
			Trunnions	250.000€
Equipment rental	Rental of ILT IHC technician Training Service/ testing	Jan: 900.000€ Apr: 700.000€	DECO (cutting scope, lump sum costs only)	300.000€
Offshore duration			+28 days at €150.000 per day (BL1)	4.200.000€
Total		900.000 – 1.100.000€		5.400.000€

Table 3.4: Costs of lift point types for the V&V 2020 campaign

What can be concluded from the two tables is that the internal lifting tool has more pros and has less cons than the fixed lifting points. While the fixed lifting points are a proven concept, i.e. the engineers know that it works and what to expect, the ILT entails more safety because there is no personnel needed on the jacket to connect and disconnect the rigging while it is necessary for the fixed lifting points. As safety is very important, this is a big pro for the ILT.
When looking at the cons of the fixed lifting points it can be seen that because it is a proven concept there is no risk related con, whereas the ILT do has some risk related cons. This is because the proposed ILT concept is new and therefore has to be checked if it is possible in a safe way by means of detailed design and functional testing. In addition, a new DAD has to be made by Lloyd register.
While these cons of the ILT entail more costs and some risks, the fixed lifting points need a lot more preparation time: a rigging platform and mobile crane need to be installed, lifting points need to be engineered, fabricated and installed and the time window to do this is in the critical time path. These tasks are expensive and take time to install which entails even more costs than that for the ILT. And those costs can further increase if the weather conditions are worse than anticipated. The additional vessel time needed for the preparation of the fixed lifting points is also a major expenditure, which the ILT does not have. These costs do not outweigh the costs that have to be made for the spacer frame for the internal lifting tools.
All these points would suggest that the ILT, despite its risks, would be a safer and cheaper, thus a better option. The aim of Boskalis is to make as much profit as possible while maintaining a safe working environment, which is why the ILT has preference over the fixed lifting points. The second table confirms that the ILT concept has less total costs: the ILT would in the worst case cost 1,1 million euros while the fixed lifting points would cost 5,4 million euros. That is a

difference of 4,3 million euros. Therefore the ILT has been chosen as lift point for the execution. So based on the pros and cons as detailed, the use of ILTs is the safest and most cost-effective solution for lifting the jackets of the V&V 2020 campaign.

3.3.3 Result and Evaluation

Each meeting/session is started with a safety statement (NINA), as safety is governing. It was decided that the Boskalis NINA program would be implemented in all facets of the project and that it would be adopted by the client and all subcontractors. All personnel involved in the operations were trained in the NINA program, resulting in a high level of safety awareness and commitment. The project was therefore completed without lost-time incidents or accidents. This is a very good achievement. So the decision to implement the NINA program really paid off.

Freeze meetings were held where certain decisions were being made and 'locked'. During the Method Freeze meetings subjects/items will be finalized in order to enable clear engineering focus. Examples of such decisions are the number of removal trips or whether to use an OSV or not. These meetings therefore provide clarity and ensure that decisions are made so that the project stays on course, reducing the risk that the project will take longer than planned.

In the end the execution of the second campaign of the V&V project would start in April 2020. The 4 jackets and the topside of the BA platform would be removed with the use of ILTs and the spacer frame. Through engineering and modelling, the spacer frame eventually became a cross, see Figure 3.16. The project was executed with execution strategy 4a: 6 trips of the Bokalift 1 without the use of an OSV.

Figure 3.16: The final spacer frame for the V&V 2020 campaign

3.3.4 Conclusion

The trade-off between the two start dates shows that the option with the smallest total duration is often chosen. An important factor in the duration is the downtime. It can be seen that it is much lower in April than in January. So the risk of downtime is lower in April. Therefore, the risk of downtime and the total duration are both important in the start date selection process.

This can also be seen when choosing the number of trips and whether an OSV is needed or not. Options 3b & 4b may have the shortest duration, but the associated probability of downtime is much greater than the probability of downtime associated with options 2 & 4a. Because this uncertainty is less with options 2 & 4a, preference is given to these options. Ultimately, option 4a was chosen because this option had more flexibility in the planning, which leaves more room for setbacks or other things that do not go as planned.

In addition, options 2 & 4a are also the cheapest options. The option with the longest duration is also the most expensive and was therefore not considered further. So besides the total duration and the downtime, the costs and flexibility are also decisive.

When looking at the lift point selection process, something similar can be found. One of the two options would require more prep work and should be installed in the critical time frame. As a result, the chance of downtime and delay is greater than when this is not necessary. In addition, there is less flexibility for installation in the critical time frame: there is little or no time buffer if things don't go as planned which can result in a delay of the project.
Secondly, the costs of installing those lift points are many times higher than the costs that would be incurred for the ILT. And the situation with the ILTs is safer because no people are needed to attach and detach the rigging. The fact that the fixed lift points are a proven concept and the concept with the ILTs quite new, such that it still had to be properly calculated and approved, did not outweigh the disadvantages of costs, ease of installation and time associated with the fixed lift points.
Therefore, safety, cost, total duration, (risk of) downtime and ease of installation are important factors in the lift point selection process. The downtime also includes critical time path and flexibility. Because if a lift point has to be installed in a critical time frame, there is less flexibility in the planning as there is a time window in which the work has to be done, increasing the chance of downtime. This in turn can reduce the easy of installation as well, because it can make the installation more complex. Downtime and ease of installation are therefore related, but in order to be able to distinguish between the two criteria, downtime includes the time and the risk of overrun to install the lift point and ease of installation involves the physical installation and possible preparatory work such as a work platform needed for installation.

3.4 L10

Boskalis was awarded the contract by Neptune Energy Netherlands B.V. for the removal, transport and load-in of three platforms. These platforms were located in the Dutch North Sea in the L10 field, approximately 90km west of Terschelling. The operation involved the removal of the L10-C, L10-D and L10-G platforms and was executed in the spring of 2020, between the V&V 2019 and V&V 2020 projects.
One difference with respect to the Viking & Vulcan campaigns is that the project team assembled for the L10 project was small and consisted of people who had some experience with decommissioning. Due to the experience in the group the team could more easily decide which options to consider and which not, without the need of a trade-off table with for instance Pros and Cons or a trade-off of costs per option. In addition, the small team made the decision-process faster because fewer people had to agree. Therefore these trade-off tables are absent in this section.

3.4.1 Execution Strategy

The execution strategy must be determined for a cost-effective execution of the L10 project. This includes determining the start date, whether an OSV is needed or not and what the optimal amount of trips is.

Start date

As a starting date there were not many choices for the L10 project: the project would be executed between the V&V 2019 and V&V 2020 campaign, leaving little room for different starting dates, i.e. only in the beginning of 2020 as the V&V 2020 campaign would start in April. Therefore, no trade-off has been made to determine the best start date, but it has been decided to start the project as soon as possible in early 2020, somewhere around the beginning of spring.

Additional vessel

The second point is to assess whether the deployment of an additional support vessel would benefit the execution. After investigation by the project team it became clear that the additional vessel would only lead to more costs, but not to more benefits: if an OSV would be used there are two ships to manage increasing the day rate expenditures. It would also increase the chance of (double) downtime and it results in less flexibility in the planning which is not preferred. And if the two vessels would have to work simultaneously at the same location, also a SIMOPS is required. The only advantage was that the project would be completed a little faster than without an OSV. But the extra speed did not outweigh the extra costs and other downsides, therefore only the Bokalift 1 was used for the decommissioning of the platforms.

Amount of trips

Finally, it must also be determined how many trips are required as a minimum and whether that is the optimal number of trips, or whether another amount of trips would be a better choice. Initially the client had offered to transport all jackets on deck in one trip and the topsides in another, but Boskalis indicated that this would not be possible. In addition, this would also mean that three different grillages would have to be designed, made and installed on deck which is expensive. That is why Boskalis came up with a different plan to get a more cost-effective approach. Instead of transporting all three jackets at once, there would be three trips: 1 trip per platform, three in total. In this plan, the grillages used in the V&V 2019 campaign could be reused with some adjustments. This would be much cheaper than buying three new ones. In addition, the money to buy those grillages would flow out of Boskalis, whereas the costs for the extra trip would stay partly in Boskalis as it owns the vessel. This makes the extra trip instead of new grillages even more attractive.
Also, having three trips instead of two gives more flexibility, which is preferable as it allows room for adjustment when problems arise and the execution cannot go according to plan. An example is, for instance, that the jacket does not come loose from the ground. If necessary, its transport can then be shifted to another trip to give more time to solve the problem. Then the planning is just adjusted a little and some activities are shifted.
The grillages would be used for the topsides, so in each trip a topside is placed on deck in the grillage and the jacket will be suspended in the crane hook. The reason to suspend the jacket is because the jacket is very dirty after removing it form the seabed which makes welding and securing it to deck more complicated.
So instead of two trips it became three. In principle, one platform was first removed before the next one. But in the end there were some deviations and the final sequence became:

- Trip 1: L10-C generator, L10-C helideck, L10-G topside, L10-G jacket
- Trip 2: L10-D generator, L10-D helideck, L10-C topside, L10-C jacket
- Trip 3: L10-D topside, L10-D jacket

A work platform had to be installed on each jacket to create a safe workspace and it was designed in such a way that it could be used on all three jackets. A lift is required to install the platform for which weather conditions must be taken into account: this could cause delays if the weather is not favourable. When removing the jackets, the weather window starts just before cutting the last leg until the HLV is in sheltered waters. In this critical time frame you want to work as quickly as possible so that the work is done within the weather window. Therefore an extra lift, besides the one for the jacket, is not desirable. For this reason, Boskalis had chosen to lift and transport the jacket together with the work platform in one go every time. And on arrival at the disposal site, where the weather window for removal at sea no longer applies, the platform could be removed from the jacket in a non-critical time frame.

3.4.2 Lift points

In order to get a good overview of the decision-making process of the lift point design of the L10 project, each topside will be treated individually as they all had a different approach, starting with the L10-C platform. At the end the jackets will be treated together.

L10-C platform

The decommissioning of the L10-C platform involved the removal of a helideck, generator, topside and jacket. See Figure 3.17. This figure shows the L10-G platform, which is representative for all platforms as they all look the same, but not identical. Before removing the topside, the helideck and generator building will be removed. This will allow some of the topside's lift points to be accessed from the main deck. The helideck is the first item to be removed, since it is above the generator.

The old lift points on the helideck were still present. Prior to the decommissioning project, the client investigated whether these old padeyes could be reused. This inspection was done during a preparation phase to reduce expenses as the client was already on site for other activities. Additionally, the reuse of the existing padeyes is beneficial for all parties involved, as it is the cheapest and simplest option. The old padeyes turned out to be sufficiently strong, therefore the client could already offer the reuse of the old lift points to Boskalis. As a result, there was no reason for both parties, Neptune & Boskalis, to think of alternatives. As a second check, a visual inspection of the existing padeyes will still be performed prior lifting.
After the helideck, the generator is removed to get access to the topside's lift points. As with the helicopter deck, the client inspected the old lifting points of the generator during the preparatory work prior to the decommissioning. It is done by means of Magnetic Particle Inspection (MPI), a NDT method, and offered the reuse to Boskalis. Boskalis could not clearly see though from the MPI reports whether all the welds connecting the lifting points and the generator have

been inspected, since there is floor sheeting around the padeyes covering those welds. Therefore a visual inspection will be performed to assess whether the welds were inspected properly or not; if not, the steel plate around the padeyes will be removed and the weld will be tested. It turned out that the four padeyes were indeed in good enough condition to be reused for the removal and thus this option was chosen and no other options were devised.
After the generator the topside can be removed. On all four platform legs, there are existing padeyes that were used for platform installation. Once again, the reuse of the existing padeyes is beneficial for all parties involved, which is why this was first investigated by the client. After the investigation it turned out that the two padeyes on legs A1 and A2 were strong enough to be reused so this was presented to Boskalis and eventually used in the execution. But the investigation also found that the padeyes in legs B1 and B2 lack the capacity to perform the lift; therefore new additional lift points will be installed on these two legs to reduce the load applied on the padeyes at Row B. As a result, four possible concepts were devised and investigated:

- Concept 1; a second padeye will be installed on top of the existing one in order to divide the loads between the two padeyes.
- Concept 2; reinforcement of existing padeye.
- Concept 3; the existing padeye will be replaced by a completely new one.
- Concept 4; a second padeye will be installed mirrored around the main leg axis.

The second padeye in concept 1 will be sticking through the main deck. Installation of this second padeye will not be possible before arrival of the vessel in the field, since the generator will be located above the padeye at location B2. The installation will therefore be in the critical path which is not preferred.
Concept 2 and 3 are investigated to determine the required dimensions for the new proposed padeye: In concept 2 the modified padeye will consist of a combination of S235 and S355 steel; the existing padeye material is S235 and additions will be S355 material in order to reduce the amount of material to be added to minimize the weld scope. The proposed modifications were verified for all load cases making use of a FEM-model. In concept 3, a full replacement padeye, the new padeye will consist of S355 material only. Since the orientation of the padeye will be free to choose, the new padeye should be pointing towards the CoG for maximum efficiency.
Initially concept 4 was not detailed out further due to similar access restrictions of concept 1 and since the amount of welding is comparable to options 2 and 3. Therefore, option 2 and 3 seemed to be the best options. But as options 2 & 3 were further developed and in both cases it was investigated how the new lift point should be installed, Boskalis ran into problems in terms of engineering and feasibility: the connection could not be calculated well enough and the installation not easy. For that reason Boskalis decided to look again at concept 4. It turned out that, contrary to what was previously thought, it would be easier and faster to install the mirrored padeyes. These new lift points could be installed by lifting them through the hatches above the lift points, fitted in position and welded to the topside leg without the need of removing the genereator first. Finally, a NDT inspection will be performed on all new welds of the new padeyes.

L10-D platform

As with the L10-C platform, the decommissioning of the L10-D platform consisted of the removal of a helideck, generator, topside and jacket. First, the helideck will be removed since it is above the generator. Then the generator will be removed so that the topside lift points are accessible from the main deck.
In the case of the helideck and generator, it is the same as for the L10-C platform: The client had inspected the old lift points of the helideck and generator during the preparation phase. Again it was unclear from the MPI reports of the generator inspection if all the welds connecting the lift points and the generator have been inspected, since there is floor sheeting around the padeyes covering those welds. A visual inspection will be performed to assess whether the welds were inspected or not; if not, the steel plate around the padeyes will be removed and the weld will be tested. The padeyes of both the helideck and generator proved to be sufficiently strong so the client had offered the reuse of the old lift points to Boskalis. Because of this, no other options have been investigated and the helideck and generator were lifted at their old lift points.

Once the generator is removed, preparations for removing the topside can begin as the lift points can then be accessed from the main deck. The old lift points of the topside were inspected by the client during the preparation phase as well. It turned out that all the old padeyes had sufficient capacity and therefore the client offered this to Boskalis. After a second check by Boskalis through calculations by structural engineers this was confirmed. Due to this reason no other options were devised and all the old lift points of the topside were reused.

Figure 3.17: The L10-G platform

L10-G platform

The decommissioning of the L10-G platform involved the removal of a topside and jacket. As with all the other old lift points, the client investigated during the preparation phase whether the existing lift points of the L10-G topside were suitable for reuse. The investigation showed that two lift points of row A still had sufficient capacity, but the other two of row B did not. Therefore the client offered the reuse of the padeyes of row A only. Due to this no other options were thought of as alternative lift point for row A.
The existing lift points of row B had insufficient capacity, therefore new lift points had to be designed and installed. Three options were devised for this:

- A padeye
- A trunnion with weld
- A trunnion without weld

Option 1 consists of two new padeyes. These padeyes will have to be installed by means of welding. Because welding is expensive as it is time consuming and requires material and people, this option is not preferred. The same applies for option 2 where the two trunnions have to be welded on the two legs.
Option 3 does not involve such a welding scope. Instead of welding the trunnions onto the legs, the trunnion is installed by creating two holes and then to push the trunnion through the holes and fixing it with small welds. Because the client could easily come to the platform as they were already on site for other work during the preparation phase, the client was able to make the holes for Boskalis at a lower cost than usual. And because it could be done in the preparation phase, it would not have to be done in the critical time window of the execution phase, which is preferred. As a result, option 3 was the quickest and cheapest option of the three, therefore option 3 was chosen: two trunnions will be installed on legs B1 and B2 to be used as lift points for the topside lift.

L10-C/D/G Jacket

The lift point design of all three jackets will be discussed in this section. Not because the jackets are three identical ones, but because the approach and lift point design of all three jackets are the same in the scope of this research.

In order to be able to remove the jacket, some preparations have to be made. A problem that is often encountered with jackets is that not every part of the jacket is (easily) accessible through existing walkways. And because the jacket is standing in the sea, most of the walkways that are present are degraded and in poor condition, making standing and working on them unsafe. Therefore, to support all remaining activities related to the jacket removal operation a working platform will be installed on the jacket after the topside is removed, to provide a safe working area for the preparations of the removal. As mentioned, the platform is designed in such a way that it will fit on all three jackets. In addition, one cutting platform will be constructed in scaffold around each jacket leg. The cutting platforms will be used for the topsides cutting operation as well as supporting the jacket lift point preparation, soil plug removal, internal cutting operations and rigging installation. To gain safe access to the platform, a motion compensated gangway fitted with a tip ladder will be used.

After removing the topside, the work platform can be installed and the preparations for removing the jacket can be started. Because the topside has been cut off, the four legs have become open at the top. This makes it possible to use ILTs for lifting the jacket. So at first, the use of ILTs was considered. One problem that arose was that the ILTs had to come from another project and had to be refurbished before they could be used again. This turned out to be very expensive for the L10 project. In addition, not all ILTs were available, which is a major risk. Therefore it was decided to look for an alternative without ILTs.
The first alternative that was devised was the use of two shackles per leg, eight in total. When it was clear that this could be possible, the plan was calculated as a backup. While working it out, this backup plan turned out to be better than the primary plan, so they were swapped. Ultimately, the option with shackles would be much cheaper than with ILTs and there would be less risk involved: the risk of unavailability does not apply to the shackles and when the shackles are installed the connection, the lift point, is in place whereas the ILTs still run the risk that if the ILT is inserted into the leg the connection cannot be made properly. Because this alternative turned out well, other options were no longer looked at.
So to allow the jacket to be lifted, two 300mT shackles will be fitted on top of each pile as shown in Figure 3.18. To create these lift points, two 250mm lifting holes will be prepared and fitted with bushings. The shackles will then be installed in the bushing. Once inserted in the holes, the bushings will be secured by the inserted bolt in the inside of the leg and by the lifting padeye on the outside. The jacket lift will be performed after the completion of the preparation scopes and consists of rigging preparation, installation and lifting operation. The weather window for the jacket lifting operation starts before the cut of the 4th jacket leg and continues until the HLV is in sheltered waters. To provide control of the load during lifting and allow maneuvering/positioning of the jacket, tugger lines will be installed. Due to the induced side load by these lines, they cannot be connected to the main rigging and therefore have to be connected to the jacket below the lift points. A stretcher is added to the tugger arrangement and to mitigate risk a back-up wire sling is also added in case of stretcher failure, as can be seen in Figure 3.18.

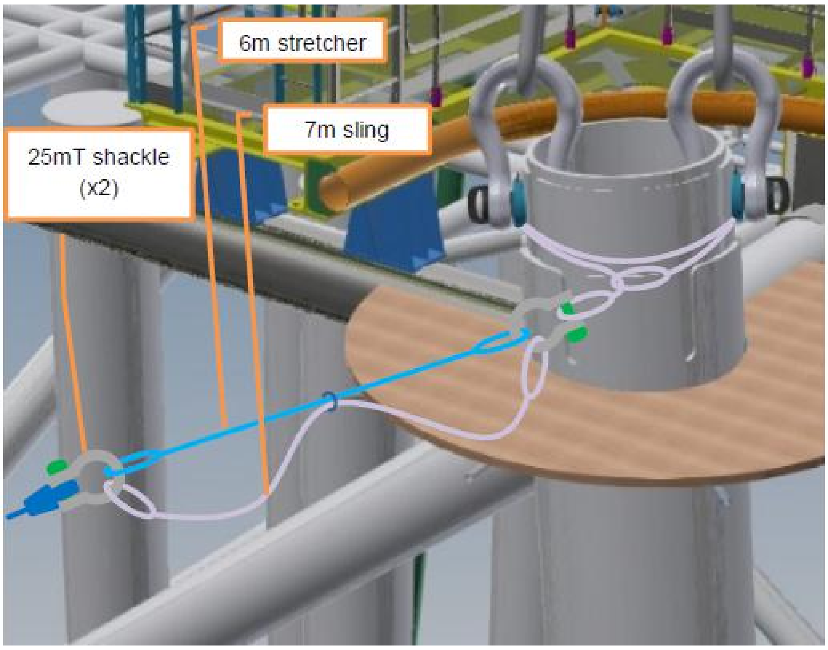


Figure 3.18: L10 jacket lift point and tugger connection

3.4.3 Result and Evaluation

To maintain safety during the execution of the project the NINA program was implemented in all facets of the project and adopted by the client and all subcontractors. All personnel involved in the operations were trained in the NINA program, resulting in a high level of safety awareness and commitment. The project was completed with zero lost time incidents, a good accomplishment.

The decision-making process of the L10 project resulted in the following executions:

L10-C

Of the L10-C platform the helideck and the generator are lifted at their old liftpoints. This is because they still had sufficient capacity and therefore the client had offered the reuse to Boskalis. In the end the reuse of the existing padeyes is beneficial for all parties involved, as it is the cheapest and simplest option. No alternatives were devised because of this. For the topside, only two of the four old padeyes could be reused. Two additional new padeyes had to be installed to be able to lift the topside. Four concepts were devised for this, but eventually the mirrored padeyes proved to be the best choice as they were the easiest and fastest to install and because it consisted of the same amount of welding as the other options.

L10-D

With the L10-D platform the helideck, generator and topside are lifted at their old lift points as they still had sufficient capacity which is why the client had offered the reuse to Boskalis. Therefore, no alternatives have been devised.

L10-G

The L10-G topside is lifted at two old lift points as they still had sufficient capacity and at two new ones. Three options were devised as new lift point: a padeye, a welded trunnion and a trunnion without weld. The trunnion without weld is chosen as it is the quickest and cheapest option of the three: because the client could easily come to the platform as they were already on site for other work during the preparation phase. And because no welding was required. So two trunnions are installed to be used as lift points for the topside lift together with the two old padeyes.

L10 Jackets

The jackets of all three platforms were not the same, but in the scope of this research had the same approach of lift point design. On all three jackets a work platform had to be installed to create a safe work environment. And for all three jackets the initial plan was to use ILTs but this turned out to be very expensive. Besides, there was the risk that they would not be available when needed and there remained a risk associated with inserting the ILTs into the legs. Therefore an alternative was devised. This alternative proved to be a better solution than the initial plan of ILTs, so they were swapped. The alternative consisted of the use of two shakles per leg, eight per jacket. These shackles are cheaper to use than the ILTs and they would involve less risk. Because this alternative turned out well there were no other options investigated. And so all three jackets are lifted at eight shackles.

In total there were three trips, one per platform. Initially the client had offered two trips, but this was not possible according to Boskalis. Therefore an extra trip was suggested. This would also give more flexibility in the planning. Due to some unforeseen problems, the schedule had to be adjusted slightly, but the execution could still be done in three trips.

3.4.4 Conclusion

From the L10 project, the following can be concluded.
Because this project does not contain a selection process for the start date, it does not provide any additional insight into Boskalis' selection process. On the other hand, a trade-off has been made for the use of an extra OSV. Cost, risk and time played a part in this decision. Research showed that the gain in time did not outweigh the extra costs and extra risk associated with the OSV: if an OSV were to be used, there are two vessels to manage, which increases the risk of downtime and makes the planning less flexible. And its requires a SIMOPS. Therefore, the time gain in this case did not reduce the risk, as in the case of the V&V 2019 project, but increased it. It shows that downtime, flexibility in planning, costs and risk are important in the selection process and that a reduction in total duration is not always decisive.

For the number of trips the client had already made a choice. However, this turned out to be unfeasible according to Boskalis because it required new grillages and only two trips. The two trips would make for a tight schedule. Therefore Boskalis opted an extra trip to implement some flexibility in the planning. In addition, the extra trip ensured that old grillages could be reused, which saved a lot of money. This decision of Boskalis shows the importance of flexibility and costs in the decision-making process.

The choice not to lift the work platform in a critical time path indicates that flexibility and the risk of delay or downtime play a role in making a decision. Rather choose a situation where the action does not have to be in a critical time path.

With regard to the lift point selection process: if the old lift points are still present, they are inspected and tested to see if they can be reused. This is because reusing old lift points is the simplest and cheapest option to create a lift point. If the old lift points can be reused, this will be done and other options will no longer be explored, as can be seen at the generator, helideck and a part of the topside of the L10C platform. And at the generator, helideck and topside of L10D platform. And at a part of the topside of L10G platform.

For the L10C topside, two new lift points had to be chosen. These were not the 'standard' options as described in section 1.4, but multiple concepts of just a padeye. Option 1 where a new padeye was put on the old one was rejected because the installation could only be done after removing the generator, so this falls in the critical time frame which is better to be avoided. And this means a low 'ease of installation'. Options 2 and 3 were dropped because in the end they could not be calculated properly: it could not be properly verified whether it was structurally possible. And installing one of the two options was more difficult than option 4. That is why option 4 was eventually worked out and chosen, because this option was easier and faster to install than the rest.

Two new lift points also had to be made for the L10G topside. Three options were devised for this: a padeye, a trunnion with a weld or a trunnion without a weld. The first two options include a large welding scope. The third option does not. In addition, the holes for the trunnions could be made by the customer in the preparatory phase. As a result, the third option was the cheapest and fastest of the three, and did not require installation in the critical time frame, and providing greater ease of installation.

Finally there was the selection process of the jackets. A work platform was made to create a safe working environment for the prep work, such that the NINA program is maintained.
As a lift point, the use of ILTs was considered as the first option because the legs are open at the top. But an alternative had to be found when the ILTs turned out to be very expensive. And it was possible that not all ILTs would be available, which is a big risk. If the ILTs are not available when requested, it will cause overrun so this risk will be placed under downtime. The first alternative was the shackle-hole combination, two per leg. This turned out to be a good plan. After working out it proved to be even better than the original plan. Because the shackle-hole combination did not have the risk of unavailability and because it was cheaper to realise, that option was chosen. For that reason no other options were investigated.

The lift point selection process of the L10 project therefore shows that old lift points are reused whenever possible. And that the critical parameters used to make the decisions are safety, cost, (total) duration, risk of downtime and ease of installation.

3.5 Conclusion

This chapter analysed three of the decommissioning projects Boskalis had carried out in the last couple of years to get insight in the decision-making process with regard to the lift point design.

First, Boskalis says that safety is a core value and a top priority and that it has incorporated safety into their way of working, the WoW, with the No Injuries No Accidents program, NINA. This approach should ensure that safety is guaranteed on every project such that employees can go home safely and without injury every day.
After studying all three projects, it became clear that there is a lot of attention to ensure that this is actually carried out. For example, in the V&V2020 project and in the L10 project, NINA sessions were held at the start of each meeting to keep people on their toes with regard to safety. Also, the NINA program was implemented in all facets of the projects and was adopted by the client and all subcontractors. As a result, there was a high level of safety awareness and commitment. This resulted in zero lost-time incidents or accidents in both projects.
In addition, in the V&V2019 project, safety was guaranteed by, for example, making a HazID in order to map out all dangers so that people can anticipate them. And to make sure that everyone is aware of it and understands the content. That way, a safe working environment was established that resulted in no lost-time incidents or accidents.
So, safety is indeed a core value and top priority at Boskalis. An option is only considered if the safety of all personnel can be guaranteed.

Secondly, it was investigated whether Boskalis takes certain standard steps in the lift point design process and what these steps could be. After studying the projects, a certain trend in tackling the lift point design became visible. It is not a pre-agreed way of acting, because every project is different and has its own unique situation that must be taken into account according to the experts, but the same approach could be found in all three projects:

* The first thing that is looked at is what the client has offered. It often happens that the customer has a certain lift point in mind. For example, during the L10 project, the client had already inspected and tested the old lift points

and therefore offered them to Boskalis for reuse. Boskalis examined the test data provided and concluded that the old lift points were strong enough. For this reason, Boskalis no longer had to devise and install new lift points itself. Or as, for example, with the V&V2019 project. There a jack-up made certain options more attractive, such as welding which normally takes a long time but could now be done by the jack-up in a preparatory phase. Therefore the welding scope was no longer a problem. What is offered by the client thus influences the further selection process of the lift point design.

* If no type of lift points are offered by the client, the second thing checked is whether the old lift points are still usable, as can be seen with all three projects. This is because it is the cheapest, fastest and easiest option: nothing new needs to be designed and installed if they can be reused. Reinforcements may be needed, but they cost less time and material than a brand new lift point. The old lift points are first visually assessed and if they seem good enough they are tested using NDT methods. If the old lift points prove to be strong enough and can be used, no alternatives are devised and the old ones are reused. The review process therefore works well, because the old lift points have already been chosen in this way several times.

* If the old lift points cannot be reused, because it is structurally impossible, several alternatives are devised, elaborated and compared with each other. This often comes down to the same options as described in section 1.4: shackles, trunnion, internal lifting tool and padeye. However, often the shackle option is investigated first, because this option is easy to implement, does not take much time to install and does not cost a lot of money compared to the other options. This can be clearly seen with the CD and ED platform of the V&V2019 project, but also with the jackets of the L10 project.

* If this option is also not possible, then the ILT and trunnion options are often investigated and compared with each other. It has become clear from the two V&V projects that it depends on the structure and circumstances which of the two is a better option. For example, the ILT in the V&V 2019 project was much more expensive than the trunnion for which the trunnion was chosen. But for the V&V2020 project, the ILT was a better choice.

* It is possible that all these options are not applicable and that a new type has to be devised, such as the Extended Leg Piece in the V&V 2019 project. But as can be seen with that project, such an option is only considered if the other options mentioned are not possible.

* It can also happen that after working out 1 alternative it is already clear that that option is a good choice and then no other options are worked out. This was clearly visible with the jacket of the L10 project, but also with the V&V 2019 project.

When several options are compared, they are assessed on the basis of certain criteria. The best option can then be selected. This does not necessarily have to be the cheapest option, but an optimum of all criteria combined, which will be elaborated in a bit. So even though the exact steps in the engineering process may differ, the engineering process itself works well. That process allows for the best use of available information, which is project specific.

Finally, it was investigated what these criteria are that determine the best option. It became clear from the three projects that one of these criteria is safety. As mentioned, safety is extremely important at Boskalis and an option is only considered if safety can be guaranteed. Therefore, safety will be treated as a threshold that is always met and thus can be removed from the optimization problem.
Such a second point is structural integrity. If a choice is structurally impossible, it will no longer be considered. It is therefore assumed that all choices included in the trade-off are structurally possible.
Two other criteria that became apparent due to all three projects is the total duration and the risk of downtime. In general, the option with the shortest duration is chosen because the costs for, for example, the rental of the vessel will be less. And because everything can then be used more quickly for other projects. Downtime or the chance of it plays a role here and this includes flexibility in the planning & the critical time path. The total duration can be extended due to downtime. That is why it is preferable to choose an option that has less chance of downtime. Sometimes an option is selected that costs more than its alternative, but reduces the chance of downtime, which could mean that the project could be completed faster than with its alternative. This happened in the V&V 2019 project and in the V&V 2020 project.
The next criterion is ease of installation. All three projects show that the way in which the lift point should be installed plays a role in making a choice. It involves the physical installation and possible preparatory work such as a work platform needed for installation. For example with the ED platform in the V&V 2019 project. There was the choice between the extended piece of leg and the shackle-hole combination. The latter was chosen because it was much easier to install, without a large welding scope. Such a situation was also present at the JD platform. Or with the V&V 2020 campaign where the fixed lift point had much more preparatory work than the ILT, which resulted in a lower ease of installation.

The last criterion is the cost of an option. Ultimately, Boskalis wants to spend as little money as possible, so the option with the least cost are preferred. This concerns the total costs that must be incurred to realize the type of lift point, such as designing and fabricating a new lift point. Or the purchase of a work platform, for example.

The sequence found could be a good basis for AI. This is explored in the next chapter.

Chapter 4

Artificial Intelligence

In this chapter, the findings from the previous chapter are used to gain insight into the applicability of Artificial Intelligence to the decision-making process of the lift point design.

4.1 Background

In recent years, artificial intelligence (AI) has grown to such an extent that it is impossible to imagine the world without it. It is integrated into internet search engines, music apps, streaming services and so on. There are companies that use AI for the analysis of their data, or to improve for instance their production process in the factory. And the applicability is only increasing.
The first type of AI is Reactive Machines: programs which have limited capability with no memory-based functionality and that can only respond to a limited set or combination of inputs [30]. It is the most basic form of AI. It merely reacts to current scenarios and cannot rely upon taught or recalled data to make decisions in the present. They are given specific tasks and that is all they can execute. Reactive Machines do not interact with the world, they respond to identical situations in the same way every time those scenarios are encountered. An example of a reactive machine is IBM's Deep Blue chess AI or some recommendation engines [31].
As AI was further developed, a new type emerged: machine learning. This type of AI has the capability to extract knowledge from previously learned information, facts, stored data or events [32]. Machine learning started with limited memory machines. As distinct from reactive machines, limited memory is able to learn from the past by analysing actions or data given to them with the purpose of building probationary knowledge. After limited memory, Deep Learning was developed. It is a subset of machine learning [33]. It is generally referred to as a deep artificial neural network, and these are the algorithm sets that are extremely accurate for problems like sound recognition, image recognition, etc. Deep learning is also defined as it enables a computer to learn without being programmed to do so [33]. This subset makes the computation of a multi-layer neural network feasible [34]. Machine learning, especially Deep Learning, needs a large data set to be able to learn. This is often referred to as 'Big Data'.
All existing AI programs are one of these two types. Hypothetically, there are two more types: Theory of mind and Self-aware AI [30]. Theory of mind is an AI that can discern the needs, emotions, beliefs and thought processes of the entities it is interacting with. Self-aware AI is a type of AI where the machines are aware of themselves and perceive their internal states and others' emotions, behaviours, and acumen.

4.2 Trend in the decision-making process of Boskalis

In the previous chapter three decommissioning projects of Boskalis were examined and analysed. A trend has been found in the way Boskalis chooses a lifting point and which criteria play a role in that decision. This process is depicted in Figure 4.1 in a simply manner. The process is as follows:

1. It happens that the client offers the use of certain lift points. In that case, no lift point selection process is needed to chose a lift point type. The offered lift points are used.

2. If the client has not offered the use of certain lift points, the first step taken is to investigate whether the old lift points of the structure can be reused. This is done through visual observation and Non Destructive Testing (NDT). If the old lift points can be reused, this will be done and no other options will be explored.

3. When the old lift points cannot be reused, a new lift point must be selected. To do this, the simplest type of lift point is first examined: the shackle-hole combination. If this option is possible, the selection process ends and this option is used.

4. Sometimes it is not entirely certain after investigation whether the shackle-hole combination is actually the best choice. Or it is clear after the investigation that this option is not possible. In such cases, other types of lift points are investigated, such as the ILT, trunnion or another new type. This often starts with investigating 1 extra lift point option. And if after elaboration it is still not clear that one option would be better than the other, another option is investigated. These options are then compared with each other on the basis of criteria. The option with the best optimum of the criteria is then chosen.

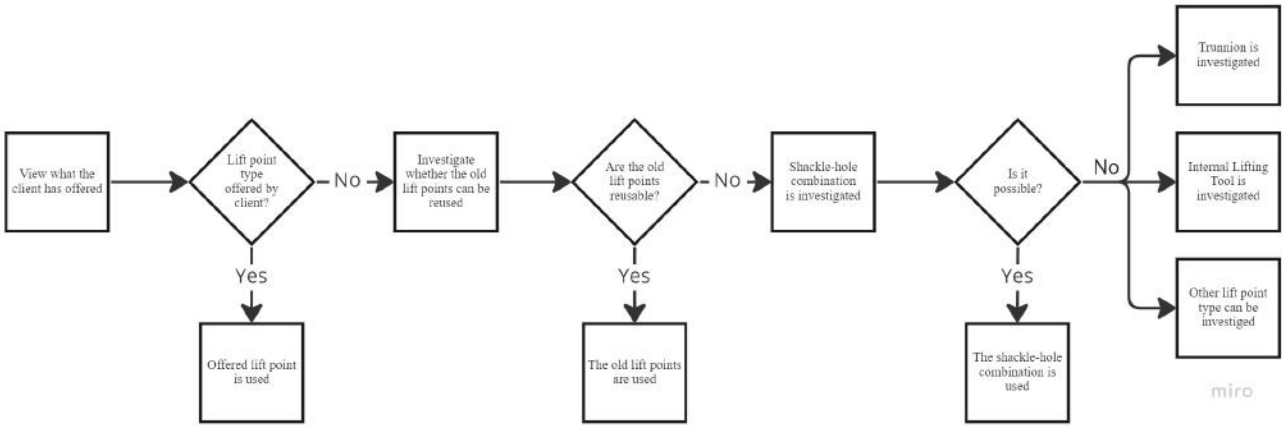


Figure 4.1: General process of the lift point design

The application of AI to the decision-making process should aim to select the best choice from the possible options for the engineer. Looking at Figure 4.1 this would be the rightmost part of the process. This is because there a choice has to be made from several options. In section 4.4 it is investigated which AI applications could be used to achieve this.

4.3 The criteria

When several types of lift points have to be examined because it is not clear which type would be the best option, they are compared based on certain criteria. From the analyses of the previous chapter it became apparent that safety is always maintained and can therefore be treated as a threshold that is met and thus can be excluded from the optimization problem. Another criteria that can be excluded is the structural integrity. It is assumed that all the options involved are structurally possible, because if an option is not possible in advance, it is of no use to include that option in the optimization.
The criteria found in the analysis that are used in the decision-making process to find the best lift point option and can therefore be included in the optimization are:

- Total duration of the procurement and installation of the lift point.
- Risk of downtime associated with the lift point option including flexibility in the planning and the critical time path.
- Ease of installation: how easy it is to physically install the lifting point and whether any preparatory work is required such as a work platform.
- Total cost of the lift point option.

4.4 Applicability to AI

In this section it will be investigated which AI applications could be used to improve or optimize the selection process of the lift point design based on the given criteria. Because machine learning is now widely used worldwide and has multiple applications, this option will be explored first.

4.4.1 Machine Learning

Machine learning (ML) is a subset of AI. It makes use of statistical models to develop predictions [47]. As mentioned, a machine learning AI is capable to extract knowledge from previously learned information, facts, stored data or events. It learns by analysing actions or data given to them with the purpose of building probationary knowledge. In this way, the AI can discover trends through the data and can compare different units such as time and costs, where, for example, an optimization function cannot. The latter is discussed further in subsection 4.4.3.
By analysing the data, the computer creates a neural network to make data-driven recommendations and decisions based on only the input data. It is often described as a form of predictive modelling and has been defined as the ability of a computer to learn without explicitly being programmed to do so. For the AI to be able to do this, an immense amount of data is required [48]. Often this amounts to 1000 to 10,000 data points.

Types of ML

There exist three types of ML: supervised learning, unsupervised learning and reinforcement learning [49]

- Supervised learning: the computer is trained on a set of data inputs and outputs, with the goal of learning a general rule that maps the given inputs to the given outputs.
- Unsupervised learning: the learning algorithm is not given guidance such as with supervised learning. Instead, it works to discover the pattern or structure in the input on its own.
- Reinforcement learning: it is the closest machine learning type to how humans learn. The algorithm used learns by interacting with its environment and getting a positive or negative reward. This will reinforce its learning and goal seeking effort.

Applications of ML

ML has numerous applications across different industries, such as in Healthcare, Finance, Social Media or Retail [50]. For instance, in financial markets, ML is used for automation, portfolio optimization, risk management, and to provide financial advisory services to investors [47]. ML can help in evaluating large amounts of data, determining patterns, and finding solutions for given problems with regard to balancing risk and reward. ML can also help in detecting investment signals and in time-series forecasting. In Healthcare, ML can help doctors and medical practitioners to accurately predict how long patients with fatal diseases will live. Medical machine learning systems will learn from data and help patients save money by skipping unnecessary tests. And there are much more applications, such as voice assistants, self-driving cars, spam filters or search engines.

All these applications are a kind of optimization, namely data fitting [51]. Optimization is one of three things ML can be used for. The other two are: estimate a model & estimate a controller based on a model or reduce the model or parameter uncertainty. According to some experts, estimating the model is not necessary, because this can be done without a model.
Estimating the controller is interesting, but then you need a large control/choice dimension. In this case there is no such large dimension, because as can be seen in Figure 4.1, one of the standard type of lift points is often chosen. And there are about 5 of them.
Optimization is possible, but according to the experts, depending on how the function is set up, there are probably easier options for this. ML can be used for many things, but if a system with few uncertainties can be modeled and expressed in observable variables, then you simply don't need ML. Because if it can be expressed in observable variables, then ML does not have to be used because the system can be modeled by literally writing it out. Only if those variables are very uncertain, then an uncertain stochastic term can be made of it or a random walk process according to an expert.

Conclusion

Looking at the problem as shown in the right part of Figure 4.1, it must be determined which of the last options should be used conditionally that the other choices are not possible. All lift point options could be expressed in time or cost, because the criteria against which they are compared are time (total duration, downtime, ease of installation) and (total) cost. Therefore it appears that the system can be described by writing it out and ML would not be necessary.
In addition, there is simply the fact that there is very little data: only three projects are analysed. And as mentioned, ML needs a large dataset of about 1000 to 10,000 datapoints to create its neural network. This would only work if the database is extended with more projects. And due to the small database, the model cannot be tested to see if it is correct. This model is created by machine learning algorithms that use function optimization to fit a model to a

training dataset [52].
So ML does not seem to be applicable to the current problem in this state, because there is not enough data to create the neural network. Only when the database and/or the control/choice dimension is enlarged will machine learning become interesting.

4.4.2 Genetic algorithms

Another way to solve optimization problems is with genetic algorithms (GA). A genetic algorithm is used to solve complicated problems that have a large number of variables & possible outcomes or solutions [53]. By means of a Darwinian based algorithm the best solutions are found out of a set of combinations of different solutions. The poorer solutions are then replaced with the offspring of good solutions. Optimal solutions are solutions with a higher quality, for instance a solution with the least cost. In Genetic Algorithm research artificial benchmark problems are used for experimental research. These functions are explicitly given and analytically solvable. Hence, their characteristics, their structure, and their optima are well known [54].

Genetic Algorithms are the translation of the biological concept of evolution into algorithmic recipes. They belong to the area of computer science related to machines and computer programs. As they are part of many intelligent systems, Genetic Algorithms are frequently counted to the areas of computational intelligence and artificial intelligence, which aim at constructing methods that imitate and even overcome human intelligence. Meanwhile, a huge collection of methods has been proposed that fall into these categories. Genetic Algorithms are biologically-inspired algorithms for optimization [54].

Close related to Genetic Algorithms is Swarm Intelligence and Fireworks Algorithms. They all have in common that they employ exploration and exploitation mechanisms. Eiben and Smith [55] give a good overview to Genetic Algorithms. The book is an attractive introduction of Genetic Algorithm concepts and gives an overview to many related fields. It turns out that the genetic search of Genetic Algorithms crucially depends on the choice of adequate parameters.
Practical optimization problems are often constrained. Not the whole solution space is allowed, but only a feasible subset. Genetic Algorithms have to be adapted to cope with constraints. One strategy is to choose representations and operators that avoid infeasible solutions. An easy way to cope with constraints is the use of penalty functions, which deteriorate the fitness of a solution.

Genetic algorithm breakdown

Genetic Algorithms are heuristic search approaches that are applicable to a wide range of optimization problems [54]. The most important genetic operators are: crossover, mutation, and selection. These will be explained in a moment. The classic Genetic Algorithm is based on a set of candidate solutions that represent a solution to the optimization problem to be solved. A solution is a potential candidate for an optimum of the optimization problem. Its representation plays an important role, as the representation determines the choice of the genetic operators. The coding of the solution as representation, which is subject to the evolutionary process, is called genotype or chromosome. At the beginning, a set of solutions is initialized. This initialization is recommended to randomly cover the whole solution space or to model and incorporate expert knowledge. The representation determines the initialization process. For bit string representations a random combination of zeros and ones is reasonable, for example the initial random chromosome 1001001001 as a typical bit string of length 10. The main generational loop of the Genetic Algorithm generates new offspring candidate solutions with crossover and mutation until the population is complete. An example of a basic GA is given in Figure 4.2.

Algorithm 1 Basic GENETIC ALGORITHM

```
initialize population
repeat
    repeat
        crossover
        mutation
        phenotype mapping
        fitness computation
    until population complete
    selection of parental population
until termination condition
```

Figure 4.2: A basic Genetic Algorithm [54]

Crossover Crossover is an operator that allows the combination of the genetic material of two or more solutions. Crossover operators in Genetic Algorithms implement a mechanism that mixes the genetic material of the parents. A famous one for bit string representation is n-point crossover. It splits up two solutions at n positions and alternately assembles them to a new one. For example, if 0010110010 is the first parent and 1111010111 is the second one, one-point crossover would randomly choose a position, let us assume 4, and generate the two offspring candidate solutions 0010-010111 and 1111-110010. The motivation for such an operator is that both strings might represent successful parts of solutions that when combined even outperform their parents. This operator can easily be extended to more points, where the solutions are split up and reassembled alternately.
For continuous representations, the crossover operators are oriented to numerical operations. Arithmetic crossover, also known as intermediate crossover, computes the arithmetic mean of all parental solutions component-wise. For example, for the two parents (1, 4, 2) and (3, 2, 3) the offspring solution is (2, 3, 2.5). This crossover operator can be extended to more than two parents. There also is dominant crossover, it successively chooses each component from one of the parental solutions. And uniform crossover, it uses a fixed mixing ratio like 0.5 to randomly choose a bit from either of the parents. The question comes up, which of the parental solutions take part in the generation of new solutions. Many Genetic Algorithms simplify this step and randomly choose the parents for the crossover operation with uniform distribution.

Mutation Mutation operators change a solution by disturbing them. Mutation is based on random changes. The strength of this disturbance is called mutation rate. In continuous solution spaces the mutation rate is also known as step size. There are three main requirements for mutation operators: reachability (each point in solution space must be reachable from an arbitrary point in solution space), unbiasedness (the mutation operator should not induce a drift of the search to a particular direction, at least in unconstrained solution spaces without plateaus) and scalability (each mutation operator should offer the degree of freedom that its strength is adaptable). The implementation of the mutation operators depends on the employed representation. For bit strings bit flip mutation is usually used. Bit flip mutation flips a zero bit to a one bit and vice versa with a defined probability, which plays the role of the mutation rate. If the representation is a list or string of arbitrary elements, mutation randomly chooses a replacement for each element. This mutation operator is known as random resetting. For continuous representations, Gaussian mutation is the most popular operator. A vector of Gaussian noise is added to a continuous solution vector. If $\mathbf{x}$ is the offspring solution that has been generated with crossover,

$$\mathbf{x}' = \mathbf{x} + \sigma \cdot N(0,1) \tag{4.1}$$

is the Gaussian mutation with N(0, 1) as notation for a vector of Gaussian-based noise. Variable σ is the mutation rate that scales the strengths of the noise added. The Gaussian distribution is maximal at the origin. Hence, with the highest probability the solution is not changed or only slightly. With a scalable σ, all regions in continuous solution spaces will be reachable. Due to the symmetry of the Gaussian distribution, it does not prefer any direction and is hence driftless.

Genotype-Phenotype Mapping After crossover and mutation, the new offspring population has to be evaluated. Each candidate solution has to be evaluated with regard to its ability to solve the optimization problem. Depending on the representation a mapping of the chromosome, the genotype, to the actual solution, which is denoted as phenotype, is necessary. This genotype-phenotype mapping should avoid introducing a bias. The genotype-phenotype mapping is not always required. For example, in continuous optimization, the genotype is the solution itself.

Fitness After mapping the Phenotype is evaluated on a fitness function (Evaluation function). The fitness function measures the quality of the solutions the Genetic Algorithm has generated [54]. The practitioner (the maker of) can have an influence on design choices of the fitness function and thus guide the search. For example, the fitness of infeasible solutions can be deteriorated like in the case of penalty functions. In case of multiple objectives that have to be optimized at the same time, the fitness function values of each single objective can be aggregated, for example by computing the weighted sum (the weighted sum is a simple method of Multi-Criteria Decision Analysis). It sounds simple to presume that a worse solution should employ a worse fitness function value, but a closer look is often necessary. For example, should a solution that is very close to the global optimum, but constrained, have a worse fitness value than a bad solution that is feasible? And should a solution that is close to the optimum of the first objective in multi-objective optimization, but far away from the optimum of a second objective, which is much less important, get a worse fitness function value than a solution that is less close to the first optimum but much closer to the second one? To summarize, the choice of the penalty for infeasible solutions and the choice of appropriate weights in multi-objective optimization are important design objectives.
Most approaches aim at minimizing the number of fitness function calls. The performance of a Genetic Algorithm

in solving a problem is usually measured in terms of the number of required fitness function evaluations until the optimum is found or approximated with a desired accuracy. In general, fewer function calls means less cost and time needed. Finally, the accuracy of the prediction model has to be evaluated on a test set in order to get a precision score that can be used as fitness function value.

Selection To allow convergence towards optimal solutions, the best offspring solutions have to be selected to be parents in the new parental population. So the best solutions of the first solution space are chosen and taken as the start for the new iteration for a second new solution space (this procedure together with all that is stated above is repeated until the optimal solution is obtained within the defined accuracy, until the termination condition is met and the evolutionary loop ends). A surplus of offspring solutions is generated and the best are selected to achieve a progress towards the optimum. This selection process is based on the fitness values in the population. In case of minimization problems low fitness values are preferred and vice versa in case of maximization problems.

- Elitist selection operators select the best solutions of the offspring solutions as parents.
- Comma selection selects the μ best solutions from λ offspring solutions.
- Plus selection selects the μ best solutions from λ offspring solutions and the μ old parents that led to their creation.

Many selection algorithms are based on randomness. The probability for being selected depends on the fitness of a solution. The advantage of this fitness-proportional selection operators is that each solution has a positive probability of being selected.

Termination The termination condition defines, when the main evolutionary loop terminates. Often, the Genetic Algorithm runs for a predefined number of generations. This can be reasonable in various experimental settings. Time and cost of fitness function evaluations may restrict the length of the optimization process. A further useful termination condition is convergence of the optimization process. When approximating the optimum, the progress of fitness function improvements may decrease significantly. If no significant process is observed, a stagnation in fitness difference per generation, the evolutionary process stops. A stagnation could mean that the search might have got stuck in local optima, hence missing the global one. By using 'Restart Strategies' this can be avoided. If the same optima is obtained while starting from a different point, this optima could be the global one, or the chance is high that the local optimum is a large attractor, and a better local optimum is unlikely to find.

Conclusion

Now that it is clear what GA is and how it works, it is investigated whether this would be a good application for the selection process of the lift points. The optimization problem to be solved here is to select (a combination of) the best option(s) of lift point type(s) from a selection of multiple lift point types using the given criteria. The best option will be the lift point type that costs the least, has the shortest duration to install, or is an optimum of that.
The Genetic Algorithm is based on a set of candidate solutions that represent a solution to the optimization problem to be solved. It will combine given solutions to make a new generation, by means of crossover, mutation, fitness and selection. It is repeated until the optimal solution is obtained within the defined accuracy, until the termination condition is met and the evolutionary loop ends.
The lift point types to the right of Figure 4.1 would then be the set of candidate solutions. According to a GA, these would be merged into new generations. So part of each option is taken and merged with the part of another lift point. The output would thus consist of new type lift points that are a combination of the standard lift points. This is not the outcome that is sought, so GA also does not seem to be a good application for the problem.

4.4.3 Single variable optimization

Optimization problems can also be solved using single variable optimization, which is done using an optimization function. Optimization by means of an optimization function consists of three elements [52]:

1. The input to the function, e.g. x.
2. The objective function itself, e.g. f().
3. The output from the function, e.g. cost.

The input to the function, or candidate solution, is evaluated by an objective function or target function. A candidate solution is a single input to the objective function. The form of a candidate solution depends on the specifics of the objective function. It may be a single floating point number, a vector of numbers, a matrix of numbers, or as complex as needed for the specific problem domain [52].
The objective function is specific to the problem domain and is easy to define, although expensive to evaluate. Efficiency in function optimization therefore refers to minimizing the total number of function evaluations. The result of evaluating the input is then a minimization or maximization, e.g. the lowest cost or the maximum surface area. Mathematically speaking, optimization is the minimization or maximization of a function subject to constraints on its variables.

In a minimization problem, poor solutions would be represented as hills in the response surface and good solutions would be represented by valleys. This would be inverted for maximizing problems. This minimum or maximum output from the function is called the optima of the function. There are two kinds of optima, Global and Local optima:

- Global Optima: The candidate solution with the best result from the objective function.
- Local Optima: The candidate solutions are good but not as good as the global optima

An objective function may have a single best solution, which is the global optimum of the objective function. Alternatively, the objective function may have many global optima, in which case one may be interested in locating one or all of them. The function may also have local optima, which are good solutions that may be relatively easy to locate, but not as good as the global optima. Local optima may appear to be global optima to a search algorithm in which case they are referred to as deceptive, as the algorithm will easily locate them and get stuck, failing to locate the global optima [52]. So the end goal is to find the global optimum.

Example

The basic idea of optimization problems is the same: there is an interest in maximizing or minimizing a particular quantity with some auxiliary condition that needs to be satisfied, the constraints. To illustrate how single variable optimization works, an example is elaborated:
A rectangular garden is to be constructed using water as one side and a wooden fence for the other three sides, see Figure 4.3. Given wood to make a fence of 100m, determine the dimensions that would create a garden of maximum area. So what is the maximum area?

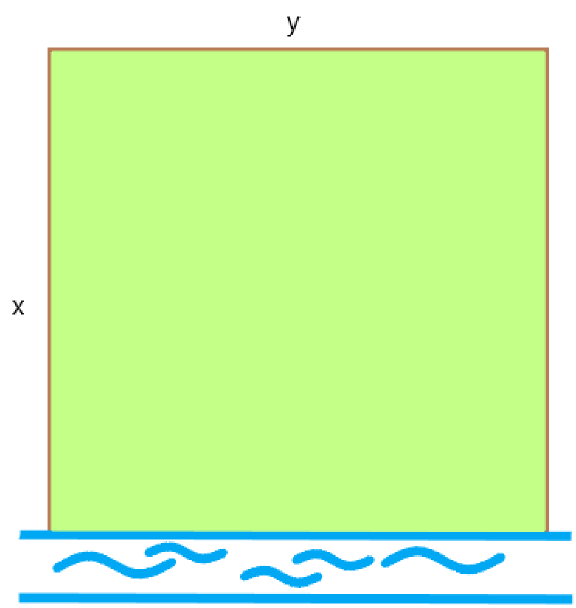


Figure 4.3: Garden to be optimized

Let x denote the length of the side of the garden perpendicular to the water and y denote the length of the side parallel to the water. Then the area of the garden is

$$A = x \cdot y \tag{4.2}$$

Three of the four sides will be a wooden fence, for which there is 100 meter of wood. Therefore the total amount of fencing will be, 2x + y = 100. Solving this equation for y: y = 100 - 2x. Substituting this in Equation 4.2 results in:

$$A(x) = x(100-2x) \tag{4.3}$$

Now that there is an expression for the surface area with only one variable, it can be maximized to get the optimal surface area. But before this can be done, the domain needs to be defined. Both lengths, x and y, need to be positive: x > 0, y > 0. Since y = 100 − 2x , if y > 0 , then x < 50 . So the range for x is 0 < x < 50 , or the open domain (0,50). It is not known whether a function necessarily has a maximum value for an open interval. But it is known that a continuous function has an absolute maximum (and absolute minimum) over a closed interval [56]. Therefore, consider the function of A(x) over the closed interval [0,50]. If a maximum value is found for a value of x in the closed interval, then this x-value will also maximizes the area of the garden in the open interval. So $A(x) = x(100-2x)$ will be maximized over the interval [0,50].
To maximize A(x), the derivation is needed:

$$A'(x) = 100-4x \tag{4.4}$$

When solving for A'(x) = 0, x = 25. So there is one critical point for which the garden will be maximized and that is for x = 25. That means that the maximized area will be 1250 m^2 with two fences of 25 meter and one of 100 - 2 · 25 = 50 meter.

Applicability to the decision-making process

Now that it is clear what single variable optimization is and how it works, it is investigated whether this could be a solution for optimizing the decision-making process of the lift point design. Looking at Figure 4.1, the optimization needs to be applied to the rightmost part where a choice has to be made from several lift point options, which in this case are three options. Two things are important for this optimization:

- Describe a function for each form of optimization, the optimization function. This describes what you want to optimize (maximize or minimize).
- What limits the model → what is not possible, what is possible. These are the constraints.

Thus, it should be clear what needs to be optimized and that should be worked out in parameters and variables. In this case this would be the criteria found in chapter 3: total duration, downtime, ease of installation and total cost. For the optimization function to work, these criteria need to be expressed in the same unit. Because variables with different units cannot be added together: cost + time + ease = ?
Looking at the criteria, they can be broken down into two main points: time and cost. Total duration and downtime are time related in themselves. Ease of installation is about the ease of installing the lift point, this could also be expressed in terms of time. And total cost is self explanatory. Thus, both time and cost are important to the decision-making process.
All criteria must have the same unit. So, for example, total duration, downtime and ease of installation should be expressed in costs. Or the total costs in terms of time. Describing all criteria in terms of time or cost would then ensure that only 1 of the 2 criteria has an influence on the optimization. Because the best option of the available type of lift points has to be found in terms of time and cost, a combination of time and cost would be better, such that both criteria play a role in the optimization. Therefore, all criteria should be expressed in cost per time.

So cost and time have to be optimised. Because the option that costs the least, lasts the shortest or is an optimum of both is chosen, the optimization comes down to minimization of these criteria. Now the task is to break down what the cost and time depend on. This should be made into a function that has the unit cost per time. Since there are three options in this case, three functions must be created, 1 per option. In this way, each lift point option is described with a function. These functions can then be combined and used in the optimization. A representation of a function with such a combination is given in Equation 4.5, where a, b and c must be integers.

$$(Cost/Time)_{total} = a*(Cost/Time)_{Option1} + b*(Cost/Time)_{Option2} + c*(Cost/Time)_{Option3} \tag{4.5}$$

The optimization of this function then results in the best option per time and cost, so the type of lift point that costs the least, takes the shortest time to install, or is a combination of both.

Conclusion

Optimization through single variable optimization means that the final function is derived and set equal to zero, as shown in the example. The function can then only contain 1 variable. If this is not the case and there are therefore

several variables in the function, then partial derivatives are also involved and the problem becomes more complex. There are other algorithms for more complex problems like this, according to the experts.
If it would also be examined, for example, whether a mix of different types of lift points would be better than using one type of lift point for all required lift points, there is an extra variable. In that case, the cost per time should be locked so that the number of each option is the only variable. In this way, it is optimized for the best ratio. But since it is not necessarily about the amount per type, but also which is cheaper and/or has the shortest duration, there should be two variables: cost per time and quantity per type. Only then it becomes multi variable optimization and the method as in the example is no longer possible.

So, in order to optimize by means of single variable optimization, an optimization function must be defined with only 1 variable. In that case, the question of whether a combination of different lift points would be better than just 1 type, cannot be answered. It is therefore a very limited method. In addition, all aspects, or criteria, on which the options that are compared depend, must be expressed in the same unit in order to optimize by means of single variable optimization. It can be quite difficult to get this done.
For these reasons, the use of this AI application also does not seem a good solution to optimize the lift point selection process, because on the one hand the answer is limited as it cannot give a combination of the options. And on the other hand, it can be difficult to express all aspects in the same unit.

Chapter 5

Conclusion & Recommendations

5.1 Conclusions

Many offshore structures have been built in the last decades. When these structures reach their end of life, they are removed in a decommissioning project. A lot of those offshore structures are bottom founded. Of that amount, a big part has a jacket substructure. Jackets are often removed with a heavy lift vessel. The crane hook of such a vessel is connected to rigging, which in turn is connected to the structure by means of lift points.

In decommissioning projects a lot of uncertainties are encountered by the industry that can lead to issues. Due to these uncertainties, all aspects of a decommissioning project have to be reconsidered each time, which makes the preparation phase costly and time-consuming. An aspect of the preparation is the selection of the lift point type, therefore this thesis aims to optimize the decision-making process of the lift point design. One way to optimize such a decision-making process is by means of artificial intelligence. The key objective of this thesis is therefore:

Can Artificial Intelligence software be used to improve the decision-making process of the lift point design process for offshore decommissioning projects?

This question has been answered using several smaller questions, as shown in section 1.8. Each of them is responded to in the following paragraphs.

Safety

The way in which Boskalis tackles projects is described in a general approach of Boskalis, the Way of Working (WoW). Because safety is a core value and top priority according to Boskalis, safety is incorporated into the WoW with the No Injuries No Accidents program, NINA. This approach should ensure that safety is guaranteed on every project such that employees can go home safely and without injury every day.
After studying all three projects, it became clear that there is a lot of attention to ensure that this is actually carried out. In most cases a NINA session was held at the start of each meeting to keep people on their toes with regard to safety. Also, the NINA program was implemented in all facets of the projects and was adopted by the client and all subcontractors. As a result, there was a high level of safety awareness and commitment. In addition, a Hazard Identification Document was set up to map out all dangers so that people can anticipate them. And to make sure that everyone is aware of it and understands the content. Due to these actions there were no lost-time incidents or accidents. Therefore it can be concluded that safety is indeed a core value and top priority and will be maintained. And that all choices made, whether it concerns the choice of a lifting point or an execution method, guarantee the safety of all people involved.

Trend

Every time a jacket has to be removed in a decommissioning project, it must be determined which lift points will be used for this. Although Boskalis has a general way of approaching a project, the WoW, it does not describe a general way of selecting a lift point. It is therefore investigated whether there exist a trend in the decision-making process of selecting the lift point type(s) to be used for lifting. And if so, what steps are taken.
After studying the projects, a certain trend in tackling the lift point design became visible.

1. First it is looked at what the client has offered, because often the decision on the type of lift points is defined in advance by the client. If this happens and the offered lift points can be used, they are used and no other options are devised.
2. If the client has not offered the use of certain lift points, it is first investigated whether the old lift points can be reused. This is because the reuse of existing lift points is beneficial for all parties involved, as it is the cheapest and simplest option. The old lift points are first visually assessed and if they seem good enough they are tested using NDT methods. If the old lift points prove to be strong enough and can be used, no alternatives are devised and the old ones are reused.
3. When the old lift points cannot be reused, because it is structurally impossible, a new lift point must be selected. Often the 'shackle-hole' combination is investigated first, because this option is easy to implement, does not take much time to install and does not cost a lot of money compared to the other options. If this option is possible, the selection process ends and this option is used.
4. Sometimes it is not entirely certain after investigation whether the shackle-hole combination is actually the best choice. Or it is clear after the investigation that this option is not possible. In such cases, other types of lift points are investigated, such as the ILT, trunnion or another new type. This often starts with investigating 1 extra lift point option. And if after elaboration it is still not clear that one option would be better than the other, another option is investigated. These options are then compared with each other on the basis of criteria. The option with the best optimum of the criteria is then chosen.

Criteria

When several types of lift points have to be examined because it is not clear which type would be the best option, they are compared based on certain criteria. In addition to finding a trend, it was also investigated what these criteria are. From the analyses of the projects it became apparent that safety is an important factor in the decision-making process. But as stated above, safety is always guaranteed such that every option is a safe option. Therefore safety can be treated as a threshold that is met and thus can be excluded from the optimization problem.
Another criteria that can be excluded is the structural integrity. It is assumed that all the options involved in the trade-off are structurally possible, because if an option is not possible in advance, it is of no use to include that option in the optimization.
In addition to these two criteria, four other criteria emerged that play a role in the decision-making process. These criteria are:

- Total duration of the procurement and installation of the lift point. In general, the option with the shortest duration is chosen because the costs for, for example, the rental of the vessel will be less. And because everything can then be used more quickly for other projects.
- Risk of downtime associated with the lift point option, including flexibility in the planning and the critical time path. The total duration can be extended due to downtime. That is why it is preferable to choose an option that has less chance of downtime. Sometimes an option is selected that costs more than its alternative, but reduces the chance of downtime, which could mean that the project could be completed faster than with its alternative. The downtime includes critical time path and flexibility, because if a lift point has to be installed in a critical time frame, there is less flexibility in the planning as there is a time window in which the work has to be done, increasing the chance of downtime.
- Ease of installation: how easy it is to physically install the lifting point and whether any preparatory work is required such as a work platform. All three projects show that the way in which the lift point should be installed plays a role in making a choice. The option that is easier to install is preferred.
- Total cost of the lift point option. Ultimately, Boskalis wants to spend as little money as possible, so the option with the least cost are preferred.

AI applicability

Because a trend has been found in Boskalis' approach to the lift point design, it can be investigated whether this process can be optimized by means of artificial intelligence (AI). Therefore three AI concepts are compared with the findings as described above to see if they can be applied to this problem: the optimization of the decision-making process of the lift point design.

Machine learning

First the application of machine learning is investigated. The problem is that this amount of data is not available due to the limited number of projects. And due to the small database, the model created by the AI cannot be tested to see if it is correct. So ML does not seem to be applicable to the current problem in this state, because there is not enough data to create the neural network and to test the model.
In addition, all lift point options could be expressed in time or cost, because the criteria against which they are compared are time (total duration, downtime, ease of installation) and (total) cost. Therefore it appears that the system can be described by writing it out and according to experts, ML is then not necessary.

Genetic algorithm

Another way to solve optimization problems is by means of genetic algorithms (GA). The optimization problem to be solved here is to select (a combination of) the best option(s) of lift point type(s) from a selection of multiple lift point types using the given criteria. The best option will be the lift point type that costs the least, has the shortest duration to install, or is an optimum of that. The different lift point types that are structurally possible would then be the set of candidate solutions. According to a GA, these would be merged into new generations. So part of each option is taken and merged with the part of another lift point. The output would thus consist of new lift point types that are a combination of the standard lift points. This is not the outcome that is sought, so in this way, a GA also does not seem to be a good application for the problem.

Single variable optimization

The last AI application that is investigated is single variable optimization. The optimization needs to be applied to the part where a choice has to be made from several lift point options, which in this case are three options. Then, for each lift point option a function needs to be defined which is based on the criteria found in the analysis: total duration, downtime, ease of installation and total cost. Those four options can be divided under time and cost.
The optimization only works when there is one variable in the optimization function. If more variables are in the function, partial derivatives are involved which makes the problem to complex to solve in this way. In such a case another AI application is needed.
Because both time and cost are important, a combination is needed, such that both criteria play a role in the optimization. Therefore, all criteria are expressed in cost per time. Now all separate functions have one variable with the same unit and can be added up to get the optimization function. The optimization of this function then results in the best option per time and cost, so the type of lift point that costs the least, takes the shortest time to install, or is a combination of both.
So, in this application an optimization function must be defined with only 1 variable. In that case, the question of whether a combination of different lift points would be better than just 1 type, cannot be answered. It is therefore a very limited method. In addition, all aspects, or criteria, on which the options that are compared depend, must be expressed in the same unit in order to optimize. It can be quite difficult to get this done.
For these reasons, the use of this method also does not seem a good solution to optimize the lift point selection process.

The final conclusion is therefore that the three AI applications in this way with this data set are not an improvement for the decision-making process of the lift point design. There is too little data to allow an AI to make a model of that data itself. Genetic algorithms do not seem to give the desired output. And single variable optimization is too limited in its solution.

5.2 Recommendations

Although the three AI applications studied do not seem to improve the decision-making process of the lift point design in this way, it could be investigated whether it would succeed with other preconditions. And there also exist other AI applications. Therefore, the following aspects might pose perfectly for follow-up research. The recommendations are divided into two sections: general recommendations and recommendations for Boskalis.

5.2.1 General Recommendations

- Machine learning was not applicable due to the small dataset. With ML the criteria can be compared without having to express them all in the same unit. The AI finds a way itself to do this. But in order to do this it needs a lot of data. If the dataset were expanded by analysing more projects, ML could eventually be applied. It is also possible that the data already exists within Boskalis, but that it has not yet been put together nicely so that it can be used. This could be further investigated.
- In this thesis, only a limited number of AI applications were investigated. There are many nowadays, so they could be investigated. For example, multi variable optimization could be a start for further research. Because there the optimization function can have two variables such that, for example, time and costs can be entered in different units. Or other variables can be included, such as the amount of each lift point type.
- Before an option is further elaborated, it is first examined whether the option is structurally possible. So the process could be speeded up by automating this check, if possible, such that the engineer has the answer quickly and can proceed.
- In single variable optimization it is assumed that the variables can be expressed in a certain value, after which they must all have the same unit. If that succeeds, it becomes practically an addition and AI is too crude a tool. But when multiple variables have a dependency and can therefore not easily be expressed in a value, AI becomes interesting again. It is quite possible that a variable is time-dependent or depends on something else. It can be investigated whether single variable optimization becomes interesting when such dependencies are taken into account.
- The analysis of the three projects has shown that the planning can be disrupted by risks and opportunities. It can be explored how to implement this in the AI application so that the model takes risks and opportunities into account.
- It could be investigated in future research whether genetic algorithms can be used if the input is changed. In this analysis the inputs were the different lift point types, but if these types were to be expressed in another way, GA might work.

5.2.2 Recommendations for Boskalis

- Improve the structure of the heap of information in 'scratch'. It was a hell of a job to find the necessary documents. It took a lot of time. Improving the or adding a structure in which people save and place their documents in scratch would make searching for documents easier and faster, saving time for other work.
- It became apparent that the positioning of the lift points can still be a challenge, therefore it could be investigated how to best position lift points for decommissioning. Due to lack of experience a decision was made that was a lot of work, took a lot of time and which costed more money than anticipated. With more research this lack of experience could be filled.

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Appendix A

Workability & Downtime Calculation

The workability is one of the criteria that influences the choices that are made in the decision-making process of a decommissioning project. This thesis focuses on the lift point design and investigates how much the workability affects the decisions made in this design process, which is briefly explained in 1.5.2. The workability of an operation is determined by means of the downtime associated with that operation. The downtime depends on the weather sensitivity and the weather window of an operation. It can be calculated, which will be explained in this Appendix.

The weather sensitivity of an operation translates into certain maximum environmental values in which the operation can be performed. Such values can be the maximum significant wave height. An example is provided in Figure A.1

Direction	Tp [sec]									
[deg]	3	4	5	6	7	8	9	10	11	12
0	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.98	0.97
30	3.00	3.00	3.00	3.00	3.00	3.00	3.00	0.97	0.74	0.51
60	3.00	3.00	3.00	3.00	3.00	3.00	1.24	0.52	0.42	0.26
90	3.00	3.00	3.00	3.00	3.00	2.75	0.87	0.47	0.32	0.23
120	3.00	3.00	3.00	3.00	3.00	2.92	1.09	0.62	0.46	0.32
150	3.00	3.00	3.00	3.00	3.00	3.00	2.82	1.37	0.91	0.61
180	3.00	3.00	3.00	3.00	3.00	3.00	3.00	2.90	1.96	0.96
210	3.00	3.00	3.00	3.00	3.00	3.00	2.66	0.97	0.80	0.54
240	3.00	3.00	3.00	3.00	3.00	2.67	1.28	0.63	0.55	0.29
270	3.00	3.00	3.00	3.00	3.00	2.41	0.92	0.52	0.50	0.30
300	3.00	3.00	3.00	3.00	3.00	3.00	1.13	0.58	0.52	0.34
330	3.00	3.00	3.00	3.00	3.00	3.00	2.85	1.23	0.93	0.63

Figure A.1: Workability table

In the x- and y-axis the wave peak period, T_p, and the wave heading with respect to the vessel are given, respectively. A value of each of the two will together give a significant wave height, H_s. So a peak period of 6 seconds and a heading of 60 degrees will give a significant wave height of 3 meters. This H_s value is the maximum significant wave height at which the operation can be executed. Together with weather data of the specific location from the past 20 years, the amount of downtime in days can be determined: the H_s and T_p combinations will give a line in a graph, this is the threshold, the limit. In the same graph the wave conditions from the data will be plotted. Then, each period of time the wave conditions will become higher than the threshold the operation cannot be executed. This can be done for multiple durations, for example a period of 3 hours, 6 hours or 9 hours. The duration depends on the time needed for the operation. The amount of time that the operation cannot be executed is the downtime, in days. When compared to the data of the last 20 years, this downtime can be expressed in a P-value. Often the P50 and P80 value are determined. P50 means that there is a 50% chance that the downtime will be less than the downtime value given for the P50 value. This determines the workability.

Appendix B

Removal Engineering Flowchart

The Boskalis Way of Working is an aid, a guideline for executing projects in a consistent and good manner. It ensures that, among other things, quality and safety are guaranteed. In section 1.6 the general phases were depicted. This will be expanded in this appendix. The focus of this research is on the decision-making process of the lift point design, therefore the initial phases are mainly extended in the flowchart and the Execution and Close Out phases are not. See Figure B.1.

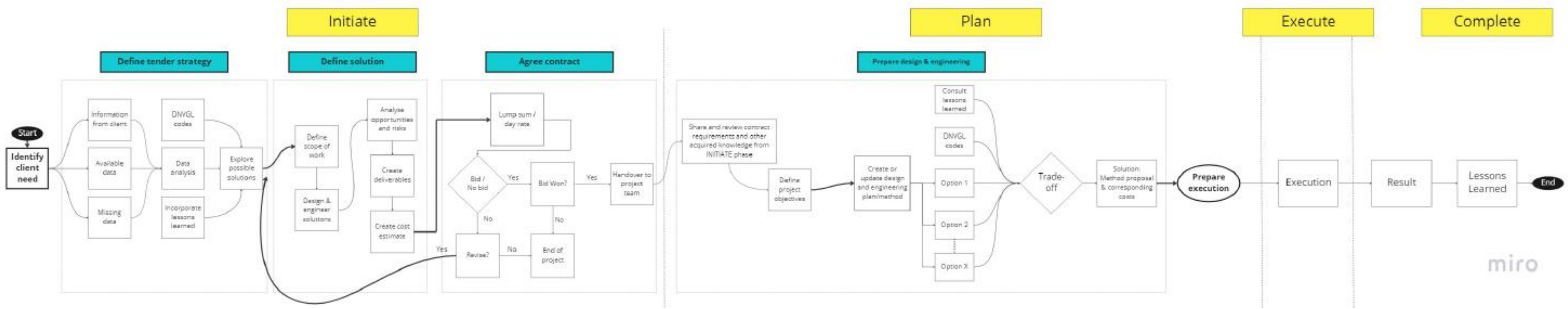

Figure B.1: Flowchart of the Boskalis project process