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Weight Margins and Flexibility in Offshore Rigs

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“Given for one instant an intelligence which could comprehend all the forces by which nature is animated and the respective situation of the beings who compose it – an intelligence sufficiently vast to submit these data to analysis – it would embrace in the same formula the movements of the greatest bodies of the universe and those of the lightest atom; for it, nothing would be uncertain and the future, as the past would be present to its eyes.”

A Philosophical Essay on Probabilities,
Pierre Simon marquis de Laplace,
New York, 1902

Preface

The following master thesis is written in partial fulfillment of the M.Sc. program in Marine Technology, with a focus on Marine Design and Logistics at the Department of Marine Technology (IMT) at the Norwegian University of Science and Technology (NTNU), in cooperation with Aker Solutions (AKSO). The thesis was written during the spring semester of 2013. The topic of the thesis *Weight margins and flexibility in offshore rigs* was developed in cooperation with Aker Solutions and professor Bjørn Egil Asbjørnslett at IMT.

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Tim Bjerkelund

Acknowledgment

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T.B.

Executive Summary

The subject of this paper is the use of weight margins in the design and fabrication of large offshore oilrigs. Margins are a way of increasing the freedom of choice of the designers and a method of increasing the overall flexibility and reducing risk of the project. The underlying justification of the use of margins is the riskiness of developing such a complex and technically advanced system as an oilrig.

The problem evaluated is "*What consequences does the combination of practical project management and economic models yield in the evaluation of weight margins and flexibility in the design of large offshore floating units?*" Furthermore, the theoretical background of project execution, practical experience and valuation methods are used to describe the subject in a more comprehensive manner.

The project execution models used in Aker Solutions focus on progress and change management, essentially combining the iterative and linear project execution model. Failed projects can be distinguished from successful projects, not only by the uncertainty encountered, but the ability of the project team to utilize flexibility to counter this uncertainty. Weight margins are central in this regard, but not the only tool.

Project analysis indicates that a large change in weight at a given stage yields an increased probability of large changes in the next stage. That is, change fosters further changes. Simulation, and the newsvendor model indicated that the current service level of Aker Solutions with respect to margins is close to optimum.

The total value of options held by project management is significant, although seldom utilized. Project A is an example that yielded significant savings due to optionality utilization. The Contractor has a huge incentive to further develop and value these options in the future.

Executive summary Norwegian

Temaet for denne avhandlingen er bruken av vektmarginer innen design og fabrikasjon av store flytende oljeplattformer. Bruken av marginer gir designerne økt fleksibilitet og valgfrihet i design- og byggeprosessen. Bakgrunnen for behovet for denne fleksibiliteten er risikoen og kompleksiteten som følger med designet og byggingen av så store systemer.

Problemstillingen for oppgaven er "*Hvilke konsekvenser gir kombinasjonen av praktisk prosjektgjennomføring og økonomiske modeller for evalueringen av vektmarginer og fleksibilitet i design av store offshore flytere*?" I tillegg ble den teoretiske bakgrunnen for prosjektgjennomføring, praktisk erfaringer fra prosessen og verdsettelsesmetoder brukt til å beskrive temaet på en mer helhetlig måte.

De prosjektgjennomføringsmodeller som brukes i Aker Solutions kombinerer den iterative og lineære prosjektgjennomføringsmodellen. I hvor stor grad et prosjekt er en suksess er avhengig av både endringene man møter på, men også prosjektgruppens evne til å håndtere disse endringene gjennom bruken av den latente fleksibiliteten i prosjektet. Vektmarginer er sentrale i denne forbindelse, men ikke det eneste verktøyet tilgjengelig.

Prosjektanalysen indikerer at en stor forandring i vekt ved et gitt stadium gir en økt sannsynlighet for store forandringer i det neste stadiet. Simulering og newsvendor-modellen indikerer at dagens marginnivå på prosjekter hos Aker Solutions er nær det optimale.

Verdien av opsjoner i denne typen prosjekter er betydelig, men sjelden utnyttet. Project A er et eksempel hvor utnyttelsen av opsjonene i prosjektet ga store merverdier. Kontraktørselskapet har betydelige insentiver til å videreutvikle og verdsette disse opsjonene i fremtiden.

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1. Introduction

This paper will discuss how margins are used in the design and building of large offshore oil rigs, how they influence the development of the project and their relation to the end product. For the purpose of this paper, the most relevant period is from the Front-End-Engineering-Design (FEED) and onwards. There are numerous layers to this discussion; the overall theme is how the project moves from uncertainty to certainty and from requirement to product. The immediate subsets are the flexibility and practical management of projects. Margins are per definition (Merriam-Webster, 2013) an allowance that gives the designers some freedom of choice when developing the product. This flexibility is a key part of the discussion. The practical management of projects provides a context to this discussion, and limits the scope and assures that the discussion is confined to the possibility space as defined by experienced industry professionals. The third layer is the analysis, simulations and connections between subjects that serve as a base for the discussions and conclusions provided by this paper. These include the connection between theoretical foundation and practical use of margins, estimates and project execution.

1.1. Review of state of art

The underlying riskiness of developing and delivering such a complicated system as an oilrig means that the process will be heavily affected by this risk. Miller & Lessard (Miller & Lessard, 2001) analyze this risk, such that it can be layered and assessed in its individual parts. Furthermore, Ford & Sobek (Ford & Sobek, Adapting Real Options to New Product Development by Modelling the Second Toyota Paradox, 2005) use the framework of real options to evaluate the risk and flexibility of the Toyota product development process and shows how increasing the flexibility of the process can have an advantageous effect on the result. The importance of creating a framework that can handle uncertainty in large-scale engineering projects is emphasized by Floricel & Miller (Floricel & Miller, 2001). Ford, Lander & Voyer (Ford, Lander, & Voyer, A real options approach to valuing strategic flexibility in uncertain construction projects, 2002) shows how the real options method can be utilized to increase the value of large engineering projects, despite the large early commitments required. Triantis (Triantis, 2005) discuss the willingness of managers and the methods used to value flexibility in investment decisions. Ford and Lander (Ford & Lander, Real option perceptions among project managers, 2011) tests to what extent managers are able to intuitively value flexibility. A comprehensive discussion of real options and flexibility is provided by Trigeorgis (Trigeorgis, 1996) and Boer (Boer, 2000) shows how this method can be used to close the gap between market prices and traditional valuation methods. The two requirements for successfully developing platforms according to Knudsen & Høyby (Knudsen & Høyby, 2004) is having a sufficiently defined product and the progress must be continuously measured against a set milestone plan. Birkeland et al. (Birkeland, Kviljo, Brustad, & Aasgaard, 2002) underline the importance of a hands-on follow-up strategy with regards to management of changes and the integration of suppliers and contractors in the project.

1.2. The problem

This paper seeks out to take a more broad and strategic view on the process of designing and building offshore floating units. Projects are planned, executed and evaluated in an environment with a substantial level of uncertainty, necessitating adaptability through the ability to retrieve, understand and implement new information. This is the flexibility of the project, and encompasses a great range of tools, methods and qualitative abilities, but also some quantitative measures that serve as a reference point for the overall flexibility of the projects. Weight margins are one of the quantitative measures, giving the engineers a very powerful method of managing flexibility.

The structure of the process, as described in chapter 2.1, is very important with regards to overall success of the project. With time being one of the primary cost drivers for the Company, structuring the project such that the time spent from contract to first oil is minimized, is an important competitive advantage to get the contract. This will naturally increase the risk of the project to the Contractor, so the question the industry has asked is how to cut the time while still maintaining control of cost and project risks. This profit driver has lead to developments in the way projects are structured, and the structure will be discussed as one of the primary reasons why margins are even needed.

On a more detailed level, the actual variables of the offshore engineering projects are also interesting in this regard. What are the specific factors influencing the overall structure of the rig, and to what extent do they change during the project? An important question is how the uncertainty of the information received and the estimates made an impact on the need for flexibility in general, and specifically for weight margins.

Other than the specific project parameters and structure, numerous other factors can contribute to either increase or reduce the risk. Seeing as any large engineering project is to a great extent a human endeavor of cooperation between individuals, the inter-human relations and culture is part of this discussion. Similarly, the process includes a number of stakeholders, each with their own interests, providing a context for both an industry structure discussion and the relation between individual companies.

The decision to include a certain level of weight margins must be made in the earlier phases of the project, as the implications are quite large. This also means that an overall view or strategy of what purpose they shall serve and which level of margins is optimum must be made. The author of this paper has not been able to find research discussing this very question: Why are margins needed and how large should they be?

As with most other problems, finding the optimum margins is a cost/benefit issue. There is clearly a cost to building a larger hull in order to allow for a potential increase in topside weight, and in a world where the Company requires the hull to be optimized to reduce costs, the Contractor must have a method that is able to calculate the extra value of the total project by incurring this expense. The ultimate objective of this paper is to structure the knowledge and inputs affecting the execution of projects with regards to margins, and to develop a method to evaluate and value these margins.

1.3. Problem statement

The problem statement of this thesis is:

What consequences do the combination of practical project management and economic models yield in the evaluation of weight margins and flexibility in the design of large offshore floating units?

This is shall be described in terms of the role of weight management measures, the factors that influence the outcome of the project, the modeling of the process and the consistency of the answers of the different models used.

1.4. Limits of scope

It is important to notice that the fact base (lessons learned, project development etc.) of this paper to a large extent is provided by Aker Solutions and is of a confidential character. The fact that this information is not readily provided by other industry participants makes an assessment of the general validity (as opposed to being only applicable to AKSO) of this information very challenging.

Floating offshore units have for many years been key to the exploration and development of petroleum resources off the coast of Norway. While the close relationship between the educational institutions and the oil-related companies has led to a focus on vessels relevant for petroleum development, the generic models used by educational institutions may not be useful when discussing problems in more detail. For that reason, this paper is strongly influenced by the methods used by Aker Solutions in order to develop projects, and provides context to the information presented.

Building a knowledge base of the context in which changes occurred requires a lot of conversations and discussions with people involved in the projects, this will to a large extent limit the number of projects one can get involved in. In addition, the fact that only a few of them are executed each year limits the available information.

The raw data on the weight and margin development of an assorted range of projects was attained from AKSO through weight reports produced during the projects. For Project A and Project B the complete set of weight reports were provided, while for the others only the final report. These reports are made on the basis of the amount of new information provided by and to the project. The time increment between reports is usually between one and two months, but at times larger. While time is the common increment when measuring volatility, the fact that the reports are based on the amount of information received a structure with report number being the increment is more relevant.

1.5. Importance of subject

While margins are a common feature of in most engineering, certain aspects are not often discussed and perhaps not fully understood. The aim of this paper is to fill out some of the blanks: How margins are applied, used and how this relates to their theoretical valuation. Combining the experience of industry professionals with theory will contribute to the industry being able to make better decisions on this matter in the future and encourage further discussion and development of the subject.

1.6. Structure of paper

As the execution of projects like designing and building offshore floating units are immensely complex, the number of factors influencing the process is large. In its essence, this paper can be divided into three parts; the practical and theoretical foundation of the process of constructing an offshore floating unit, the economic theory describing flexibility in monetary terms and the merging of these two in an analysis. The economic theory presented in this paper is very versatile, and must be understood and applied in a context, in this case the process of designing rigs.

In order to provide some context and a fundament to understand project execution, this paper starts out with discussing different ways to model projects: Both on the subject of project execution and how the margins fit into the process. Furthermore, floating offshore units have some specific features; making it important to briefly introduce some facts and to discuss what effect they have on margins.

The process of producing good estimates for the overall project is normally integral to the important early phases of a project. The different philosophies, along with a discussion of their suitability and effect on project success follow in chapter 2.3. Chapter 2.4 uses economic models to describe margins as flexibility in monetary terms.

Performing the analysis of such a multifaceted subject is only possible if approached in multiple ways, each illuminating a new aspect of the subject. The initial task performed was to evaluate the projects themselves and learn from the experiences of the participants and structure that in an organized way, this can be found in chapter 3.1 and 3.2. The human nature of project execution has, however, lead to the application of this information and these considerations throughout the analysis of the project. This chapter also includes some of the raw data attained from AKSO, the full background material can be found in the appendix.

Statistical analysis and simulations were used to evaluate the general development and visualize the effects of weight volatility on the final results and spread of these in chapter 4. The results served both as an initial basis for discussion with AKSO employees, but also later on to compare different methods.

The implications of the relationships between project participants, the weight development of previous projects and requirements, internal and external, were used to answer the main problem of chapter 5. What is the appropriate level of margins, given the available information? In this paper, three methods are used to illuminate different aspects of this discussion. The newsvendor model is a quantitative way of estimating the optimum service level, a more empirical method is utilized through the use of a DTA, and finally the real options analysis is used as third method.

The results of the paper are presented in chapter 5, with a discussion in chapter 6 and a conclusion in chapter 7.

1.7. Abbreviations and glossary

50/50	– A value which is given with a 50% probability on the upside and 50% on the downside
AKSO	– Aker Solutions ASA
BM	– Distance between the center of buoyancy and the metacenter
CoG	– Center of gravity
Company	– The company that orders the rig
Contractor	– The company with the responsibility to design and build the rig according to and EPC/EPCH contract
DTA	– Decision tree analysis
EPC(H)	– Engineering, Procurement and Construction (and Hook-up)
FEED	– Front End Engineering and Design
GM	– Distance between the center of gravity and the metacenter
KB	– Distance between the keel and the center of buoyancy
KG	– Distance between the keel and the center of gravity
MEL	– Master Equipment List
MTO	– Material Take Of, list of materials required to build a design, used, amongst others, to estimate weight of an item
NPV	– Net Present Value
RO	– Real Option
ROV	– Real Option Valuation
VO	– Variance Order, a change accepted by Contractor, imposed by Company

2. Theoretical background

The theoretical background consists of four parts: How projects are structured both in theory and practice (chapter 2.1), what aspects are particular to floating units (chapter 2.2), the initial estimation process (chapter 2.3) and finally how economic models can be utilized to value flexibility (chapter 2.4). The last chapter must be read in conjunction with the first three, as the theories are nothing more than mathematical relationships without the context. The practical experiences described in this chapter have its origin with AKSO and has been reviewed by Anders M. Moe (Moe, 2013) of AKSO.

2.1. Project execution models

A number of models have been developed and used with the aim of improving the execution of projects; making them more transparent and easier to manage. The specifics of any one project are often of such an importance, that minor changes have to be made to suit the problem at hand, but overall similar projects are executed using the same framework. Regardless of these complications, the models are still valid tools used to enlighten certain aspects of the project. The two main ways of modeling such a process is through an iterative model and a linear model.

2.1.1. Iterative model

Using an iterative model as a framework for a design project is based on the fact that the design effort rarely is a single task, but a process where information is continuously implemented. This requires rework, adjustments and a number of iterations. Evans defined already in 1959 a model that incorporated the iterations into a graphical representation where the project is continuously modified, while converging to the final solution (Hagen, 1993).

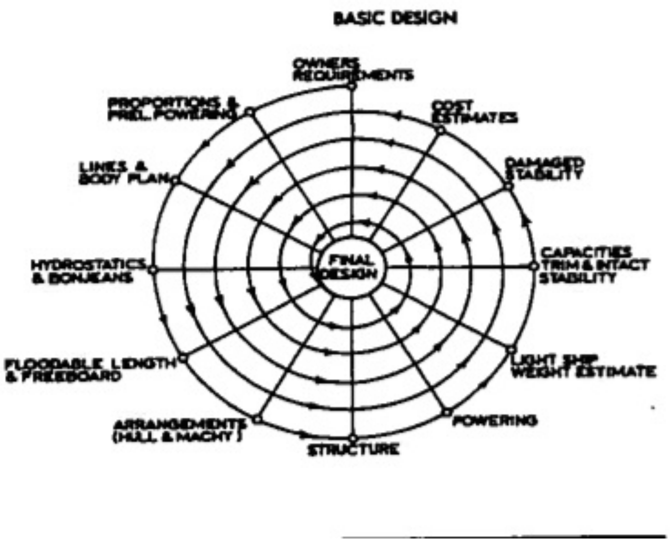

Figure 1 – Iterative project execution model

The original model is was intended for ship design, and while the differences between ships built in the 50s and 60s and modern semisubmersible offshore rigs are quite substantial, the model is commonly used and is applicable given some adjustments.

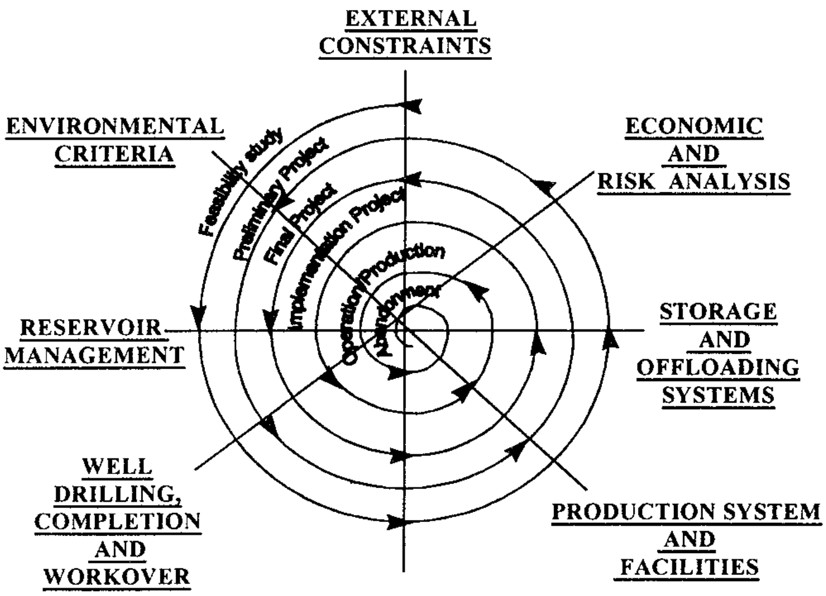

Figure 2 – Oilfield development process

A revised model shown in figure 2 (Morooka & Galeano, 1999) is constructed to suit an oilfield development process, making it a good guideline for the process of designing an offshore production unit.

2.1.2. Linear model

While the classic circle of the iterative process is much used, and useful in terms of explaining the iterative process of project execution, a linear graphical representation is better to show how the project progresses. The figure below (Knudsen & Høyby, 2004) shows a simplified version of the project execution model used by Aker Solutions. It shows an overview of the phases and stages involved in the design and building of an offshore platform.

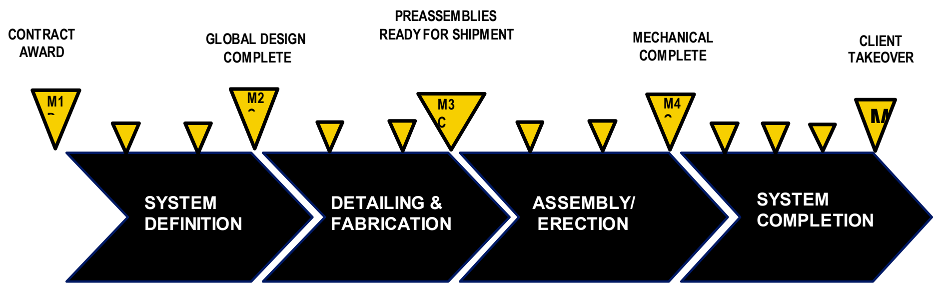

Figure 3 – Simplified linear model Aker Solutions

The first process is called "System Definition". It is supposed to refine the concept developed previously in the FEED through more detailed layout plans and provide some global design engineering. The layout and main structure of the rig are frozen in this phase. At this point, there is still a lot of cross-discipline work done.

Moving over to the "Detailing & Fabrication" the number of specialized single-discipline-engineers have increased. At this phase, the individual solutions are developed for each section and system of the rig, and include the process from detailed design to fabrication of components.

"Assembly / Erection" is the third phase, finalizing the building of the unit. Assembly of components and mechanical completion are key aspects of the third phase. The engineering work from the EPC contractor has at this point been reduced to follow-up.

The final phase is "System Completion", which includes the processes going from commissioning to Close-Out.

A more detailed description of these processes can also be found in Knudsen & Høyby. One important reason why linear models are suitable for managing the overall progress of the execution of platform projects is the time aspect; most projects are schedule driven (Knudsen & Høyby, 2004).

2.1.3. Integrated projects

The main reason why margins are needed at all is because of the way projects are executed, not the complexity of the task at hand. It is intuitive that if each phase of the project is executed completely before the next is started, as was the model in the 1980s, the need for flexibility is very small (Kaasen, et al., 1999). According to AKSO employees, experienced professionals executing projects similar to ones previously completed, will encounter very few problems due to their said experience. The need for flexibility has its origin in the integrated project structure used today; as opposed to the linear model outlined previously, the projects are executed with a number of parallel processes that interact, thereby creating a riskier situation, which in return is compensated for by requiring additional flexibility.

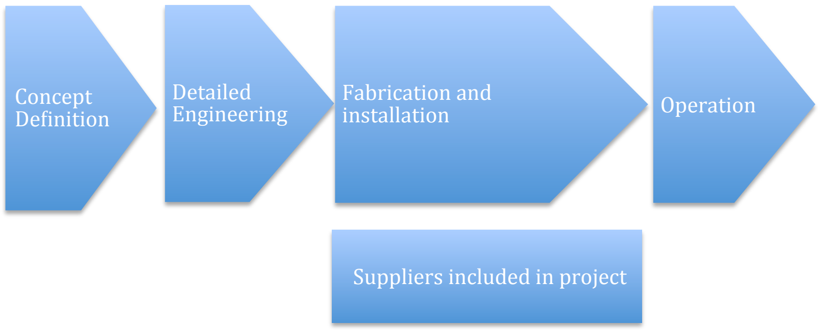

Figure 4 – Old Project Execution Model

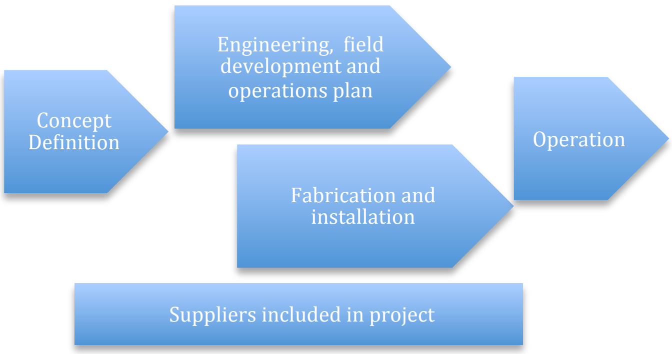

Figure 5 - New Project Execution Model

This is also clear from the actual models used, where different processes are grouped. Consequently, progress and interrelations can be monitored. Reducing time to first production is an important motivation for reducing the completion time of the project. For an oilfield, a year delay in startup gives an obvious reduction in the net present value, which has to be weighed against the increased costs and risks of accelerating the project. As the new normal is shorter, integrated projects, the industry conclusion seems to be that it is worth the risk.

The conceptual difference between a purely linear project execution model and a more integrated one is the amount of information required to proceed to the next phase. The Project Execution model used in AKSO today is in this paper categorized as an integrated project model, as the information required to proceed to the next phase is on a higher level and there is a presence of uncertainty in the information used. This makes the integrated model a combination of the schedule-driven linear model and the rework-driven iterative model. A key question in this regard is what information is important to have at each stage. Projects are managed using milestone plan where important processes are to be completed for each of these stages, similarly certain information needs to be "frozen" in order to secure proper progress in the project. These two define the main project parameters as the internal and external factors; the work performed (internal) and the information/input received (external).

2.1.4. Margins

The project execution structure is dependent on a certain level of flexibility. While 3D-tools have allowed designers to construct and plan the building of these units to a very high level of accuracy, the methods are not without fault, and the uncertainty require some freedom of choice at every level from designer to welder in order to complete the product successfully. In the broadest meaning of the word, margins mean flexibility; to allow for changes in input without needing to change the overall structure. This explains why margins are relevant as the project progresses; the margins applied early on, are continuously transferred, reapplied and consumed. The transfer of margins is not obvious unless one looks at the detailed way that estimations are performed in projects. This is discussed in more detail in chapter 2.3, *Estimation*. The margins are also used as a management tool; it is a single number that all project participants can relate to, which describes how the project is progressing or if resizing is necessary to give the rig the required capabilities.

2.2. Characteristics of floating units

The process of designing and building large objects, whether on land or offshore is complex and challenging. However some complications, impacting both design and construction, are specific to offshore floating units.

One of the interesting facts about floating units is that, at the time of design, the team might not know where the unit is supposed to operate during its lifetime. A number of drilling, but also production units, are designed and built to be able to operate at a number of locations across the globe. In many of these locations, the weather is a key issue. The level of severity of the weather combined with the salt and the operational requirements could make the solutions very complicated for offshore units compared with onshore engineering projects. In addition, they are often far from infrastructure, meaning that each unit must be operational in any condition, and include systems, equipment and people that can handle virtually any contingency or failure without risking the safety of the crew.

Any rig will, due to its individual characteristics, have a different costs and weight relations between hull and topside. Still, a general rule of thumb (Laukeland, 2013) is that a 1000 tonne increase in topside weight leads to a 500 tonne increase in hull weight for a North Sea semi submersible. The weight cost effect is approximately 500,000 NOK per tonne on the topside and 100,000 NOK per tonne on the hull. It is crucial to note though, that these are the marginal effects on the overall cost and weight of the vessel. As will be discussed more in detail later, these numbers are not accurate for late changes and changes were a weight budget overrun is incurred.

2.2.1. Design Basis

As any other large object built today, floating units are subject to a wide range of requirements that serves as a fundament for developing the design basis. These requirements can, for the purpose of this thesis, be divided into four categories:

- Functional requirements
- Safety requirements
- Environmental requirements
- Regulatory requirements

While they might seem to be very distinct, there is considerable overlap between these categories of requirements. In general, however, they can be defined as follows: Functional requirements entail everything that is needed to perform the operation, safety requirements include everything that is needed to ensure the health and safety of the employees involved, environmental requirements ensures that the effect on the local and global environment is minimized and regulatory requirements includes all the additional requirements that are not covered by the previous categories.

The functional requirements are the most interesting during the initial phase (D'Souza & Basu, 2011). Important to the discussion is what equipment and capabilities to include; extra equipment to improve production will lead to higher weight, not just through the equipment, but also through extra power generation capabilities and potentially higher manning requirements, to mention some.

When the broad functional requirements are frozen, the work can move focus into detailing the very solutions discussed in the previous paragraph. D'Souza & Basu group the rig into five major functional areas and explains further:

- *Process (manifold, separation, compression, treatment and export)*
- *Well bay and drilling rig*

- *Drilling (mud pits, pumps, bulk mud and cement)*
- *Power generation and distribution*
- *Quarters and utilities*

The first three are classified as hazardous areas because of the presence of unstable hydrocarbons, while the latter two are non-hazardous or "safe" areas.

This is the general division used on rigs, both in terms of how you separate the tasks of the rig, but also from an area perspective; the hazardous/non-hazardous classification has the effect that the functional areas are very much confined. The same paper includes an overview drawing of a typical production TLP (D'Souza & Basu, 2011):

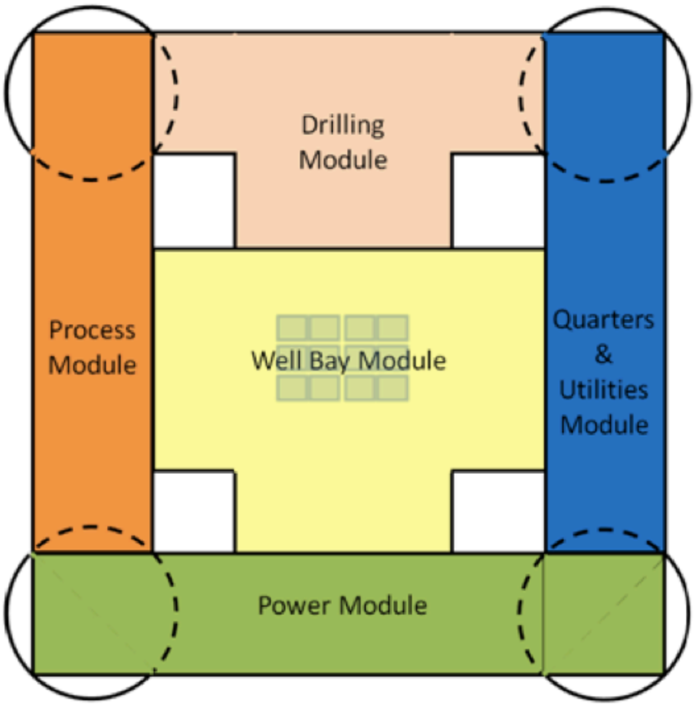

Figure 6 – Typical area distribution TLP

The same kind of setup can be found on other semisubmersibles, both Aker and non-Aker designs, in this case a drilling rig:

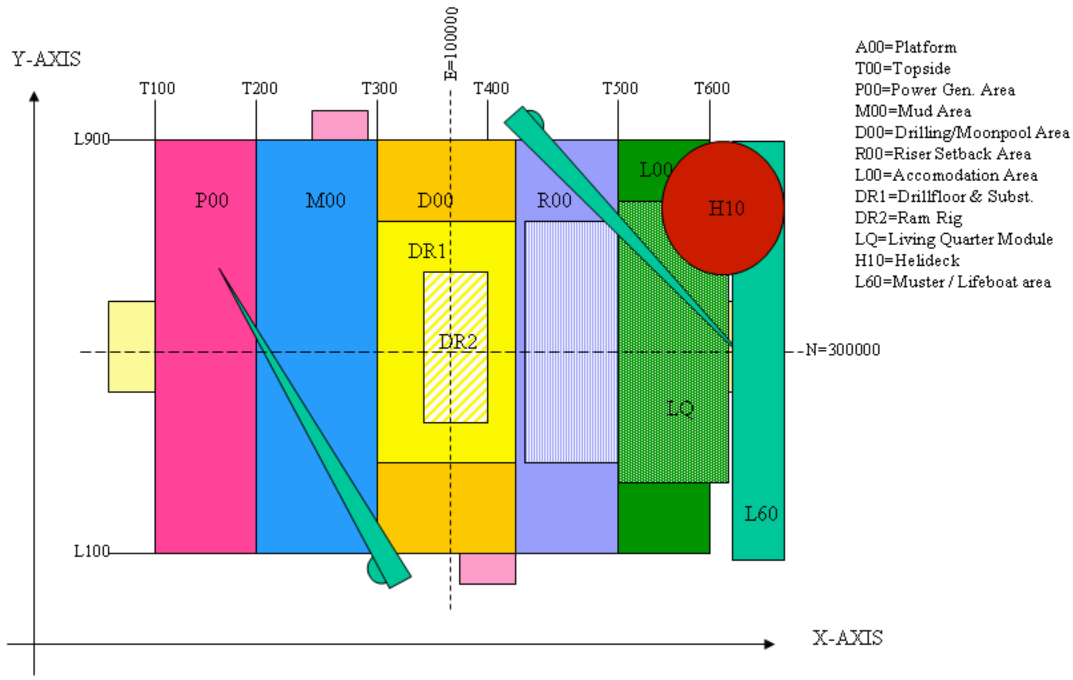

Figure 7 – Area distribution drilling rig

For production units, the process is the main driver of all other requirements of the rig (Aas-Jacobsen, 2013). This can be traced back to the primary objective of the rig: To retrieve, process and export the oil and gas. In practice this means that it is the process engineers who set many of the requirements that others in the project group have to comply with. These are based on a set of requirements provided by the Company. A distinct difference in philosophy exists between the different areas of responsibility within a project; the process unit is very much made to the exact specifications set by the Company. Furthermore, not all the information and the uncertainty of it is known to the process team, making them to some extent unable to plan for future changes and the work more specification driven. As a contrast, the engineers working on the hull are able to take a step back and assess the situation in more general terms; the decision process is more driven by the perceived risks of future changes in requirements. Another factor is the discontinuities of process engineering that could impact the other disciplines:

In order to be able to export the oil, a compressor train, that is multiple compressors placed in serial, is used to increase pressure. A train will have a *given maximum export rate which, if exceeded, means that multiple trains have to be used. This means that only a small percentage change in export capacity could lead to, in this case, a doubling of size and weight of some of the equipment* (Aas-Jacobsen, 2013).

This small change leading to a doubling of the component size is a good example of the discontinuous effects of changes made to the design.

2.2.2. Stability, weight and layout

One of the main limiting factors of any floating unit is how it performs in terms of movements and stability. The eigenperiod in heave must be above 22 seconds and the GM of the unit must be within a certain range in any load condition. This connects the weight of the unit, its center of gravity and the shape of the hull. The initial stability of the vessel can be determined by using the classical formula (Amdahl, et al., 2003):

$$GM = KB + BM - KG$$

Where the BM is the key connector between motion characteristics and stability: BM is defined as the second area moment of inertia of the water plane area divided by displacement, and motion characteristics are adversely affected by increased water plane area. The most efficient way to increase stability while keeping the motion characteristics acceptable is to move this area further away from the center of the vessel. For more information, please refer to (Amdahl, et al., 2003).

As the area of topside increases, relative to the size of the hull, the bending moments on the topside structure and topside/hull interface increases. From a structural perspective, this cannot exceed a certain level, imposing a maximum deck footprint on the topside (D'Souza & Basu, 2011). This will limit both the size and weight of the topside relative to the hull. For any floating vessel, having to adjust the hull to allow for larger topside would mean having to increase stability to compensate for the increase in center of gravity. The configuration for a semisubmersible can be adapted by, as previously explained, moving the columns further away from the center. For a spar or TLP-platform, this is often a lot more complicated, for the TLP, it is the introduction of the tension legs that include a third factor to consider, while for the spar the flexibility of the design is constrained by the concept: Increasing the diameter of the hull will lead to more problematic heave motions, which can only be compensated for by changing the length or dimensioning of the substructure, which can be very complicated and expensive.

The spar has the additional complication of the layout being hard to compile even before changes are made. For the same level of payload, the semisubmersible will have a larger area available, about 50-60% more than for the spar (D'Souza & Basu, 2011). This will naturally make it more complicated to distribute the five functional areas, especially with respect to the distance between hazardous and non-hazardous areas.

When trying to evaluate these numbers individually, it is very hard to determine which one limits the design of the vessel. As a consequence, a normal way to connect these is to assume that the center of gravity for the remaining margin is positioned a couple of meters above the first deck. In the case of the Project C platform the center of gravity for the margins are positioned four meters above the first deck. This assumption connects the weight of the overall unit with the stability, and the project team has a single number to relate to when discussing how close the rig is to its operational limit. Regardless of the type of project, this allows for a common understanding of the available flexibility, regardless of the type of project.

As some margins usually are included on the heave motion of the vessel, instead of moving the columns further away from the center their size can be increased to improve stability. For reasonably small improvements in stability, this increase in can be accomplished by adding a smaller module to the columns in the waterline. These are called sponsons, and adding them is the usual solution when stability unexpectedly has to be improved at a late stage of the project (typically after start of construction).

2.2.3. Industry structure considerations

As a result of the scale and structure of the projects in later years, the number of companies involved in the design and building process of rigs is very high. As a general assumption of this paper, the structure has been simplified to a structure where there is one EPCH contractor (Contractor) responsible for executing the order and requirements of the customer (Company) for a lump sum of money. In addition, any considerations of value created or destroyed are seen as an overall effect on the project, thereby ignoring the relationship and distribution of this effect between the Company and Contractor. This allows for a discussion of how to create value to the overall project, rather than contract and relationship specific aspects. The structure creates incentives that are not fully aligned; the Contractor tries to build as cheaply as possible, while the Company continuously tries to refine their requirements to increase the value of the oilfield they want to exploit. In reality, the picture is a lot more complex, but a few important factors are important to understand the relation between the Company and Contractor and how this affects the margins of said Contractor. While the cooperation between Company and Contractor can be very close, the full assessments, information and priorities of the Company are seldom clear to the Contractor (Laukeland, 2013).

The hull engineers try to compensate for all changes made on the rig, both uncertainties in their estimates and future changes. The cost, however, of preparing for future changes will fall on the Contractor, while the benefits are given to the Company. This is one of the reasons why each of these two parties operates with their own margin that the other is not supposed to adversely affect. There is also the added factor that the Company usually reserves some extra capacity to be able to install more equipment or other refits on the rig over its lifetime.

The nature of the margins is as a consequence different; the Contractors margin is a contingency that Contractor does not plan to consume, while the Company margin is supposed to be consumed at some point, either during the design and building phase or later in its lifetime.

The norm of contract structures and the cooperation between the companies are a continuously changing aspect of the business. How the contracts between the parties are structured may seem like a commercial aspect of a project, not a key influence on the engineering, and therefore the margins. The incentive structures created are, however important determinants for whether the project management is able to keep the weight within allowed margins. According to Kaasen et al. in the 1980s the normal project structure in Norway was that of an oil company doing most of the project management, ordering engineering and fabrication of the products they wanted. This developed further into a more integrated approach in the 1990s where the oil company, instead of demanding certain technical specifications, imposed more functional and performance based requirements to a single actor, which then had the task of developing the final product through sub suppliers. Today, the picture has again changed, but more towards that of the 1980s; the oil company play a key role in managing the process, but the players are more integrated than ever before. Employment of each other's personnel is used to create project teams where the Company people are working next to the Contractors people, thereby creating a more integrated organism where the interfaces between the companies are purposely blurred. These structures are created to reduce the risks and improve the flexibility of the overall project, thereby improving the flow of the project, and reducing the need for flexibility and margins.

2.3. Estimation process

Key to the outcome of a project is the ability of the project team to make good estimates early on in the process. The reason for this is that it minimizes rework as the project progresses. Virtually all components on the rig are in some way connected, meaning that a revised estimate of the size or weight of a component would propagate throughout the unit.

Weight, area and volume are the three most important data points of the different sections of the rig in the early phase. These are to a large extent determined by using historical data from previous projects. There are conceptually two approaches as to how this data can be utilized: As a bottom-up estimate or as a top-down estimate. Where the bottom-up estimate is based on component data, summed up and given a percentage allowance, the top-down approach use the historical data of sections of previous rigs to come up with an estimated final weight. While the former option seems more precise at first glance, according to Aker employees it fails to provide accurate estimates due to the enormous number of components involved. For this reason, this paper will use the top-down approach as a basis for discussion.

2.3.1. Initial Estimate

Making early and accurate estimates are very important in order to successfully design and fabricate a rig. From a financial point of view, it is obvious: Make a too low estimate and you will lose money, make a too high estimate and someone else will get the contract. In terms of engineering, the picture is a bit more complex, but the key issue is that changes made to a project at a later stage is complicated to implement and can create delays and problems. Therefore it is important to create a foundation that is close to the optimum, while also being robust enough to handle changes and miscalculations. Some important aspects of this work include estimating the topside and hull weights and area requirement for the different modules of the topside. Broadly speaking, this information constrains the future engineering, as it is the foundation of all future requirements. This process is often referred to as the Front-End-Engineering and Design (FEED) phase.

More in detail, the FEED is used to define the functional requirements, overall solutions and layout of the rig. These three parts are essential to the further progress of the project; it was repeatedly underlined during meetings with AKSO employees that “maturing the FEED-process” is key to getting good results throughout project (Sommerseth, 2013). As all these factors are connected, changing one of them will impose large changes for other areas as well; naturally it is very important to settle these factors so that changes in the design does not propagate excessively throughout the rig. To illustrate this, the overall layout of the rig is an important factor for all disciplines and sections of the rig. Decreasing the available area for e.g. the drilling area would require additional engineering work on the drilling area, but it would also propagate to adjacent areas, as they could be connected by piping and utilities. The area distributed to each section is also important because it can be used to estimate the weight of the area, influencing the hull design, as can be seen in figure 7.

As in the financial management most organizations and projects, budgeting is used to control the weight of the unit. As a final part of the FEED, a weight estimate is developed to find the probable final weight. This estimate is based on historical data, developed as a top-down estimate.

The key items and groundwork laid by the FEED is the layout and functional requirements of the unit. Changing any of these would increase the workload and create unpredictable consequences later on in the project. The way to counteract such problems and changes is to include some leeway in the initial calculations. Extra area and weight capacity is included to compensate for the different types of challenges that project teams always face in this type of projects: Normal project growth (known unknown), future company margin (known known) and a contractors margin (unknown unknowns).

The normal project growth margin is included in the FEED-budget, and this margin is expected to be consumed. Five percent is roughly where AKSO are in terms of average weight growth. Future company margin is an allowance included in the estimates to prepare the rig for additional equipment that the rig owner might want to install in the future. Any changes, or variance orders (VOs), that the owner requests from contract signing to vessel delivery, would usually be subtracted from this margin, but this is a contractual as well as practical issue. Contractors margin is the most challenging factor, as it firstly is not supposed to be consumed; it is a contingency. This makes it ambiguous in terms of purpose, and uncertain in terms of cost and benefit. A contractor margin of about 10% of the operational weight is usually included to reduce the impact of unforeseen changes. There is, however a very human component to this discussion, as was underlined by Aker employees. Large margins make the project teams more prone to lessen their focus in terms of weight control, while small margins have the opposite effect. High margins may consequently be a driver of increased weight, and thereby defying the purpose and increasing the costs.

Any generic description of the estimation process would be incomplete when compared with current and former projects, as the individual characteristics are highly influential on the process. A few of these aspects can be identified; experience and relationship are two of them. The experience of all stakeholders involved is very important; an inexperienced Company that is not able to fully define their functional requirements creates complications for the Contractor in the FEED phase and later on, as it may not be quite certain of what it wants. An insufficient focus on the FEED in general can also be a consequence of lack of experience. This has been a source of late changes in previous projects (Sommerseth, 2013). Additionally the relationship between the Company and the Contractor is highly influential; the Company usually has comparable data for previous projects in terms of cost, size weight and time to delivery, submitting estimates that fall outside or close to the limit of the expected range of these values will not be accepted unless the Company is certain that the Contractor possess a high level of knowledge on this area.

2.3.2. Revising – Going through the process

As outlined in the previous part of this paper, the process of designing a rig consists of numerous revisions and refinements of the concept. By its very nature, this is how projects are usually realized, but there are also a couple of outside factors that increase the need for a continuous revision of the concept. An obvious one is whenever solutions that were thought to be possible are not. Any non-standard project will experience this occurring to some degree, and it could fall under both Contractors margin and "normal project growth", depending on the project. The same applies for revised information from suppliers; information become more certain as the project progresses to its end, but the final weight of the components are not known until they have been weighted and installed.

The company margin is in theory, not very relevant for the design and building process. This is however subject to the owner not revising their requirements, which in reality is not realistic. Therefore, some of the company margin is consumed in the project. There is a strong connection between the number, size and timing of company changes and overall ability of the contractor to hit the weight budget target. Any changes from the original plan will adversely affect the ability of the contractor to reach their weight target and also complicate establishing the full effect of the changes. Adding to that, the process of estimating the cost, layout and weight effect of changes is complicated and uncertain (more so than the initial estimate), the discussion between the company and contractor as to how to distribute the weight, and in effect the costs, of these changes between company and contractor margin becomes very difficult. These propagating issues are major vulnerability of the process, and the reason behind many loss-making projects.

There are some factors to consider when trying to understand how weight increases propagate. Any equipment must have a fundament and probably some supplies. This means deck steel and bulks. According to AKSO-employees, and AKSO weight reports, equipment count for about 25% of the overall weight of a rig; consequently the AKSO-employees use a factor of 4-5 when they estimate the total effect of an extra unit of equipment weight. This must, however, be used in context. As long as the layout of the unit doesn't change much, factors like this can be used with some level of accuracy. If, on the other hand the layout change in a major fashion, they are not accurate, as the project process would have to be moved backwards to the layout stage and new overall weight estimates have to be made.

Controlling the weight development of the rig is important in order to know how the project has developed compared to the budget, and if adjustments have to be made. Weighing the equipment installed and the different sub-sections makes it possible to calculate the final weight of the rig. Moving from a pure top-down estimate to a measured ("as-built") weight of the unit, must however, involve a process where one gradually moves from one type to the other. This means that the top-down approach has to be such that it can be combined with revised supplier data, to create more accurate estimates as to the total weight of the unit. This combination is clearly shown in a weight report from the project, shown in the graph below:

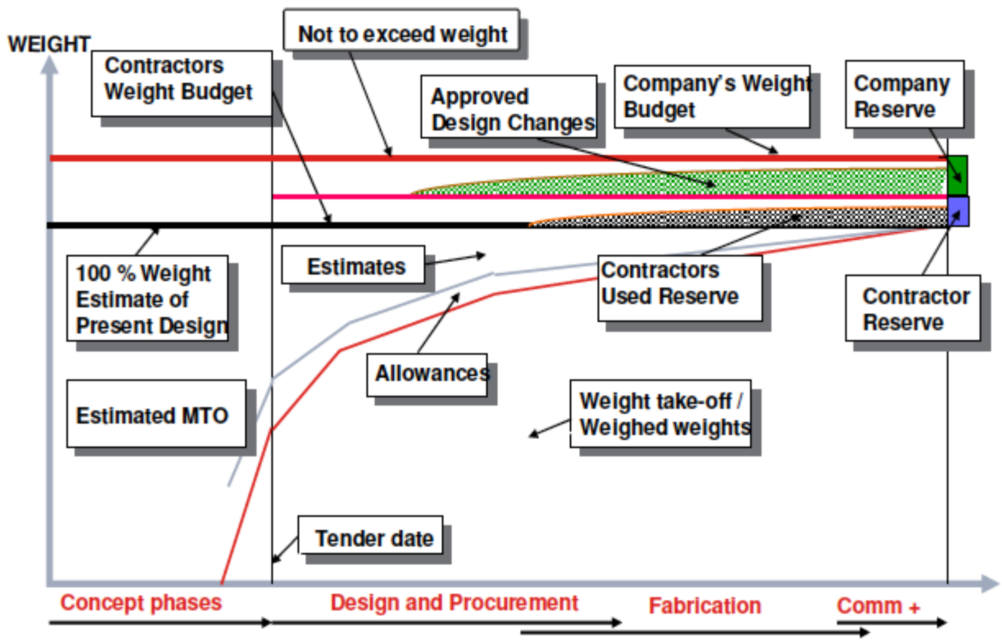

Figure 8 - AKSO weight development structure

In this transition period, the previous estimates are used on the sections, equipment and areas where the data in not known yet. Where the manufacturer has supplied data (included in the MEL) to some extent, this is included along with an allowance to compensate for the uncertainty of and the equipment not included in the estimate. These allowances are naturally connected to which stage the project (or sub sections) has reached, as the uncertainty decreases and level of knowledge increase throughout the project.

2.3.3. Weight control – a non-Aker Solutions example

To show that the process outlined earlier is not purely an Aker Solutions phenomenon, an example is included from the 1984 Offshore Technology Conference. K.P. Caveny (Boeing Engineering Co. Intl. Inc.) and P.R. Marquez Jr. (Conoco Ltd.) presented a paper describing a process very close to the one used by Aker Solutions, and with conclusions corresponding to statements made by Aker Solutions employees during interviews (Caveny & Marquez Jr., 1984).

While semisubmersibles are quite robust in terms of weight, thereby allowing large margins of error, the design of a tension leg platform (TLP) is much more sensitive to changes in weight. This means that the margins have to be smaller, and the weight control that much more rigid, which makes for an interesting case when discussing weight margins. The reason for its sensitivity is the tether tension, which must stay within a certain range regardless of weather conditions.

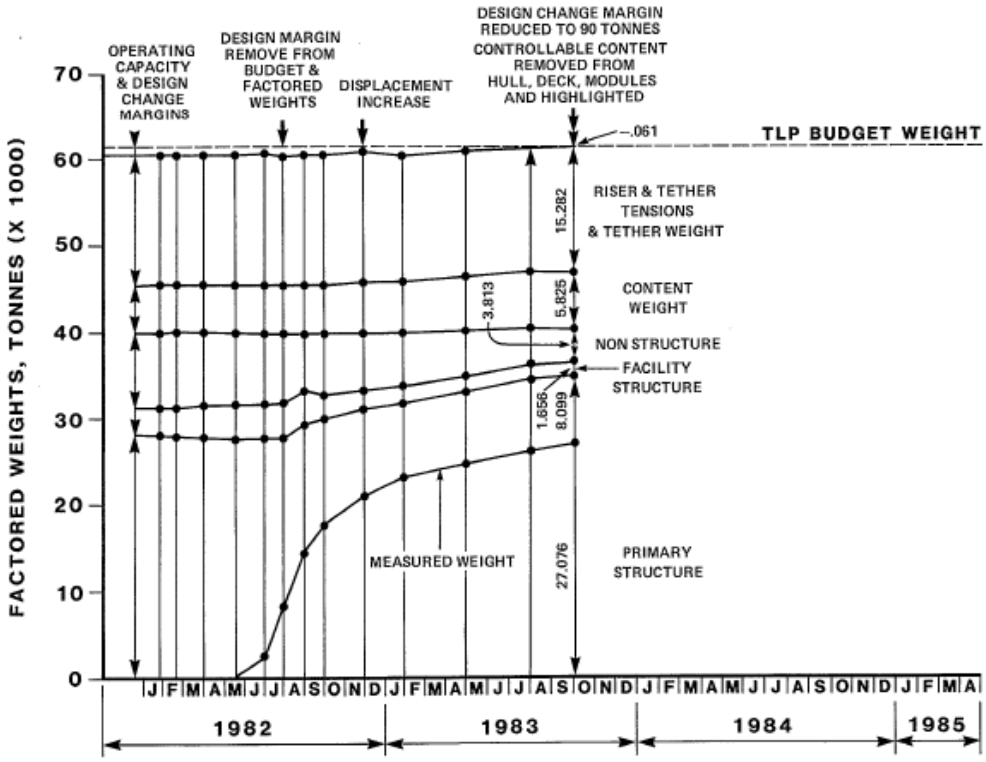

Figure 9 - Weight graph taken from (Caveny & Marquez Jr., 1984)

The graph above shows how the weight of the unit developed throughout the project, including the transition from calculated to measured weight on the primary structure. While small, the margin relative to the weight budget can be seen on top.

Quote from the Caveny & Marquez report:

> *It was recognized that any preliminary weight data would grow due to foreseeable influences and, therefore, percentage factors were applied to the initial and subsequent data base weights. These allowances, or margins, were not intended to cover errors or inaccuracies.*

The previous quote describes what is called normal project growth in this paper. As weight sensitivity is high, the project team would want to keep the contingency margins as small as possible, while still serving their purpose as a hedge against weight growth and uncertainties. This is where the technical aspect of estimating weights and applying margins intersects with practical project management. Keeping these margins small is possible, as shown by this and other projects with a big focus on weight by simply communicating the scarcity of flexibility. Another important issue is which components get the most attention; according to the report equipment over 4 tonnes contributed to 85% of the equipment weight, making the importance of these few key components essential when addressing both overall weight and margins in particular.

2.4. Flexibility

As previously stated, margins can be seen as way of implementing flexibility in the project. Additional weight capacity makes the possibility space less constrained, potentially improving the final solution. While the relationship is quite obvious, the direct connection might not be as evident due to the generic nature of the statement. One very specific example on this matter is taken from Project A and is written as a summary of a longer conversation with AKSO employee Terje Nymoen (Nymoen, 2013):

> *During the detailed engineering phase of Project A, it became increasingly likely that sponsons would have to be added to the hull in order to achieve the required weight capacity of the unit. The decision was not yet made to include these, but the design of the hull was prepared such that sponson "modules" could be easily added at a later stage. These changes included changing some dimensions and weld types, increasing the amount of work required, but not the overall weight significantly. As the fabrication of the hull had already started, three sizes of sponsons were designed, such that different levels of weight capacity increases could be implemented with a minimal amount of work. As the project progressed, the decision was made to include sponsons, and the required size was easily implemented despite the fact that the hull to a large degree was already finished. This accomplishment was made possible due to the enhanced design of the hull and the preparatory design work performed on the different sponson sizes.*

This example connects a wide range of different types of flexibility, from how a project is managed to the detailed design of the hull, which allowed for multiple future outcomes. The latter one is the focus of this paper, but in practical engineering they are all interconnected. This project highlights an important aspect of engineering; certain steps can be made in order to reduce the risks and improve the outcome of the project by being proactive. This factor is important throughout the process, but as a matter of nature, problems show up later on in projects, when the rigidity and number of interdependencies has increased to a higher level.

The flexibility of a project is not something that can be measured by a single parameter; it is abstractness of it and, perhaps more importantly, the immense complexity of the project itself makes even simple comparisons a subjective assessment. Weight margins have, however, been used as the quantitative representation of project flexibility, a further discussion of flexibility would include, amongst others, both management flexibility as outlined in this chapter and contract structures. For this very reason any analysis of flexibility as a concept and more specifically weight margins in particular, must confront the problem in numerous ways to explain the different aspects of the subject.

Moving over to the practical side of project planning; making the decision as to how large margins to include, where to apply them and how to treat them through the project is key to the successful execution of a project. These margins do, however come at a cost and finding the right level of margins become increasingly complex as floating offshore production rigs grow to 50,000-100,000 tonne vessels. In addition, it is important to remember that there could be lower cost sources of flexibility than weight margins.

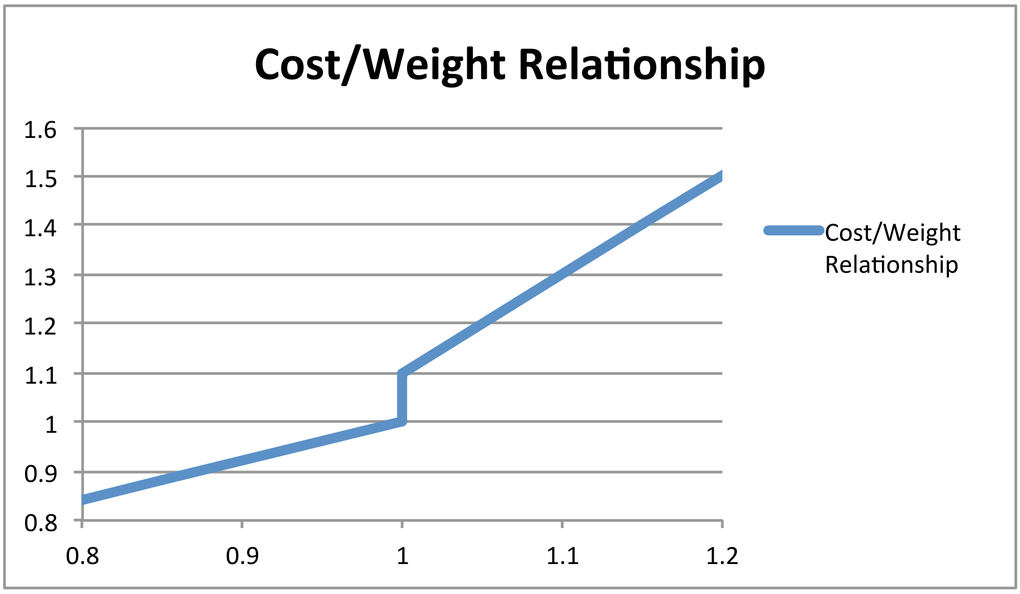

Figure 10 – Cost/weight relationship for a semisubmersible rig

Flexibility functions as a counteracting measure to cope with uncertainty, it is useful to evaluate the resulting cost structure of this uncertainty. Figure 10 shows the general relationship between cost and weight for a semisubmersible drilling or production rig and is based on the same assumptions as the newsvendor model. The cost (vertical axis) and weight (horizontal axis) have been normalized to the maximum weight capacity of the initial hull design. As will be further discussed in chapter 5.1, the cost/weight relationship should not be a linear function; first of all will the rig be costlier as a result of exceeding the weight limit, due to reengineering and other non-variable costs incurred. Secondly, the weight variable costs will be higher on a per-tonne basis as work will have to be performed at a less than optimum stage.

2.4.1. The structure of flexibility value

As profitability is the driver of any large offshore unit project, the issue of improving the flexibility of the project must be weighed against the costs involved. This gives the question posed by this paper a second aspect in addition to the question of how to increase flexibility; how to increase flexibility most cost effectively.

As previously stated, the route to understanding this question is not through a single path, but a multitude of smaller explanations painting a larger picture. While the first step is to understand the project structure, described in chapter 2.1, the next step is to model this environment such that quantitative analysis methods can be applied. These methods are often used stepwise, where an increasingly refined and complex model is used. This is the case for this paper as well, with the simplest model used being the newsvendor model. Traditionally this model is used in operations research to model the optimum level of stock kept of a certain goods to be sold. The more refined models apply the decision tree analysis and real options analysis to give a more comprehensive and exact valuation of the flexibility. The latter methods are similar in terms of the way they are performed, but the underlying assumptions and applicability is different. The objective of the newsvendor model is to compare the internal and external requirements on the weight variations of projects with what is economically preferable to AKSO. The decision tree analysis and real option analysis is used to estimate the value of certain flexibilities held by the project management.

Two aspects of flexibility is described in this chapter; the passive approach of applying margins to minimize the total expected cost, as in the newsvendor model, and an active approach as described with decision tree analysis and real options analysis, where the decisions of managers are taken into account.

2.4.1.1. Traditional valuation

The common starting point of a valuation of an investment is the use of net present value (NPV) analysis based on the expected project profits. This profit is discounted, using a risk-adjusted interest rate, to find the current value of the (Trigeorgis, 1996). This method is intuitively reasonable as a NPV analysis is simply asking the question: “What rate of return do I get for this project compared with what I require for this risk?” There is a very important limitation to this method however: The NPV method models an investment as a passive one in an asset with uncertain cash flow, what is left out in this process is the active role and effect management can have on the overall profitability of the project.

In theory NPV is the correct way to evaluate the current value of a project. The problem is that is does a poor job of valuing the flexibility of management to for example increase the size of profitable projects or decrease the size of loss-making projects (Trigeorgis, 1996). The issue is the complications these options impose, when the only variable available is the discount rate. Finding the appropriate discount rate is a fairly manageable process for simple projects. For projects where the management have significant freedom of choice (real options) to improve the overall profitability of the project, the abstractness of the rate makes it very complicated. According to Trigeorgis: " finding the correct risk-adjusted discount rate via standard DCF analysis is practically infeasible in most actual situations involving real options". The discussion of the applicability of NPV-methods in this context is the discussion on how to value flexibility: A key subject of this paper.

2.4.1.2. Newsvendor model

Managers have throughout time been faced with uncertainty in demand, when investing in stock. This has lead to the development of the newsvendor model, or newsboy problem, which have proven to be highly useful in a multitude of situations and settings. The story used to depict this situation is the following: A newsboy has to each morning decide how many papers to buy from the publisher, given the uncertain demand faced and the costs involved (Hillier & Lieberman, 2010).

A more detailed version of the model, including the underlying mathematics can be found in chapter 2.4.2.2.

The flexibility that is evaluated with the newsvendor model is a practical one: How much flexibility do you "buy" in order to avoid potential problems later. In the case of building rigs, the question is how much do you oversize the hull, that is increase the weight margins, in order to handle the possible outcomes of the overall weight of the unit. As described previously, the costs of building the vessel is directly related to the weight of the vessel. It is obvious that increasing weight capacity would increase weight and thereby costs, giving a cost of increasing the margins. Similarly, the exceeding the weight margins must have a cost, overage cost, equal or larger than increasing the margins themselves. This leads to the conclusion that there exists a minimum expected cost where the sum of margin costs and expected overage cost is minimized.

2.4.1.3. The decision tree analysis concept

Moving one step further from the newsvendor problem would include looking at the actual decisions made during a project. Throughout the process of building a large floating unit, management has substantial influence over the progress of the project. Consequently, it is useful to look at this process as a scenario tree where the end result is dependent both on “random” events (uncertainty) and management decisions. This is what a Decision Tree Analysis (DTA) is based on. The way a DTA is structured makes it highly flexible; the user decides the number of stages, events and decisions and the graphical presentation of the model make it easy to understand.

The focus of the DTA is on decisions. The discrete stages of the method structure makes it highly suited for valuing technological risks, but less so for commodity risks, like the price of oil (Koller, Goedhart, & Wessels, 2010). At first look, this makes it suitable for valuing the risks discussed in this paper, where the product is sold before it is built and the EPCH-Contractor assumes development risks, while the Company assumes the market (commodity) risks of the oil. The suitability of modeling the weight risk as a technological risk is discussed in more detail in chapter 5.6.

One key difference between how the Newsvendor model and the DTA-model is used to analyze the problem is to what level the decisions of the managers is discussed. Where the Newsvendor model is only interested in the overall cost of overage and deficit, the DTA analyze the whole process, and as such requires looking at the managerial flexibility available throughout the project. The flexibility has a value, and the relevance of the DTA model is naturally connected to the value of this flexibility compared with the overall value of the project. Koller, Goedhart & Wessels includes this figure to illustrate the relationship between two important determinants of flexibility value:

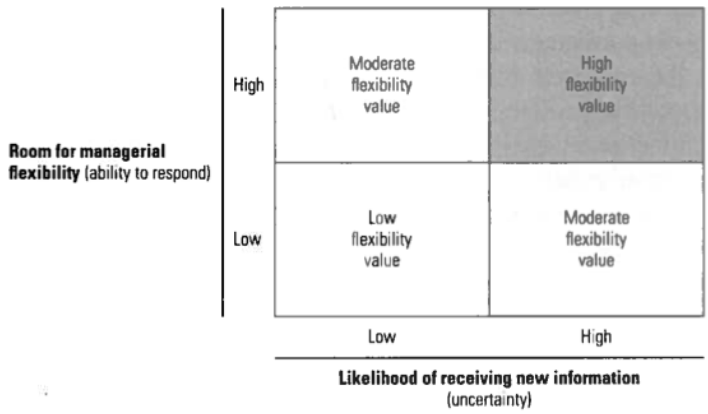

Figure 11 – Managerial flexibility and uncertainty KGW

As shown in figure 12, a very simple model is able to describe and value and R&D project in the pharmaceutical industry. This case is highly comparable to the project at hand, as both are subject to technological risk as a key determinant. Here, an investment is made to be able to do research on a drug. If this research fails, the project stops, and if it succeeds the company have the option of moving to the testing phase. Similarly, if the testing is a failure the project is cancelled, while if the testing is successful the company can make the decision to market the drug.

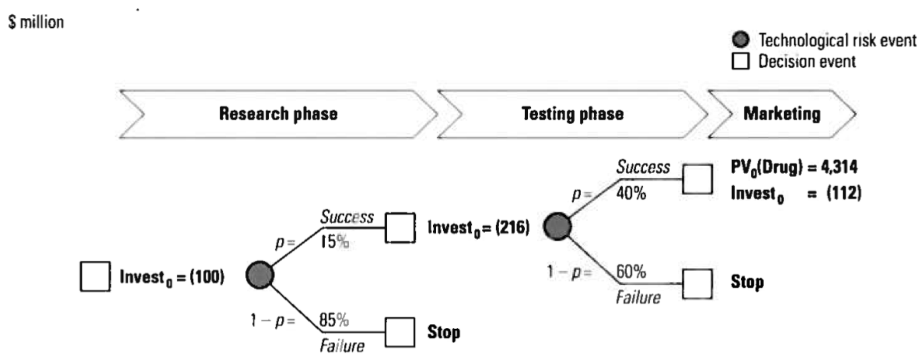

Figure 12 – R&D development valuation

2.4.1.4. Real options concept

Real options analysis seeks to model the managerial flexibility with a discounting method applied to the expected cash flows that are consistent. Consequently real options analysis is a further development of the decision tree analysis and the common valuation method net present value (NPV) (Trigeorgis, 1996).

Where the DTA, due to the binary nature of the result, often use pharmaceutical R&D projects as an example, the structure of real options makes commodity risks more suitable. This difference stems from one of the fundamental differences; the decision tree analysis is based on the practical application of management decisions given discrete events, real options are based on a continuous process, for example a geometric Brownian motion. Mathematically, this makes general closed-form solutions possible, although the final solution might have the characteristics of a “black-box” due to its complexity.

While the weight changes experienced during a project is obviously a technological risk, it consists of numerous changes and the best guess of all the engineers developing the weight estimates. When these changes are also continuously implemented through time, the weight development looks increasingly like commodity price fluctuations.

While the valuation and description of real options are complicated by the fact that they are not standardized, financial options are standardized and as such they are an example of an area where these closed-form solutions are used. As their purpose and underlying fundamentals are often quite similar, it is convenient to simplify the real options to fit the financial options structure. A description of this can be found in chapter 2.4.2.4.

Option structures

The choices available to project management might at first sight seem almost infinite in number. Dissecting these choices into finer parts would reveal that most of these choices could be modeled either as a call option, a put option or a combination of the two.

A call option is the right, but not the obligation, to buy a given asset at a certain price and date (Trigeorgis, 1996). Similarly, a put option is the right, but not the obligation, to sell a given asset at a certain price and date. This is where the usability of the real options method differ from DTA; where the DTA can be used directly in assessing complex optionality in projects, real options analysis require more work. First the options have to be dissected into their finer parts, the call or put options, then they would have to be assembled again to correct for interactions between them. For example, an option to reduce production has no value if the option to close production has already been exercised.

Trigeorgis illustrate the versatility of options by exemplifying different types and shows how they relate to project management:

- Option to defer investment
- Option to default during staged construction
- Option to expand

- Option to contract
- Option to shut down and restart operations
- Option to abandon for salvage value
- Option to switch use
- Corporate growth options

An explanation of the options can be found in Trigeorgis, but to illustrate their applicability, they are explained using the context of this paper:

Option to defer investment

The equipment used on offshore vessels is heavily specialized and often very expensive. This means that any investment made for non-standard equipment has to be evaluated along with the option of postponing the installation of it. One example of this is an investment in equipment enabling the vessel to operate in arctic environments, often called winterization of the topside. This would be an investment on the magnitude of $12 million (Dryships Inc., 2011), while the potential for a reasonable return could be present, it could be even more beneficial to wait and defer the investment until the uncertainty has been reduced. This could be modeled as a call option, where the price of the option is the cost of making the decision to defer the investment and the exercise price is the cost of making the investment.

Option to default during staged construction

This is an option most realistically held by the Company; designing and building a large offshore vessel takes about three to four years and consists of numerous phases, as previously described. It is easy to imagine that the Company could cancel (default on) a production unit project in the earlier phases if the oil price were to plummet to a level where the project is no longer profitable. This would be equivalent to a put option on the production unit. The difference between the strike price and the break-even level in this type of option would be equivalent to the costs incurred by the company, unwinding the project early, for example contractual obligation and wasted engineering work.

Option to expand

Adding new equipment to the rig during the design phase is not an uncommon event. This is basically to expand the scope of the rig, and can be modeled as a call option on the profit generated by this equipment, with a strike price of the total costs including the equipment

Option to contract

Fabricating and equipping vessels able to work on for example large depths is very expensive, and requires that a rather significant premium be paid compared with vessels operating in shallower waters. If this premium decreases below a certain level, it could be profitable to reduce the scope of the rig to reflect the new market situation, reducing capital investments and thereby improve overall profitability. This could be modeled as a put option on the relevant equipment.

Option to shut down and restart operations

While not discussed specifically in this paper, it is not uncommon that project groups are stopped (shut down) and restarted. The reason behind the decision to stop a project is usually that one of the discipline-teams have encountered a problem that will significantly affect the other disciplines, making any project progression unproductive, as changes will have to be made to the discipline interfaces later anyway. For the Contractor this can be modeled as a put option on the work performed by the discipline teams, where the project management hold the right to transfer workers from the project to the overall (Contractors) company. Similarly, the project management usually holds the right to increase their workforce, that is a call option on the hours worked by the employees.

Option to abandon for salvage value

Looking at the business side of the Contractor, the management holds the option to abandon certain market segments, for example fabrication, to focus on the design and engineering side or to abandon drilling rigs to focus on production units. These are all put options on the departments themselves, rather than the more project specific examples previously.

Option to switch use

Switching the use of an asset, in the context of project teams in a contractor, could be modeled as one project team holding a put option to on the whole or parts of a project, with another project team as the counterparty. What this means in practice could for example be that a team could be transferred from working on one project, to be working on another project, depending on where they are most productive. Looking at the actual engineering, a rig could be switched from being a production and drilling unit to a purely drilling unit, as described with options to contract.

Corporate growth options

Corporate growth options are very much connected with strategy. A rig designer investing in a new product might not be profitable on that very design, but investing would also mean that a call options on the next generation of the design is available, which can be of considerable value to the firm.

2.4.2. Valuation models

When making investment decisions, understanding how to value a project is as important as anything. Where traditional valuation models, such as NPV, may yield a value, managers are known to use this as a base value with a strategic value added onto. This creates a valuations gap between the market place valuation and the theoretical value of an investment (Boer, 2000). Moving from a pure subjective assessment of this additional value to a model that incorporate the full scope of value would clearly be an improvement. While a number of models exist, the appropriateness of them is subject to discussion. Therefore multiple models have been presented in order to describe the structure of flexibility value in offshore floating project better. As the underlying input to the models are not exactly measured, the objective of the use of the models is to understand the underlying factors and how they affect each other, not the final value generated.

2.4.2.1. Assumptions of the models

Newsvendor

According to Lieberman et al. there are seven assumptions of the newsvendor model that have to be satisfied in order for the model to be applicable:

- The product must be perishable, that is have limited lifespan
- The application of it must be constrained to a single time period.
- At the end of the period it is possible to dispose of the product, possibly at a salvage value
- There may be some initial inventory
- The only decision is that of ordering a given number of units to place in inventory
- The demand of product is a random variable, with a known probability distribution
- The objective is to minimize costs, as the revenue of demand is independent of the decision of the order size

Simplifying the realities of applying weight margins, yields a model consistent with these assumptions: The margins are only usable during the design and fabrication phase and are subject to a single period demand until the rig is finished. The salvage value of the margins is equivalent to the extra value the extra weight capacity provides for the Company, for example with future modifications. The initial inventory has no meaning in this context, and as such is set at zero. The project management makes a decision as to the size of the margins and they are subject to a random level of demand, in this case assumed to be a lognormal distribution.

DTA and Real options price risk

An important practical requirement of the DTA model is that the (price) risks modeled are technological-like and not commodity-like. The distinction is based on how the value is determined. A technological risk can be thought of as a risk with a binary outcome unaffected by outside factors, as in the pharmaceutical example of chapter 2.4.1.3; either the project succeeds or it fails. A commodity risk, however, can be defined as a pricing risk where the value is dependent on some underlying market price, leading to a continuously changing market price (Koller, Goedhart, & Wessels, 2010). This distinction is highly relevant from a diversification point of view: Where commodity price risk is a market risk that cannot be diversified away, a pure technological risk like pharmaceutical research outcome, the risk of each individual project failing can be diversified away by buying enough similar projects. Whether the risk can be diversified away is a key question when determining if decision tree analysis or real options analysis is most appropriate.

DTA

Except for the underlying risk, the DTA model requires few assumptions; the method models time as discrete events and project outcome as binary or at least discrete. While these two restrictions might seem like problematic, by adding layers of events and outcomes, the model can be adapted to cover a wide range of outcomes. Greatly expanding the model in this fashion will, however adversely affect the usability of the model.

Real options

Where the two other models are based on very general principles and assumptions, the mathematical nature of real options model includes some restrictions making the requirements for explaining the model a bit more comprehensive.

Using an option model to price an assets, whether traded or not, require some sort of market input. This input does not exist for rig design and fabrication, as there are no traded commodities, stocks or futures even remotely similar to the underlying value of flexibility discussed in this paper. Consequently, a market has to be constructed based on a set of factors affecting this value.

It is common in the industry to assume a 1:1 relationship between cost and weight, as previously discussed. This postulate is, however, hard to challenge as the costs are not measured during the process, but estimated using a static cost/weight factor. Nevertheless, the claim is accepted in the models used.

In addition, weight data for a number of projects are available, as this is a key piece of information in the project management. Combining these two provides an imaginary market, with the market participants being the project management routinely evaluating the project and changing the weight (price) according to their best estimate and the perceived estimate of the risks.

The method of using weight data as a market price also provides volatility data, further enabling the use of more complex mathematical models. As opposed to in the DTA, this means that the risk in the real option analysis is modeled as a commodity risk. The underlying process of the market price (weight) is in this regard essential; more complex processes can be used, but for the purpose of this paper a geometric Brownian motion has been used as it yields simple mathematical methods for pricing. Assumptions of constant volatility and interest rates have been made for the same reason.

2.4.2.2. Newsvendor model

The mathematics of the newsvendor model is quite simple, and the full derivation can be found in the appendix. Obviously, the profit of selling, in this case, newspapers are based on the number of newspapers sold and the cost of papers not sold, leading to a formula based on the selling price, the salvage value and the units sold (Hillier & Lieberman, 2010):

$$\pi(Q) = pEmin(Q, D) + sE(Q - D)^{+} - cQ$$

Formula 1 – Profit formula newsvendor

Where $\pi(Q)$ is the expected profit, given by p (the selling price), c (the unit cost) and s (the salvage value). Q is the stock level and D is the random demand, with a mean $\mu=E(D)$ and a variance $\sigma^2=Var(D)$. This means that the expression can be rewritten:

$$\pi(Q) = \mu(p - c) - G(Q)$$

Formula 2 – Transformed profit formula

As the first part of this equation is constant, the cost of overage or deficit can be found by using the following equation:

$$G(Q) = (c - s)E(Q - D)^{+} + (p - c)E(D - Q)^{+} > 0$$

Formula 3 – Cost function newsvendor

To simplify even further, $c - s$ can be seen as an overage cost, while $p - c$ can be seen as a deficit cost.

$$h = c - s = Overage\ cost$$

Formula 4 – Overage cost

$$b = p - c = Deficit\ cost$$

Formula 5 – Deficit cost

Both of these numbers can be manipulated in order to include, for example, the costs of unsatisfied demand. The real meaning of these variables and constants in this context can be understood as:

$$\pi(Q) = \ Expected\ profit\ from\ margins$$

Formula 6 – Expected profits

$$\mu(p - c) = Optimum\ profit\ from\ margins$$

Formula 7 – Optimum profits

$$\mu = Mean\ margin\ requirement$$

Formula 8 – Mean margin requirement

$$p = marginal\ cost\ of\ increasing\ weight\ within\ margin\ spectrum (late\ phase)$$

Formula 9 – Marginal cost of increasing weight margin – late

$$c = marginal\ cost\ of\ increasing\ weight\ of\ the\ rig\ (early\ phase)$$

Formula 10 – Marginal cost of increasing weight margin – early

$$s = Value\ of\ increased\ Company\ margin$$

Formula 11 – Value of increased margins

$$h = cost\ of\ having\ too\ large\ margins$$

Formula 12 – Cost of too large margins

$$b = cost\ of\ rework\ / -design\ \ of\ vessel\ to\ increse\ margins$$

Formula 13 – Cost of margin increase

In more detail, this model would structure the costs and benefits the following way for the design and building phase of offshore floating units:

Cost of increasing overall weight - c

As previously mentioned, cost and weight is highly correlated in rig building projects. Determining the suitable size of the rig and what equipment to include is a major decision. The benefits of increasing the functionality must be weighed against the costs of having to build a larger unit. This marginal cost is c.

Cost of increasing weight within spectrum - p

As long as the changes are kept within the margins applied to the project, increases in weight could have small impact on cost. The reason for this is that these cost do not necessarily propagate through the rig; if the hull is still suited to hold the increased weight, an increase in crane weight could only impact the crane cost.

Cost of overage – h

The cost of applying to large margins is almost purely a function of the increased margin available to the Company. As the rig is finished, any remaining Contractors margin will be transferred to the Company margin, and as such value is increased for the Company, the overall costs of the rig would, however, be larger, making too large margins a cost for the Contractor.

Cost of deficit - b

This is in many ways the challenge to avoid. Having to redesign the hull in order to allow a higher total load means, for even small changes in weight capacity, disproportional large costs. Increased amounts of engineering work, rework at the yard or the use of lighter materials as aluminum all have serious cost and schedule implications. It is however, possible to estimate, as numerous projects have experienced this happening.

Finding the optimum

Using these values, the optimum level of margins can be calculated. Assuming a lognormal distribution, the optimum is simply found by minimizing $G(Q)$. The same can be done if one assumes any other type of distribution, including empirical ones, which might be very useful for this type of problem. A Monte Carlo simulation is one example of a solution that is very flexible in this regard and more accurate for practical applications. The optimal service level can be found by using the formula (Hillier & Lieberman, 2010):

$$Optimal\ service\ level = \frac{b}{b+h}$$

Formula 14 – Optimal service level newsvendor

By implementing these costs into the relevant probability distribution, the absolute value of optimal margins applied to a project can be easily attained. One very important restriction of this formula is that the overage/deficit costs are linear, which is not an accurate assumption. This is discussed in chapter 5.1.

2.4.2.3. DTA method

Koller, Goedhart & Wessels suggest a four-step method to value the overall project value, and the value of the flexibility:

- Step 1: Estimate present value without flexibility
- Step 2: Model uncertainty using event tree
- Step 3: Model flexibility using decision tree
- Step 4: Estimate value of flexibility

Step 1 is simply a case of discounting the probability-weighted income with the relevant cost of capital and subtracting the investments, discounted with the risk free interest rate, equivalent to a normal net-present-value (NPV) method. For risky R&D projects, the probability of success can be so low that the resulting net present value is negative.

$$NPV = PV(Expected\ Cash\ Flows) - PV(Investments)$$

Formula 15 – Net present value

Step 2, as defined by Koller, Goedhart & Wessels, adds the risks involved in the project; what are the scenarios and events relevant to the project, and what are the probabilities of the different outcomes. Depending on the information available, this can be structured as a very general assessment or at a high level of detail.

Step 3 involves finding the flexibility available to the project participants. In the previous example, this would be cancelling the project early, if the project fails to yield a positive outcome at a stage. Moving from the right to the left and at each point evaluating whether a cost is applicable, will accomplish this step. For example, one would only invest in marketing if there is a product to sell.

Step 4 calculates the value of flexibility, given the information provided previously. This is maximizing the value at each stage by making the actual decisions and calculating the corresponding value. Moving again, from right to left (Koller, Goedhart, & Wessels, 2010):

> *"At the end of the testing phase, we proceed with launching the product only if there is a marketable product. The value at this point in time is therefore Max[(4,314 – 112),0]=$4,202 million"*

This flexibility essentially means, as is implicit from the formula stated, that at each stage the value is either zero (project is cancelled) or positive (project is continued). As this method propagates towards the project initiation, this also means that the overall value of the project must be either zero (project is not started) or positive (project is started). This could be a very important factor in determining whether to start the project, given a negative initial NPV valuation. The model can also be expanded to include the possibility of cancellation costs, meaning that instead of maximizing value between zero and project value, the maximization is based on highest of the cancellation cost and the project value.

2.4.2.4. The real options method

Evaluating and understanding all the types of options and options structures relevant to a project would be very demanding, but the principle of the value of the option is quite easy to understand. Imaging having the right to buy an asset worth $10 at $2, it is obvious that that right is worth at least $8. It would also make sense that this right is worth less than $10, as you might as well buy the asset if the price were to be higher. These are the fundamental principles of option pricing, the challenge is to calculate where in the $8-$10 range the real value of the option is.

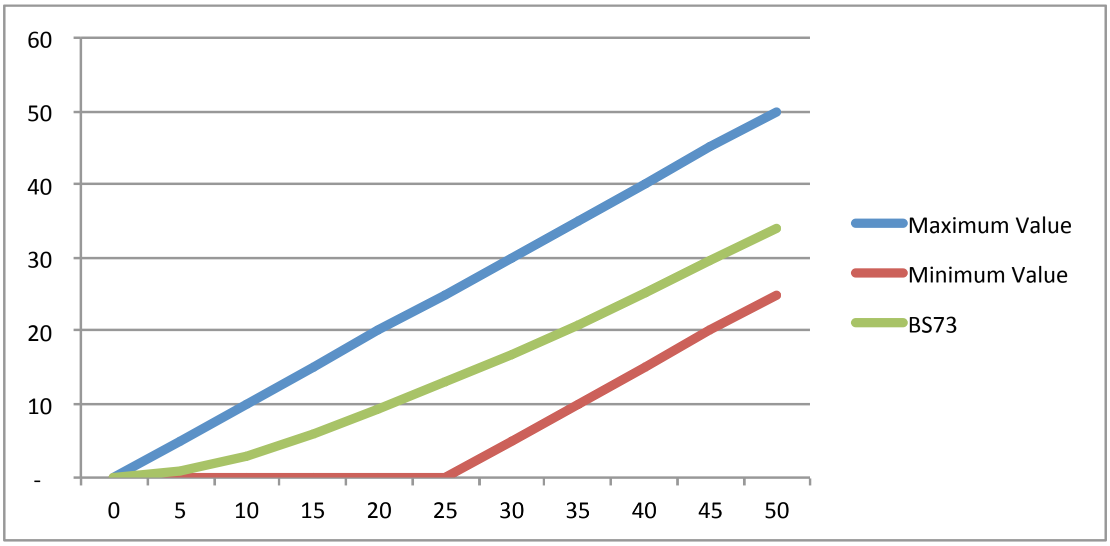

Figure 13 – Minimum, maximum and calculated (Black-Scholes 73) value of option

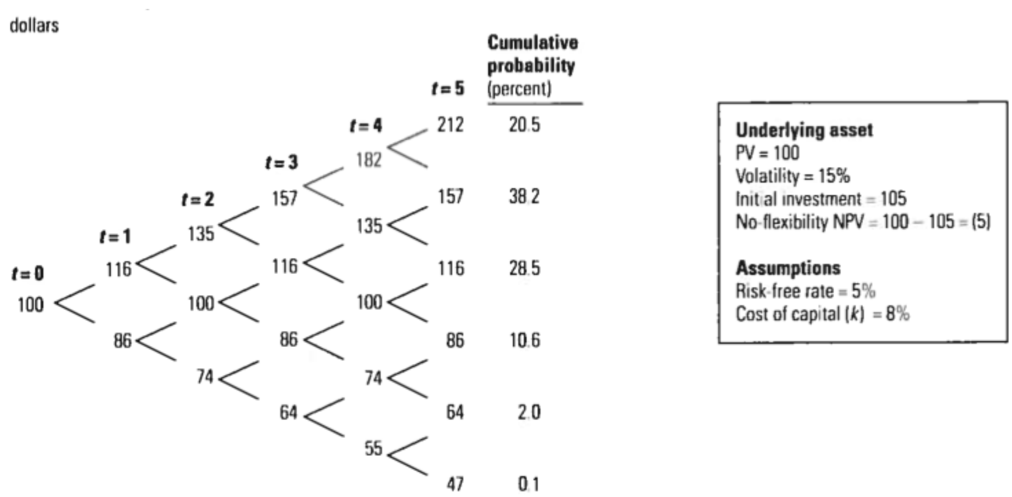

Figure 14 - Value tree Real Options

There are two main methods used to evaluate the value of real options: Scenario trees and PDEs. The first is used in this paper due to its versatility, while the second is mathematically more advanced and include the Black-Scholes model. The basis of both the real options theory using scenario trees and decision tree analysis is the same; scenarios are evaluated in order to value the flexibility of making the available decisions. The conceptual difference is that while the DTA is based on creating a tree of actual possible scenarios, the market characteristics of the underlying of real options means that creating the tree is a mathematical exercise rather than a deliberate evaluation of possible outcomes. The real options approach is in this regard able to create larger, more complex, trees as they are based on a formula, focusing the human effort on just a couple of variables.

The pricing of margins using real options can be structured in the same fashion as the method used for DTA. The four steps outlined by Koller, Goedhart & Wessels for real options are only different in terms of the second step where the up (u) and downwards (d) movement of each node is defined as:

$$u = e^{\sigma\sqrt{T}}$$

Formula 16 – Up-factor real options

$$d = e^{-\sigma\sqrt{T}} = \frac{1}{u}$$

Formula 17 – Down-factor real options

$$\frac{dS}{S} = \alpha dt + \sigma dz$$

Formula 18 - Geometric Brownian motion

This specific way of constructing the options tree is contingent on the underlying process being a geometric Brownian motion (Trigeorgis, 1996) with a mean α and variance σ^2. Although the specific example of using real options to evaluate margins in floating offshore oilrigs have not been found in the literature, other comparable examples exists, illuminating the usefulness of real options, and also DTA, as a useful tool in a similar context. The nature of the real options model, making the assumption of the underlying process, means that this option tree model can be extended to a fully continuous model where the outcome at each stage is totally random. In order for the process to develop to the full Black-

Scholes model, the underlying distribution must be the same, that is, the development in the binary tree must be equivalent to that of the formula 19.

In order to describe some of the qualities of the real options analysis, an example of an oil field development is often used with the oil price being the only source of uncertainty. Further discussions on the subject of real options in oil field development projects can be found in (Trigeorgis, 1996) and (Johnson, Taylor, & Ford, 2006).

> *A company holds a license to produce oil from two oil fields: Gro and Jonas. Gro is a large field containing 100 mboe, while Jonas is a smaller field containing only 10 mboe. The license for Gro requires that the decision to develop the field must be made immediately, or it will expire worthless. The license for Jonas has an expiration date two years from now. The capital investments required to develop oil fields are of such a scale that Gro requires an oil price above $121 per boe to have a positive net present value, while Jonas is too small to be developed on a standalone basis. The current oil price is $120 per boe, with a yearly standard deviation of 15%, making neither projects profitable on a NPV-basis. The Jonas field can, however, be developed as satellite development to the Gro field with a NPV-neutral oil price of $123 per boe. Both fields have a cost of production of $20 per boe. In other words, if the Gro field is developed now, the company holds the option to develop the Jonas field with a maturity date two years from now. The risk-free interest rate is 4%, the risk-adjusted discount rate used is 10%, the capital investments needed to develop the Gro field is $5,642 million and the capital investments needed to develop the Jonas field is $800 million. The fields will start production two years after the investment is made and will produce 10 and 1 million boe per year for the Gro and Jonas field respectively for ten years thereafter.*
>
> *Using this information the project can be valued both using net present value/discounted cash flow and as a financial option. The full spreadsheet can be found in the appendix.*

The value of the production of the Gro using DCF is $5,586 million, compared with $5,642 million in capital investments, giving a net value of -$56 million. The Jonas field provides $780 million in present value on capital investments of $800 million, leading to a net value of -$20 million. Overall, developing both fields would yield a negative present value of $-76 million. The full value of the Jonas field is however, not accounted for in this calculation, as the Jonas field license has a maturity two years from now. Postponing the decision could yield significant addition value to the company. Using the Black-Scholes model, the value of the option to invest in the Jonas field in the future is $108 million, leading to a positive overall project value of $52 million.

This example illustrates how the decision of whether to invest in a project can be significantly affected by whether the optionality of the projects is included in the calculations.

The real options valuation using trees is very flexible, and can be adjusted to suit specific needs. If, however, a more standardized option is assessed, as in the example or for financial options, closed-form solutions exists that can do the same calculation with less work. The model developed by Black & Scholes (Black & Scholes, 1973) is mathematically advanced, but quite easy to use:

$$C(S,\tau;E) = SN(d_1) - Ee^{-r\tau}N(d_2)$$

$$d_1 = \frac{\ln\left(\frac{S}{E}\right) + \left(r + \frac{1}{2}\sigma^2\right)\tau}{\sigma\sqrt{\tau}}$$

$$d_2 = d_1 - \sigma\sqrt{\tau}$$

Formula 19 – Black Scholes option pricing

Intuitively, the pricing of options, whether real or financial, must be based on the likely benefit of holding it. This benefit must be based on how the price of the underlying develops in the future and how far into the future the option is valid (maturity). Looking at the formula, these factors are represented by the exercise price (E), stock price/ price of underlying (S) and the volatility of the price of that underlying (σ). Translating these into a more concrete example would make the exercise price the capital costs of developing the oil field, the price of the underlying equal to the value of the oil in the oilfield and the volatility would be the standard deviation of the oil price. The time (τ) factor and risk-free interest rate is introduced to account for the fact that the possibility space obviously increase with time and that even a risk-free investment, as can be constructed using options and the underlying assets, require a return.

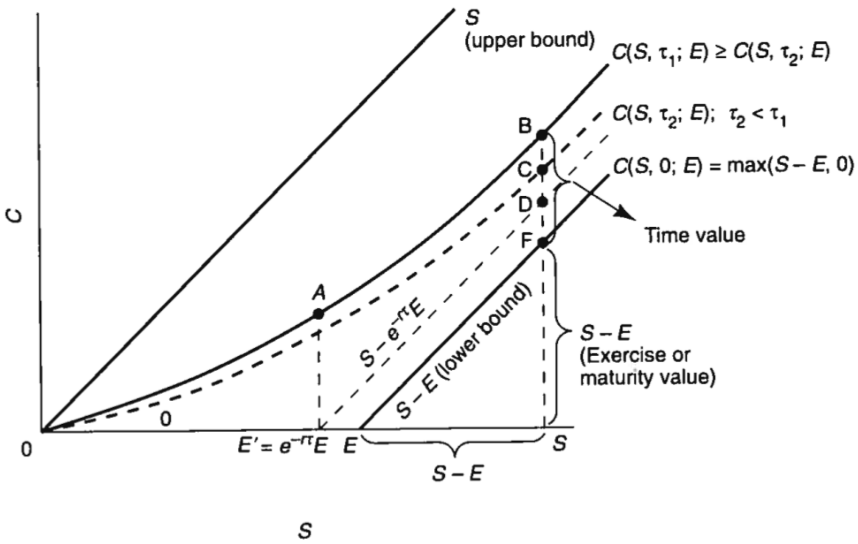

Figure 15 – Detailed option value/underlying value relationship

This can be seen in the graph above where, using the Black-Scholes model, the price of the option is calculated as a function of the underlying price of the stock. It also illustrates how the value of the option is always positive, meaning that flexibility has a value of zero or above regardless of the underlying conditions.

2.4.3. Comparing DTA and real options

Ignoring for a second the closed-form solutions to real options valuations, decision tree analysis and real options analysis looks very similar as methods. In practical use as well, the methods applied would often be somewhere between the two types (Triantis, 2005). It is, however, clear that the more intuitive decision tree analysis is more appropriate as a management tool, than the mathematics intensive real options approach.

In the context of this paper, there is certainly a point that the applicable method must be practical in use, but on the theoretical side one key aspect, the type of risk, is a subject of discussion and uncertainty. In general, the price risk evaluated in the DTA and real options method are distinctly different: Decision tree analysis is appropriate for technological risk, that is diversifiable risks (Koller, Goedhart, & Wessels, 2010), in other words, a risk that can be diversified by investing in a adequate number of similar projects. Comparably, the real options analysis is most appropriate for commodity risks, non-diversifiable risks, such as the oil price. Obviously, investing in more than one project will not mitigate the risk of oil price changes.

While the development of a rig will obviously include technological risks, the real question is which factor has the greatest influence on the outcome of the project. As is described in chapter 4.1.1, the supplier market conditions can have a serious effect on the weight development, and as the suppliers are, broadly speaking, the same for all projects, this risk is consequently non-diversifiable. This is important for the profitability of the projects; basic financial theory states that an investor must be rewarded for incurring higher risks; if (a large portion of) the risks are diversifiable the result is that the required profitability is lower.

2.4.4. Further discussions of DTA and real options in literature

There are other aspects of real options that are relevant to this discussion, going beyond the discussion of methods. Real options analysis has a value not only as a mathematical tool, but also as a tool for framing decisions (Triantis, 2005). Furthermore, while the definition of real options analysis is defined somewhat differently, the consciousness of flexibility as an important value driver is often present. Research also indicates that managers intuitively understand the value of real options in projects (Ford & Lander, Real option perceptions among project managers, 2011), however Ford (Ford, Lander, & Voyer, A real options approach to valuing strategic flexibility in uncertain construction projects, 2002) also concludes that:

> *Frequently managers do not capture project value that is hidden in dynamic uncertainty but is available through the use of flexible strategies.*

This indicates that more work is required to increase the usability of real options in practical applications. This also one of the key critiques of real options analysis according to Triantis; that often the decision tree analysis is a more reasonable in many cases, as the complexity involved is considerably less. Furthermore, another common critique real options reflect a perfect world rather than the economic reality of business, making them unrealistic.

It is clear that flexibility can create significant value through cost, but also schedule (Ford & Sobek, Adapting Real Options to New Product Development by Modelling the Second Toyota Paradox, 2005). Product development is a key feature of rig design, and the paradox of Toyota being able to achieve the fastest development times in the industry by purposely delaying selection, is interesting as it shows how flexibility can have a large direct impact, not only on cost, but also on other aspects of the development.

Discussing the actual variables used in decision tree analysis and real options analysis illustrates some of the imperfections of their application. The use of real options analysis is dependent on understanding and applying the correct process in the calculations, in order to get a reasonable answer (Perlitz, Peske, & Schrank, 1999). Similarly, the choice of discount rate is one of the primary reasons to move from a decision tree analysis to a real options analysis (Mattar & Cheah, 2006). Boer has stated that the goal of financial valuation is to "supplement or replace intuition" (Boer, 2000). In the context of the uncertainties just discussed, it is, however, hard to see where the financial valuation end and intuition start.

3. Data used

Few companies have as long experience of designing and building offshore rigs as Aker Solutions, at least on the NCS. Therefore the information from previous projects available for analysis was quite extensive. The information gathered is divided into two types: Quantitative and qualitative information. The quantitative information is mostly provided by weight reports made during the projects evaluated and is supplemented by the qualitative information: Project participants were interviewed in order to understand the context and the underlying reasons for the project development.

3.1. Project analysis

The project analysis of this paper includes the historical developments of previous projects, simulations to as a basis of comparison and the discussion with AKSO employees that followed the assessment of information and the comparison with the simulations.

Aker Solutions, including its predecessors, have experience from designing and building offshore rigs dating back to the first Norwegian drilling rig Ocean Viking built in 1967 (Bryhn, 2012). As such, there were a number of projects available for analysis, but a couple was chosen as it was deemed important to not only get the data from reports, but also talk to people involved in the projects to get a better understanding of how the projects developed. This limited to some extent the number of available projects. The projects evaluated included the five projects described in the appendix, all anonymized. This chapter provides the context in which these projects evolved from FEED to start-up, and is important in order to understand why the quantitative measurements evaluated later.

3.1.1. Project A

The Project A PDQ (Production, Drilling and Quarters) is a semisubmersible with a dry weight of about 37,000 tonnes, producing oil at an oil field in the North Sea. It entered the EPCH-phase late 2006 and was finished in mid-2010. Looking at the weight development of the unit, it is clear that a number of changes have been implemented from the first EPCH weight report to the "As-built" report: The final "as-built" report use a topside weight 15% higher than the initial estimate and above what is deemed appropriate in these types of projects in AKSO. Below is the dry total weight development of the rig shown, indexed to the initial weight budget:

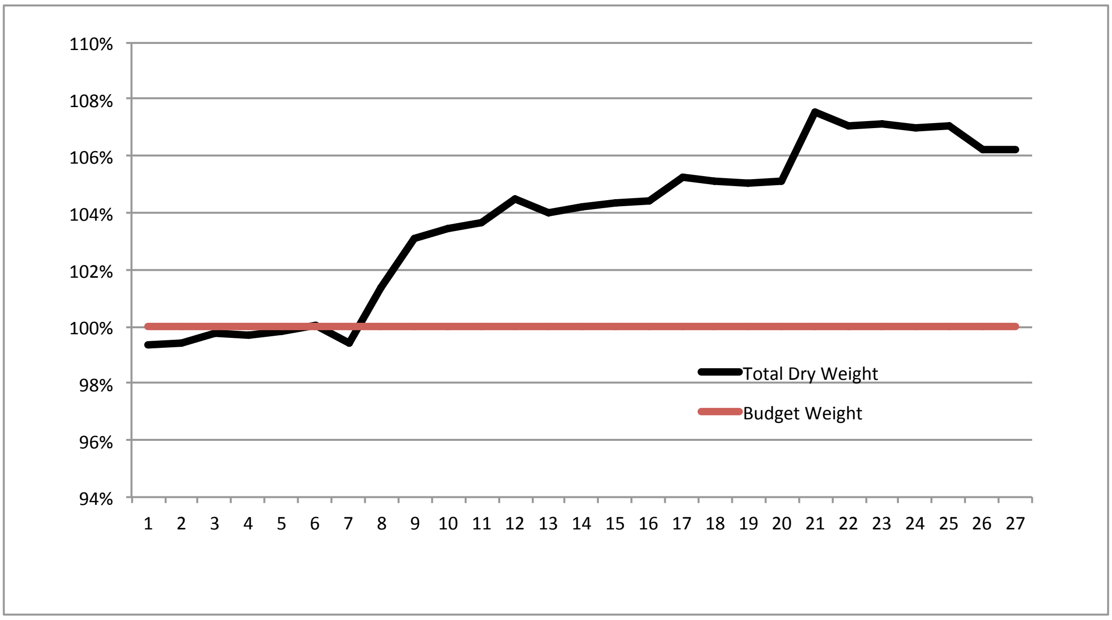

Figure 16 – Indexed weight development of Project A

While the normal number to evaluate is the operating weight, the dry weight of the rig is included to illustrate how the rig itself has grown in size. During conversations with AKSO employees, a number of issues and reasons were given for the high weight growth of the rig. From a technical perspective, the perhaps most interesting one was the effect of supplier information. Due to a high demand in the supplier market, the suppliers were stretched in term of capacity, and as a consequence the accuracy of their weight estimates fell. Additionally, the first tier producers were fully booked, meaning that AKSO had to order components from lower quality producers. According to project participants, this lead to heavier components than normal, transmitting further to inaccurate estimates and insufficient margins. The margin development is shown below is not an accurate representation of the weight margins of the project, but a revised one where the base margin is changed to 3000 tonnes due to the private nature of the information. The graph does however give a fair presentation of the development, although the starting point has been changed.

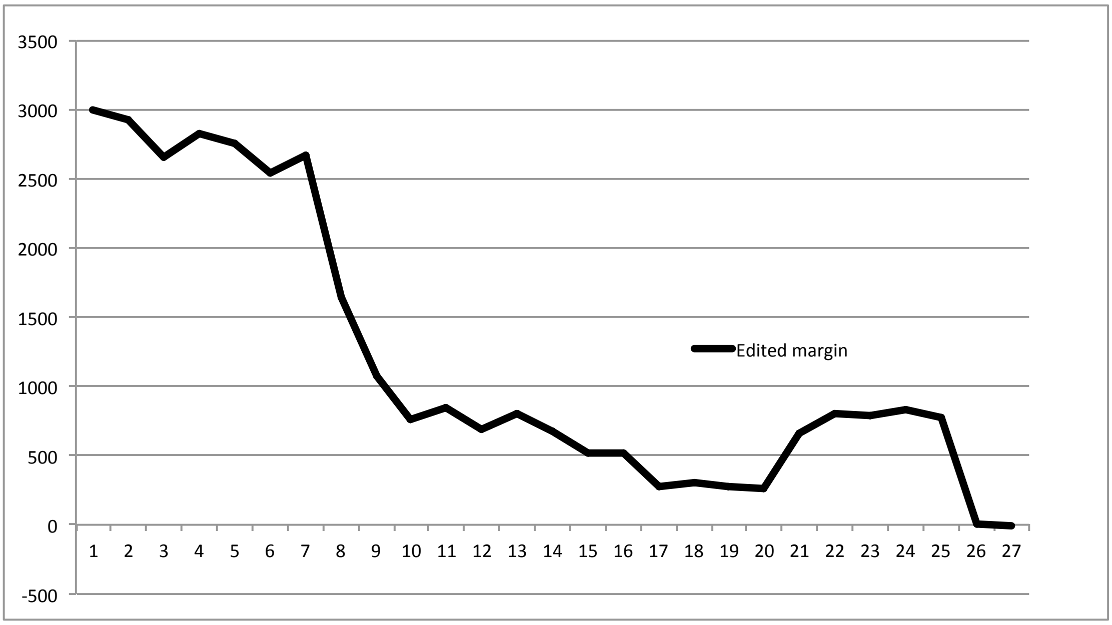

Figure 17 – Revised margin development Project A

While the normal progression of projects includes some variation, both on the upside and downside, the graph above clearly show that this project suffered from a virtually continuous decline in margins. A second issue was changes in design basis; these are, in theory, supposed to be accumulated by the company margin, but as previously discussed, the cumulative effect of these changes are not understood and individually they may take months to be fully implemented.

3.1.2. Project B

Originally, the Project B was an internal project with the goal of proving AKSO ability to design and build drilling platforms, by use of in-house resources where possible. The project was performed for an internal customer. Due to the special structure of this development, it was decided not to perform a FEED, and as such the development of the rig design has a somewhat different structure compared with other projects. The difference in project maturity will therefore affect the initial development of the project, and the weight graph must be read in that context:

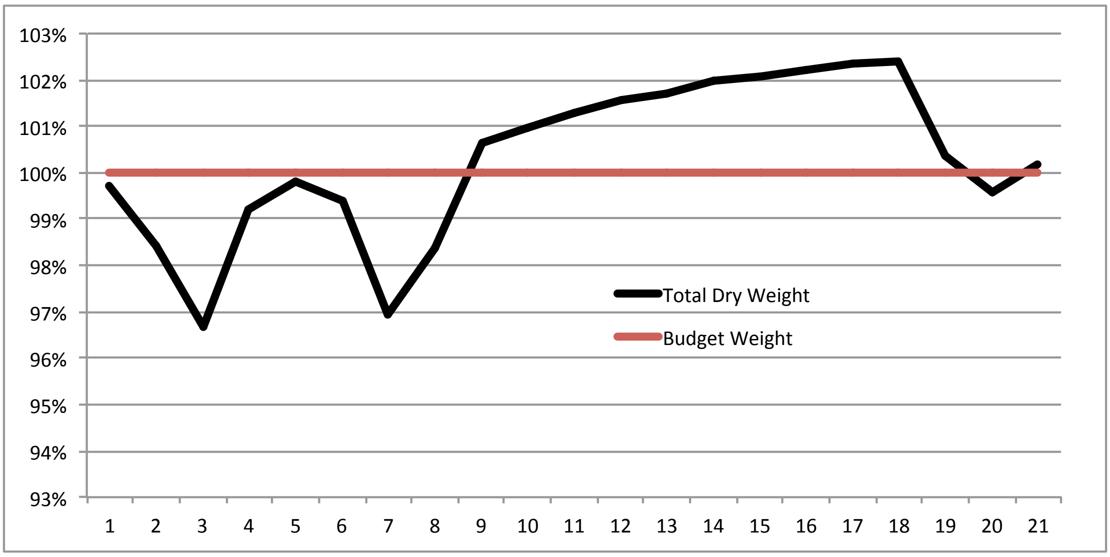

Figure 18 – Indexed weight development of Project B

The weight development of Project B was similar to what you would expect: Both positive and negative changes throughout the project. One key aspect to remember here is that, as the design was performed for an internal customer, requirements could be changed easily, as the underlying goal was not to deliver a specific product, but to deliver a good vessel and to prove the capability of AKSO to design and build advanced drilling vessels.

The project is seen as a continuation of the very popular H-3 design (Aker Solutions, 2013). The vessel was built to be the most technically advanced, capable of operating in the most extreme conditions. While AKSO had designed a several production units the latter years, they had not designed drilling units for a number of years. This meant that the learning curve was somewhat steeper than usual.

3.1.3. Project C

The Project C project is considered to be one of the most successful projects completed on the NCS. Completed ahead of schedule and, adjusted for VO's, 270 tonnes below the initial budget weight for the topside is an impressive feat. Total weight growth for the unit as a whole was about 5.5%, of which 2.9% points were due to VO's.

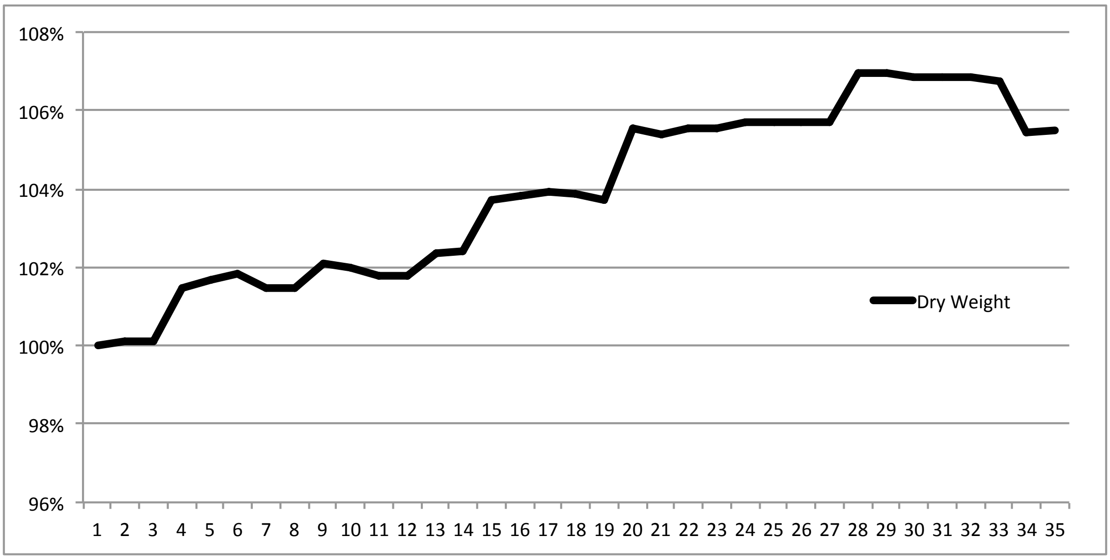

Figure 19 – Indexed weight development of Project C

Completing the definition work to a sufficient level is one of the drivers of a successful project. This was achieved on Project C and is seen as a reason for its success (Knudsen & Høyby, 2004). This was all performed despite the extraordinary challenges that the Project C field posed for the development of the production unit. The reservoir contains gas and condensate under very high pressure and temperature, higher than for any other field on the Norwegian continental shelf (Statoil, 2007).

3.1.4. Project D

The Project D semi submersible platform is part of a larger oil field development, including a production ship and a storage vessel. The oil field has become somewhat infamous, being the symbol of many of the large cost overruns in oil field developments in the Norwegian and North Sea during the 1990s. This eventually lead to a public examination of many of the field developments of the 90s (Kaasen, et al., 1999). While the reason for the cost overrun for the whole field is a combination of many factors, the cost of the Project D platform was certainly a part of the problem: The total cost overrun for the Project D platform from PUD to CCE10 (control estimate 10) is 49%. The reason this cost is important is the previously discussed connection between cost and weight. This is evident from the weight development as well: From February 1997 to the final weight report of June 2001, the dry weight of the topside increased by 21%. Overall the dry weight of the rig increased by 16.5%

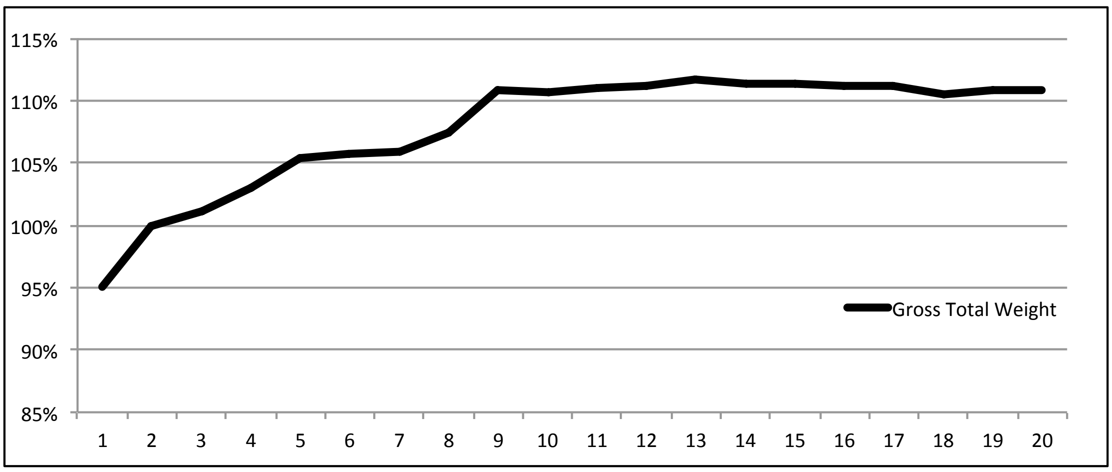

Figure 20 – Indexed weight development of Project D

As seen in the graph above, the weight development of the unit can be divided into two phases: The initial year and a half (first 9 periods) where the weight continuously increased by an average of 1.5% per month, and the period from period 9 onwards with a total increase of 1.5%. Kaasen illuminates some of the issues faced by the project, which lead to this unfortunate development. During the engineering of the rig, it came to light that the gas would have a higher than believed pressure and temperature, increasing the overall weight due to tougher functional requirements. Fatigue problems in the rig structure, due to the long life requirement of 50 years, was also a technical challenge during the project.

3.1.5. Project E

The Project E platform is a floating production and drilling unit, similar in concept to the Project A platform. In terms of size, the unit has a displacement of 56,500 tonnes and capable of a production of 118,000 boepd (Almeland & Pettersen, 2002). While the total dry weight of the unit grew from about 30,000 tonnes to a total of about 32,500 tonnes over the development of the project, most of these changes came about during the initial phase. Measuring from the 8th revision to the end date the increase is less than 1%. This would be before the fabrication had started, according to the fabrication schedule.

There are some discrepancies between the numbers provided by Almeland & Pettersen and the weight margins provided by the actual reports. The conclusion is nevertheless that the margins were not significantly impaired during this project. In the case of the Contractors margin, except for large reductions in the second and third report, the weight margin is roughly flat for the rest of the project. This indicates that the impact of the initial changes in weight initiated a strong focus on keeping weight under control throughout the rest of the project.

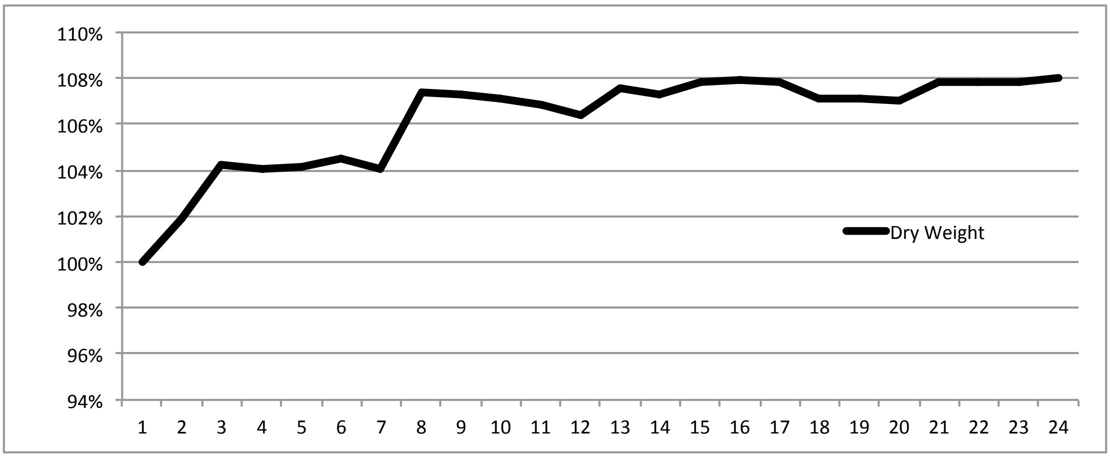

Figure 21 – Indexed weight development of Project E

3.1.6. Lessons learned

These projects were specifically picked in order to get a comprehensive picture of how the project execution of large offshore project can develop. The lessons learned from these projects would consequently encompass a representative selection of the issues encountered by AKSO over the years.

An underlying factor in all the projects is to what extent the project was allowed to mature: Whether the main requirements and layout were developed early and kept frozen through the latter phases. For Project D, the change in field characteristics meant that huge changes had to be implemented in the process unit, propagating further onwards to increase the overall weight of the unit significantly. Similarly, the lack of change in requirements and area distribution in Project E and Project C, ensured an execution without large a divergence from the initial weight estimate.

The market condition effect on the weight development was not a primary concern before Project A. The two effects from poorer estimates and second tier products had been experienced previously, but according to AKSO employees the result of the market conditions during the execution of Project A was exceptional. An interesting comparison to all the externally driven projects is the internal project of developing, designing and building the Project B rigs. While the functional requirements of external projects are to a large degree set, the internal project has, in theory, the freedom of choice to choose the most profitable solution at each crossroad. Ignoring the internal issues and structures, this is part of the explanation why the project finished on the weight budget, without having performed a full FEED in the initial phase of the project. The project structure and challenges in the execution of Project B lead, according to AKSO employees, to cost overruns, unrelated to the weight development. This proves that the statement that weight equals cost has limitations.

3.2. Discussions with Aker Solutions employees

Both within the academic world and in the industry there is substantial theoretical background information available discussing how to ensure a positive outcome from a project. This is the case for AKSO as well; in chapter 2.1.3, the models show how they, in theory, develop and execute projects. A different aspect is how they execute in practice, and more specifically, how the industry professionals experience the projects and their interpretation of the theoretical background. This chapter is a collection of opinions, experiences and assessments made by AKSO employees over weeks of interviews during the spring of 2013. The text has been reviewed by Anders Martin Moe of Aker Solutions to ensure the correctness of the information presented (Moe, 2013).

3.2.1. Uncertainty and growth

Everybody I have talked with at AKSO sees the overall growth in terms of weight, but also to some extent scope, of the project as an unavoidable part of a normal project. This is accordance with the quote of Caverny & Marquez in chapter 2.3.3. The primary reason is that each project includes some specific challenges that make them one of a kind, thereby introducing both uncertainty and a potential for change. Changes to be implemented later than optimal in the project are also an important factor; this is, however, often the choice of the oil company as they are usually the one to pick up the bill afterwards. The project development structure, as previously discussed, does not allow for one phase to be finished before the next is started. Thereby incurring the risk that new information will affect the suitability of the chosen solution. This is certainly a risk factor, and repeated changes will obviously have a cost effect, as some of the work has to be repeated. Compared with the overall costs of fabricating a rig, the engineering hours is a rather small factor, allowing the oil company to include new information at a late stage at a relative low direct cost, usually in order to increase the overall productivity of the oilfield. This leads to an interesting question of large engineering projects: When cost overruns are incurred, are they a result of poor project management or simply the difference between the cost of initial and final requirements? This is a significant part of the discussion in the 1999-Kaasen report:

> *It is difficult to differentiate between cost overruns due to an incorrect initial basis and cost overruns due to unforeseen issues in the execution. Cost overruns can, however, be traced back to faulty assumptions for many of the projects.*

This quote (translated to English by the author) is taken from a report ordered by the Department of Oil and Energy in 1998 due to a number of projects on the NCS experiencing huge cost overruns (Kaasen, et al., 1999).

The role of margins in this respect is very different depending on what the problem is. The primary reason mentioned here utilizes margins as a contingency against unknown developments in the underlying basis of the project. The potential inefficiencies, or indirect costs, created by the changes made to the project basis are an important aspect of this.

One of the issues discussed in Kaasen and with AKSO employees, is the difference between the maturity of information received and the maturity of the engineering. Pushing the engineering forward, despite highly uncertain information will naturally increase the risk of rework. On the other hand, delaying engineering in order to attain better information could have a high cost through the possible delay of the whole project. The balance between these two aspects is described as challenging, and solved on the basis of experience and the subjective assessments by the project management.

3.2.2. The time aspect

One aspect repeatedly underlined in the oil business is the value of time. Delays cost money, big money: The Project A platform has an oil production capacity of about 86,000 barrels of oil (Statoil, 2009) (PTIL, 2003), multiplying this with the current oil price of $112.71 gives an indication of the cost of delay of about $10 Million per day (price of oil is the ICE Brent Crude settlement price on the 26th of February for delivery in April (The ICE, 2013)). This number explains why delays to the overall schedule of the project are seen as unacceptable and to be avoided at virtually any cost.

3.2.3. The human aspect

Engineering can, at first look seem like a very technical field, where there are right and wrong answers, where the statement of Laplace that the universe is a mechanical one, is valid. As a general observation after spending weeks with Aker Solutions employees, the focus of engineers is rarely on that of the mathematics and mechanics of the engineering, but on the human interaction in the process. The subjective nature of the relationship between the people involved in a project has to a great extent challenged the aim of getting objective information and challenged the validity of that information. This complicates the use of mathematical methods to model the project process. The context in which the processes described in this paper exists in, is in other words vital to the understanding, analysis and conclusions they yield.

The primary factor, repeated on a number of occasions, is focus. In projects where weight was a main concern and the acceptable range very narrow, there was rarely any larges changes in weight, simply because everybody knew that it had to be carefully managed. This makes valuing the flexibility that margins provide much more challenging, as the ability of the project team to control weight is inversely dependent on the size of these margins, due to diminishing focus on weight as an issue. The picture becomes even less clear due to the fact that the engineers who implement changes in design, to a small degree are able to estimate the final effect of that change. This means that the delay or lack of information requires decisions being made based on subjective assessments and experience, making management of the process a substantial challenge. The relation to margins is quite obvious, as the margins must cover the current change, as well as any future developments. Deciding whether they are sufficient is consequently a key issue. The subjective nature of many of estimates made, for example what level of utilization is acceptable, makes determining remaining margins a management issue as well as a mathematical exercise.

The relationship and trust that exist between stakeholders is also very important, the flexibility granted to a supplier and customer you know well can have significant impact on the project. A relationship between a Contractor and Customer that have little trust in each other could easily be colored by both stakeholders need to cover their own organization from future liabilities. It is easy to see how this can become dysfunctional, making the “soft values” of having a close relationship with a high level of trust as influential as any other factor.

Thinking of Contractor/Company communication as a one-to-one interaction, where each party speaks with one voice would be a mistake. Leaving internal politics aside, the different departments may have a different understanding of the purpose of the project. One example is the difference between Company employees with an engineering and operational background; according to AKSO employees, they typically have different preferences in terms of equipment used and deck layout. As these employees are included in the project at different times, starting out with the engineers and later including the operators, will consequently drive additional changes.

3.2.4. Commercial

From a commercial point of view, the incentive structure is vital in determining the adequate level of margins. A wide range of contractual arrangements has been tried, and some clear opinions as to the suitability and risks of the different types were expressed in conversations. Fabricators of for instance steel structures will have most of their costs directly related to the number of tonnes of structure produced. These suppliers will often request contracts where they are paid by the tonne, to connect their cost and revenue basis. This would be problematic, as it will give the fabricator an incentive to increase the weight of the unit, adversely affecting the margin level.

3.2.5. Technology development

Technology is a key aspect of all parts of oil field developments, regardless of whether the subject is drilling, intervention or production rigs. Developing this technology is, as with any other technological development, a mixture of trying and failing and applying known methods to new problems. In any case, this will increase the risk of the project, which has to be handled in some way. The full spectrum exists within the oil business from oil companies that only order a proven design to companies that orders rigs that include new, not yet developed, technological advances. The uncertainty, and therefore the level of margins needed in each case are very different. The key question is, according to AKSO employees, the change in input: The process of designing and building rigs can be structured such that no major changes are introduced after a certain stage. For all practical purposes, this means that skilled designers are able to hit their weight and cost target with a very high level of certainty. This is however, not the most common way of structuring the project, as it can have adverse effects on the overall profitability of the oilfield. The other extreme is to order a rig with unproven and undeveloped technology. In these cases, the technology development will happen as a parallel process to the design of the overall rig. To embark on such a project, a high level of flexibility must be built into the project through weight allowances and robust deadlines for implementation.

3.2.6. Contingencies

All of the previously stated factors serve as the context in which the AKSO employees make their decisions. In order to provide some specific examples of contingencies and available solutions to compensate for higher-than-expected weights, the problem-solving aspect of engineering was discussed with a number of professionals. As previously outlined, the actions taken in Project A saved time and money through early on preparing the rig for a possible installation of sponsons. There are a few complications to this action however. Increasing the size of the pontoons will affect both the global strength of the rig as well as the mooring system due to the increased size of the columns, leading to increased environmental loads. If these loads are of material importance, this is a serious complication, but for reasonable sized sponsons the structure is able to absorb these additional loads. The cost of doing this adjustment is very dependent on how it affects the overall project; the new stability calculations require roughly a weeks' work, while producing new drawings is another 5-10 weeks. Minimizing this delay, and thereby the cost, requires preparing the hull, as outlined in chapter 2.4.1. A full resizing of the hull is another option available to the project management. As a resizing is a major task, this option is only available immediately after the FEED, and consequently not evaluated in more detail.

3.2.7. Finding the correct level of margins

The subjects of all the subsections of chapter 3.2 come together to provide the requirements for margins in a project. These requirements do however, not lead to a simple calculation of how much is needed, but a more subjective and experience based evaluation of the uncertainty at hand. Overall AKSO employees stated that a margin of 10% of operational weight was common, but for weight sensitive structures such as spar platforms, the margin is much lower. On the question of whether this was appropriate, the subject was discussed in terms of many related questions and subject. The interesting parts of these discussions were the follow-up from these statements where a number of relationships and possible issues were discussed:

- It was the experience of certain members of the project team that large margins lead to a lack of weight control and vice versa.
- The cost of allowing the hull to be suboptimal (too large) is very small compared to the potential cost savings it could lead to later, both on the hull and on the topside construction.
- The different disciplines have a vastly different focus; the hull engineers are very much focused on weight, while the process engineers focus on the operating functions of the rig.
- The real cost (downside) to a project is not cost overruns and faulty engineering, as the first is often due to an increased scope and the second one a simple question of having the right people and experience. The real cost risk to large offshore projects is the potential delays; the contracts are often such that penalties are imposed on the Contractor in case of late delivery. In addition the Contractor will often be willing to lose substantial amounts of money to keep the schedule in order not to be excluded from future projects.

All these factors are examples of how the engineering and outside-world are connected and affect each other to create a more complex picture where the exercise of calculating the optimal margins are just part of the picture and not the final answer.

4. Basic numbers analysis

The main numbers from AKSO assessed were the dry weight, the operational weight and weight margin development. These numbers were inserted into a spreadsheet to get an overview over the differences and similarities, and basic statistical tools were used in order to find possible relationships and underlying factors affecting the numbers. As a general background to these numbers, Statoil have a requirement for the accuracy of the weight development from FEED to finished rig to an 80% likelihood of less than 10% increase in weight. Similarly, AKSO have a target, and to some extent a history, of an average weight increase of about 5%.

4.1. Variance

As the information provided in the weight reports differs, the information is not always directly comparable. The dry weight development of the rigs is, however, available for all five. The standard deviation of the percentage change from revision to revision was calculated for both the first half of the available revisions and for all the available revisions. As some projects have an odd number of revisions, the standard deviation of change of these is measured ignoring the middle number.

Project	Project A	Project B	Project C	Project D	Project E
Number of revisions	26	20	33	19	23
Standard deviation full [%]	0.72%	1.28%	0.55%	1.50%	0.94%
Standard deviation first “half” [%]	0.78%	1.69%	0.48%	1.65%	1.27%
Overall weight increase	6.9%	0.5%	5.5%	21.4%	8%
Adjusted (overall) standard deviation	3.67%	5.72%	3.16%	6.54%	4.51%

Table 1 - Standard deviation of weight development

While the numbers of projects assessed are certainly not sufficient to conclude on a general basis, the table above indicates that there is no direct relationship between the volatility in the weight reported and the overall result of the project. Project A and Project D are in different ends of the scale, and even adjusting the numbers to overall project volatility yields similar results. Similarly, Project B has a large standard deviation, but a very small overall weight increase. The challenge of adapting to increased weight is not only dependent on the weight increase, but also where this weight is positioned. This can be illustrated by the difference between Project E and Project A, where Project E experienced an margin decrease of 24% on a weight increase of 8%, while Project A experienced an margin decrease of 100% on a weight increase of 7%. The Contractors margins were for the projects A and E 9.5% and 5% of total dry weight respectively. The underlying reason is that, while Project A weight overruns occurred on the Contractor estimates, Project E had virtually no change on the Contractor estimates and the Company through added requirements initiated all the weight change. This illustrates the limitations to this analysis, but it also indicates the expected range of volatility in these types of projects is estimated to be between 0.58% and 1.5%.

As shown in the previous table, the standard deviation of change is higher, in some cases substantially higher in the first half than the measured value using the overall figures. This indicates that the large changes in general are experienced during the early phases of the project. This is very much in accordance with what one would expect.

4.2. Size of changes

In addition to the mathematical exercise of calculating the volatility of the weights reported, a secondary and simpler analysis was performed to assess whether large changes in period t-1 indicated an increased likelihood of similarly large changes in period t.

Counting the number of times the absolute difference between the weight of period t-1 and t exceeded some threshold was the first task. Then, the number of times the event occurred in both t-1 and t was counted, and the number of times it occurred in t, when it had not occurred in t-1 was counted. This method was used to give an indication as to whether a large change was a warning sign. Combining the likelihood of all the projects together showed that the likelihood of large changes was higher in period t when large changes had occurred in period t-1. This result was also robust for changes in the threshold used to define large and small changes, as shown in the graphical representation below.

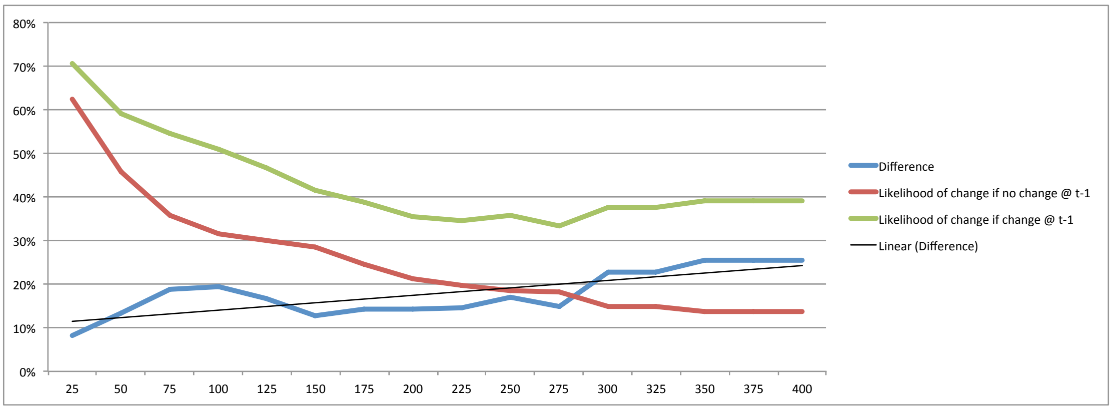

Figure 22 – Likelihood of large consecutive changes

Interestingly though, the two projects described as real successes differentiated clearly from the rest in this analysis. They showed a clear pattern of less likelihood if large changes in t, given large changes in t-1. Although, the Project E project had a pattern of increased likelihood when the threshold exceeded 250 tonnes, the number of measurements in this range for single projects is too low for any real analysis to be performed. The numbers also showed that a majority of the large changes, about 60-80% depending on the cut-off value, occurred in the first half of revisions, which is in accordance with the concept of decreasing uncertainty and the difference in standard deviation of change.

4.3. Simulation

In order to get a picture of how the vessel weight changes, simulations were performed using the total dry weight as the underlying variable.

4.3.1. Initial method

The basis of the simulations is an idealized model of how the weight develops during the project. This model is based on a couple of assumptions:

- The percentage change from node to node can be modeled to follow a lognormal distribution.
- The variance of this distribution does not change during the project.
- The expected overall weight growth of the unit is 5%

The lognormal distribution is convenient as it only provides positive values, and it can be adapted to give a low probability of extreme events, not relevant or realistic for the subject of building rigs.

The probability distribution function of the lognormal distribution is (Weisstein):

$$f(x) = \frac{1}{X\sqrt{2\pi\sigma^2}} e^{-\frac{(\ln X - \mu)^2}{2\sigma^2}}$$

Formula 20 - Probability distribution, lognormal

Giving a function generating random numbers from the distribution:

$$r = e^{N(X)\sigma + \mu}$$

Formula 21 - Random number formula, lognormal

The latter formula was implemented in Matlab, along with the exponentially adjusted variance and mean (MathWorks, 2013). The simulation was performed for five levels of volatility ranging from 0.4% to 1%. These numbers are comparable to the figures discussed in chapter 4.1.

4.3.2. Project event simulation

Using the simulation model shown in the previous chapter, a more realistic and complex model was developed. This model is able to estimate the likelihood of having to take action to compensate for a challenging weight development.

Two tools were available to counteract the increased weight: A weight decrease could be included once per rig and only in the early phases (first 11 stages), and sponsons could be added to the rig an unlimited number of times and at any stage. The model assumes that the weight increase is prioritized over the installation of sponsons. The number of times each of these measures was implemented was counted, and the weight development was adjusted down by 5% for both types whenever the weight exceeded 110% of the initial weight. An important issue in this regard is that the increased margins were modeled as a weight decrease, not an increased allowance. This is for all practical purposes equivalent. The simulations was performed in order to get four main figures:

- The probability of exceeding maximum weight (110%)
- The probability of having to reduce the weight of the rig
- The probability of having a rig with sponsons
- The number of sponsons installed as percentage of the number of rigs

The difference between the two latter is an indication of how many of the rigs would have to install large sponsons, exceeding the standard size of 5% of overall weight. These calculations were performed for four of the levels of variance described earlier, as well as a fifth alternative, where the variance was configured to fit the Statoil requirement for minimum design accuracy. The lowest level of variance was ignored, as the likelihood of a weight increase of more than 10% was too low to be relevant.

Following the findings in chapter 4.1. and 4.2. it was considered by the author to expand the simulation model to also include a decrease in weight development variance. The limited data available however, meant that it was thought to be of limited use, as it would increase the perceived quality of the simulation without having the data to make reasonable estimates for the new variables introduced.

4.3.3. Results and scenario analysis

As only 50 simulations were performed for each alternative in the initial phase, it was possible to visually evaluate each graph. Comparing the results of the simulations with the previous projects and discussions with AKSO employees yielded the conclusion that alternative three and four were most realistic.

Using the more elaborate project simulations in Matlab provided the relationship between project outcome and weight volatility:

Alternative **Standard deviation**	**2** **0.55%**	**3** **0.70%**	**4** **0.85%**	**5** **1.00%**	**Statoil** **1.10%**
Probability of exceeding max weight	4.4%	9.4%	13.3%	17.3%	19.9%
Percentage of rigs with weight adjustments	0.0%	0.1%	0.3%	1.0%	1.5%
Percentage of rigs with sponsons	5.2%	11.3%	16.1%	21.4%	24.5%
Percentage of sponsons	5.2%	11.9%	17.7%	25.5%	30.1%

Table 2 - Results of simulations

As outlined earlier, the Statoil simulation is based on hitting a probability of exceeding max weight of 20%, and the scenario analysis was performed using 15,000 simulations for all five alternatives.

The first result of this scenario analysis is that this model provides reasonable answers: The level of variance is in the same range as the projects evaluated in this paper and the likelihood of exceeding the maximum weight limit is reasonable according to experienced industry professionals. One interesting aspect of this analysis is the difference between the number of rigs that eventually exceeded the weight limit and the percentage of rigs with sponsons. One of the assumptions of this model is that the project team makes the decision to implement sponsons whenever the rig weight exceeds the limit. This lead to some rigs having sponsons, without actually needing them, as their weight decreased after they were installed. This is the case for about 20% of the rigs with sponsons, regardless of the level of variance.

Comparing the levels of the Statoil requirement to the base cases of alternative three and four reveals quite large differences in terms of how common sponsons, and other margin adjusting actions are, and can be in projects. The difference of a “sponsons probability” of 16.1% (alternative 4) and 24.5% (Statoil requirement) is substantial. Another issue is the availability of early decreases of weight; for alternative three and four, these are practically not available as a weight control tools.

5. Valuation and decision analysis

Constructing holistic methods for finding and evaluating margins and flexibility means that the economic models presented and practical information on project execution must be merged. What assumptions are made and the choice of what and how to model the different aspects of the actual process is central to the quality of the answers attained. This chapter describes how this merger has been performed, and is imperative to the understanding of the results they lead to.

5.1. Assumptions of models

Moving from a model structure to actual calculations require some assumptions and estimates. For all three models used, the underlying numbers are the same, although they are not directly measurable and therefore to be seen as a best-guess estimate.

One of the primary factors influencing all of the models is the cost related to exceeding the weight capacity. This cost has been divided into two parts: A start-up (fixed) cost and a variable cost, dependent on the size of the margin increase. The fixed cost is calculated on the basis of a delay cost and an engineering cost. The latter would be incurred due to the resizing of the hull, which would be about 350 hours of work at a rate of roughly 1,000 NOK per hour. This estimate is fairly accurate according to AKSO employees, assuming that no large problems surface. The delay costs are slightly more complex, as they are very much project specific, but as an indicative scenario the delay cost is assumed to be equivalent to a heavylift vessel waiting for 60 days at a dayrate of $300,000 per day, with a USDNOK of 5.75. The delay is determined using the *best-guess* of Anders Martin Moe of AKSO, where a scenario of the decision to install sponsons is made when the rig has been finished. The day rate is deducted from the annual report of heavy-lift vessel operator Dockwise (Dockwise, 2013). For a large floating production unit, a heavy lift vessel on the size of Dockwise Vanguard would be required. This vessel has an investment cost of about $254 million. Overall, Dockwise was able to generate revenues of $539 million on “Property, plant and equipment” of $1,366 million, leading to a ratio of yearly revenue to assets of 0.39. Applying this ratio, with a premium of 10% to account for the lack of similar vessels in the market, yields a day rate of roughly $300,000.

The variable costs were assumed to be NOK 100,000 per tonne; these are extraordinary costs simply due to the inconvenience of fabricating the hull at a later-than-optimum stage of the process. In addition, the weight to margin increase of sponsons is assumed to be 0.25.

One issue with the newsvendor model is that the marginal cost of overage implemented in the model is complicated due to the practical factors. It seems unrealistic that the project team would increase margins less than 1000 tonnes due to all the extra work it requires and the comparably small size of such an increase relative to the overall rig. Consequently, the fixed cost of overage is translated into a variable cost on the basis of the number of tonnes of minimum size increase.

5.2. Newsvendor model

The simplicity of the newsvendor problem, make the case discussed in this paper, quite easy to implement. The structure of rig projects fit very well, as described in chapter 2.4.2. A few assumptions have to be made in order to find the answers needed: First of all, the variables described in the previous mentioned chapter are to be treated as constants, yielding an answer by finding these values and implementing them into the *Optimum Service Level* equation, and secondly implement the probability into a statistical distribution to get the numerical value of the optimum margin level. Interestingly, the optimum service level in itself is a number to consider, as it is the goal, and strikes directly on how the project is evaluated afterwards. This can be compared with the level that AKSO employees thinks is appropriate.

5.3. DTA model

Modeling for a DTA is very flexible, as it is designed to incorporate practical problems. Weight reports provided by Aker solutions could be used as an indication of how the project is divided into discrete steps, with between 20 and 30 being the normal for a production unit. At each of these stages, the project team has a number of options available, but for the sake of this model, this has been simplified to a couple. While it may be practically possible, it is assumed that the cost of scaling down the size of the hull outweigh the benefits of such a change.

The event tree is developed using previous AKSO projects along with the professional experience of key AKSO employees. A multitude of variables are included in this process, so practically any event tree can be created from the information available. Two projects were chosen as extreme scenarios: Project D and Project B. The Project D project has been used as-is, while the Project B project has been adapted to include a gradual and cumulative weight reduction of 5% in addition to the overall weight development. All values between these two are linearized between the two extremes. The likelihood of upward and downward movements were adjusted to create a tree where the final values are within what is expected from the previous projects discussed and Statoil project requirements. Most importantly they were also discussed with AKSO employees, to find values that appropriately mirrored their experience.

5.4. Real options model

Instead of looking at the weight development of a rig as a technological risk, the weight development can be modeled as a random variable, taking all the properties of market risk. This would make the DTA less suitable, and a real options approach more convenient. Similar to the DTA model, the cost of down scaling the size of the hull is assumed to be higher than the benefits, and as such not an option. The options available to the managers is the same for DTA and real options valuation, as well as the division between initial design phase and detailed design phase.

A key difference between the DTA model and a real options model is how the event tree is developed; while the hands-on approach used for DTA require a lot of work, the mathematical model used for real options means that larger trees can be built with little effort. One constraint here, however is the complexity of the options involved, which for real options could make it more of a black-box method. The important distinction here is not the method, which to a large degree is similar, but the underlying assumption: Is it more appropriate to model the weight development of a rig as a technological or commodity risk? This is discussed in chapter 5.6.

The options are equivalent in the DTA and real options model, making it possible to compare the two methods directly. A couple of aspects of the real options model should be discussed more in detail. First of all, the expected weight growth of the project is included in the first node, making the total weight in this node higher than for the DTA model. Secondly, the interest rate chosen affects the probability distribution. The biggest, and probably least intuitive factor is the standard deviation of change, sigma. The value chosen for the calculation is 0.85% per period over 20 periods and the appropriateness of this value must be seen in context of the discussion in chapter 4.1.

5.5. Pricing of margin value DTA and real options

To be able to translate weight into cost and use that as a decision mechanism, this paper assumes a 1:1 relationship between cost and weight, within a reasonable specter. This means that the previously outlined method of developing scenario trees for real options are not only practical, but also theoretical consistent. The tree developed in the DTA is more flexible, and as such, any relationship between cost and weight would be acceptable.

In order to create a consistent pricing method for pricing the scenarios developed, a couple of assumptions have to be made:

- The topside weight development is compensated for by changing the size of the hull
- The weight development itself is exogenous and not subject to management decisions
- The only cost driver is the change in size of the hull, which is a lump-sum cost

Furthermore, a 10% margin is included. Following the four steps of Koller, Goedhart & Wessels, a cost is added to all the end nodes with a weight exceeding the margin. This cost is the same as the one calculated for the newsvendor problem. The process of using backtracking from right to left, as described in chapter 2.4.1.3 is then used to find the expected cost of exceeding margins.

In order to model the flexibility of managers and thereby estimate the value of said flexibility, further assumptions have to be made. The cost of increasing the size of the hull is roughly dependent on two factors: The cost of engineering and fabricating the extra steel and the delay cost, due to waiting heavy lift vessels and postponed production. The two groups have been defined such that all the base costs are included in the first, and the delay cost includes all the extra cost due to the timing of installation of the sponsons. Usually, the schedulers are able to cut down some of the delay posed by the implementation of sponsons, but their ability to do that is very much dependent on when the decision is made. Therefore the delay costs are cut by 10% for each of the phases earlier than the last the decision to include sponsons is made. Imposing this cost structure on the table, makes following calculations quite simple; the cost is minimized among the options of installing sponsons and not installing sponsons. Again moving from right to left, creating a tree calculating the final cost, and a tree visualizing the decision process.

To make the model realistic, it is assumed that the design of the unit can be divided into two stages: Initial design and detailed design. During the initial design phase, the project is quite flexible and designers can implement a wide range of actions to counteract potential increases in weight. The extent of the flexibility of project management in a rig project is significant, and as such complicated to model. While the option of actually modeling all this flexibility was a possibility, for the purpose of this paper, only two levels of flexibility were modeled. The base case, as required by the options model used (Koller, Goedhart, & Wessels, 2010), valued extra cost increasing the hull size (installing sponsons) based on the decision being made at the last minute, with all the costs that follows.

The first option model (option 1) was based on the option to install sponsons according to the worst-case scenario at an earlier stage at a rebate. The justification of this rebate is the reduction in re-engineering, building and delay cost. As evident from the cost calculations made in the newsvendor model, the delay costs are a huge part of the total costs of exceeding the weight limit. This means that there could be an incentive to prepare the rig for sponsons, in order to cut or eliminate this delay. As described previously by Nymoen in chapter 2.4, this is possible, but not modus operandi. Using this method in general could yield some extra value to the project. This extra option (option 2) is modeled as a one-time-offer at stage six to buy an option to eliminate the delay costs (of maximum NOK 100M). The overall value of this option was then compared with the overall value of the first model. Naturally, the project team can chose not to make changes at a zero cost at every stage. Table 3 shows basis for each of the models:

	DTA	Real Options
Weight development upper extreme	Equal to percentage change of Project D	Volatility 0.85%
Weight development lower extreme	Equal to percentage change of Project B	Volatility 0.85%
Mid-value methods	Linear average	N/A
Starting point (percentage of estimated weight)	100%	105%
Margin applied	10%	
Risk free interest rate	N/A	0%
Cost structure	NOK 500,000 per tonne for topside, NOK 100,000 per tonne for hull. Investment in preparatory engineering for sponsons of NOK 2,000,000. 10% rebate per stage for earlier decision on extra costs.	
Weight increase to margin increase ratio	25%	
Periods	20	

Table 3 – Basis for calculations

5.6. Weight risk

Determining the appropriate method of valuation is dependent on the assessment of the underlying risk. Many of these risk factors have been named, but not necessarily in the context of risk type. Obviously, one major driver of weight risk in an engineering project is the technological risk that exists due to the actual development of the product. As previously stated this risk factor is to a large extent controlled through the use of experienced engineers and managers. The effect of high market demand have in the same way surprised the very same engineers, implying that the market risk does have role to play. This is a longer-term effect however, which should affect the weight level with a time horizon longer than the project. As seen in Project A this level is discovered throughout the project rather than being a single event, making the effect as much a short-term as a long-term risk. Similarly an outside influence, such as the oil price or interest rate, could influence the project resulting in the weight development risk being non-diversifiable; a market risk.

6. Discussion

As previously stated, the results attained from the models used in this paper are subject to inaccurate input, and as such the focus of the results is the implication of the values and relative values rather than exact numbers itself.

6.1. Project analysis and discussions with AKSO

The project analysis of this paper shows, assuming the involvement of competent engineers, that the key driver of uncertainty in projects is the structure and requirements of the project with respect to time and cost. The implication being that a reduction in uncertainty, through more accurate estimates or overall project flexibility, will be used to further accelerate the overall project timeline. Good project management is essential in this regard, but the completion of a set plan is not they key issue. The ability of the management to prepare, structure and handle the changes that will occur to some degree on almost every single project is what distinguishes “good” and “bad” projects.

6.2. Basic numbers analysis

Weight volatility varies quite a lot between the projects assessed in this paper. While the relationship between final weight and weight volatility is not obvious from the data attained, the difference between the overall weight volatility and the “first half”-weight volatility indicates that the overall uncertainty is reduced in the latter phases. Looking at when the larger changes occur in absolute terms, the picture is similar. As the uncertainty of project execution makes planning complicated, any indication of future problems would be valuable to project management. The analysis showed that a large change in a period indicated a higher likelihood of change in the next period. This result was valid regardless of the threshold used to define a "large change", as seen in Figure 22.

The simulations performed, using volatility consistent with project data, showed results very much similar to project history, Statoil requirements and were in line with what AKSO employee thought to be reasonable. This is a good indication that the lognormal distribution is a good approximation of the realities of the projects modeled. The simulation results indicate that, as a margin control tool, an early weight adjustment is not a realistic method.

6.3. Newsvendor method

A single value is the result of a newsvendor model: The optimum service level. For the model used, as described previously and included in the appendix, the optimum service level is 86%. This is the share of the rigs that are completed without exceeding the weight capacity and is directly comparable to the 80% requirement set by Statoil and the simulations performed. These simulations yielded a share of non-sponson rigs of between 89% and 84% for the base alternatives. Despite the limitations of the model, this is a clear indication that an optimum service level is above the Statoil requirement and that AKSO is close to this level. The optimum margin level was calculated to be between 9% and 10%, using the optimum service level and a lognormal distribution with 3.8%/4.3% overall project standard deviation. This is in the same range as both the simulations performed and project history.

6.4. Decision tree analysis

Following the process of Koller, Goedhart & Wessels means three values are important: The base Expected-Cost-of-Overage (ECOB), the option alternative 1 Expected-Cost-of-Overage (ECO1) and the option alternative 2 Expected-Cost-of-Overage (ECO2). Obviously, the value of the options is the maximum of 0 and ECO-B minus ECO1 or ECO2, depending on the option evaluated.

ECO-B is NOK 22.6 million, ECO1 is NOK 20.4 million and ECO2 is NOK 17.8 million, resulting in an option value for option 1 and 2 of NOK 2.3 million and NOK 4.9 million respectively. Clearly, optionality has a significant value-effect on the project, and even more so on the profitability of the Contractor as the stakeholder most directly affected by overage costs. The increased optionality of option 2 compared with option 1 is also significant.

Calculating the resulting likelihood of weight overage for this model yields a value of an 82% likelihood of having a less than 9% overage. This value is not directly comparable to the Statoil requirement, but comparing past projects and the probability distribution used shows that they correspond fairly well.

	Maximum deviation	Probability
Basis for tables, AKSO history	5%	67%
Basis for tables, AKSO history	10%	83%
Statoil Requirement	10%	80%
Current structure, as made	9%	82%

Table 4 – Project history versus modeled probabilities

6.5. Real options

The expected costs of overage are defined in the same manner for real options as for decision tree analysis, and as such are comparable. It is, however, important to note that the underlying probability tree is different, yielding a different ECOB value as well as ECO1 and ECO2.

ECOB for the real options valuation is NOK 11.1 million, ECO1 is NOK 10.7 million and ECO2 is NOK 10.5 million. This yields a value of option 1 of NOK 0.4 million and a value of option 2 of NOK 0.6 million. These values are insignificant compared to the overall cost of a drilling or production rig. The real options method, as used, yields a probability of non-overage of 80.6%.

6.6. Weaknesses of models

The biggest problem when constructing any model is the trade-off between the accuracy of the model and the complexity of it. The same issue is clearly present here as well. As previously discussed, designing and building an offshore floating unit consists of numerous tasks and millions of hours of work. Each person involved in the project will, to some extent, be able to affect both the final result and the process up to that result through the latent flexibility. Each of these contributors of flexibility could, in theory be modeled, but it would make for a complex model, not many people would be able to understand. Therefore, the choice has been made to include two simple options, which, although simplified, explain the value of certain flexibilities held by the project management. The inputs of these models has been an area of discussion and are uncertain, but has been adjusted to reflect the best guess of the parties contributing to the project from Aker Solutions. The models are also quite sensitive to change in input, making a further upside on the options value possible. For the newsvendor model, the issue is quite simply the accuracy of the input and the assumption of a linear relation. These issues are however, not a problem for the project as a whole, as they affect the accuracy of the values attained, not the applicability of the models themselves. As the number of offshore floating rigs built is limited and the industry is reluctant to share data, the applicability of the data is a challenge, as sufficient data cannot be attained to conclude with a high degree of statistical certainty.

Modeling the human factors described in this paper is a complicated issue and their effect on the applicability of the mathematical models is not immediately clear. For single projects, the qualitative data of the human component is in some cases clearly important, as previously discussed in chapter 3. When describing a larger set of projects however, the simulations seem to cover the outliers sufficiently, even the projects where the human component was substantial.

7. Conclusion

Change is an inherent feature of executing large-scale projects such as the design and building of large floating offshore units. The project execution models used also shows this, focusing on progress while allowing for changes. The feature that distinguishes successful from failed projects is the ability of the project team to utilize flexibility to counter uncertainty. Weight margins are the most important quantitative determinant of flexibility, but the high cost of increasing the hull weight makes qualitative measures interesting.

Project history focus heavily on the importance of the human component in the management of projects; the execution is more than anything else dependent on the people involved and how they steer the project. Looking at the actual numbers indicates that change fosters change; large changes during the process greatly increase the likelihood of large changes in the next period. Simulating the process of weight change with a 10% margin yielded similar results to the project history and experience of AKSO employees.

Interestingly, using the newsvendor model to calculate to optimum service level, that is likelihood of not exceeding the weight limit, returned values similar to the simulation, indicating that the current level of volatility in the AKSO projects are quite close to optimum.

Moving towards a system of exploiting the qualitative flexibilities of project execution utilized a decision tree analysis and a real options model. While the actual values and costs related to weight overage diverged somewhat, and seems small compared to the overall cost of for example a production rig, the relatively cheap optionality evaluated should still be worth exploiting for the Contractor. The value calculated is not as important as what it proves; that the value of flexibility can be further utilized, as in Project A, to increase the overall value of the projects. With the option value in the range as indicated, the Contractor have a huge incentive to further refine and adapt the method used to increase their profitability.

8. Further work

Further work would primarily be based on describing the issues presented in this paper in more detail using more comprehensive data. Statistical analysis on a larger set of projects would certainly contribute to improve the understanding of the process. The underlying process of weight development is central to the issues described in this paper. Work focused on understanding whether a market risk model or a technological risk model is more appropriate would improve the pricing of the underlying flexibility and increase the understanding of the drivers of weight growth.

9. Bibliography

Aas-Jacobsen, I. (2013, 02 28). Personal communication. Lysaker, Norway.

Aker Solutions. (2013). *Semisubmersible drilling rigs*. Retrieved 02 21, 2013, from Aker Solutions: http://www.akersolutions.com/en/Global-menu/Products-and-Services/technology-segment/Engineering/Floater-designs/Semisubmersible-drilling-rigs/

Almeland, I.-B., & Pettersen, D. J. (2002). Snorre B Hull: Fabrication, Erection and Transportation. *Offshore Technology Conference.* Houston: Offshore Technology Conference.

Amdahl, J., Endal, A., Fuglerud, G., Minsaas, K., Rasmussen, M., Sillerud, B., et al. (2003). *TMR4100/TMR4105 Kompendium.* Trondheim: NTNU.

Birkeland, V., Kviljo, K., Brustad, H., & Aasgaard, G. (2002). The Snorre B Project: Main factors contributing to the success. *OTC 14225.* Houston: Offshore Technology Conference.

Black, F., & Scholes, M. (1973). The Pricing of Options and Corporate Liabilities. *The Journal of Political Economy* , 637-654.

Boer, F. (2000, 07). Valuation of Technology Using "Real Options". *Research - Technology Management* , 26-30.

Bryhn, R. (2012, 10 25). *Aker AS - Store norske leksikon*. Retrieved 01 14, 2013, from http://snl.no/Aker_AS

Caveny, K., & Marquez Jr., P. (1984). Hutton Tension Leg Platform: An Exercise in Weight Control. *1984 Offshore Technology Conference* (pp. 389-398). Houston: OTC.

Dockwise. (2013). *Annual Report 2012.* Dockwise.

D'Souza, R., & Basu, S. (2011). Importance of Topsides in Design and Selection of Deepwater Floating Platforms. *Offshore Technology Conference.* Rio de Janeiro: Offshore Technology Conference.

Dryships Inc. (2011, 09 22). *Drypships irwebpage.* Retrieved 04 03, 2013, from Dryships: http://dryships.irwebpage.com/files/information_statement.pdf

Floricel, S., & Miller, R. (2001). Strategizing for anticipated risks and turbulence in large-scale engineering projects. *International Journal of Project Management* , 445-455.

Ford, D., & Lander, D. (2011). Real option perceptions among project managers. *Risk Management , 13* (3), 122-146.

Ford, D., & Sobek, D. (2005). Adapting Real Options to New Product Development by Modelling the Second Toyota Paradox. *IEEE Transactions on Enigneering Management , 52* (2), 175-185.

Ford, D., Lander, D., & Voyer, J. (2002). A real options approach to valuing strategic flexibility in uncertain construction projects. *Construction Management and Economics , 20* (4), 343-351.

Gallego, G. (1995, 04 06). *The Newsvendor Problem*. Retrieved 02 15, 2013, from Columbia University: http://www.columbia.edu/~gmg2/4000/pdf/lect_07.pdf

Hagen, A. (1993). *The Framework of a Design Process Language.* Trondheim: Institutt for Marin Teknikk.

Hillier, F. S., & Lieberman, G. J. (2010). *Introduction to Operations Research.* New York: McGraw-Hill.

Johnson, S. T., Taylor, T., & Ford, D. N. (2006). Using System Dynamics to Extend Real Options Use: Insights from the Oil & Gas Industry. *The 24th International Conference of the System Dynamics Society.* Nijmegen: System Dynamics Society.

Kaasen, K., Isaksen, I., Bergseth, S., Grønner, E., Hervik, A., Moe, B., et al. (1999). *Analyse av investeringsutviklingen på kontinentalsokkelen.* Olje- og energidepartementet, Investeringsutvalget. Oslo: Statens forvaltningstjeneste.

Knudsen, A., & Høyby, K. (2004). Successful deepwater platform execution. *Offshore Technology Conference.* Houston: Offshore Technology Conference.

Koller, T., Goedhart, M., & Wessels, D. (2010). *Valuation - Measuring and Managing the Value of Companies.* Hoboken, New Jersey: John Wiley & Sons Inc.

Laukeland, L. (2013, 02 28). Personal communication. Lysaker, Norway.

Nymoen, T. (2013, 05 15). Personal communication. Lysaker, Norway.

MathWorks. (2013). *Lognormal random number*. Retrieved 04 24, 2013, from MathWorks: http://www.mathworks.se/help/stats/lognrnd.html

Mattar, M., & Cheah, C. (2006). Valuing large engineering projects under uncertainty: private risk effects and real options. *Construction Manageent and Economics , 24* (8), 847-860.

Merriam-Webster. (2013). *Margin - Definition and More from the Free Merriam-Webster Dictionary*. Retrieved 04 05, 2013, from Merriam Webster: http://www.merriam-webster.com/dictionary/margin

Miller, R., & Lessard, D. (2001). Understanding and managing risks in large engineering projects. *International Journal of Project Management* , 437-443.

Moe, A. (2013, 04 04). *Personal communication* . Lysaker, Norway.

Morooka, C. K., & Galeano, Y. D. (1999). Systematic Design for Offshore Oilfield Development. *International Offshore and Polar Engineering Conference* (pp. 237-243). Brest: The International Society of Offshore and Polar Engineers.

Perlitz, M., Peske, T., & Schrank, R. (1999). Real options valuation: the new fronties in R&D project evaluation? *R&D Management , 29* (3), 255-269.

PTIL. (2003, 12 02). *Units for measurements of oil and gas*. Retrieved 02 27, 2013, from PTIL: http://www.ptil.no/information-services/units-of-measurement-for-oil-and-gas-article423-170.html

Sommerseth, T. (2013, 01 28). Personal communication. Lysaker, Norway.

Statoil. (2009). *Gjøa Brochure*. Retrieved 02 27, 2013, from Statoil: http://www.statoil.com/en/OurOperations/ExplorationProd/partneroperatedfields/Gjoea/Downloads/Brochure.pdf

Statoil. (2007). *Kristin*. Retrieved 04 24, 2013, from Statoil: http://www.statoil.com/en/ouroperations/explorationprod/ncs/kristin/pages/default.aspx

The ICE. (2013, 02 27). *ICE Report Center*. Retrieved 02 27, 2013, from The ICE: https://www.theice.com/marketdata/reports/ReportCenter.shtml?reportId=10&productId=254&hubId=403#report/10/reportId=10&productId=254&hubId=403

Triantis, A. (2005). Realizing the Potential of Real Options: Does Theory Meet Practice. *Journal of Applied Corporate Finance , 17* (2), 8-16.

Trigeorgis, L. (1996). *Real Options, Managerial Flexibility and Strategy in Resource Allocation.* Cambridge, Massachusetts, USA: The MIT Press.

Weisstein, E. W. (n.d.). *Log Normal Distribution*. Retrieved from Mathworld - A Wolfram Web Resource: http://mathworld.wolfram.com/LogNormalDistribution.html

10. Appendix

10.1. Newsvendor Problem

$$\pi(Q) = pE(min(Q, D)) + sE(Q - D)^+ - cQ$$

And

$$\min(Q, D) = D - (D - Q)^+$$

Can be rewritten such that:

$$\pi(Q) = pE(D - (D - Q)^+) + sE(Q - D)^+ - cQ$$

Algebra gives that:

$$cQ = c\mu + cE(Q - D)^+ - cE(D - Q)^+$$

Assuming Q>D

$$cQ = c\mu + (cQ - c\mu) - 0$$

Assuming D>Q

$$cQ = c\mu + 0 - (c\mu - cQ)$$

Furthermore

$$\pi(Q) = p\mu - pE(D - Q)^+ + sE(Q - D)^+ - c\mu - cE(Q - D)^+ + cE(D - Q)^+$$

Rewritten to be

$$\pi(Q) = \mu(p - c) - (p - c)E(D - Q)^+ - (c - s)E(Q - D)^+$$

Simplified to

$$\pi(Q) = \mu(p - c) - G(Q)$$

Where

$$G(Q) = (c - s)E(Q - D)^+ + (p - c)E(D - Q)^+$$

10.2. Project names

Confidential

10.3. Simulations

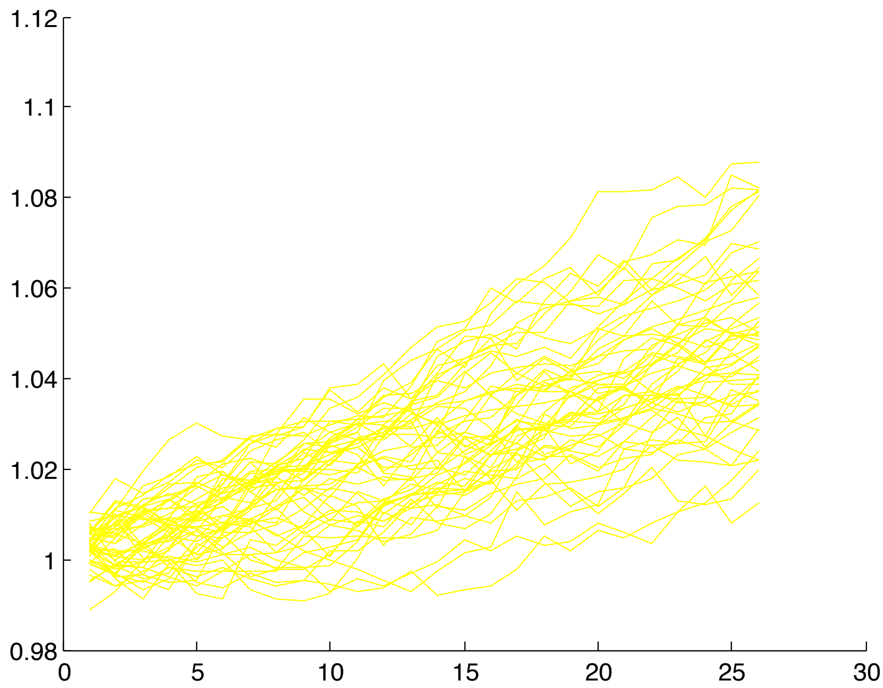

Figure 23 - 0.4% SD

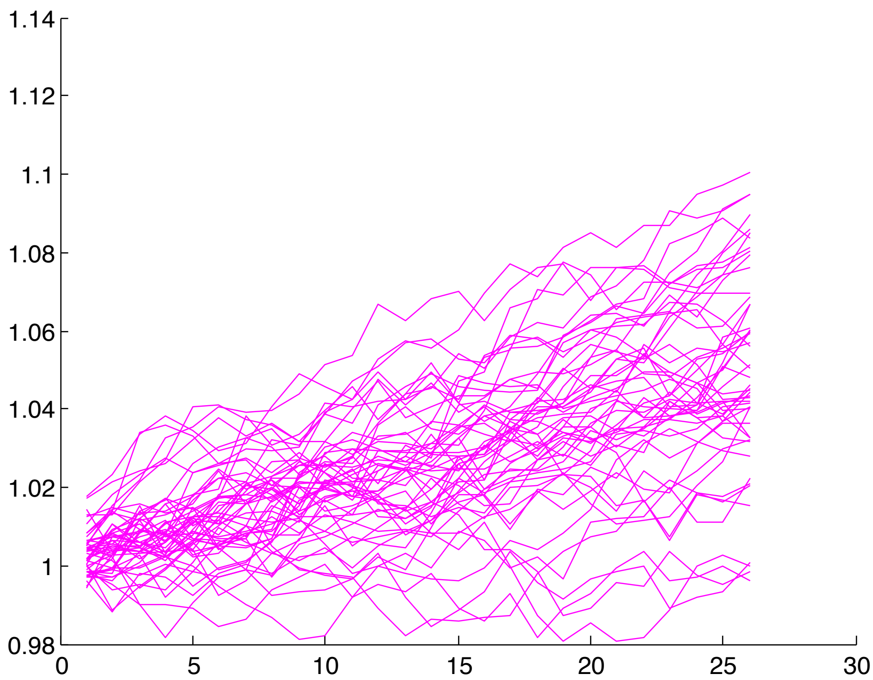

Figure 24 - 0.55% SD

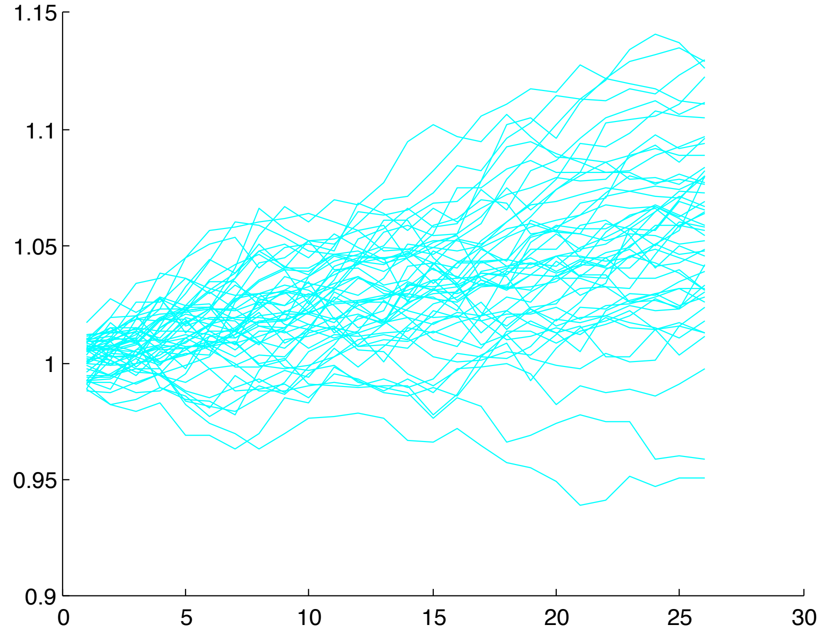

Figure 25 - 0.7% SD

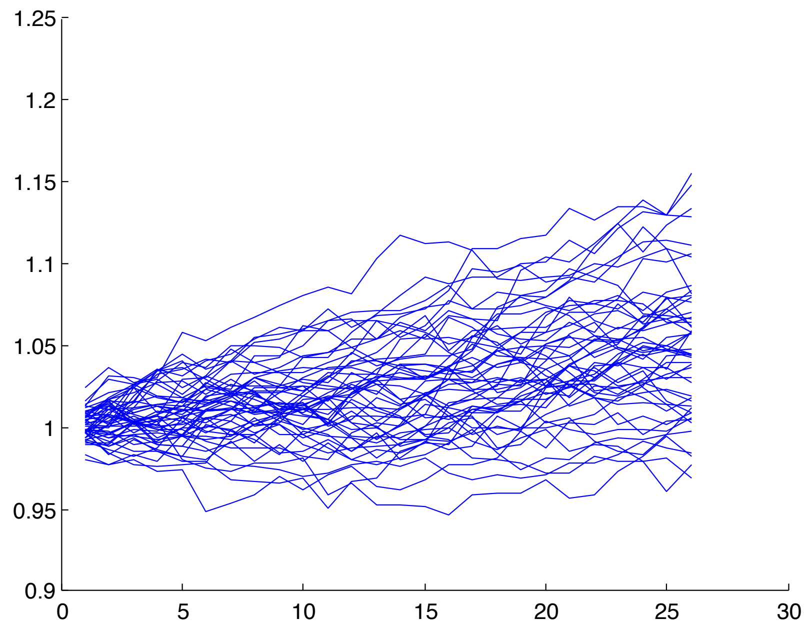

Figure 26 - 0.85% SD

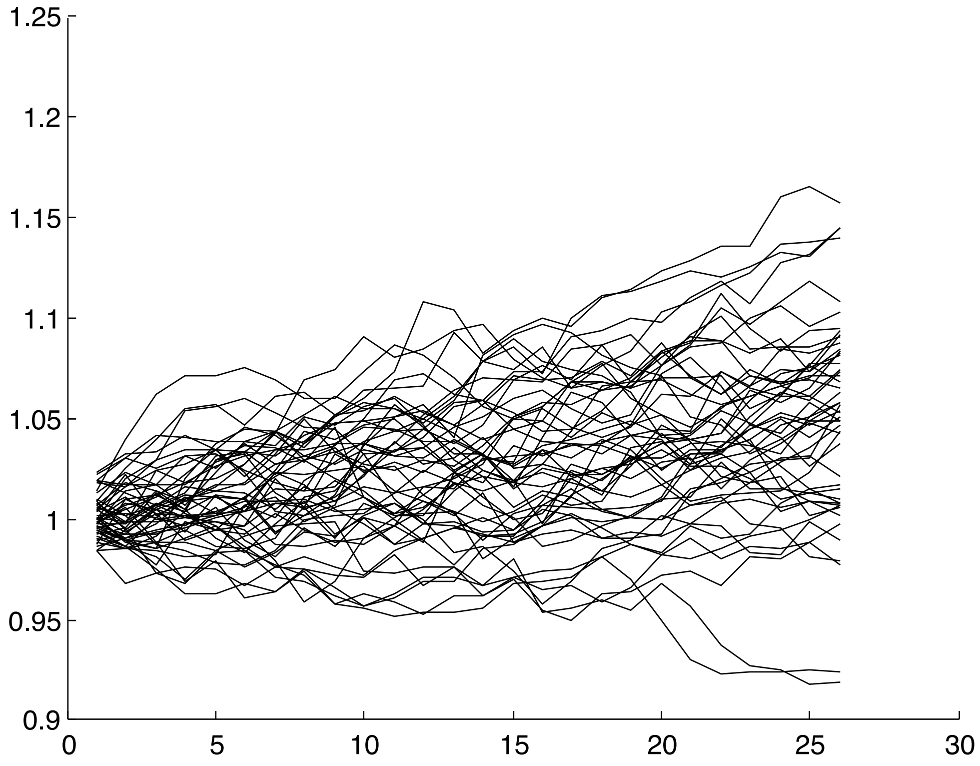

Figure 27 - 1% SD

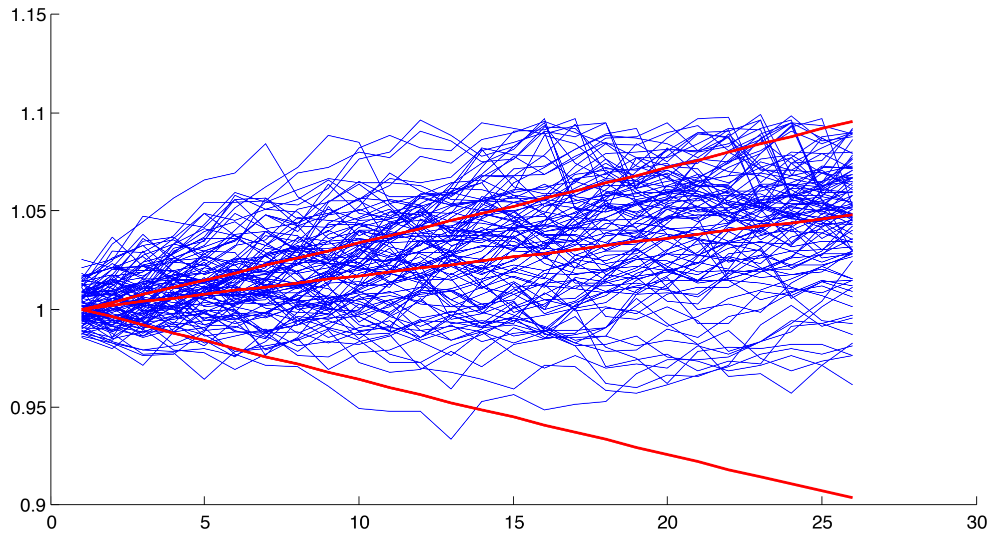

Figure 28 - 0.85% with red line showing +10%/+5%/-10%

10.4. Matlab code

10.4.1. Matlab code basis

```
n=100; % Length of simulation
l=50; %Number of simulations
m=1;
v=0.0001;
mu = log((m^2)/sqrt(v+m^2));
sigma = sqrt(log(v/(m^2)+1));

r=exp(randn(l,n).*sigma + mu);

for i=1:l
    y(i,:)=zeros(1,n);
    y(i,1)=r(i,1);
    for j=2:n
        y(i,j)=y(i,j-1).*r(i,j);
    end
end


hold on
for i=1:l
    set(0,'DefaultAxesColorOrder',[1 0 0;0 0 0;1 0 1])
    plot(y(i,:));
end
```

10.4.2. Matlab code full

```
n=26; % Length of simulation
l=100; % Number of simulations
g=0.05; %Expected total growth
gx=0.10; %Maximum positive growth
gn=-0.1; %Maximum negative growth

m =(1+g)^(1/n); % Expected growth per increment
mx =(1+gx)^(1/n); %Max average growth per increment
mn =(1+gn)^(1/n); %Max negative average growth per increment
v =0.00007225; % Variance of data

%All math based on MathWorks reference

sigma = sqrt(log(v/(m^2)+1));
mu = log(m)-0.5*sigma^2 ;

r=exp(randn(l,n).*sigma + mu);
c = 0;
N = 0;
q = 0;
s = 0;
spons = 0;


for i=1:l
    y(i,:)=zeros(1,n);
    y(i,1)=r(i,1);
    x(i,:)=zeros(1,n);
    x(i,1)=r(i,1);
    a(i)=0;
    b(i)=0;
    d(i)=0;
    for j=2:n
        y(i,j)=y(i,j-1).*r(i,j);
        x(i,j)=x(i,j-1).*r(i,j);
        if y(i,j)>=1.10
            if (a(i)==0)&&(j<11)        %Requires that hte weight reduction is not
already performed and that there is enough time, 15 periods is roughly 1.5 years
                y(i,j)=y(i,j)-0.05;     %LQ in made lighter, single option, cuts
weight by 5%
                a(i) = a(i) + 1;
            else
                y(i,j)=y(i,j)-0.05;     %Sponsons added, increase weight cap. by
5%, modelled as 5% weight cut

                b(i)=b(i)+1;
                d(i) = 1;

            end

        end
    end
end
```

```
for i=1:l
    if x(i,n)>=1.10
        c=c+1;
    end
    if x(i,n)<=0.9
        c=c+1;
    end
end

for k=1:3
    z(k,1)=1;
end
for j=2:n
    z(1,j) =z(1,j-1)*mx;
    z(2,j) =z(2,j-1)*m;
    z(3,j) =z(3,j-1)*mn;
end

hold on
t = 0:n;
for i=1:l
    plot(y(i,:),'b');
end

for k=1:3
    plot(z(k,:),'r','LineWidth',1.5);
end


%Average number of sponsons per project
for i=1:l
    s = s + b(i);
    q = q + a(i);
    N = N + d(i);
end
spons = s/l
Nspons = N/l
LQ  = q/l
prob = c/l
```

10.5. Weight reports

10.5.1. Project A

Confidential

10.5.2. Project B

Confidential

10.5.3. Project C

Confidential

10.5.4. Project D

Confidential

10.5.5. Project E

Confidential

10.5.6. Newsvendor model

Overview of basis and results of simulations

	Volatility	Variance*1000
Alternative 1	0.40%	0.0160000
Alternative 2	0.55%	0.0302500
Alternative 3	0.70%	0.0490000
Alternative 4	0.85%	0.0722500
Alternative 5	1.00%	0.1000000
Simulated	1.10%	0.00012

Statoil requirements yield a probability of sponsons of about 30% (30.24%)
Simulation give an average outside of limit probability of 20%

Result Matlab @ Statoil				
SD	1.10%	spons =	30.1%	Sponsons per try
		Nspons =	24.5%	Number of rigs with sponsons
		LQ =	1.5%	Number of rigs with weight adjustments
		prob =	19.9%	Probability of exceeding max weight
Alternative 5				
SD	1.00%	spons =	25.5%	
		Nspons =	21.4%	
		LQ =	1.0%	
		prob =	17.3%	
Alternative 4				
SD	0.85%	spons =	17.7%	
		Nspons =	16.1%	
		LQ =	0.3%	
		prob =	13.3%	
Alternative 3				
SD	0.70%	spons =	11.9%	
		Nspons =	11.3%	
		LQ =	0.1%	
		prob =	9.4%	
Alternative 2				
SD	0.55%	spons =	5.2%	
		Nspons =	5.2%	
		LQ =	0.0%	
		prob =	4.4%	
Acceptable results Aker		spons =		Sponsons per try
		Nspons =		Number of rigs with sponsons
		LQ =		Number of rigs with weight adjustments
		prob =		Probability of exceeding max weight

Alternative	**2**	**3**	**4**	**5**	**Statoil**
Standard deviation	**0.55%**	**0.70%**	**0.85%**	**1.00%**	**1.10%**
Probability of exceeding max weight	4.4%	9.4%	13.3%	17.3%	19.9%
Number of rigs with weight adjustments	0.0%	0.1%	0.3%	1.0%	1.5%
Number of rigs with sponsons	5.2%	11.3%	16.1%	21.4%	24.5%
Sponsons per try	5.2%	11.9%	17.7%	25.5%	30.1%

Calculation of costs of exceeding margin

	Total cost	**Marginal cost**	**Weight [Te]**
Chosen Weight increase			1000
Minimum Increase of hull weight			250
Weight increase-to-margin rate			25%
Startup cost	103,850,000	415,400.00	
Cost per tonne of ordinary hull	25,000,000	100,000	
Extra cost per tonne of hull	25,000,000	100,000	
Chosen average cost of increase		615,400	
Optimum service level	**86%**		
Optimum margin level ex. growth	110%		
Total cost minimum increase	153,850,000		
Total cost applied increase	153,850,000		
Stage factor	0.9		
Stage number	20		
Cost, given stage number	153,850,000		

Extraordinary costs realted to sponsons/extra weight capacity

Start-up Costs

	Rate	Currency	Units	Sum
Heavylift vessel and other delay costs	$300,000	5.75	60	NKr103,500,000
Engineering costs	NKr1,000		350	NKr350,000
Yard costs	NKr0		70	NKr0
Penalties	NKr0		0	NKr0
Total				**NKr103,850,000**

Variable costs

	Rate	Currency	Units	Sum
Ordinary construction costs	NKr100,000		1	NKr100,000
Inconvenience costs	NKr100,000		1	NKr100,000
Penalties	NKr0		1	NKr0
Total				**NKr200,000**

	Vanguard	**Overall Dockwise**	
Capital commited	51.00		
Capitalized cost	203.00	1,366.00	Properti plant and equipment
Revenue	109.50	539.00	Annual Revenue
Day rate	300,000.00		
Factor	0.43	0.39	

10.5.7. Oilfield valuation using real options

Oilfield valuation

Oil price	120		USD/boe
Oil price Volatility	20%		p.a.
Cost of production	20		USD/boe
Risk free interest rate	4%		p.a.
Dicount rate	10%		p.a.
	Gro	Jonas	
Investment	5,642	800	Million USD
Production length	10	10	Years
Reservoir	100	10	Million boe
Break Even Level	121	122.6	USD/boe
Maturity	0	2	Year

Net Present Value

	Revenue (million USD)		**Present value (million USD)**		
Year	Gro	Jonas	Gro*	Jonas*	Year
Y0	(5,642)	(800)	(56)	(20)	0
Y1	-	-	5,586	780	1
Y2	1,000	100	5,586	780	2
Y3	1,000	100	4,760	687	3
Y4	1,000	100	4,008	599	4
Y5	1,000	100	3,325	513	5
Y6	1,000	100	2,704	431	6
Y7	1,000	100	2,140	352	7
Y8	1,000	100	1,627	276	8
Y9	1,000	100	1,160	203	9
Y10	1,000	100	736	133	10
Y11	1,000	100	350	65	11

*The present value is calculated backwards, that is, the present value presented under year 10 is the sum of the present value of production in year 10 and 11.

Option valuation vs. NPV

	Gro	Jonas	Total
NPV	(56)	(20)	**(76)**
Option	(56)	108	**52**
d1		0.34847891	
d2		0.06563619	