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Writers: Benjamin Ferstad Lars Totland Djuvik	……………………………………… ……………………………………… (Writer's signature)

Faculty supervisor:
Atle Øglend
External supervisor(s):

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Benjamin Ferstad

Lars Totland Djuvik

University of Stavanger

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Preface

Six years ago we had our trade certificates in our hands and had to make a choice: go the hard way or take the high way. We chose the first and haven't looked back ever since. Now six years later, at the culmination of a long and interesting education, we are proud to present a product founded on friendship and hard work. This thesis sums up not only the experience from our formal education, but also knowledge gained throughout life.

As Michael Jackson would have said it: *"This is it!"*

Acknowledgments

First we would like to thank Aker Solutions for letting us participate in an exciting project, which has given us the opportunity to learn a great deal about how projects are evaluated in a large and highly competent organisation.

Secondly we would like to thank specialist engineer Juha Mero for his extraordinary help, patience and support with all the technical and case related questions we have had throughout the process.

We would also like to thank our advisor Atle Øglend for his quick responses, helpful guidance, constructive criticism and not to mention his "open door" policy, which has been utmost valuable for us.

The two bachelor students Endre Angeltveit and Aron Amundsen also deserve some of the honour, with their bachelor thesis acting as a foundation for our master thesis.

And last but not least we would like to thank our parents for supporting us through six years of education, giving us the opportunity to become Masters of Science.

Summary

This thesis is a result of a request from Aker Solutions regarding a modification project of a high pressure cap running tool. This tool is used to set and retrieve the high pressure cap from the flow line mandrel when the xmas tree is not installed. Aker Solutions has identified challenges concerning the complexity, costs and time associated with the operation of the tool, and come up with four concepts that may solve these challenges. The task of this thesis is to look into the engineering challenges and the life cycle costs of each of the concepts. The goal is to provide a recommendation for which concept Aker Solutions should pursue through the research question: What is the best-suited modification solution for the Aker Solutions high pressure cap running tool?

The four identified concepts that have been analysed and evaluated, seek to solve complexity, cost and time issues concerning the current method of operation, which utilises an umbilical for hydraulic power supply for the tool. The first is a pre-charged accumulator concept, which uses an internal hydraulic reservoir to supply the tool. Concept number two uses a topside hotline to provide the hydraulics. Concept number three uses a subsea hotline from an ROV. Concept number four uses a hotline from a subsea powerpack.

The different concepts are analysed and evaluated against the current method on nine different scored and weighted criteria, based on 36 interviews. The criteria reflect the identified issues and are as follows: feasibility, physical parameters, maintainability, reliability, complexity in use, economic impact, development cost and time, degree of risk reduction and environmental impact. These unbiased and weighted criteria scores, reflect the impression of how each criterion's criticality are perceived in Aker Solutions as an organisation. The analysis and evaluation utilises a Pugh matrix for pairwise comparison as a decision-making tool and delivers a best-suited concept suggestion.

Based on this analysis and evaluation the Pugh matrix suggests that the pre-charged accumulator concept is the best alternative, with a significantly better result than the opposed concepts. The Pugh matrix does however not consider which of the "+" rated concepts perform best on each criterion in relation to the other concepts in the matrix. This is addressed in a qualitative evaluation where the pre-charged accumulator concept is compared to the other concepts on each criterion and the nuances are highlighted. It further shows that the pre-charged accumulator concept has a lower life cycle cost that mitigates the slightly lower performance on maintainability and development cost and time. The only innuendo is that it does not reduce risk as much as the hotline subsea concepts. This can however be accounted for with a thorough operational procedure.

The conclusion is that the best-suited modification solution for Aker Solutions Subsea high pressure cap running tool is the pre-charged accumulator concept. This contributes with potential savings for Statoil of 72.7 MNOK, increased rig time efficiency of 57.9%, increased redundancy, reduced operational risk and a more eco-friendly solution.

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Abbreviations

BBL	Oil Barrel
BOM	Bill Of Materials
FLM	Flow Line Mandrel
HPC	High Pressure Cap
HPU	High Pressure Unit
HPCRT	High Pressure Cap Running Tool
HSE	Health, Safety and Environment
MMBOE	Million Barrels Of Oil Equivalent
MQC	Multi Quick Connection
NCS	Norwegian Continental Shelf
NPD	Norwegian Petroleum Directorate
NPV	Net Present Value
RNNP	RisikoNivå i Norsk Petroleumsvirksomhet
ROV	Remote Operated Vehicle
WACC	Weighted Average Cost of Capital
WOCS	Work Over Control System
XT	Xmas Tree

Nomenclature

Wireline:

Wireline is a cabling technology used in the oil- and gas industry to perform well intervention or to lower subsea equipment onto the seabed. The technology may also be used to gain access to downhole plugs and valves.

Hotstab:

Hotstab is a male connector used subsea in order to pressurise tools and equipment from an external source. The hotstab is typically ROV operated and used during intervention, installation or retrieval of tools. The difference between a single- and dual port hotstab is the number of lines that can be operated through the stab, e.g. pressure, return or monitor lines.

Red zone:

The area on a drilling rigs drill floor, where potential high-risk activity is performed.

Fast Track:

Fast track is a working method that aims to halve the development time for smaller and less complex fields at the NCS. Fast track seeks standardization and efficiency for the field development, which later can be copied to similar fields.

Moon pool:

A moon pool is an opening in the middle floor of the rig that allows the operator to lower tools and equipment from the rig to the seabed. The moon pool is located underneath the drill floor and is also used for e.g. connection of umbilical clamps.

Demobilisation:

A process where the tool is discharged from service, maintained and preserved before being stored.

Intervention:

Intervention or well intervention is a process where the productivity of the well is increased by different techniques. This includes gas & water injection, coiled tubing, sand packing and others. Intervention is normally carried out at the end of the well life or when the productivity of the well has dropped to a critical level.

1. Introduction

This thesis is a result of a request from Aker Solutions Subsea. As final year master students they want us to utilise the multidiscipline skillset we possess within our subsea technology bachelor degree and the economic insight acquired from the industrial economics masters degree. This is a multidiscipline combination that Aker Solutions Subsea currently does not possess in the engineering department, and they are therefore very interested in our take on the challenge posed in this thesis. It has previously been performed a technical concept analysis of the equipment at hand, but it did not include a detailed study of the economic influencing factors regarding the identified concepts.

The bachelor thesis previously performed showed that Aker Solutions could make the HPCRT operation a lot less complex with a new umbilical-free concept, but it included only a small economic analysis of the potential savings generated from the rig rent. It did not include any estimates of the actual reduction of time that could be achieved with the new concept. Neither did it include a Life Cycle Cost (LCC) analysis showing the generated cost savings over a 10-year period. With the economic evaluation knowledge acquired in our master degree and the experience gained from our time as apprentices in the oil & gas industry and the mechanical industry, we could quickly determine that the cost analysis performed in the bachelor thesis was rather incomplete and that the potential cost savings for Statoil was much greater than expected.

The main motivation for our thesis is that Aker Solutions know that the first thesis did not cover all the economical factors influencing the total cost picture and therefore want us to cover the whole picture and create a LCC analysis of the modification concepts for the HPCRT. We saw that this would lead us to utilise knowledge acquired in subjects such as investment analysis, decision analysis, operations & maintenance and risk analysis. Secondly we were encouraged by the fact that we could contribute with reducing the costs of an operation in a time were this is highly focused on in the oil & gas industry. This was also supported by the fact that Aker Solutions stated that this was a real project and not just a project given to let us have something to write about.

All in all we feel that Aker Solutions have treated the project and us very professionally, which has only led to increase the motivation throughout the process.

1.1. Research question

What is the best-suited modification solution for the Aker Solutions Subsea High Pressure Cap Running Tool?

1.2. Scope of work

This thesis will analyse the following:

- Evaluate the possibilities of operating the HPCRT with:
  1) Pre-charged accumulators
  2) Hotline from surface hydraulic unit
  3) Hotline from subsea hydraulic unit
- Propose modification solutions for the possible concepts listed above
- Calculate the costs of modifying the HPCRT to be operated with the different concepts.
- Comparison of each concept against the current method through the utilisation of a Pugh matrix.
- Comparison of the Pugh matrix proposed concept against the other concepts.

1.3. Limitations

- The thesis will not deliver a finished engineered solution, but act as a decision-making tool with recommendations for Aker Solution.
- The thesis will not discuss possible synergetic opportunities regarding the concepts.
- Future economic risk regarding the proposed concepts will not be discussed in this thesis.

1.4. Disposition

The thesis is divided into 8 chapters:

- Chapter one covers the introduction of the thesis.
- Chapter two covers the background of the thesis with a technical description of the tool and the current method.
- Chapter three depicts the research method, which include a general part and a case specific part.
- Chapter four covers theory about the evaluation criteria and how the decision-making process is conducted.
- Chapter five presents the case study with a technical analysis of the proposed concepts and comparison of each of the concepts against the current method.
- Chapter six discusses the preferred concept and how it performs against the other proposed concepts.
- Chapter seven holds the conclusion of the thesis.
- Chapter eight introduces possible future work.

2. Background

2.1. Trends in the oil and gas industry

Statoil has set a goal of producing 2.5 mmboe per day within 2020 (Statoil, 2012). This requires new technology and solutions for well intervention in order to be achieved. It includes fast track as a new development method for smaller and more marginal fields. The new fast track fields will require equipment that is more efficient for exploration, drilling and intervention phases (Statoil, 2014). In order to meet their planned oil recovery rate for 2020, four drilling rigs were hired in 2011, each for a period of eight years. The mission of the rigs is to drill 115 increased oil recovery wells at Troll up to 2023 (Statoil, 2012).

Aibel along with FMC, ABB, KCA Deutag and others, have during the last year downsized their workforce as a result of Statoil's cost reduction announcement (offshore.no, 2014). Statoil plan to reduce the investment costs with more than 5 billion dollars over the next two years (Aftenbladet.no, 2014). The yearly cost savings from 2016 are set to 1.3 billion dollars. Statoil's strategies for future value creation and growth will from 2014 include a comprehensive efficiency improvement program (e24.no, 2014).

It is fair to say that the new plans proposed by Statoil, require solutions that can perform better on both time and money. This thesis aims to contribute on both aspects.

2.2. About Aker Solutions

Aker Solutions is a global provider of a wide range of products, systems and services to the oil & gas industry. The company delivers all products and services included in the field life cycle, from field development to decommissioning and aftermarket services. All products and services provided compete on a standalone basis in the market. The company has more than 26.000 employees in about 30 countries located around the world and the Headquarter is located at Fornebu outside Oslo, Norway (Aker Solutions, 2014).

Aker Solutions is a part of Aker ASA, as it owns more than 40% of Aker Solutions through Aker Kværner Holding AS.

In 1841, Aker was started as a small mechanical workshop right next to the Aker River in Oslo. During the first century, the main market activities for the company included shipbuilding and machinery manufacturing.
As the 1960s came and the Ekofisk oilfield was discovered, Aker changed focus from shipbuilding in Oslo to the North Sea and the delivery of the exploration-drilling rig "Ocean Viking". In 2002, Aker became Aker Kværner as a result of the merging between Aker Maritime ASA and Kværner ASA. Only six years later, in 2008, Aker Kværner changed name to Aker Solutions (Aker Solutions, 2014).

2.3. About Statoil

Statoil is an international oil, gas and energy company with more than 23.000 employees located in 34 countries worldwide. Statoil's headquarter is located in Stavanger, Norway.

Statoil is the largest operator on the Norwegian continental shelf (NCS) and is the responsible operator on more than 25 fields, including Ekofisk, Troll and Statfjord. Beside the operation on the Norwegian continental shelf, Statoil refines oil and gas at five processing plants in Norway (Statoil, 2014).

2.3.1. The Troll Field

The Troll field is located 65 kilometres vest of Kollsnes in Hordaland.
Norske Shell was chosen as operator in April 1979 and later the same year a huge oil & gas find was proven. The field holds more than 40% of Norway's gas reserves and the field is expected to produce for at least 70 more years. Additional key figures are found in table 1 (Statoil, 2014) (offshore.no, 2014).

Table 1: Key figures for the Troll field (offshore.no, 2014) (Statoil, 2014)

Depth of seabed	300m<
Depth of reservoars	1600m
Horziontal length of well	3200m
Operator	Statoil
Total subsea XT	135
Aker Solutions XT	100
Remaining reserves	
Oil	226 440 000 bbl
Gas	984900000000 Sm^3

2.4. Technical description

Aker Solutions Ågotnes is part of the "Subsea Lifecycle Services" and provide products and services within the subsea segment. Aker Solutions operates just under 200 of Statoil's subsea Xmas Trees (XT) (Mero, 2014). This includes construction, installation, retrieval, maintenance and testing.

The High Pressure Cap Running Tool (HPCRT) is used to set and retrieve the High Pressure Cap (HPC) at the Troll field. Aker Solutions currently operate four HPCRT on the Troll field. The HPC is placed at the flow line mandrel (FLM) located at the template when the production XT is not installed. The FLM is connected to the production line, which leads to the main manifold for the template. The HPC is used to protect the FLM and the production line from corrosion and debris. Once installed, the production line and the FLM are filled with inhibitor fluid, which prevents corrosion.

The method used to operate the HPCRT today is to run the tool on drill pipe while an umbilical supplies the tool with hydraulic fluids from the Work Over Control System (WOCS). The umbilical is clamped to the drill pipe with umbilical clamps every 15m, and it takes just underneath 4 minutes to clamp each umbilical clamp to the drill pipe Figure 1 shows an umbilical clamp used to attach the umbilical to the drill pipe.

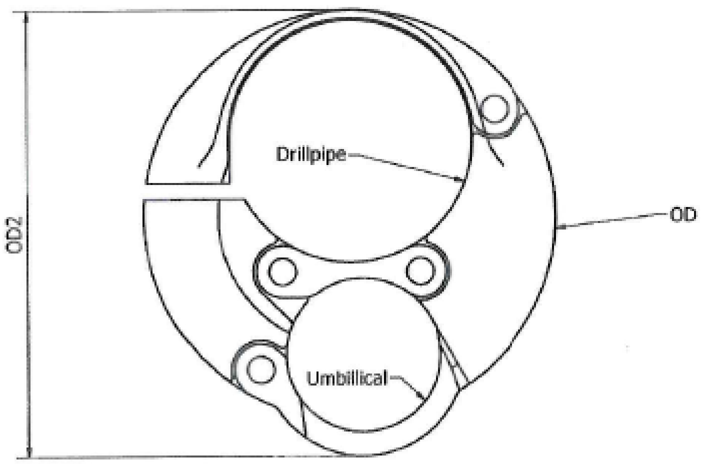

Figure 1: Umbilical drill pipe clamp (Aker Solutions, 2014)

The HPCRT and the umbilical are connected through a Multi Quick Connection Stab Plate (MQC) consisting of Walther quick connection couplers. The umbilical contains 17 lines, which are pressurised and monitored from the WOCS. The HPCRT is landed at the template by the help of guide wires, guideposts and funnels. From here, the HPCRT can latch onto the HPC and unlock it from the FLM. The position of the HPC can be monitored both visually by the ROV and by measuring the pressure of the fluid in the monitoring line. The working pressure for the HPCRT is 209bar (3000psi) and the hydraulic fluid used is Oceanic HW-443, which is a water based hydraulic oil (Djuvik, 2008).

The experiences from using this method to operate the tool have shown that Aker Solutions faces many cost- and time-consuming challenges when the tool is used. This includes:

- Approximately one out of three times the umbilical is damaged during an operation and needs to be replaced onshore (Mero, 2014).
- The method is time-consuming considering:
    1) The time needed to assemble and run the drill string
    2) The man-hour needed to clamp the umbilical to the drill string
    3) The time needed to wire and connect the umbilical to the WOCS
- The HPCRT occupies the drill floor, moonpool and WOCS during operation.
- The umbilical needs to be wired and connected to the WOCS for each operation.

It is desirable to perform this operation without the need of an umbilical and replace this with pre-charged hydraulic pressure from an accumulator, powerpack or a hotline. For Statoil this will reduce the costs associated with the operation of the HPCRT from the rig, while the modification will ease the offshore operation of the HPRCT for Aker Solutions. By removing the need of an umbilical for the HPCRT, it gives new opportunities with regards to where the operation can take place from, e.g. a boat, since there will be no need to run the HPCRT on drill pipe. Figure 2 is a stack-up drawing of the HPCRT setup used today and shows how the drill pipes, umbilical and HPCRT are connected.

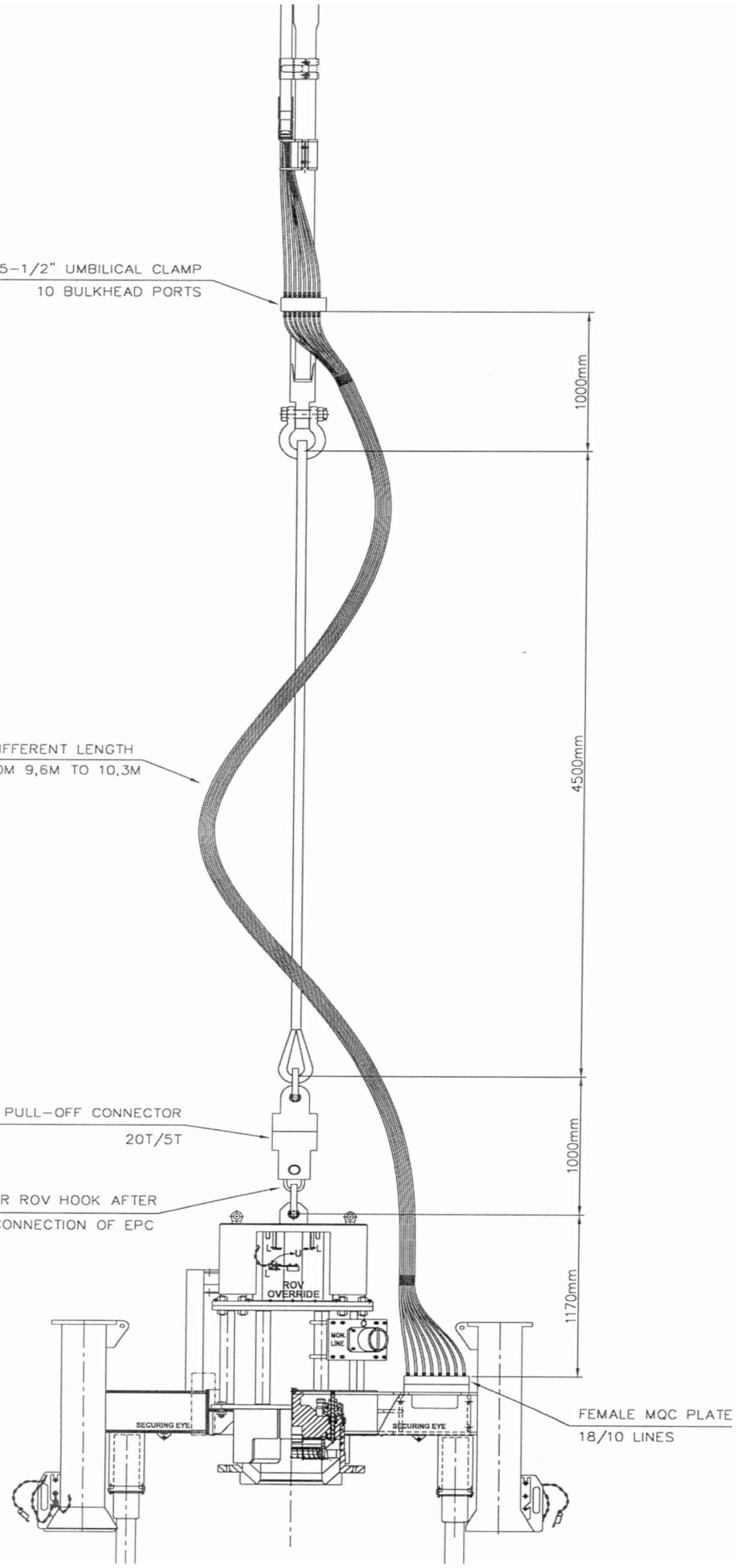

Figure 2: HPCRT stack-up (Aker Solutions, 2014)

3. Research method

Decision-making in general is something everybody does every day. It is the process of evaluating inputs and generating outputs. This process can be highly prominent in some cases and more autonomous in other cases. It is fair to say that one would spend more time and effort in deciding which car to buy than which pair of jeans to buy. There are however many similarities between the two of them. The result of both cases are dependent on which criteria weighs the most, and at some point these must have been evaluated in some form. Some key elements that these two have in common are, whether the decision is made based on qualitative or quantitative criteria and methods. When buying a pair of jeans, the qualitative criteria of comfort and looks may weigh more than the quantitative criteria of price. For the car it may be the other way around. The truth is that in all decision making scenarios; both categories are present to some extent.

3.1. Qualitative methods and criteria

Qualitative methods are best described as subjective knowledge based approaches. They rely on the background knowledge of the assessor and will always be limited to the boundaries set by the assessor's insight. Qualitative approaches are best used in problem solving when it is hard to measure or pinpoint exact performance. It is therefore widely used in activities such as brainstorming sessions, interviews and generating checklists. Stuart Pugh states that qualitative approaches are best used as aids in creative thinking. He further explains that this approach is well suited when solving problems with a relatively low grade of complexity, but "*-cease to be of real value in complex design problems subjected to real-life constraints*" (Pugh, 1996, p. 147).

3.2. Quantitative methods and criteria

Quantitative methods are best described as objective and factual approaches that can be repeated by other researchers with the same or an evolved result. They rely on measurements, scoring and experiments, and often utilise laboratory tests and field experiments to establish data (Pugh, 1996).

3.3. Balanced design

In order to achieve the most optimal solution to a problem, a mix between the two categories is usually present. When initiating the design process it is important to start with simple premises. In figure 3 it is noticeable that the method recommended by Pugh is not even listed. He highly suggests that the most effective way to start of a design process is to have informal group sessions with positive discussions regarding various solutions. It is through this process that the most appropriate approaches and scope of design methods can evolve. From that point on, the more specific methods are to be chosen and the relevant ones will be discussed further in the report (Pugh, 1996).

3.4. Method for this case

In the case at hand, several methods are utilised in order to achieve a solution that the client can find viable for the tool modification. The initial planning starts out with a status quo of the equipment, a thorough review of all the technical details and the client's thoughts about how they would like to see the result. This leads to an initial brainstorming session with both the client and the students, with the result of a preliminary project scope. Since there already exists a preliminary concept study, this is addressed in the session. The project scope consists of an attribute listing, a checklist of relevant topics to cover, solution requirements and the preferred methods for evaluation.

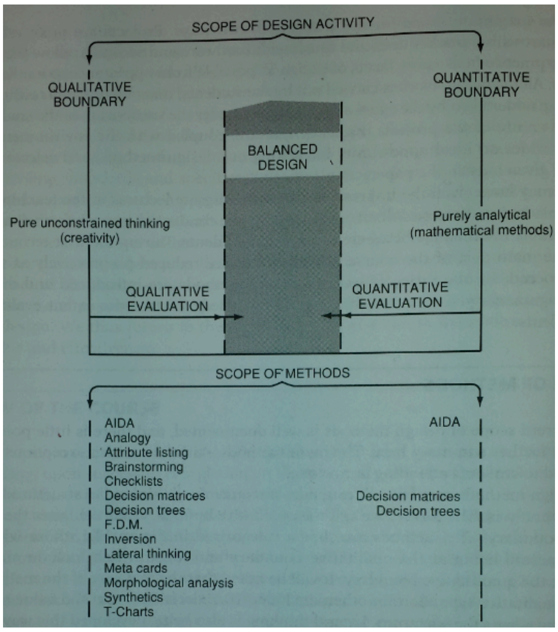

Figure 3: Pugh´s scope of design and methods (Pugh, 1996)

3.4.1. Attribute listing

The attribute listing consists mainly of technical data regarding the equipment. This covers the following:

- Operation procedures
- Operating water depth
- Specific pressures
- Specific volumes
- Specific safety factors
- Redundancy requirements
- Specific types of hydraulic fluids

3.4.2. Topic checklist

The checklist consists of the identified topics that need to be addressed in order to provide a sufficient platform for the project. All formulas and evaluation tools must be described and addressed in such a way that the scientific integrity is maintained. The checklist consists of the following:

- Formulas for hydraulic calculations
- Formulas for calculating economic factors
- Means to quantify risk
- Means to quantify evaluation criteria weighting
- Explanation of decision making tools

3.4.3. Solution requirements

Two parties regulate the requirement framework for solutions utilised on the NCS: NORSOK and the operating company. Any solution used on the NCS must meet the regulations found in NORSOK. As long as these are met, the company is free to extend the requirements based on their own internal policies. Essential regulatory points regarding this project are as follows:

- Redundancy strategy
- Environmental impact reducing measures

3.4.4. Evaluation methods

As the project scope consists of a concept selection with an engineering part, a risk evaluation part and an economic evaluation part for each concept, it requires a tool to assess these in an equal environment. Evaluating all factors in their native form before applying relative weighting and compare the concepts in a decision matrix does this. Relevant concept evaluation criteria for this project are as follows:

- Feasibility
- Physical parameters
- Maintainability
- Reliability
- Complexity in use
- Economic impact
- Development cost and time
- Degree of risk reduction
- Environmental impact

3.5. Data collection through interviews

As the criteria rely upon a quantitative way of comparison, it is necessary to produce relevant data. This poses as no big challenge when it comes to the criteria that can be measured directly from statistics in time, money or frequency. There is however some of the criteria that requires interviews in order to discover a useful set of data. As these interviews are done with experts within their fields, it is important to ask questions that facilitate the unveiling of correct answers, and not just those the interviewer thinks he will get. In the world of interviewing, this is called open-ended interviews. The idea is that instead of planting the interviewers' thoughts into the interviewed subjects mind, the goal is to discover the subject's own perception of the issue at hand, (Patton, 2002)

In order to obtain these types of answers, Patton has defined six different categories of questions. Amongst these are "opinion/value questions" and "knowledge questions". Opinion/value questions are used to reveal the objective thoughts the subject has about the matter, but not to an emotional extent. Typical questions asked are such as: "What do you think about ____?", "What is your opinion regarding ____?" and not like "How do you feel about ____?" or "How did you respond to the change in ____?". The knowledge questions will further try to discover what factual information the subject knows. Typical questions asked in this context are: "To what extent is ____ a factor?", "How would you rate ____ based on ____?" (Patton, 2002).

4. Theory

4.1. Pugh matrix

Stuart Pugh is recognised as one of the biggest influencer when it comes to industrial design and he is the inventor of the concept selection matrix, also known as the “Pugh Matrix” or “Pugh Decision Matrix” (Pugh, 1996). The main purpose of the matrix is to be able to compare different design solutions in an easy and comprehensible manner. It utilises people’s ability to pairwise compare simple criterion, instead of entire solutions, and thus reduces the degree of subjective opinion regarding the solution as a whole. It was initially developed to aid in design concept selection processes, but it can be used in almost any setting where different alternatives are to be chosen from.

Table 2: Example of a Pugh matrix

	Criteria weighting	Base concept	Design concept A	Design concept B	Design concept C	Design concept D	Design concept E	Design concept F
Criteria 1	4	0	0	+	+	+	0	+
Criteria 2	3	0	0	+	-	-	+	0
Criteria 3	2	0	0	-	0	0	0	-
Criteria 4	6	0	0	0	-	-	+	+
Criteria 5	3	0	-	0	-	-	+	+
Criteria 6	5	0	+	+	+	+	-	+
Criteria 7	2	0	0	0	+	+	-	-
Criteria 8	2	0	+	+	0	0	+	0
Criteria 9	5	0	0	+	0	0	-	+
Criteria 10	3	0	-	-	-	-	0	+
Sum concept			1	14	15	-4	2	22

4.1.1. Concept

The matrix is arranged into rows and columns with the rows showing the evaluation criteria and the columns on the different suggested design concepts. All design concepts are pairwise compared with the base concept, one criteria at the time. If the design concept is considered to be better than the base concept, it is marked with a plus, if it is worse it is marked with a minus and if it is equal it is marked with a zero. The base concept is the existing solution to the problem that the project seeks to solve. If there is no existing solution, there are other ways to use the matrix, but since this is not relevant for the thesis, this will not be discussed here.

Based on the criticality and importance of each criterion, they are given a weight. The weight does not have an upper limit, but the lowest weight must be greater than zero. If zero is considered as a correct weight, the criteria itself can just be removed, since it will not contribute to the final score anyway. As said, there is no upper limit, but it is wise to choose a range with relatively few steps. This is because the range represents conditions from “not very important” to “very important”. In the example in table 2 above, the chosen range is one through six, where one and two represent degrees of “not very important”, three and four represent degrees of “important” and five and six represent degrees of “very important” (American Society for Quality, 2014). As said earlier, people have an innate ability to pairwise compare factors. With more than two variables within each part of the range, it gets harder two establish a reasonable assessment of the relative importance of each criterion.

When all the criteria have been assigned a weight, and all the design concepts have been pairwise compared with the base concept, a score is calculated for each design concept. This is done by multiplying the weight with the respective plus, minus or 0 for each criteria and concept, generating a positive or negative difference between the design concept and the base concept. In the end, the final scores will tell which design concept is the most preferable. In the example above it is clear that design concept F would be the most preferable as it has a significant higher score than the other alternatives. Concept A and E are both almost equal to the base concept and it would be wise to consider not to take any action if they were the highest scoring alternatives. Concept B and C are both good alternatives that are worth looking into, in terms of understanding why they yield such a good score, should this be relevant. It also reveals that alternative D is actually worse than the base concept, and should be fully excluded from further investigation.

4.1.2. Criteria selection

Feasibility

Feasibility is the level of ability to deliver on project-required specifications. It reflects a project group's level of knowledge, available resources and time, showing whether the group is capable to produce the sought for solution within the constraints. It is self explanatory that a project with high feasibility will be preferred, but as things may look good on paper, challenges are often seen when the project group is to be assembled. Key personnel within the organisation may be more needed in other projects, there may not be enough engineering capacity and these factors can cause the project to span over a longer timeframe. This usually causes the risk involved in the projects to go up. In real life situations, there will always be a trade off between how low the feasibility and how high risk the company is willing to take. In order to score the feasibility of the proposed concepts, the degree of new technology introduced will act as measurement.

Physical parameters

Physical parameters refer primarily to size and weight. They are important factors when it comes to transportation, equipment handling, storage and space requirements, during operation and storage. In any offshore operation, all of these are influencing factors on the operational feasibility. It is preferable to have the equipment as small and light as possible due to both the scarcity of space and the limitations and safety hazards with heavy objects during lifting operations. In order to score the concepts on this criterion, total floor space requirement will be used as measurement, where smaller is preferred.

Maintainability

Equipment used in offshore operations needs to meet the requirements at all times. This is ensured through regular inspections and service activities. Normally this is done between operations and scheduled for in order to achieve the highest possible up time for the equipment. Any unscheduled maintenance is therefore cost driving, since it affects the uptime and the available resources in the maintenance department. To score the proposed concepts on this criterion, concepts with lower maintenance costs than the current method are scored positively in the Pugh matrix.

Reliability
Reliability regarding technical solutions can be described as *"The probability of failure-free performance over an items useful life, or a specified timeframe, under specified environmental and duty-cycle conditions. Often expressed as mean time before failure…"* (Business Dictionary, 2014). When equipment is to be used in offshore operations, it is thoroughly tested onshore to make sure that the equipment can handle the workload it is designed for. A general opinion found in the industry is that *"We do not use equipment we cannot trust"* (Interviewee 19, 2014). It does however happen that equipment fails to function during an operation. This can be the result of for instance a flaw in the equipment, a human error or a malfunctioning support system. When this happens, it is important to have independent redundancy systems to allow for the job to be finished safely. For scoring purposes, the proposed concepts that have redundant systems allowing the tool to be operated with a secondary redundancy system still intact, will be scored positively compared to the current method.

Complexity in use
Any offshore operation requires a certain amount of both skills and manpower in order to meet the demands. In a report concerning the execution of recent large offshore projects implemented on the NCS, delivered by the Norwegian Petroleum Directorate (NPD), shortage of beds were identified as a problem in four of the five projects that were evaluated (Norwegian Petroleum Directorate, 2013). Any addition of personnel to the job will therefore be cost driving and may also lead to delays in the operation due to shortage in housing capacity.

Another problem with high complexity equipment is the possibility of needing extra manpower to oversee all the systems topside. A typical scenario is when equipment is in need of a WOCS. This is normally a stand-alone unit installed in a container and requires at least one extra person in order to be handled. The resulting problem is the same as just described. In order to mitigate these challenges, technically low complex solutions, with as few secondary support units as possible are preferred. To score the concepts, the sum of personnel from the various activities performed will be used.

Economic impact
The economic aspect is relevant in any engineering challenge. It is important that the benefit of the result supersedes the cost of the project. A typical way of revealing this is to perform an LCC analysis. This will look into the economic picture of the products entire life span, from engineering to decommissioning.

A typical way to measure the economic impact is to calculate the Net Present Value (NPV) of the investment. This will set the capital expenditure up against the operational expenses and reveal the true cost of the project. For scoring purposes in this specific thesis, any solution that has a lower NPV than the original solution will be scored positively, and vice versa. Out of the three NPV scenarios presented in the case study, the "drilling rigs only" is the one that will be used as comparison basis, as this is the most conservative scenario.

Development cost and time
To sum up this decision parameter, the good old saying "time is money" can be used. The sooner and cheaper a new and improved solution to a problem can be developed, the faster savings can be made, risks be mitigated and focus moved on to the next challenge at hand. It is however difficult to score new solutions on cost and time, when there is an existing solution already developed. This is due to the fact that the existing solution has a developing time $t=0$ and any new proposed solution will have a $t>0$. The same goes for the costs as the existing solution already exists and no investment is needed. This would in other words always give a negative score for any alternative solution, and thereby not contribute to the decision making process in any way. In order to address this in a fair manner for the specific case in this thesis, the concept that has the lowest development cost will be given the positive score as the cost incorporates both time and monetary spending. The other concepts will then be given a neutral score compared to the existing solution.

Degree of risk reduction
A number of different aspects contribute to the high level of risk associated with offshore operations. According to the report "Trends in risk level 2013" (RNNP, 178), roughnecks are exposed to the highest level of risk, as their work is mainly performed in the red zone of the drill floor. Of the activities performed, installation and retrieval of manual slips has caused the associated risk to increase to a red level. Another common high-risk activity associated with operating tools relying on hydraulic pressure as a power source, is pressure testing of equipment, hoses and fittings. High-pressure testing have in several cases resulted in explosion of hoses, torn fittings or displacement of the equipment itself. In some high-pressure test operations, use of wrong fittings or fittings with worn threads have caused the fitting to be torn off, resulting in an extreme high-energy shot of the fitting. It is in other words beneficiary to reduce or eliminate the need for work in the red zone or pressure testing activities. For scoring purposes in this thesis, a reduction or elimination of these activities is used as measurement.

Environmental impact
A mobile drilling rig is a complex unit with many functions. It has production facilities related directly to the drilling activities, offices, laboratories, housing areas, leisure areas and propulsion systems among others. The common denominator for all of them is that they need power to be operated. This power is delivered through the use of generators running on fossil fuel and thus generates a certain amount of climate pollution. As the total amount of pollution produced during an operation is a function of how much time it is necessary to spend on the operation, any activity that can reduce this time will also reduce the carbon footprint of the operation. For scoring purposes regarding the proposed concept, operational time offshore will be used as measurement, giving a positive score if the time is lower than the current method.

5. Case study

5.1. Introduction of identified alternative concepts

The Bachelor thesis *"Konseptstudie for modifisering av High Pressure Cap Running Tool"* identified the concepts listed below. Common for all concepts is the opportunity for umbilical-free operation. All concepts described use wireline and tugger winch when installing and retrieving the HPC. This replaces the need for operation on drill pipe and allows the HPCRT to be operated with other means than the rig (Angeltveit & Amundsen, 2013).

5.1.1. Pre-charged accumulators

This concept is based on modification of the HPCRT to be equipped with pre-charged accumulators that contain an adequate amount of pressurised hydraulics to operate the HPCRT. With this concept the HPCRT can be operated as an "All-in-one" tool with an intern hydraulic system. As a safety factor the accumulators will need to be dimensioned with hydraulics sufficient enough to run the HPCRT in lock or unlock mode 3.5 times. Since there are no hydraulic lines to the surface when using this concept it will become necessary to monitor the pressure during operation with the help of subsea manometers. The ROV is used to read the value from the manometers after the lines has been pressurised. All subsea manometers are placed at the ROV-panel (Mero, 2014).

5.1.2. Hotline from surface power unit

This concept is based on the use of a free hanging hotline connected to a hydraulic unit located above surface. The hotline is significantly smaller and 5 times lighter than the umbilical, and as seen in table 3 it only needs to include two or three lines. Line 3 is the monitor line used to ensure that the HPC has been successfully locked to the FLM and a tight connection has been achieved. This line can be replaced with a subsea pressure manometer (Mero, 2014).

Table 3: Hydraulic line configuration for hotline from surface power unit

Line no #	Name	Length
1	Pressure	350m
2	Return	
3*	Monitor	

This concept allows the WOCS or a High Pressure Unit (HPU) to be connected to the HPCRT with only a dual port hotstab, rather than the 17-line umbilical, which needs to be attached to the MQC. A dual port hotstab enables one-point connection for both pressure and return lines.

The principle of a free hanging hotline requires contingencies for avoiding that the hotline is exposed to forces that can damage the line.
There are two options that can be used in order to secure that the hotline is not damaged during operation:

- Use wire clamps to attach the hotline to the wire. This will reduce the tension the hotline is exposed to when connected to the tool
- Use hotline with high-tensile-strength reinforcement to reduce the tension the hotline is exposed to when connected to the tool

5.1.3. Hotline subsea

This concept uses a subsea hydraulic unit to power the HPCRT. The hotline, which as seen in table 4 consists of two hydraulic lines, is connected between the HPCRT and the subsea hydraulic unit. Like the accumulator concept, this system also requires subsea manometers in order to monitor the pressure for all operations carried out (Mero, 2014).

Table 4: Hydraulic line configuration for hotline from subsea power unit

Line no #	Name	Length
1	Pressure	3-25m
2	Return	

A subsea hydraulic unit can include:

Remote Operated Vehicle (ROV)
The HPCRT is powered with hydraulics from the ROV's hydraulic power reserve. The ROV and the HPCRT are connected through the dual port hotstab-line. With this concept a very short hotline can be used (Mero, 2014).

Powerpack
An external powerpack consisting of several pre-charged accumulators supplies the HPCRT with hydraulics. The powerpack can be landed on the seabed or the template. The ROV connect the hotline between the powerpack and the HPCRT (Mero, 2014).

5.2. Engineering analysis of identified alternative solutions

5.2.1. Pre-charged accumulators

Dimensioning the accumulators
The pre-charged accumulator concept requires, as described in the introduction of the identified concepts, a large enough amount of hydraulics to operate the functions of the HPCRT 3.5 times. To secure that the accumulators are capable of delivering a sufficient amount of hydraulics it has been calculated that 46.94 litres are the total work volume of the HPCRT including the 3.5 safety factor.

Based on these calculations it becomes necessary to equip the HPCRT with 2x37 litres accumulator pressure tanks and 1x54 litres accumulator return tank. This gives a total extra weight of 250 kg. It is, in consultation with Aker Solutions, assumed that the accumulators deliver 75% of the total hydraulic volume contained. This gives the following calculation:

$$Total\ hydraulic\ volume = Number\ of\ accumulators\ x\ Accumulator\ size\ x\ \%\ of\ volume\ delivered$$

$$Total\ hydraulic\ volume = 2\ x\ 37\ litres\ x\ 75\%$$

$$\underline{Total\ hydraulic\ volume = 55.5\ litres}$$

Total hydraulic volume is 55.5 litres, which is 1.5 litres more than the total volume of the return tank and thus cannot be included in the available hydraulic volume.
Therefore, the total theoretical usable amount of hydraulics available is 54 litres, which gives:

$$Total\ number\ of\ runs = \frac{Total\ usable\ amount\ of\ hydraulics}{\frac{Total\ work\ volume\ of\ HPCRT}{Safety\ factor}}$$

$$Total\ number\ of\ runs = \frac{54\ litres}{\frac{46.94\ litres/run}{3.5}}$$

$$\underline{Total\ number\ of\ runs\ \approx 4\ runs}$$

According to Aker Solutions the number of operations available with this accumulator setup is slightly low and it is hence desirable to increase the number of operations available, or implement a safety measure that can be used in cases where the total number of operations is exceeded (Mero, 2014). To accommodate the requirement of a safety measure the modified HPCRT have been equipped with the possibility of hotline ROV override.
This gives the pre-charged accumulator concept an extra redundancy that today's method does not possess. The technicians have with this setup an extra opportunity to operate the HPCRT without pulling it, in cases where the proposed concept fails to operate or the accumulators have been depleted. The accumulator system gives an internal hydraulic supply and the hotline ROV override gives an extern hydraulic supply.

The following figure 4 shows how the schematics for the HPCRT will need to be modified in order to pressurise the tool with pre-charged accumulators. P_1 is the accumulator pressure whilst P_2 is the hotline ROV-backup measure. *R* is the 54 litres return tank. The old MQC plate and its couplers will remain at the HPCRT. This enables the tool to still be operated in umbilical mode in cases where this is desired and also acts as a secondary redundancy system.

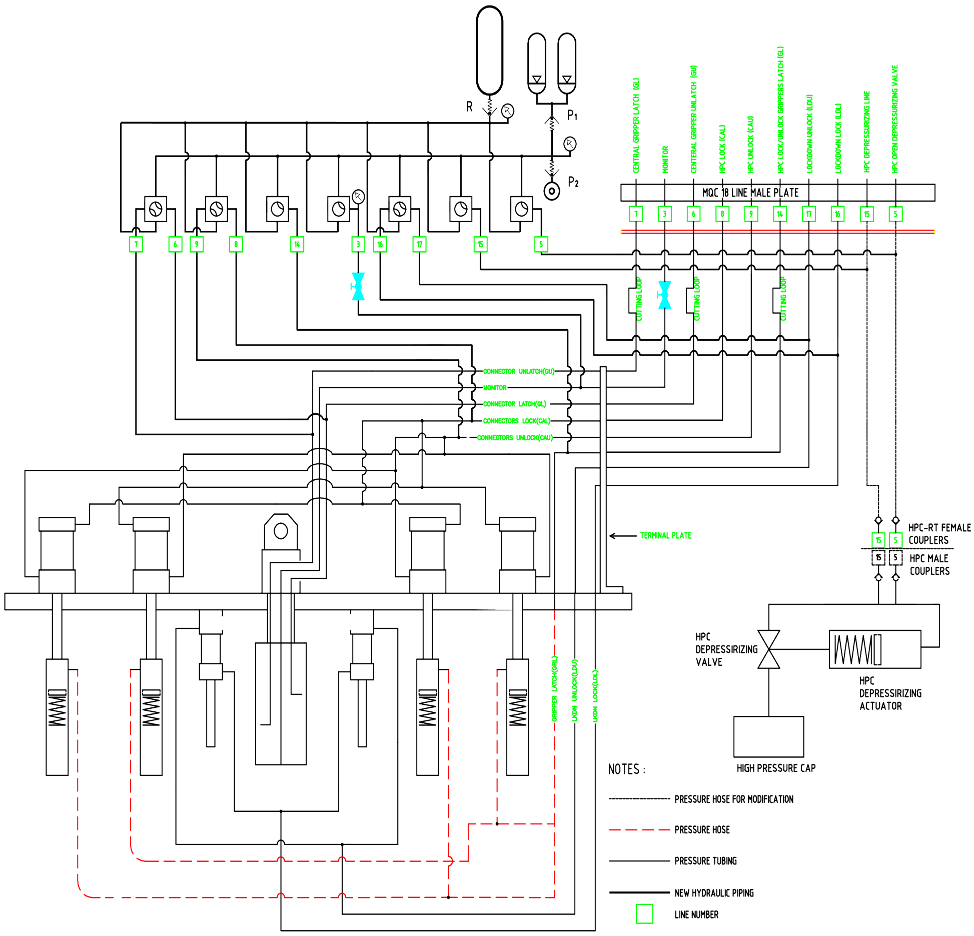

Figure 4: HPCRT hydraulic schematic for Pre-charged accumulators concept

Designing the HPCRT

In order to operate the HPCRT in subsea mode it will need to be equipped with an ROV panel. The new ROV panel along with the accumulator tanks will generate weight that can easily unbalance the HPCRT. To overcome the challenge of unbalance it is important that the ROV panel and the accumulator tanks are mounted symmetrically. In addition it might be necessary to use weight loads to balance the tool. The two figures, 5 and 6, show the three accumulator tanks and the ROV panel mounted at the HPCRT. The ROV panel contains seven ROV ball valves and one dual bore receptacle for hotline override. The subsea pressure manometers are not included in these figures.

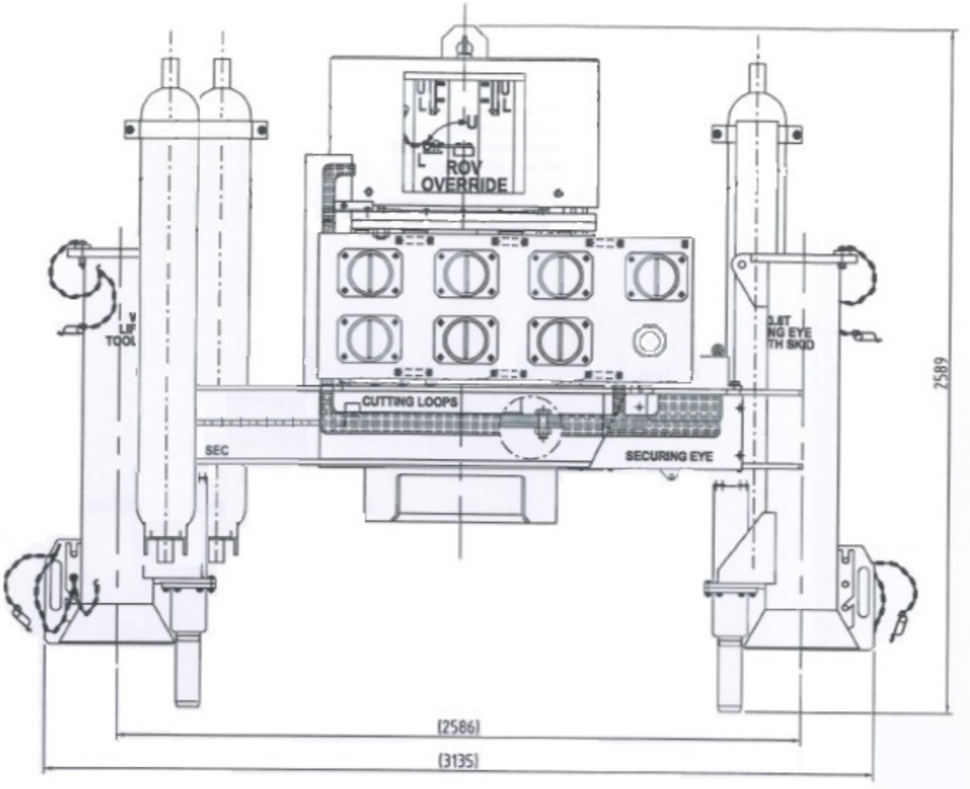

Figure 5: HPCRT seen from the side (Aker Solutions, 2014)

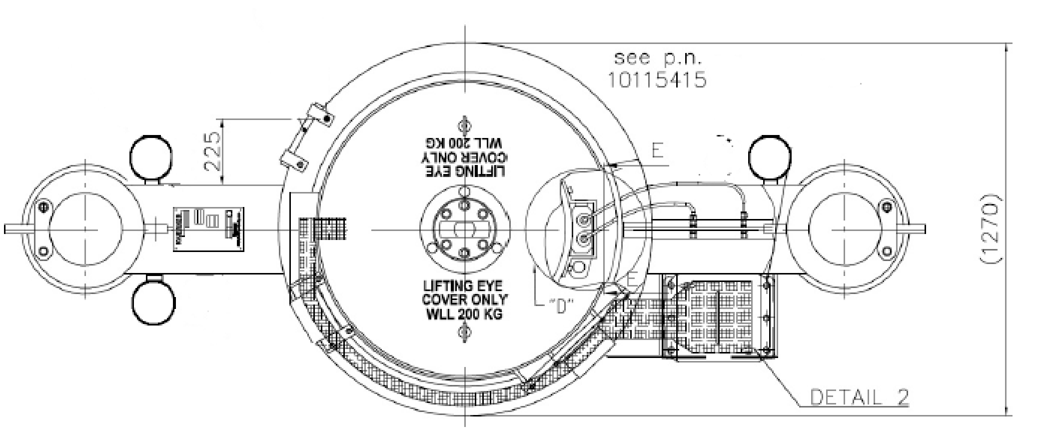

Figure 6: HPCRT seen from above (Aker Solutions, 2014)

Additional characteristics

There is a common routine that it is not allowed to send pressurised equipment offshore (Mero, 2014). This is done to secure that no damage can occur from a high-pressure leak and that no functions of the tool can release itself during transportation. Therefore, the accumulators on the HPCRT must be pressurised on arrival at the rig. This has been calculated to take approximately one hour and includes preparation of the HPU / WOCS from where the pressurising is carried out.

5.2.2. Hotline topside

Dimensioning the hotline
The hotline used for this purpose contains two lines, pressure and return. The rigs used at the Troll field are equipped with several hotline reels with different areas of use (Mero, 2014). The total weight of the hotline is essential for how it should be fastened to the wireline during operation.

Based on the hotline reels available at the Troll rigs today the weight of a filled two-line hotline covered with a protective cape is approximately 2 kg / meter. This gives a total weight of the hotline used during operation:

$$Total\ weight = Weight\ per\ metres\ x\ Number\ of\ metres$$

$$Total\ weight = 2\ kg/metres\ \ x\ 350\ metres$$

$$\underline{\underline{Total\ weight = 700\ kg}}$$

To ensure that the hotline is not exposed to damaging tension during operation it is necessary to either fasten the hotline to the wireline with wire clamps, or use a hotline that is equipped with a mantle that increase the tensile strength of the line. Wire clamps are available at the Troll rigs and thus the economically best option.

Designing the HPCRT
The HPCRT will need to be modified as described for the powerpack concept, chapter 5.2.4, "*Designing the HPCRT*". This also includes the new schematics for the HPCRT.

Additional characteristics
All of the hotline reels are owned, operated and maintained by the rig company and available through the rig rent. The cost for the reels, hotlines and wire clamps has thus not been included in the cost analysis (Mero, 2014).

5.2.3. Hotline subsea - ROV

Dimensioning the ROV
The subsea hotline concept requires hydraulic supply from a ROV reservoir. Based on feedback from Aker Solutions, this concept is difficult to implement since the ROVs used at the Troll field today does not have the capacity, nor the reservoir necessary to provide an adequate amount of hydraulics for the HPCRT (Mero, 2014) (Aker Solutions, 2014). In order to meet the ROV requirements for this concept, Statoil will need their ROV service company to modify the existing ROV to be equipped with a more heavy and larger hydraulic supply system.

Designing the HPCRT
The HPCRT will need to be modified as described for the powerpack concept, chapter 5.2.4, "*Designing the HPCRT*".
This also includes the new schematics for the HPCRT.

Additional characteristics
Regardless of the concept used, an ROV is applied to monitor and control the HPCRT during operation and the ROV cost will remain fixed. This cost is included in the rig rent and thus not included in the cost analysis (Mero, 2014).

5.2.4. Hotline subsea - powerpack

Dimensioning the powerpack
The powerpack consists of a rack with two slots, each to be fitted with four 54 litres accumulator tanks. This gives a grand total of 216 litres hydraulics available with an equal return volume. Based on the available volume, it gives:

$$Total\ runs = \frac{(Total\ hydraulics\ available\ x\ \%\ of\ volume\ delivered)}{Total\ work\ volume\ of\ HPCRT}$$

$$Total\ runs = \frac{(216\ litres\ x\ 75\%)}{46.94\ litres/run}$$

$$\underline{Total\ runs \approx 3.5\ runs}$$

In this result, the safety factor of 3.5 is included, which makes the actual number:

$$Actual\ number\ of\ runs = Total\ runs\ x\ Safety\ factor$$

$$\underline{Actual\ number\ of\ runs = 3.5\ runs\ x\ 3.5\ \approx 12\ runs}$$

As seen from the calculations above, the number of available runs with this setup is considerably higher than the required 3.5 safety factor. Nevertheless, the large reserves of hydraulics make it possible to use the powerpack for other equipment and operations than the HPCRT.

Designing the powerpack
When designing the powerpack one must choose whether to attach the accumulators in a vertical or a horizontal direction in the rack. In order for the accumulators to be able to deliver all of the hydraulics stored within, it will need to be attached in a vertical direction.
This on the other hand, might cause the centre of gravity for the powerpack to be moved to a height where the powerpack becomes unstable when installed on the seabed. Attaching the accumulator tanks in a horizontal direction eliminates this.

The powerpack will also need to be equipped with an ROV panel. From here the hotline is connected to the HPCRT and the control of the hydraulics managed by the ROV operator. Figure 7 illustrates how the powerpack will look when the eight accumulator tanks and the powerpack rack are assembled.

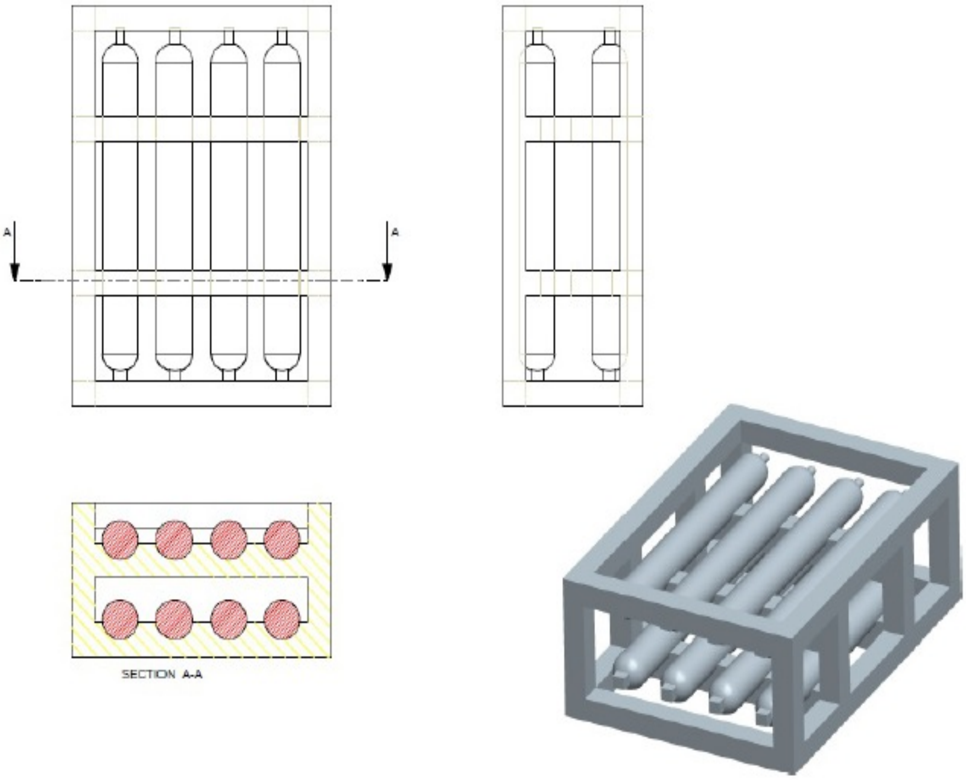

Figure 7: Proposed design for the powerpack (Angeltveit & Amundsen, 2013)

Designing the HPCRT
In order to operate the HPCRT in subsea mode it will need to be equipped with an ROV panel. The new ROV panel generates weight that can easily unbalance the HPCRT and it might be necessary to use weight loads to balance the HPCRT (Angeltveit & Amundsen, 2013). The ROV panel contains seven ROV ball valves, subsea manometers and dual bore receptacle for hotline connection.

The following figure 8 shows how the schematics for the HPCRT will need to be modified in order to pressurise the tool with a hotline. *P* is the pressure line whilst *R* is the return line. These are connected to the hotline through the dual port multi stab receptacle. The old MQC plate and its couplers will remain at the HPCRT. This enables the tool to still be operated in umbilical mode in cases where this is desired and acts as a primary redundancy system.

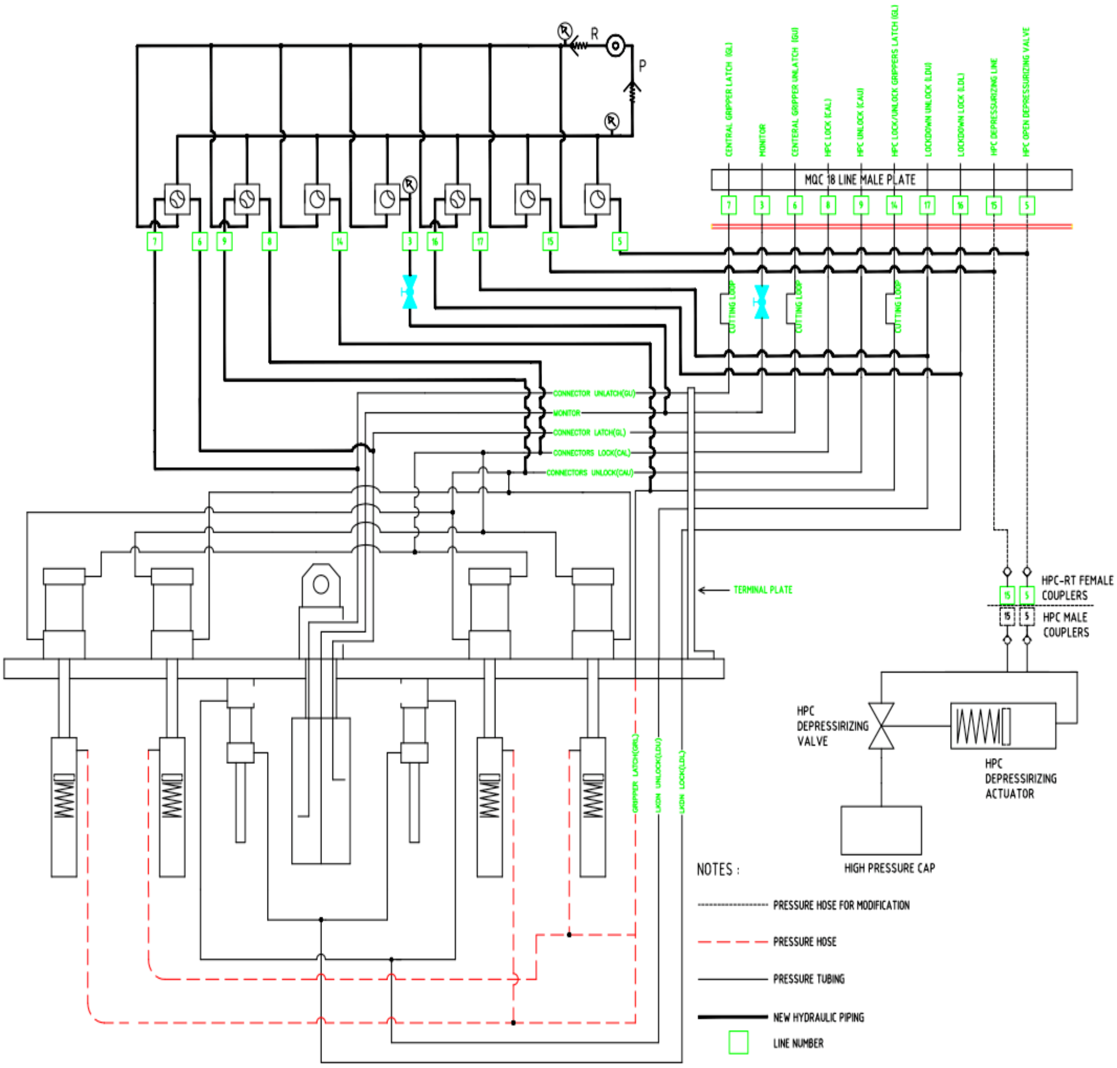

Figure 8: HPCRT hydraulic schematic for the powerpack concept

Additional characteristics

The powerpack has, due to its large hydraulics reserves, several areas of use. In order to enable powerpack support with other equipment it is recommended that the ROV panel for the powerpack is equipped with both single- and dual port multistab receptacles.

Although the powerpack concept includes an extra device during shipping the transport costs remain fixed. It is, due to the overcapacity in the transport basket used today, no need for an extra transport basket when the HPCRT and powerpack are shipped offshore. The price of the HPCRT basket remains the same independently of the weight and size of the content (Mero, 2014).

5.3. Interview

The Pugh matrix requires that the different criteria are used in combination with a weighting score. This score is a result of how the company perceives the importance of each criterion. In order to get an accurate score for each criterion 36 interviews have been conducted at Aker Solutions Subsea. Employees from eight different departments have been asked the same nine questions, and each department has been weighted in relation to the other departments, in order to give each department an equal say on each criterion. In cases were one employee holds several roles in, or experience from, different departments, the cross average of these weightings are used as the interviewee´s weight.

Each of the interviewees were asked to give a score from one through six, where one is the least important and six is the most important, for each of the nine questions. In addition, the interviewee was asked to give his or her thoughts about the importance of the questions, which later could be used to detect critical criteria areas for each of the potential concepts.

The interviewees were asked the following questions:

To which department are you affiliated?

( ) Sales engineer
( ) Cost controller
( ) Project manager
( ) HSE
( ) Engineering
( ) Mechanical completion / Quality surveillance
( ) Offshore technician
( ) Mechanic

1) Feasibility:

Q: What is your opinion regarding the importance of high feasibility in the early phase of a project, and how critical would you rate this on a scale from one through six?

2) Physical parameters:

$Q_{engineer}$: To what extent are size and weight key factors when designing equipment for use offshore, and how critical would you rate this on a scale from one through six?

$Q_{offshore\ technician/mechanic}$: What is yours opinion regarding size and weight as factors influencing the operation performed, and how critical would you rate this on a scale from one through six?

3) Maintainability:

Q: What are your thoughts regarding maintainability of equipment used in offshore operations, and how critical would you rate this on a scale from one through six?

4) Reliability:

Q: What are your thoughts regarding reliability of equipment used in offshore operations, and how critical would you rate this on a scale from one through six?

5) Complexity in use:

Q: What is your opinion regarding handling complexity of equipment used in offshore operations, and how critical would you rate this on a scale from one through six?

6) Economic impact:

Q: What is your opinion regarding economic valuation as a key contributor to project decision making, and how critical would you rate this on a scale from one through six?

7) Development cost and time:

Q: What are your thoughts regarding development cost and time of projects as a decision making factor, and how critical would you rate this on a scale from one through six?

8) Degree of risk reduction:

Q: What are your thoughts regarding risk reducing measures when implementing new solutions, and how critical would you rate this on a scale from one through six?

9) Environmental impact:

Q: What is your opinion when it comes to environmental issues in project decision making, and how critical would you rate this on a scale from one through six?

5.4. Interview data

Table 5: Average criteria scores by department

	Sales engineer	Cost controller	Project manager	HSE	Engineering	Quality surveilance	Offshore technician	Mechanic	Average
Feasibility	4,5	6,0	5,3	5,0	4,6	5,3	4,6	4,7	5,0
Physical parameters	1,0		4,3	3,3	4,5	3,5	4,1	3,3	3,4
Maintainability	5,0	5,0	4,8	4,5	4,1	5,5	3,9	4,7	4,7
Reliability	5,8	5,5	5,8	6,0	5,5	5,5	5,7	5,5	5,7
Complexity in use	4,0	5,0	3,0	3,5	3,8	2,0	3,5	3,5	3,5
Economic impact	5,0	5,3	5,2	3,5	3,8	4,3	2,0	6,0	4,4
Development cost and time	2,0	4,0	4,3	5,0	3,8	3,5	3,7	3,5	3,7
Degree of risk reduction	5,7	5,3	5,5	6,0	5,1	5,8	5,0	5,2	5,4
Environmental impact	5,3	4,7	5,2	5,7	4,9	5,0	4,4	4,4	4,9

Table 5 shows the average scores given to the criteria, broken down by department. It is quite clear that employees from the various departments have different perceptions concerning the criticality of some of the criteria. This is also visualised in the radar charts in figure 9. Here it seems that they are more or less coherent when it comes to feasibility, maintainability, reliability, degree of risk reduction and environmental impact, while the rest tend to vary more. This is also the reason why the departments have been weighted against each other based on how many responses they have contributed with. The weighted average scores found in table 6, rather than just the average scores in table 5, is therefore a more accurate picture of how Aker Solutions Subsea as an organisation perceives the criticality of each criterion.

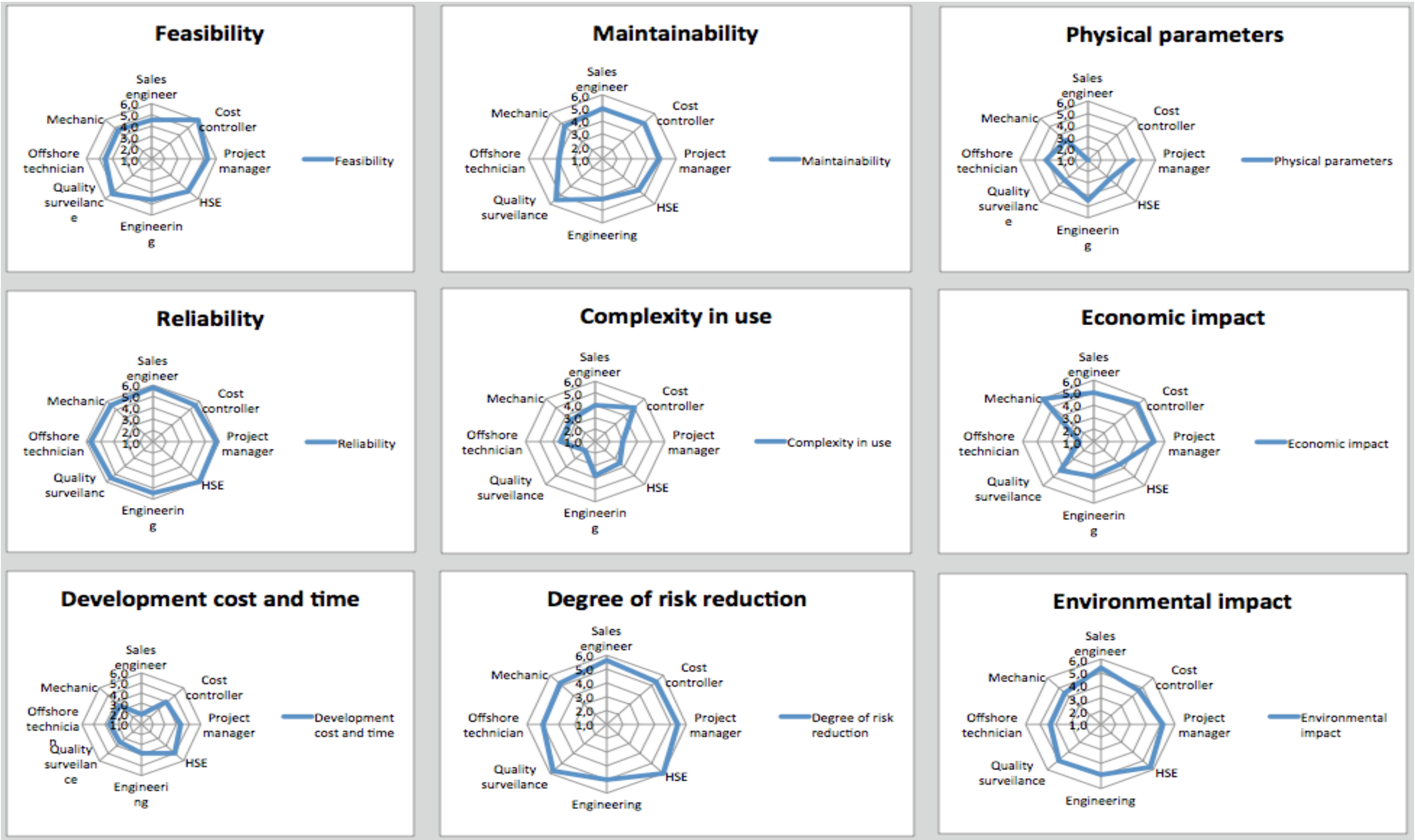

Figure 9: Variance in criteria scoring by department

Table 6: Weighted average criteria scores

		Interview 1	Interview 2	Interview 3	Interview 4	Interview 5	Interview 6	Interview 7	Interview 8	Interview 9	Interview 10	Interview 11	Interview 12	Interview 13	Interview 14	Interview 15	Interview 16	Interview 17	Interview 18	Interview 19	Interview 20	Interview 21	Interview 22	Interview 23	Interview 24	Interview 25	Interview 26	Interview 27	Interview 28	Interview 29	Interview 30	Interview 31	Interview 32	Interview 33	Interview 34	Interview 35	Interview 36	Responses	Sum	Weighted average
Interview scores	Feasibility	6	5	5	3	6	5	5	3	5	-	-	3	5	5	6	4	5	-	4	-	5	6	-	-	5	6	-	6	6	5	-	-	-	4	2	-	25	-	-
	Physical parameters	5	6	5	6	-	3	6	5	5	5	4	5	2	3	4	3	6	3	4	6	3	5	3	3	5	-	2	3	-	4	5	4	2	1	-	-	31	-	-
	Maintainability	5	3	4	4	-	3	2	2	3	3	5	5	3	-	4	5	5	2	5	6	4	5	5	6	-	6	6	6	5	5	5	5	5	5	-	4	32	-	-
	Reliability	4	-	5	5	6	5	-	-	6	5	6	6	-	4	5	6	6	6	6	-	6	6	-	6	6	-	5	6	6	6	6	6	6	5	6	5	29	-	-
	Complexity in use	-	3	-	3	5	-	5	5	4	2	-	5	-	2	-	-	4	2	3	-	3	5	4	2	-	-	3	-	-	-	3	-	4	4	3	5	22	-	-
	Economic impact	5	-	-	-	6	-	-	5	-	-	-	-	-	3	6	2	2	-	-	6	3	4	4	-	4	6	-	6	6	6	5	-	-	3	5	4	20	-	-
	Development cost and time	3	2	2	-	-	3	-	4	5	-	6	-	4	6	4	5	2	-	2	4	5	-	-	2	-	6	-	4	3	-	-	-	-	1	2	3	22	-	-
	Degree of risk reduction	5	3	2	6	-	5	6	5	-	3	3	6	6	5	6	6	6	5	5	6	6	6	4	6	6	6	5	6	5	6	4	5	6	6	6	5	34	-	-
	Environmental impact	-	2	-	5	-	6	6	5	-	3	5	-	5	-	5	5	-	-	3	6	5	6	5	5	6	6	2	5	4	5	5	5	6	6	6	4	28	-	-
Disciplines weight	Sales engineer	-	-	-	-	4,8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4,8	-	-	-	-	4,8	4,8	-	4	-	-
	Cost controller	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6,3	-	-	6,3	-	-	-	-	-	-	6,3	3	-	-
	Project manager	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3,2	-	-	-	-	3,2	3,2	-	-	-	-	-	-	-	-	3,2	3,2	3,2	-	-	-	-	6	-	-
	HSE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6,3	-	-	-	6,3	-	-	-	-	-	-	-	6,3	-	-	-	3	-	-
	Engineering	1	1	1	1	-	1	1	1	1	-	1	1	1	1	-	1	1	-	1	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	19	-	-
	Quality surveilance	4,8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4,8	-	-	-	-	-	-	-	4,8	-	-	-	4,8	-	-	-	-	-	-	-	-	4	-	-
	Offshore technician	-	-	-	-	-	1,6	1,6	-	1,6	1,6	1,6	1,6	1,6	-	-	-	1,6	1,6	1,6	-	-	-	-	-	-	-	1,6	-	-	-	-	1,6	-	-	-	-	12	-	-
	Mechanic	-	-	-	-	-	3,2	-	-	-	3,2	-	3,2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3,2	3,2	-	-	-	-	3,2	-	-	-	6	-	-
	Interview weight	2,9	1	1	1	4,8	1,9	1,3	1	1,3	2,4	1,3	1,9	1,3	1	3,2	2,9	1,3	1,6	1,3	2,1	3,5	1	1	4,8	6,3	6,3	2,4	4	5,5	3,2	3,2	2,4	4,8	4,8	4,8	6,3	-	100,4	-
Weighted criteria scores	Feasibility	17	5	5	3	29	9,6	6,5	3	6,5	-	-	5,8	6,5	5	19	12	6,5	-	5,2	-	18	6	-	-	32	38	-	24	33	16	-	-	-	19	9,5	-	25	338,1	3,37
	Physical parameters	14	6	5	6	-	5,8	7,8	5	6,5	12	5,2	9,6	2,6	3	13	8,6	7,8	4,8	5,2	13	11	5	3	14	32	-	4,8	12	-	13	16	9,5	9,5	4,8	-	-	31	273,3	2,72
	Maintainability	14	3	4	4	-	5,8	2,6	2	3,9	7,1	6,5	9,6	3,9	-	13	14	6,5	3,2	6,5	13	14	5	5	29	-	38	14	24	28	16	16	12	24	24	-	25	32	394,8	3,93
	Reliability	12	-	5	5	29	9,6	-	-	7,8	12	7,8	12	-	4	16	17	7,8	9,5	7,8	-	21	6	-	29	38	-	12	24	33	19	19	14	29	24	29	32	29	487,6	4,86
	Complexity in use	-	3	-	3	24	-	6,5	5	5,2	4,8	-	9,6	-	2	-	-	5,2	3,2	3,9	-	11	5	4	9,5	-	-	7,1	-	-	-	9,5	-	19	19	14	32	22	204,5	2,04
	Economic impact	14	-	-	-	29	-	-	5	-	-	-	-	-	3	19	5,8	2,6	-	-	13	11	4	4	-	25	38	-	24	33	19	16	-	-	14	24	25	20	327,7	3,26
	Development cost and time	8,6	2	2	-	-	5,8	-	4	6,5	-	7,8	-	5,2	6	13	14	2,6	-	2,6	8,3	18	-	-	9,5	-	38	-	16	17	-	-	-	-	4,8	9,5	19	22	219	2,18
	Degree of risk reduction	14	3	2	6	-	9,6	7,8	5	-	7,1	3,9	12	7,8	5	19	17	7,8	7,9	6,5	13	21	6	4	29	38	38	12	24	28	19	13	12	29	29	29	32	34	513,4	5,11
	Environmental impact	-	2	-	5	-	12	7,8	5	-	7,1	6,5	-	6,5	-	16	14	-	-	3,9	13	18	6	5	24	38	38	4,8	20	22	16	16	12	29	29	29	25	28	427,2	4,26

5.5. Description of cost analysis

5.5.1. External economic factors

There is a set of external factors that are used to calculate the cost of each concept and which is not possible to influence from within the project. These include the exchange rate between US Dollars and Norwegian Kroner, the weighted average cost of capital (WACC) for Aker Solutions Subsea and daily rates for drilling rigs and intervention vessels operating on the Troll field. The values presented below will be used in the further evaluation of the different concepts.

Exchange rate USD – NOK

As exchange rates vary constantly, a five-year average from year 2009 till year 2013 is utilised. As seen in table 7 the average rate over these years has been relatively constant, revolving around 6 NOK per 1 USD.

Table 7: Exchange rate USD-NOK between 2009 and 2013

Exchange rate USD-NOK	
2009	6,28
2010	6,05
2011	5,61
2012	5,82
2013	5,88
Average	5,93

WACC for Aker Solutions Subsea

Aker Solutions publish their WACC in their annual report. For this thesis, the post-tax WACC of 8,9%, published in the 2013 report will be used (Aker Solutions, 2014, p. 50)

Daily rates for drilling rigs and intervention vessels
The daily rate for a mobile drilling rig or an intervention vessel is the main cost contributor for any offshore operation. As shown in table 8 they are literarily very expensive to hire, and time saving opportunities are therefore often embraced with open arms. On the Troll field, Statoil currently has four rigs operating on contract for them, with a fifth joining in 2015 (Hofland, 2014). With the rates ranging from 335 000$ to 496 000$ per day, and the fact that it is not possible to know which one of the rigs will be used for the tool in this thesis, an average rate for the five rigs will be used. After the tool has been modified, Statoil also has the option to utilise an intervention vessel, with a much lower daily rate, instead of a drilling rig. They currently have two intervention vessels operating on contract for them on the Troll field. It is hard to say to what extent this opportunity will be put to use, as it relies on non-available future logistics. It will however be conservatively incorporated as a scenario in the evaluation of each concept.

Table 8: Daily and hourly rates for mobile drilling rigs and intervention vessels (Hofland, 2014)

Mobile drilling rigs	Stena Don	West Venture	COSL Innovator	COSL Promoter	Songa Equinox	Average
Daily rates 1000USD	496	390	335	335	440	399,2
Hourly rates 1000NOK	122,48	96,30	82,72	82,72	108,65	98,58
Intervention vessels	Island Frontier	Island Wellserver				Average
Daily rates 1000USD	280	280				280
Horly rates 1000NOK	69,14	69,14				69,14

5.5.2. Operational costs

The operations listed in tables 9, 10 and 11 are identified from Aker Solutions' "*HPC Installation & Retrieval procedures*" and from discussions with Juha Mero – Specialist Engineer in Aker Solutions. All operations included in the table are main activities conducted during an intervention of a subsea well and include sub-activities from the related operation procedures. The total number of man-hours and technicians required for each concept are based on historical data from both previous and similar operations (Mero, 2014).

The operations listed for the new concepts are known activities and are frequently used in offshore operations. What is special for the new concepts in the table is the composition of these activities. Since the available data from these operations are based on single use, or use in combination with other activities, the estimated time for each of the activities may vary dependent on the combination they are used in. Nevertheless, the estimated time will not vary significantly purely based on the combination of use. In consultation with Aker Solutions, the estimated time used in the table will remain the same as for single use.

Table 9: Operational costs - Use of drilling rigs only

	Drilling rig	Intervention ship
Hourly rate (1000 NOK)	98,58	69,1

	Technician
Hourly costs (1000 NOK)	1,764

Operational costs - Use of drilling rigs only	Current method		Accumulators		Hotline topside		Hotline Subsea - ROV		Hotline Subsea - Powerpack	
Operation	Hours	Technicians	Hours	Technicians	Hours	Technicians	Hours	Technicians	Hours	Technicians
Pressuretest of umbilical from WOCS to HPCRT	1	3								
Running and installation of Imenco guidewire anchors	1	3	1	3	1	3	1	3	1	3
Running of drillpipe and umbilical reel	5	3								
Installing umbilical clamps	1,5	3								
Pressuretest of hotline from HPU to HPCRT					1	3				
Pressuretest of hotline from ROV to HPCRT							1	3		
Precharge HPCRT accumulators			1	3						
Running of HPCRT on tugger winch			1	3			1	3	1	3
Running of HPCRT on tugger winch with hotline reel					1	3				
Installing wire clamps					0,5	3				
Running of powerpack on tugger winch									0,75	3
Connect hotline between HPCRT and subsea powerpack							0,5	3	0,5	3
Operate and running valves top side	1	3								
Operate and running valves subsea			1	3	1	3	1	3	1	3
Summarised	9,5	15	4	12	4,5	15	4,5	15	4,25	15
Individual cost (1000 NOK)	936,47	50,27	394,30	21,17	443,59	23,81	443,59	23,81	418,95	22,49
Total cost per operation (1000 NOK)	986,75		415,47		467,41		467,41		441,44	
Total cost per annum - Pilot modification (1000 NOK)	2960,24		1246,42		1402,22		1402,22		1324,32	
Total cost per annum - Full scale modification (1000 NOK)	11840,97		4985,67		5608,88		5608,88		5297,27	

Table 10: Operational costs - Use of intervention ship were applicable

Operational costs - Use of intervention ship were applicable	Current method		Accumulators		Hotline topside		Hotline Subsea - ROV		Hotline Subsea - Powerpack	
Operation	Hours	Technicians	Hours	Technicians	Hours	Technicians	Hours	Technicians	Hours	Technicians
Pressuretest of umbilical from WOCS to HPCRT	1	3								
Running and installation of Imenco guidewire anchors	1	3	1	3	1	3	1	3	1	3
Running of drillpipe and umbilical reel	5	3								
Installing umbilical clamps	1,5	3								
Pressuretest of hotline from HPU to HPCRT					1	3				
Pressuretest of hotline from ROV to HPCRT							1	3		
Precharge HPCRT accumulators			1	3						
Running of HPCRT on tugger winch			1	3			1	3	1	3
Running of HPCRT on tugger winch with hotline reel					1	3				
Installing wire clamps					0,5	3				
Running of powerpack on tugger winch									0,75	3
Connect hotline between HPCRT and subsea powerpack							0,5	3	0,5	3
Operate and running valves top side	1	3								
Operate and running valves subsea			1	3	1	3	1	3	1	3
Summarised	9,5	15	4	12	4,5	15	4,5	15	4,25	15
Individual cost (1000 NOK)	936,47	50,27	276,57	21,17	311,14	23,81	311,14	23,81	293,85	22,49
Total cost per operation (1000 NOK)	986,75		297,73		334,95		334,95		316,34	
Total cost per annum - Pilot modification (1000 NOK)	2960,24		893,20		1004,85		1004,85		949,03	
Total cost per annum - Full scale modification (1000 NOK)	11840,97		3572,81		4019,41		4019,41		3796,11	

Table 11: Operational costs - 10% use of intervention ship were applicable

Operational costs - 10% use of intervention ship were applicable	Current method		Accumulators		Hotline topside		Hotline Subsea - ROV		Hotline Subsea - Powerpack	
Operation	Hours	Technicians	Hours	Technicians	Hours	Technicians	Hours	Technicians	Hours	Technicians
Pressuretest of umbilical from WOCS to HPCRT	1	3								
Running and installation of Imenco guidewire anchors	1	3	1	3	1	3	1	3	1	3
Running of drillpipe and umbilical reel	5	3								
Installing umbilical clamps	1,5	3								
Pressuretest of hotline from HPU to HPCRT					1	3				
Pressuretest of hotline from ROV to HPCRT							1	3		
Precharge HPCRT accumulators			1	3						
Running of HPCRT on tugger winch			1	3			1	3	1	3
Running of HPCRT on tugger winch with hotline reel					1	3				
Installing wire clamps					0,5	3				
Running of powerpack on tugger winch									0,75	3
Connect hotline between HPCRT and subsea powerpack							0,5	3	0,5	3
Operate and running valves top side	1	3								
Operate and running valves subsea			1	3	1	3	1	3	1	3
Summarised	9,5	15	4	12	4,5	15	4,5	15	4,25	15
Individual cost (1000 NOK)	936,47	50,27	382,53	21,17	430,35	23,81	430,35	23,81	406,44	22,49
Total cost per operation (1000 NOK)	986,75		403,70		454,16		454,16		428,93	
Total cost per annum - Pilot modification (1000 NOK)	2960,24		1211,10		1362,48		1362,48		1286,79	
Total cost per annum - Full scale modification (1000 NOK)	11840,97		4844,38		5449,93		5449,93		5147,16	

5.5.3. Maintenance costs

The periodic maintenance types for the tool are:

- Demobilisation 1 / Condition Monitoring
- Main Service

In addition, emergency maintenance is used in cases where the tool or associated equipment fails during an operation. The demobilisation 1 is frequency dependent and is carried out post operation, while the main service is performed once a year. Both maintenance types are carried out in Aker Solutions workshop onshore. The man-hours used in table 12 and the frequencies of the maintenance are based on historical data from previous maintenance activities, and give a good estimate for the future maintenance (Mero, 2014).

5.5.4. Bill of materials

Table 13 includes all parts necessary to modify the HPCRT to be operated without the need of drill pipe or umbilical. The BOM has been prepared in cooperation with Aker Solutions and is based on their analysis of the parts necessary to modify the tool. All parts, except the ROV panels and the accumulator rack, are commercial of-the-shelf products. The panels and the accumulator rack will need to be made on measure to suit the equipment (Mero, 2014).

5.5.5. Development costs

Table 14 includes all administrative and technical costs associated with the engineering, designing, testing and certification of the HPCRT. It also includes the cost for all necessary parts and equipment required.

Table 12: Maintenance costs for HPCRT

Hourly cost mechanic (1000 NOK)	1,2
Emergency maintenance contribution (1000 NOK)	5000

Pilot modification	Current method			Accumulators			Hotline topside			Hotline ROV			Hotline Powerpack		
Activity	Frequency	Time	Cost	Frequency	Time	Cost	Frequency	Time	Cost	Frequency	Time	Cost	Frequency	Time	Cost
Inspection	3	16	57,6	3	16	58	3	16	58	3	16	58	3	21	76
Main service	1	80	96	1	85	102	1	80	96	1	80	96	1	100	120
Emergency maintenance	1	1	5000			0			0			0			0
Sum (1000 NOK)			5154			160			154			154			196

Full scale modification	Current method			Accumulators			Hotline topside			Hotline ROV			Hotline Powerpack		
Activity	Frequency	Time	Cost	Frequency	Time	Cost	Frequency	Time	Cost	Frequency	Time	Cost	Frequency	Time	Cost
Inspection	12	16	230,4	12	16	230	12	16	230	12	16	230	12	21	302
Main service	4	80	384	4	85	408	4	80	384	4	80	384	4	100	480
Emergency maintenance	1	1	5000			0			0			0			0
Sum (1000 NOK)			5614			638			614			614			782

Table13: Bill of materials for HPCRT

	Accumulators		Hotline topside		Hotline Subsea - ROV		Hotline Subsea - Powerpack	
Bill Of Materials	**Units of measurements**	**Quantity**	**Units of measurements**	**Quantity**	**Units of measurements**	**Quantity**	**Units of measurements**	**Quantity**
HPCRT ROV panel								
ROV panel	ea.	1	ea.	1	ea.	1	ea.	1
Ø38 mm dual bore hot stab	ea.	1	ea.	1	ea.	1	ea.	1
Ø38 mm dual bore receptacle	ea.	1	ea.	1	ea.	1	ea.	1
Check valves	ea.	3	ea.	3	ea.	3	ea.	3
Subsea manometer	ea.	3	ea.	3	ea.	3	ea.	3
ROV ballvalve	ea.	7	ea.	7	ea.	7	ea.	7
3/8" tubings + fittings	set	1	set	1	set	1	set	1
Bolts and nuts	set	1	set	1	set	1	set	1
HPCRT accumulators								
Accumulator 54 litres	fl.	1						
Accumulator 37 litres	fl.	2						
Powerpack ROV panel								
Accumulator rack							ea.	1
ROV panel							ea.	1
Ø38 mm dual bore hot stab							ea.	1
Ø38 mm dual bore receptacle							ea.	1
Quick couplings for hose							ea.	2
Ballvalve							ea.	6
ROV ballvalve							ea.	3
Check valves							ea.	4
Subsea manometer							ea.	3
Thermoplast hose Ø1/4"							meters	20
3/8" tubings + fittings							set	1
Bolts and nuts							set	1
Precharge tool kit							set	1
Powerpack accumulators								
Accumulator 54 litres							fl.	8

Table 14: Development costs for HPCRT

Pilot modification	Accumulators		Hotline topside		Hotline Subsea - ROV		Hotline Subsea - Powerpack	
Development	Engineering	Manufacturing	Engineering	Manufacturing	Engineering	Manufacturing	Engineering	Manufacturing
Engineering activities								
Design engineering	170		170		170		170	
Manufacturing activities								
ROV panel HPCRT		350		350		350		350
ROV panel powerpack								230
Accumulator 54 liter		9,7						77,6
Accumulator 37 liter		14,6						
Testing and sertification activities								
FAT	30		30		30		30	
Logistics & transport								
Logistics	15		15		15		15	
Follow up & management								
Follow up	50		50		50		50	
Individual cost (1000 NOK)	265	374,3	265	350	265	350	265	657,6
Total cost (1000 NOK)	639,3		615		615		922,6	

Full scale modification	Accumulators		Hotline topside		Hotline Subsea - ROV		Hotline Subsea - Powerpack	
Development	Engineering	Manufacturing	Engineering	Manufacturing	Engineering	Manufacturing	Engineering	Manufacturing
Engineering activities								
Design engineering	170		170		170		170	
Manufacturing activities								
ROV panel HPCRT		1400		1400		1400		1400
ROV panel powerpack								920
Accumulator 54 liter		38,8						310,4
Accumulator 37 liter		58,4						
Testing and sertification activities								
FAT	120		120		120		120	
Logistics & transport								
Logistics	60		60		60		60	
Follow up & management								
Follow up	200		200		200		200	
Individual cost (1000 NOK)	550	1497,2	550	1400	550	1400	550	2630,4
Total cost (1000 NOK)	3544,4		3350		3350		5810,8	

5.6. Economic concept evaluation

As mentioned in the criteria selection section, the concepts are economically evaluated using NPV. In this setting the calculated NPV refers to the cost of the concepts and not the yield. This means that a lower NPV is preferred over a higher NPV. One must further notice that the annual operational and maintenance cost contributions are static for each concept. This is due to that the main cost contributor derives from the daily rates of renting drilling rigs and/or intervention vessels. These are hired on contracts with fixed prices over several years, and the details regarding when the prices in the contracts will be renegotiated is unavailable confidential information. Any estimate of this would then just be speculations. As a result of this, the maintenance costs are also kept static to ensure that the numbers are coherent. It is however worth noticing that an increase in the day rates will only lead to a bigger advantage for the proposed concepts, as the contribution is controlled by operational hours needed. This is because all of the proposed concepts require less operational time. One could therefore also say that the calculations can be considered to be conservative.

When calculating NPV it is necessary to use a discount rate that reflects the company's economic situation. As earlier mentioned, Aker Solutions WACC of 8,9% will be used as the discount rate. Time perspective is also an important factor that affects the end result. By recommendation from Anders Bergland, Head of Equity research in RS Platou, a 10-year period is the most suitable perspective for this kind of evaluation.

The concepts are compared with the current method in six different scenarios. These are divided into three categories depending on whether a drilling rig is utilised, an intervention vessel is utilised or a combination of the two. Each category is further divided into two scenarios, depending on whether Aker Solutions decides to only go through with a pilot modification or a full-scale modification. This has to do with the fact that they have four identical tools, which they potentially can modify.

5.6.1. Pilot modification – Use of drilling rigs only

This scenario represents how the modification of one tool will affect the NPV compared to the use of one tool with the current method. It is based on how the operation is performed today, with the operation run from a mobile drilling rig and with cost savings through operational time and reduced maintenance costs. It also incorporates the development costs of the proposed concepts. The potential % cost savings range from 488% to 539% and the potential monetary savings range from 41,6 MNOK to 42,6 MNOK, as seen in Table 15.

Table 15: NPV for pilot modification - Drilling rigs only

Accumulators	
NPV (NOK 1000)	kr 9 702,49

	Development	Operational	Maintenance	Total
Initial investment	639,30			639,30
Year 1		1246,42	159,60	1406,02
Year 2		1246,42	159,60	1406,02
Year 3		1246,42	159,60	1406,02
Year 4		1246,42	159,60	1406,02
Year 5		1246,42	159,60	1406,02
Year 6		1246,42	159,60	1406,02
Year 7		1246,42	159,60	1406,02
Year 8		1246,42	159,60	1406,02
Year 9		1246,42	159,60	1406,02
Year 10		1246,42	159,60	1406,02

Hotline Topside	
NPV (NOK 1000)	kr 10 643,82

	Development	Operational	Maintenance	Total
Initial investment	615,00			615,00
Year 1		1402,22	153,6	1555,82
Year 2		1402,22	153,6	1555,82
Year 3		1402,22	153,6	1555,82
Year 4		1402,22	153,6	1555,82
Year 5		1402,22	153,6	1555,82
Year 6		1402,22	153,6	1555,82
Year 7		1402,22	153,6	1555,82
Year 8		1402,22	153,6	1555,82
Year 9		1402,22	153,6	1555,82
Year 10		1402,22	153,6	1555,82

Hotline Subsea - ROV	
NPV (NOK 1000)	kr 10 643,82

	Development	Operational	Maintenance	Total
Initial investment	615,00			615,00
Year 1		1402,22	153,60	1555,82
Year 2		1402,22	153,60	1555,82
Year 3		1402,22	153,60	1555,82
Year 4		1402,22	153,60	1555,82
Year 5		1402,22	153,60	1555,82
Year 6		1402,22	153,60	1555,82
Year 7		1402,22	153,60	1555,82
Year 8		1402,22	153,60	1555,82
Year 9		1402,22	153,60	1555,82
Year 10		1402,22	153,60	1555,82

Hotline Subsea - Powerpack	
NPV (NOK 1000)	kr 10 720,00

	Development	Operational	Maintenance	Total
Initial investment	922,60			922,60
Year 1		1324,32	195,6	1519,92
Year 2		1324,32	195,6	1519,92
Year 3		1324,32	195,6	1519,92
Year 4		1324,32	195,6	1519,92
Year 5		1324,32	195,6	1519,92
Year 6		1324,32	195,6	1519,92
Year 7		1324,32	195,6	1519,92
Year 8		1324,32	195,6	1519,92
Year 9		1324,32	195,6	1519,92
Year 10		1324,32	195,6	1519,92

Current method	
NPV (NOK 1000)	kr 52 301,84

	Development	Operational	Maintenance	Total
Initial investment	0,00			0,00
Year 1		2960,24	5153,60	8113,84
Year 2		2960,24	5153,60	8113,84
Year 3		2960,24	5153,60	8113,84
Year 4		2960,24	5153,60	8113,84
Year 5		2960,24	5153,60	8113,84
Year 6		2960,24	5153,60	8113,84
Year 7		2960,24	5153,60	8113,84
Year 8		2960,24	5153,60	8113,84
Year 9		2960,24	5153,60	8113,84
Year 10		2960,24	5153,60	8113,84

Pilot - Use of drilling rigs only		
Concept	NPV	% cost reduction
Accumulators	kr 9 702,49	539 %
Hotline Topside	kr 10 643,82	491 %
Hotline Subsea - ROV	kr 10 643,82	491 %
Hotline Subsea - Powerpack	kr 10 720,00	488 %
Current method	kr 52 301,84	

5.6.2. Full-scale modification - Use of drilling rigs only

This scenario uses the same operational conditions as the previous one, with the use of drilling rigs only. The difference is that it looks at the NPV when all the four tools are modified. This leads to a slightly lower development cost per modified tool, since the engineering only has to be done once. The other difference is the emergency maintenance for the current method, which remains the same whether one or four tools are utilised throughout the year (Mero, 2014). This leads to a much lower maintenance cost per tool. The potential % cost savings range from 250% to 283% and the potential monetary savings range from 67,6 MNOK to 72,7 MNOK, as seen in table 16.

Table 16: NPV for full-scale modification - Drilling rigs only

Accumulators	
NPV (NOK 1000)	kr 39 797,17

	Development	Operational	Maintenance	Total
Initial investment	3544,40			3544,40
Year 1		4985,67	638,40	5624,07
Year 2		4985,67	638,40	5624,07
Year 3		4985,67	638,40	5624,07
Year 4		4985,67	638,40	5624,07
Year 5		4985,67	638,40	5624,07
Year 6		4985,67	638,40	5624,07
Year 7		4985,67	638,40	5624,07
Year 8		4985,67	638,40	5624,07
Year 9		4985,67	638,40	5624,07
Year 10		4985,67	638,40	5624,07

Hotline Topside	
NPV (NOK 1000)	kr 43 465,27

	Development	Operational	Maintenance	Total
Initial investment	3350,00			3350,00
Year 1		5608,88	614,4	6223,28
Year 2		5608,88	614,4	6223,28
Year 3		5608,88	614,4	6223,28
Year 4		5608,88	614,4	6223,28
Year 5		5608,88	614,4	6223,28
Year 6		5608,88	614,4	6223,28
Year 7		5608,88	614,4	6223,28
Year 8		5608,88	614,4	6223,28
Year 9		5608,88	614,4	6223,28
Year 10		5608,88	614,4	6223,28

Hotline Subsea - ROV	
NPV (NOK 1000)	kr 43 465,27

	Development	Operational	Maintenance	Total
Initial investment	3350,00			3350,00
Year 1		5608,88	614,40	6223,28
Year 2		5608,88	614,40	6223,28
Year 3		5608,88	614,40	6223,28
Year 4		5608,88	614,40	6223,28
Year 5		5608,88	614,40	6223,28
Year 6		5608,88	614,40	6223,28
Year 7		5608,88	614,40	6223,28
Year 8		5608,88	614,40	6223,28
Year 9		5608,88	614,40	6223,28
Year 10		5608,88	614,40	6223,28

Hotline Subsea - Powerpack	
NPV (NOK 1000)	kr 45 000,40

	Development	Operational	Maintenance	Total
Initial investment	5810,80			5810,80
Year 1		5297,27	782,4	6079,67
Year 2		5297,27	782,4	6079,67
Year 3		5297,27	782,4	6079,67
Year 4		5297,27	782,4	6079,67
Year 5		5297,27	782,4	6079,67
Year 6		5297,27	782,4	6079,67
Year 7		5297,27	782,4	6079,67
Year 8		5297,27	782,4	6079,67
Year 9		5297,27	782,4	6079,67
Year 10		5297,27	782,4	6079,67

Current method	
NPV (NOK 1000)	kr 112 517,33

	Development	Operational	Maintenance	Total
Initial investment	0,00			0,00
Year 1		11840,97	5614,40	17455,37
Year 2		11840,97	5614,40	17455,37
Year 3		11840,97	5614,40	17455,37
Year 4		11840,97	5614,40	17455,37
Year 5		11840,97	5614,40	17455,37
Year 6		11840,97	5614,40	17455,37
Year 7		11840,97	5614,40	17455,37
Year 8		11840,97	5614,40	17455,37
Year 9		11840,97	5614,40	17455,37
Year 10		11840,97	5614,40	17455,37

Full scale - Use of drilling rigs only		
Concept	NPV	% cost reduction
Accumulators	kr 39 797,17	283 %
Hotline Topside	kr 43 465,27	259 %
Hotline Subsea - ROV	kr 43 465,27	259 %
Hotline Subsea - Powerpack	kr 45 000,40	250 %
Current method	kr 112 517,33	

5.6.3. Pilot modification – Use of intervention ship were applicable

This scenario is included to display the maximum theoretical cost savings. It is based on using an intervention ship instead of a drilling rig for the modified tool, while the current method still requires a drilling rig. The intervention ship has the advantage of being much cheaper to rent by the hour and at the same time being capable of performing the job just as good. The previous mentioned cost savings for pilot modification, regarding operational time and maintenance also applies here. It is however not a likely scenario, as the job the tool is set to do normally is part of a larger operation, where a drilling rig is required. The theoretical potential is however displayed in Table 17, with % cost reduction ranging from 630% to 704% and monetary savings ranging from 44,0 MNOK to 44,9 MNOK.

Table 17: NPV for pilot modification - Intervention ship were applicable

Accumulators	
NPV (NOK 1000)	kr 7 425,67

	Development	Operational	Maintenance	Total
Initial investment	639,30			639,30
Year 1		893,20	159,60	1052,80
Year 2		893,20	159,60	1052,80
Year 3		893,20	159,60	1052,80
Year 4		893,20	159,60	1052,80
Year 5		893,20	159,60	1052,80
Year 6		893,20	159,60	1052,80
Year 7		893,20	159,60	1052,80
Year 8		893,20	159,60	1052,80
Year 9		893,20	159,60	1052,80
Year 10		893,20	159,60	1052,80

Hotline Topside	
NPV (NOK 1000)	kr 8 082,39

	Development	Operational	Maintenance	Total
Initial investment	615,00			615,00
Year 1		1004,85	153,6	1158,45
Year 2		1004,85	153,6	1158,45
Year 3		1004,85	153,6	1158,45
Year 4		1004,85	153,6	1158,45
Year 5		1004,85	153,6	1158,45
Year 6		1004,85	153,6	1158,45
Year 7		1004,85	153,6	1158,45
Year 8		1004,85	153,6	1158,45
Year 9		1004,85	153,6	1158,45
Year 10		1004,85	153,6	1158,45

Hotline Subsea - ROV	
NPV (NOK 1000)	kr 8 082,39

	Development	Operational	Maintenance	Total
Initial investment	615,00			615,00
Year 1		1004,85	153,60	1158,45
Year 2		1004,85	153,60	1158,45
Year 3		1004,85	153,60	1158,45
Year 4		1004,85	153,60	1158,45
Year 5		1004,85	153,60	1158,45
Year 6		1004,85	153,60	1158,45
Year 7		1004,85	153,60	1158,45
Year 8		1004,85	153,60	1158,45
Year 9		1004,85	153,60	1158,45
Year 10		1004,85	153,60	1158,45

Hotline Subsea - Powerpack	
NPV (NOK 1000)	kr 8 300,87

	Development	Operational	Maintenance	Total
Initial investment	922,60			922,60
Year 1		949,03	195,6	1144,63
Year 2		949,03	195,6	1144,63
Year 3		949,03	195,6	1144,63
Year 4		949,03	195,6	1144,63
Year 5		949,03	195,6	1144,63
Year 6		949,03	195,6	1144,63
Year 7		949,03	195,6	1144,63
Year 8		949,03	195,6	1144,63
Year 9		949,03	195,6	1144,63
Year 10		949,03	195,6	1144,63

Current method	
NPV (NOK 1000)	kr 52 301,84

	Development	Operational	Maintenance	Total
Initial investment	0,00			0,00
Year 1		2960,24	5153,60	8113,84
Year 2		2960,24	5153,60	8113,84
Year 3		2960,24	5153,60	8113,84
Year 4		2960,24	5153,60	8113,84
Year 5		2960,24	5153,60	8113,84
Year 6		2960,24	5153,60	8113,84
Year 7		2960,24	5153,60	8113,84
Year 8		2960,24	5153,60	8113,84
Year 9		2960,24	5153,60	8113,84
Year 10		2960,24	5153,60	8113,84

Pilot - Use of intervention ship were applicable		
Concept	NPV	% cost reduction
Accumulators	kr 7 425,67	704 %
Hotline Topside	kr 8 082,39	647 %
Hotline Subsea - ROV	kr 8 082,39	647 %
Hotline Subsea - Powerpack	kr 8 300,87	630 %
Current method	kr 52 301,84	

5.6.4. Full-scale modification – Use of intervention ship were applicable

This scenario uses the same operational conditions as the previous one, and with the same full-scale modification cost impacts as in the first full-scale scenario described above. It is still an unlikely scenario, but it shows just how much these modifications can contribute with, had it been possible to only conduct the associated operations from an intervention ship. The potential % cost savings would then range from 319% to 367% and the potential monetary savings range from 77,2 MNOK to 81,8 MNOK, as seen in Table 18.

Table 18: NPV for full-scale modification - Intervention ship were applicable

Accumulators	
NPV (NOK 1000)	kr 30 689,88

	Development	Operational	Maintenance	Total
Initial investment	3544,40			3544,40
Year 1		3572,81	638,40	4211,21
Year 2		3572,81	638,40	4211,21
Year 3		3572,81	638,40	4211,21
Year 4		3572,81	638,40	4211,21
Year 5		3572,81	638,40	4211,21
Year 6		3572,81	638,40	4211,21
Year 7		3572,81	638,40	4211,21
Year 8		3572,81	638,40	4211,21
Year 9		3572,81	638,40	4211,21
Year 10		3572,81	638,40	4211,21

Hotline Topside	
NPV (NOK 1000)	kr 33 219,57

	Development	Operational	Maintenance	Total
Initial investment	3350,00			3350,00
Year 1		4019,41	614,4	4633,81
Year 2		4019,41	614,4	4633,81
Year 3		4019,41	614,4	4633,81
Year 4		4019,41	614,4	4633,81
Year 5		4019,41	614,4	4633,81
Year 6		4019,41	614,4	4633,81
Year 7		4019,41	614,4	4633,81
Year 8		4019,41	614,4	4633,81
Year 9		4019,41	614,4	4633,81
Year 10		4019,41	614,4	4633,81

Hotline Subsea - ROV	
NPV (NOK 1000)	kr 33 219,57

	Development	Operational	Maintenance	Total
Initial investment	3350,00			3350,00
Year 1		4019,41	614,40	4633,81
Year 2		4019,41	614,40	4633,81
Year 3		4019,41	614,40	4633,81
Year 4		4019,41	614,40	4633,81
Year 5		4019,41	614,40	4633,81
Year 6		4019,41	614,40	4633,81
Year 7		4019,41	614,40	4633,81
Year 8		4019,41	614,40	4633,81
Year 9		4019,41	614,40	4633,81
Year 10		4019,41	614,40	4633,81

Hotline Subsea - Powerpack	
NPV (NOK 1000)	kr 35 323,90

	Development	Operational	Maintenance	Total
Initial investment	5810,80			5810,80
Year 1		3796,11	782,4	4578,51
Year 2		3796,11	782,4	4578,51
Year 3		3796,11	782,4	4578,51
Year 4		3796,11	782,4	4578,51
Year 5		3796,11	782,4	4578,51
Year 6		3796,11	782,4	4578,51
Year 7		3796,11	782,4	4578,51
Year 8		3796,11	782,4	4578,51
Year 9		3796,11	782,4	4578,51
Year 10		3796,11	782,4	4578,51

Current method	
NPV (NOK 1000)	kr 112 517,33

	Development	Operational	Maintenance	Total
Initial investment	0,00			0,00
Year 1		11840,97	5614,40	17455,37
Year 2		11840,97	5614,40	17455,37
Year 3		11840,97	5614,40	17455,37
Year 4		11840,97	5614,40	17455,37
Year 5		11840,97	5614,40	17455,37
Year 6		11840,97	5614,40	17455,37
Year 7		11840,97	5614,40	17455,37
Year 8		11840,97	5614,40	17455,37
Year 9		11840,97	5614,40	17455,37
Year 10		11840,97	5614,40	17455,37

Full scale - Use of intervention ship were applicable		
Concept	NPV	% cost reduction
Accumulators	kr 30 689,88	367 %
Hotline Topside	kr 33 219,57	339 %
Hotline Subsea - ROV	kr 33 219,57	339 %
Hotline Subsea - Powerpack	kr 35 323,90	319 %
Current method	kr 112 517,33	

5.6.5. Pilot modification – 10% use of intervention ship were applicable

This scenario is a combination of the two other pilot scenarios described above. The idea is that in 10% of the jobs, the intervention ship relieves the drilling rigs workload. The 10% is just an educated guess of how much the opportunity of changing out the drilling rig will be used, and to display how the introduction of an intervention ship can affect the savings. This is because there is no previous experience of using this combination of both rig and ship in an HPCRT setting. The potential % cost savings range from 499% to 552% and the potential monetary savings range from 41,8 MNOK to 42,8 MNOK, as seen in Table 19.

Table 19: NPV for pilot modification - 10% intervention vessel were applicable

Accumulators	
NPV (NOK 1000)	kr 9 474,81

	Development	Operational	Maintenance	Total
Initial investment	639,30			639,30
Year 1		1211,10	159,60	1370,70
Year 2		1211,10	159,60	1370,70
Year 3		1211,10	159,60	1370,70
Year 4		1211,10	159,60	1370,70
Year 5		1211,10	159,60	1370,70
Year 6		1211,10	159,60	1370,70
Year 7		1211,10	159,60	1370,70
Year 8		1211,10	159,60	1370,70
Year 9		1211,10	159,60	1370,70
Year 10		1211,10	159,60	1370,70

Hotline Topside	
NPV (NOK 1000)	kr 10 387,67

	Development	Operational	Maintenance	Total
Initial investment	615,00			615,00
Year 1		1362,48	153,6	1516,08
Year 2		1362,48	153,6	1516,08
Year 3		1362,48	153,6	1516,08
Year 4		1362,48	153,6	1516,08
Year 5		1362,48	153,6	1516,08
Year 6		1362,48	153,6	1516,08
Year 7		1362,48	153,6	1516,08
Year 8		1362,48	153,6	1516,08
Year 9		1362,48	153,6	1516,08
Year 10		1362,48	153,6	1516,08

Hotline Subsea - ROV	
NPV (NOK 1000)	kr 10 387,67

	Development	Operational	Maintenance	Total
Initial investment	615,00			615,00
Year 1		1362,48	153,60	1516,08
Year 2		1362,48	153,60	1516,08
Year 3		1362,48	153,60	1516,08
Year 4		1362,48	153,60	1516,08
Year 5		1362,48	153,60	1516,08
Year 6		1362,48	153,60	1516,08
Year 7		1362,48	153,60	1516,08
Year 8		1362,48	153,60	1516,08
Year 9		1362,48	153,60	1516,08
Year 10		1362,48	153,60	1516,08

Hotline Subsea - Powerpack	
NPV (NOK 1000)	kr 10 478,09

	Development	Operational	Maintenance	Total
Initial investment	922,60			922,60
Year 1		1286,79	195,6	1482,39
Year 2		1286,79	195,6	1482,39
Year 3		1286,79	195,6	1482,39
Year 4		1286,79	195,6	1482,39
Year 5		1286,79	195,6	1482,39
Year 6		1286,79	195,6	1482,39
Year 7		1286,79	195,6	1482,39
Year 8		1286,79	195,6	1482,39
Year 9		1286,79	195,6	1482,39
Year 10		1286,79	195,6	1482,39

Current method	
NPV (NOK 1000)	kr 52 301,84

	Development	Operational	Maintenance	Total
Initial investment	0,00			0,00
Year 1		2960,24	5153,60	8113,84
Year 2		2960,24	5153,60	8113,84
Year 3		2960,24	5153,60	8113,84
Year 4		2960,24	5153,60	8113,84
Year 5		2960,24	5153,60	8113,84
Year 6		2960,24	5153,60	8113,84
Year 7		2960,24	5153,60	8113,84
Year 8		2960,24	5153,60	8113,84
Year 9		2960,24	5153,60	8113,84
Year 10		2960,24	5153,60	8113,84

Pilot - 10% use of intervention ship were applicable		
Concept	NPV	% cost reduction
Accumulators	kr 9 474,81	552 %
Hotline Topside	kr 10 387,67	503 %
Hotline Subsea - ROV	kr 10 387,67	503 %
Hotline Subsea - Powerpack	kr 10 478,09	499 %
Current method	kr 52 301,84	

5.6.6. Full-scale modification – 10% use of intervention ship were applicable

This scenario is basically the same as the one above in a full-scale version. The potential % cost savings range from 256% to 289% and the potential monetary savings range from 68,5 to 73,6 MNOK, as seen in table 20.

Table 20: NPV for full-scale modification - 10% intervention vessel were applicable

Accumulators	
NPV (NOK 1000)	kr 38 886,44

	Development	Operational	Maintenance	Total
Initial investment	3544,40			3544,40
Year 1		4844,38	638,40	5482,78
Year 2		4844,38	638,40	5482,78
Year 3		4844,38	638,40	5482,78
Year 4		4844,38	638,40	5482,78
Year 5		4844,38	638,40	5482,78
Year 6		4844,38	638,40	5482,78
Year 7		4844,38	638,40	5482,78
Year 8		4844,38	638,40	5482,78
Year 9		4844,38	638,40	5482,78
Year 10		4844,38	638,40	5482,78

Hotline Topside	
NPV (NOK 1000)	kr 42 440,70

	Development	Operational	Maintenance	Total
Initial investment	3350,00			3350,00
Year 1		5449,93	614,4	6064,33
Year 2		5449,93	614,4	6064,33
Year 3		5449,93	614,4	6064,33
Year 4		5449,93	614,4	6064,33
Year 5		5449,93	614,4	6064,33
Year 6		5449,93	614,4	6064,33
Year 7		5449,93	614,4	6064,33
Year 8		5449,93	614,4	6064,33
Year 9		5449,93	614,4	6064,33
Year 10		5449,93	614,4	6064,33

Hotline Subsea - ROV	
NPV (NOK 1000)	kr 42 440,70

	Development	Operational	Maintenance	Total
Initial investment	3350,00			3350,00
Year 1		5449,93	614,40	6064,33
Year 2		5449,93	614,40	6064,33
Year 3		5449,93	614,40	6064,33
Year 4		5449,93	614,40	6064,33
Year 5		5449,93	614,40	6064,33
Year 6		5449,93	614,40	6064,33
Year 7		5449,93	614,40	6064,33
Year 8		5449,93	614,40	6064,33
Year 9		5449,93	614,40	6064,33
Year 10		5449,93	614,40	6064,33

Hotline Subsea - Powerpack	
NPV (NOK 1000)	kr 44 032,75

	Development	Operational	Maintenance	Total
Initial investment	5810,80			5810,80
Year 1		5147,16	782,4	5929,56
Year 2		5147,16	782,4	5929,56
Year 3		5147,16	782,4	5929,56
Year 4		5147,16	782,4	5929,56
Year 5		5147,16	782,4	5929,56
Year 6		5147,16	782,4	5929,56
Year 7		5147,16	782,4	5929,56
Year 8		5147,16	782,4	5929,56
Year 9		5147,16	782,4	5929,56
Year 10		5147,16	782,4	5929,56

Current method	
NPV (NOK 1000)	kr 112 517,33

	Development	Operational	Maintenance	Total
Initial investment	0,00			0,00
Year 1		11840,97	5614,40	17455,37
Year 2		11840,97	5614,40	17455,37
Year 3		11840,97	5614,40	17455,37
Year 4		11840,97	5614,40	17455,37
Year 5		11840,97	5614,40	17455,37
Year 6		11840,97	5614,40	17455,37
Year 7		11840,97	5614,40	17455,37
Year 8		11840,97	5614,40	17455,37
Year 9		11840,97	5614,40	17455,37
Year 10		11840,97	5614,40	17455,37

Full scale - 10% Use of intervention ship were applicable		
Concept	NPV	% cost reduction
Accumulators	kr 38 886,44	289 %
Hotline Topside	kr 42 440,70	265 %
Hotline Subsea - ROV	kr 42 440,70	265 %
Hotline Subsea - Powerpack	kr 44 032,75	256 %
Current method	kr 112 517,33	

5.7. Pugh matrix concept analysis

5.7.1. Pre-charged accumulators

The concepts criteria scores refer to table 21 below.

Table 21: Pugh matrix with emphasis on pre-charged accumulators

	Criteria weighting	Current method	**Pre charged accumulators**	Hotline topside	Hotline Subsea - ROV	Hotline Subsea - Powerpack
Feasibility	3,37	0	**0**	0	-	0
Physical parameters	2,72	0	**0**	0	0	-
Maintainability	3,93	0	**+**	+	+	+
Reliability	4,86	0	**+**	0	0	0
Complexity in use	2,04	0	**+**	0	0	0
Economic impact	3,26	0	**+**	+	+	+
Development cost and time	2,18	0	**0**	+	+	0
Degree of risk reduction	5,11	0	**+**	+	+	+
Environmental impact	4,26	0	**+**	+	+	+
Sum concept			**23,5**	18,8	15,4	13,8

Feasibility
The accumulator concept does not introduce any new technology that poses any threats for the feasibility of the engineering in the project. It is only a new composition of existing technology. It is therefore given a score equal to the current method.

Physical parameters
The size of the modified HPCRT with attached accumulator tanks and redesigned ROV-panel does not require any significant more floor area both offshore and onshore. It is therefore scored equal to the current method.

Maintainability
One of the main challenges with the current method is the associated emergency maintenance. Even though the accumulator concept has a slightly higher need for scheduled maintenance, this disadvantage is made up for, through the elimination of the current methods frequent emergency maintenance. It is therefore scored positively compared to the current method.

Reliability
The design of the accumulator concept includes double redundancy, with the opportunity to be run from both hotline topside and the old umbilical found in the current method. Since the loss of one running option does not force the concept to be run by the old method, it is scored positively compared to the current method.

Complexity in use
The current method requires a sum of 15 technicians in order to complete one operation. With the accumulator solution, the sum adds up to 12. The accumulator solution is therefore scored positively compared to the current method.

Economic impact
With a NPV considerably lower than the current method, reducing the costs with 589% for the pilot scenario and 283% for the full-scale scenario, the accumulator concept is clearly a better option. The score is therefore positive compared to the current method.

Development cost and time
Based on the number of activities required to develop, manufacture and test the accumulator concept, it ranks third amongst the four proposed concepts. This gives it a neutral score of zero.

Degree of risk reduction
With the elimination of required work in the red zone and only one hour of exposure to pressurised equipment for the technicians, compared to 9,5 hours for the current method, the accumulator concept is given a positive score compared to the current method.

Environmental impact
The operational time required on the rig for the accumulator concept is 4 hours. Compared to the current method that requires 9,5 hours, the operational carbon footprint produced by the rig or vessel is reduced by over 50% and the concept is therefore scored positively.

5.7.2. Hotline topside

The concepts criteria scores refer to table 22 below.

Table 22: Pugh matrix with emphasis on hotline topside

	Criteria weighting	Current method	Pre charged accumulators	**Hotline topside**	Hotline Subsea - ROV	Hotline Subsea - Powerpack
Feasibility	3,37	0	0	**0**	-	0
Physical parameters	2,72	0	0	**0**	0	-
Maintainability	3,93	0	+	**+**	+	+
Reliability	4,86	0	+	**0**	0	0
Complexity in use	2,04	0	+	**0**	0	0
Economic impact	3,26	0	+	**+**	+	+
Development cost and time	2,18	0	0	**+**	+	0
Degree of risk reduction	5,11	0	+	**+**	+	+
Environmental impact	4,26	0	+	**+**	+	+
Sum concept			23,5	**18,8**	15,4	13,8

Feasibility

The hotline topside concept does not introduce any new technology that poses any threats for the feasibility of the engineering in the project. It is only a new composition of existing technology. It is therefore given a score equal to the current method.

Physical parameters

The size of the modified HPCRT with a redesigned ROV-panel and hotline connector does not require any more floor area both offshore and onshore. It is therefore scored equal to the current method.

Maintainability
Required scheduled maintenance for the hotline topside concept and the current method is exactly the same. The hotline topside concept is however not exposed for the frequent emergency maintenance found in the current method. It is therefore scored positively.

Reliability
The design of the hotline topside concept includes single redundancy. In case of hotline failure, it is reduced to function just like the current method, with the associated pitfalls that comes with. It is therefore scored equal to the current method.

Complexity in use
The current method requires a sum of 15 technicians in order to complete one operation. The same number is required for the hotline topside concept. The solution is therefore scored equal compared to the current method.

Economic impact
With a NPV considerably lower than the current method, reducing the costs with 491% for the pilot scenario and 259% for the full-scale scenario, the hotline topside concept is clearly a better option. The score is therefore positive compared to the current method.

Development cost and time
Based on the number of activities required to develop, manufacture and test the hotline topside concept, it ranks first together with the hotline subsea – ROV concept, amongst the four proposed concepts. This gives it a positive score compared to the other concepts.

Degree of risk reduction
With the elimination of required work in the red zone and only 4,5 hours of exposure to pressurised equipment for the technicians, compared to 9,5 hours for the current method, the hotline topside concept is given a positive score compared to the current method.

Environmental impact
The operational time required on the rig for the hotline topside concept is 4,5 hours. Compared to the current method that requires 9,5 hours, the operational carbon footprint produced by the rig or vessel is reduced by over 50% and the concept is therefore scored positively.

5.7.4. Hotline subsea - ROV

The concepts criteria scores refer to table 23 below.

Table 23: Pugh matrix with emphasis on hotline subsea - ROV

	Criteria weighting	Current method	Pre charged accumulators	Hotline topside	**Hotline Subsea - ROV**	Hotline Subsea - Powerpack
Feasibility	3,37	0	0	0	**-**	0
Physical parameters	2,72	0	0	0	**0**	-
Maintainability	3,93	0	+	+	**+**	+
Reliability	4,86	0	+	0	**0**	0
Complexity in use	2,04	0	+	0	**0**	0
Economic impact	3,26	0	+	+	**+**	+
Development cost and time	2,18	0	0	+	**+**	0
Degree of risk reduction	5,11	0	+	+	**+**	+
Environmental impact	4,26	0	+	+	**+**	+
Sum concept			23,5	18,8	**15,4**	13,8

Feasibility

Even though the hotline subsea – ROV concept does not introduce any new technology on the modified tool itself, it requires a different type of ROV to be operated. This ROV is not currently available on the rigs operating on the Troll field and would require a massive investment in new or modified ROVs on the five drilling rigs and the two intervention ships in order to be feasible. The concept is therefore scored negatively compared to the current method.

Physical parameters

The size of the modified HPCRT with a redesigned ROV-panel and hotline connector does not require any more floor area both offshore and onshore. It is therefore scored equal to the current method.

Maintainability
Required scheduled maintenance for the hotline subsea - ROV concept and the current method is exactly the same. The hotline topside concept is however not exposed for the frequent emergency maintenance found in the current method. It is therefore scored positively.

Reliability
The design of the hotline subsea - ROV concept includes single redundancy. In case of hotline failure, it is reduced to function just like the current method, with the associated pitfalls that comes with. It is therefore scored equal to the current method.

Complexity in use
The current method requires a sum of 15 technicians in order to complete one operation. The same number is required for the hotline subsea – ROV concept. The solution is therefore scored equal compared to the current method.

Economic impact
With a NPV considerably lower than the current method, reducing the costs with 491% for the pilot scenario and 259% for the full-scale scenario, the hotline subsea – ROV concept is clearly a better option. The score is therefore positive compared to the current method.

Development cost and time
Based on the number of activities required to develop, manufacture and test the hotline subsea – ROV concept, it ranks first together with the hotline topside concept, amongst the four proposed concepts. This gives it a positive score compared to the other concepts.

Degree of risk reduction
With the elimination of both the required work in the red zone and the exposure to pressurised equipment for the technicians, the hotline topside concept is given a positive score compared to the current method.

Environmental impact
The operational time required on the rig for the hotline subsea – ROV concept is 4,5 hours. Compared to the current method that requires 9,5 hours, the operational carbon footprint produced by the rig or vessel is reduced by over 50% and the concept is therefore scored positively.

5.7.5. Hotline subsea - Powerpack

The concepts criteria scores refer to table 24 below.

Table 24: Pugh matrix with emphasis on hotline subsea - powerpack

	Criteria weighting	Current method	Pre charged accumulators	Hotline topside	Hotline Subsea - ROV	**Hotline Subsea - Powerpack**
Feasibility	3,37	0	0	0	-	**0**
Physical parameters	2,72	0	0	0	0	**-**
Maintainability	3,93	0	+	+	+	**+**
Reliability	4,86	0	+	0	0	**0**
Complexity in use	2,04	0	+	0	0	**0**
Economic impact	3,26	0	+	+	+	**+**
Development cost and time	2,18	0	0	+	+	**0**
Degree of risk reduction	5,11	0	+	+	+	**+**
Environmental impact	4,26	0	+	+	+	**+**
Sum concept			23,5	18,8	15,4	**13,8**

Feasibility

The hotline subsea – powerpack concept does not introduce any new technology that poses any threats for the feasibility of the engineering in the project. It is only a new composition of existing technology. It is therefore given a score equal to the current method.

Physical parameters

The introduction of an external powerpack will require extra floor space both offshore and in the maintenance area onshore. As space is a scarcity, especially offshore, it is given a negative score compared to the current method.

Maintainability

Required scheduled maintenance for the hotline subsea – powerpack concept is approximately 30% higher than what is required the current method. This is due to the added powerpack module. The hotline subsea – powerpack concept is however not exposed for the frequent emergency maintenance found in the current method. It is therefore scored positively.

Reliability
The design of the hotline subsea - powerpack concept includes single redundancy. In case of hotline failure, it is reduced to function just like the current method, with the associated pitfalls that comes with. It is therefore scored equal to the current method.

Complexity in use
The current method requires a sum of 15 technicians in order to complete one operation. The same number is required for the hotline subsea – powerpack concept. The solution is therefore scored equal compared to the current method.

Economic impact
With a NPV considerably lower than the current method, reducing the costs with 488% for the pilot scenario and 250% for the full-scale scenario, the hotline subsea – powerpack concept is clearly a better option. The score is therefore positive compared to the current method.

Development cost and time
Based on the number of activities required to develop, manufacture and test the accumulator concept, it ranks fourth amongst the four proposed concepts. This gives it a neutral score of zero.

Degree of risk reduction
With the elimination of both the required work in the red zone and the exposure to pressurised equipment for the technicians, the hotline subsea – powerpack concept is given a positive score compared to the current method.

Environmental impact
The operational time required on the rig for the hotline subsea – powerpack concept is 4,25 hours. Compared to the current method that requires 9,5 hours, the operational carbon footprint produced by the rig or vessel is reduced by over 50% and the concept is therefore scored positively.

6. Discussion

As seen in the results from the pugh matrix, the pre-charged accumulators solution scores significantly better than the three other concepts and it is most definitely a better solution than the current method. These results alone are good indicators that support a scenario where the current method is replaced and the accumulator concept is chosen. It is however important to highlight nuances between the different concepts, to further reveal if the accumulator concept is the one that Aker Solutions should pursue. This is because the matrix only rates the various concepts based on their performance against the current method, and not between the concepts. This is also why the matrix is considered to be just a support tool in the decision making process. Following is a qualitative performance analysis of the pre-charged accumulator concept against the three other concepts

6.1. Criteria discussion

Feasibility
The accumulator concept is equal to the other projects when it comes to feasibility, except for the hotline subsea –ROV solution, which is worse. There is no variation in introduction of new technology between the three relevant solutions and hence no reason to choose one of the two others over the accumulator solution.

Physical parameters
The accumulator concept is more or less equal to the other concepts when it comes to physical parameters, except for the hotline subsea, which is worse. There are slight variances due to the extra hydraulic cylinders attached to the tool, but they do not cause the tool to use any extra floor space. If weight was a big issue, one could argue that one of the other solutions would be preferable. But as that is not the case, there are no good reasons to choose one over the other.

Maintainability
The accumulator concept has a 3,75% higher maintenance cost than the hotline topside and the hotline subsea – ROV concepts. This does however only sum up to an annual extra cost of 6000 NOK for the pilot modification scenario and 24000 NOK for the full-scale scenario. It is therefore not a factor that should weigh much when the total savings from the project is in the 8-digit category.

Reliability
The accumulator concept is the only concept that incorporates double independent redundancy. All other concepts rely only on the current method as the back-up solution and the accumulator concept is therefore preferred based on this criterion.

Complexity in use
The accumulator concept is the solution with the lowest complexity during offshore operations. It has the lowest need for technicians, with only 12, compared to the other concepts, which requires 15. It should therefore be the preferred concept based on this criterion.

Economic impact

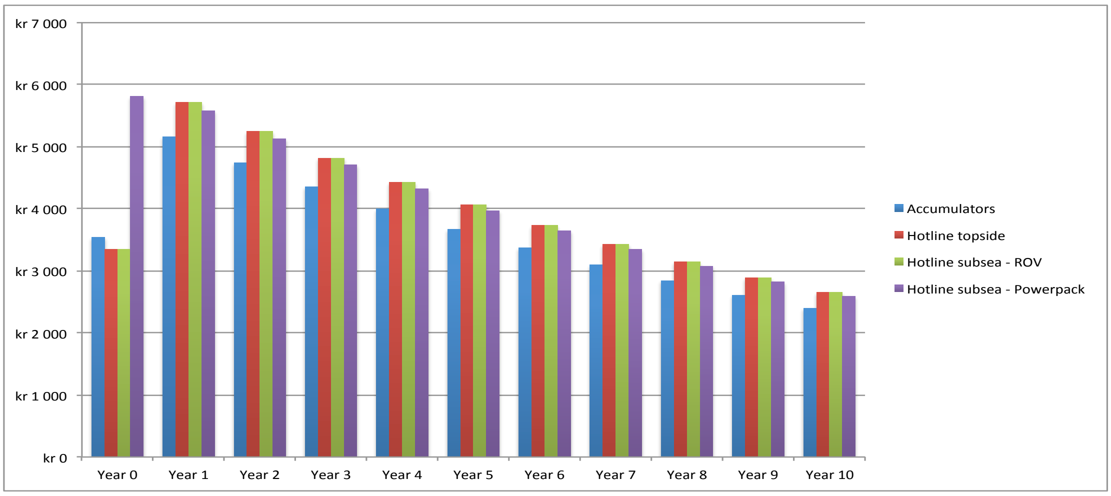

Figure10: LCC for all four proposed concepts, extracted from the full-scale – drilling rigs only scenario

As seen in figure 10 (full-scale, rigs only), the accumulator concept has the overall lowest LCC. In the full-scale modification scenario it is between 8,4% and 11,6% cheaper than the competing concepts, and generates savings of 72,7 MNOK over a 10 year period, compared to 69,1 MNOK for the second best concept. It should therefore be the preferred solution based on this criterion.

Development cost and time
The accumulator concept is a bit more expensive and time consuming to develop, than the hotline topside and the hotline subsea – ROV concepts. It amounts to approximately 24000 NOK in the pilot modification scenario and 194000 NOK in the full-scale scenario. The accumulator concept is therefore not preferable based on this criterion.

Degree of risk reduction
The accumulator is equal to all the other concepts when it comes to elimination of work in the red zone. It does however require 1 hour of work with pressurised equipment, which is better than the 4,5 hours in second best concept suggested in the pugh matrix, the hotline topside concept. The hotline subsea – ROV and hotline subsea – powerpack does however eliminate this type of work entirely and are therefore better alternatives when it comes risk reducing measures. The accumulator concept is therefore not preferable based on this criterion.

Environmental impact
The accumulator concept has the lowest operational time of all the concepts, which also means that it has the smallest carbon footprint of all the concepts. The difference is however not that much, with only 15 minutes up to the next best concept. But it does stand out as the best, and with todays focus on the environment, it is always positive to use the most eco friendly solution. The accumulator concept is therefore preferred based on this criterion.

6.2. Concept as a whole

Based on the step-by-step comparison of the pre-charged accumulator concept above, it is clear that there are many factors that are speaking for this concept as the one to choose. This is due to the facts that it has by far the best redundancy system, it is the most eco friendly solution, it has the lowest LCC and hence the highest saving potential. There is however some criteria that suggest otherwise. As standalone criteria, both maintainability and development cost and time pose arguments against pursuing this solution. They are however taken care of in the economic impact criteria, where the lower LCC more than makes up for their negative additions to the decision making process. The only innuendo against choosing this concept is the lack of eliminating work with pressurised equipment. It is possible to reduce this risk through developing a thorough procedure on how to operate the equipment. This would be recommended should this concept be chosen.

7. Conclusion

Based on the analysis of the four proposed concepts in this thesis, it is recommended that Aker Solutions Subsea choose the pre-charged accumulator concept as the modification solution of the High Pressure Cap Running Tool, as this is the best-suited solution. Compared to the current method this will potentially save Statoil 72,7 MNOK over the next 10 years. In addition it contributes to an increased rig time efficiency of 57,9%, serves as a more eco-friendly solution, severely improves the associated redundancy system and greatly reduces risks associated with operational work.

8. Future work

As listed in the limitations for the thesis, the possible synergetic opportunities are not included. It could however be interesting to see how much more Statoil can benefit from the fact that the recommended concept will free up capacity on the drilling rigs drill floor. This would raise the question of how Statoil plan parallel work offshore and require a far wider perspective when it comes to the operations that are associated with the ones described in this thesis.

References

Aftenbladet.no. (2014, April 08). Energi: Olje: Statoil vokste mens de nedbemannet. Retrieved April 10, 2014 from Aftenbladet.no: http://www.aftenbladet.no/energi/olje/Statoil-vokste-mens-de-nedbemannet-3394398.html#.U0Za-1V_tw4

Aker Solutions. (2014, January 01). About Us: History. Retrieved March 04, 2014 from Aker Solutions Web site: http://www.akersolutions.com/en/Utility-menu/About-us/History

Aker Solutions. (2014, January 01). About Us: Who we are and what we do. Retrieved March 04, 2014 from Aker Solutions Web site: http://www.akersolutions.com/en/Utility-menu/About-us/Who-we-are-and-what-we-do/

Aker Solutions. (2014). Aker Solutions Annual Report 2013. Oslo: Aker Solutions.

Aker Solutions. (2014, January 01). Technical document. Bergen, Hordaland, Norway: Aker Solutions.

Aker Solutions. (2014, March 20). Umbilical Clamp. Technical description buoyancy drillpipe to umbilical clamp . Sauda, Rogaland, Norway: Djuvik Maskinering A/S.

American Society for Quality. (2014, January 01). learn about quality: decision making tools: overview: decision matrix. Retrieved February 14, 2014 from ASQ website: http://asq.org/learn-about-quality/decision-making-tools/overview/decision-matrix.html

Angeltveit, E., & Amundsen, A. (2013). Konseptstudie for modifisering av High Pressure Cap Running Tool. Bergen: Bergen University College.

Business Dictionary. (2014, January 01). Reliability. Retrieved February 20, 2014 from Business Dictionary Web site: http://www.businessdictionary.com/definition/reliability.html

Djuvik, L. T. (2008, August 06). Subsea apprentice - Aker Solutions Subsea. (L. T. Djuvik, Interviewer)

e24.no. (2014, February 07). Energi: Statoil kutter 30 milliarder i investeringsbudsjettet. Retrieved April 10, 2014 from e24.no: http://e24.no/energi/statoil-kutter-30-milliarder-i-investeringsbudsjettet/22754539

Hofland, H. (2014, April 08). Mail correspondance. Oslo, Oslo, Norway.

B

Interviewee 19. (2014, April 03). Offshore technician. (B. Ferstad, Interviewer)

Mero, J. (2014, February 24). Specialist Engineer - Aker Solutions Subsea. (L. T. Djuvik, Interviewer)

Norwegian Petroleum Directorate. (2013). Evaluation of projects implemented on the Norwegian shelf. Stavanger: Norwegian Petroleum Directorate.

offshore.no. (2014, March 13). Nyheter: offshore.no/jobb. Retrieved April 30, 2014 from Offshore.no: http://www.offshore.no/jobbsak/60905_470_stillinger_kuttes_etter_statoil-sparing

offshore.no. (2014, January 01). Offshore data: Feltdata: Troll. Retrieved March 19, 2014 from Offshore.no: http://www.offshore.no/Prosjekter/Olje-felt-informasjon.aspx?navn=TROLL

Patton, M. Q. (2002). Qualitative research & evaluation methods (3rd edition ed.). Thousand Oaks, California, US: Sage Publications.

Pugh, S. (1996). Creating Innovative Products Using Total Design (1st Edition ed., Vol. 1). (D. Clausing, & R. Andrade, Eds.) Glasgow: Addison Wesley Longman.

Statoil. (2014, January 01). Our operations: Exploration and production: Statoi-operated fields in Norway: Troll: Troll Oil. Retrieved March 19, 2014 from Statoil Web site: http://www.statoil.com/en/OurOperations/ExplorationProd/ncs/troll/Pages/TrollOil.aspx

Statoil. (2014, January 01). Our Operations: Exploration and production: Statoil-operated fields in Norway. Retrieved April 10, 2014 from Statoil Web site: http://www.statoil.com/en/OurOperations/ExplorationProd/ncs/Pages/default.aspx

Statoil. (2014, January 01). Our operations: Future volume: Fast track. Retrieved April 10, 2014 from Statoil Web site: http://www.statoil.com/en/ouroperations/futurevolumes/fasttrack/pages/default.aspx'

Statoil. (2012, September 03). Our operations: Future volumes: Increased recovery: Oil recovery on Troll - aiming at magical IOR figures. Retrieved April 30, 2014 from Statoil Web site: http://www.statoil.com/en/ouroperations/futurevolumes/ior/pages/oljeutvinning%20p%C3%A5%20troll.aspx

Statoil. (2014, January 01). Technology & Innovation: Optimizing reservoir recovery: Well Intervention. Retrieved April 10, 2014 from Statoil Web site: http://www.statoil.com/en/TechnologyInnovation/OptimizingReservoirRecovery/WellIntervention/Pages/default.aspx