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# Valuing Flexibility in Ship Design

## A Real Options Approach

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*"In the middle of difficulty lies opportunity."*
- Albert Einstein

# PREFACE

During the spring semester of 2015 this master thesis has been produced at the Department of Marine Technology, NTNU for the sub-department of marine systems – ship design and logistics. The main supervisor has been Bjørn Egil Asbjørnslett.

This master thesis has the overall objective to evaluate the option value of owning a Multipurpose Offshore Construction Vessel that is able to operate in the markets of offshore subsea construction, well intervention and pipe laying. This has been achieved by performing a Real Options Analysis using the Black-Scholes Option Pricing Model often used when valuing European call options. Most of the time was spent studying the method, assessing the necessary deck equipment for the different vessel types and finding information about prices related to these. This created a foundation for the Real Options Analysis that is performed.

The work presented here is a continuation of my project thesis from the fall semester of 2014, where I used Real Options in marine systems design. Some of the information in this study is thus gathered from the project work. The rest of the relevant information has been provided by professors at NTNU and PUC-Rio, internet sources or helpful employees at NOV, Wärtsïla and Ulstein.

Finally, I would like to express my great appreciation to Bjørn Egil Asbjørnslett, Marco Antonio Guimarães Dias, David Hoy, Erlend Sandvik, Per Olaf Brett, Jose Jorge Garcia Agis, Mikkel Haslum, the office girls and everyone else who participated in making this thesis possible.

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# SUMMARY

This thesis is a Real Options (RO) approach to valuing flexibility in ship design. The overall object is to find the value of owning a Multipurpose Offshore Construction Vessel (MOCV) by applying the Black-Scholes Option Pricing Model. The MOCV holds the option of switching into an Offshore Subsea Construction Vessel (OSCV), a Well Intervention Vessel or a Pipe Laying Vessel. The thesis aims to discuss the owner's economic benefit of owning an MOCV instead of three separate single purpose vessels. Dimensions, equipment types and capacities on the MOCV are based on the reference vessel, The Island Performer.

To solve this task, the problem has been limited by the following boundaries: at the time T=0, the vessel will be completed as an OSCV with options for further evolvement. At the end of each contract the owner has the option to switch to a different market by switching vessel type. Each of the three markets have different contract lengths and the analysis only considers the first four contracts of the vessel's service time.

In the RO Analysis, the time to maturity of the option is considered equal to the remaining time of the current contract. The stock prices and the stock price volatility are estimated based on the vessel's daily hire rates under long-term contracts in the North Sea. The strike price is equal to the cost of switching vessel types and each switching option has a different strike price. Lastly, ten-year government bonds underlie the risk-free rate.

The main results from this analysis confirm that a vessel that can work as a working platform for different vessel types is a good investment in an uncertain market. From the results it can be seen that the value of owning a MOCV is strictly positive in all three cases. The values even exceed the initial investment. It has also been demonstrated that the maximum amount one can save by storing the deck equipment for future periods is 25 mUSD. Due to different assumptions made the for vessel types, it is difficult to comment on whether one of the vessel types is more preferred than the other two.

# SAMMENDRAG

Denne oppgaven er en evaluering av et fleksibelt skipsdesign, som er gjort ved å ta i bruk en realopsjons-tilnærming. Oppgavens hovedformål er å vurderer verdien av å benytte seg av at flerfunksjonelt offshore konstruksjonsfartøy (MOCV) ved å anvende Black-Scholes opsjonsprisingsmodell. MOCVen eier opsjonene om å operere som et offshore undervanns konstruksjonsfartøy (OSCV), et brønnintervensjonsfartøy eller et rørleggingsfartøy. Oppgaven sikter mot å diskutere hva en reders økonomiske fordeler kan være ved å eie en MOCV istedenfor tre konvensjonelle fartøy. Referanseskipet, Island Performer, brukes til valg av dimensjoner, dekksutstyr og kapasitet.

For å løse oppgaven har problemet blitt begrenset av følgende antakelser: Ved tiden T=0 ferdigstilles båten som en OSCV med forsterkninger i skrog og rundt moonpool området. Ved hver kontraktsslutt har rederen mulighet til å bytte modus på fartøyet ved å utøve en av de tilgjengelige opsjonene, eller å forbli uforandret i enda en periode. De tre kontraktstypene har ulik lengde grunnet ulikt arbeid som utføres. Kun de fire første kontaktene blir analysert i denne modellen.

I realopsjonsanalysen er opsjonens tid til utløp ansett som den gjenværende tiden i den nåværende kontrakten. Aktivaverdien og prisenes flyktighet er estimert ut i fra fartøyenes daglige rater under langtidskontrakter i Norsjømarkedet. Prisen for å utøve opsjonen estimeres ut fra kostnadene tilknyttet bytte av fartøysmodus og er antatt ulik avhengig av modusene det byttes mellom. Til slutt er den risikofrie renten hentet ut ifra tiårige statsobligasjoner.

Hovedresultatene fra denne analysen bekrefter at et fartøy som kan fungere som en arbeidsplattform for ulike skipsmoduser er en god investering i et usikkert marked. Fra resultatene sees det at verdien av å eie en MOCV er positiv i alle de tre opsjonstilfellene. Verdiene overskrider til og med den initiale investeringen. Det har også blitt vist at ved å lagre dekksutstyret til senere perioder kan man spare opptil 25 mUSD. Grunnet ulikt grunnlag for beregning av aktivaverdiene, er det vanskelig å kommentere hvorvidt en av fartøystypene er mer fordelaktig enn de to andre.

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# LIST OF ACRONYMS

| | |
|---|---|
| AHC | Active Heave Compensation |
| AHTS | Anchor Handling Tug Supply |
| BOPM | Binomial Option Pricing Model |
| BS OPM | Black-Scholes Option Pricing Model |
| DCF | Discounted Cash Flow |
| DP | Dynamic Positioning |
| E&P | Exploration and Production |
| GBM | Geometric Brownian Motion |
| KBC | Knuckle Boom Crane |
| MHT | Module Handling Tower |
| MOCV | Multipurpose Offshore Construction Vessel |
| NFF | Norwegian Society of Financial Analysts |
| NPV | Net Present Value |
| OSCV | Offshore Subsea Construction Vessel |
| OSV | Offshore Support Vessel |
| PLV | Pipe Laying Vessel |
| PSV | Platform Supply Vessel |
| RO | Real Options |
| ROA | Real Options Analysis |
| ROV | Remotely Operated Vehicle |
| RLWI | Riserless Light Well Intervention |
| R&D | Research and Development |
| VLT | Vertical Lay Tower |
| WIV | Well Intervention Vessel |

# 1 INTRODUCTION

For over half a century, the offshore industry has been moving forward with new inventions and developments. New technologies outperform old solutions frequently, and to avoid Kodak moments, companies have to be ahead of the market. However, the fundamental way of thinking when designing ships has been to optimize the vessel for only one set of tasks and requirements, which restricts the vessel to operate in one specific market. This can be unfortunate since the markets are uncertain and contain risk. Factors that are affecting the industry to a great extent is the demand for oil and the oil price. Environmental, governmental, economic and technical concerns influence the market as well. Since these are fluctuating values, the market can be seen as quite volatile.

A vessel is a big investment. Offshore Support Vessels (OSV) can cost more than a hundred million dollars. By not adapting quickly to new business actualities companies can lose large amounts of money due to their inability to scale. Tomorrow's market winners will be the companies that know how to combine investments with flexibility. A Real Options Analysis (ROA) is one of the tools that can be used by investors to find the value of investing in a flexible design.

In ship design, flexibility can be achieved by preparing the vessel to handle several types or different sizes of equipment. When facing exogenous changes in prices, a vessel can protect itself against some of the price fluctuations by switching into an alternative mode of operation that is less affected by such changes. The preparatory work should be done in the design and construction process because it will ensure the lowest cost rather than adding flexibility later in the vessel's lifetime. In cases where flexibility is added after the completion of the vessel, the ship owner must be prepared to pay extra for the changes made. An example of this is the rebuilding of the Aker Wayfarer, which is being retrofitted from an Offshore Subsea Construction Vessel (OSCV) to a Well Intervention Vessel (WIV). The dry docking period is set at three and a half to four months where the yard will be doing comprehensive preparatory work and reinforcement of parts before the tower can be put up above the moonpool. Hydraulic equipment is also to be mobilized and integrated with the ship's other systems, in addition to adding skidding rails on the deck (Stensvold, 2014).

Offshore Support Vessels are used as a toolbox in offshore and subsea operations, and each vessel type within the OSV category has its own particular purpose. Specialized single purpose vessels are usually built at a lower cost than the more advanced multifunctional vessels, which has led to a variety of specialized offshore vessels. However, over the last few years new trends have emerged: clean design, stronger and longer winches for deep-water operations, ROV capacity, helideck and most importantly multifunctionality.

The subsea market has blossomed in the past due to a high oil price and a large demand. The demand for OSCV in the development of new oil and gas fields has been large, and an increased number of subsea wells have made the demand for well intervention and maintenance increase. The cost level on the Norwegian shelf has increased. Simultaneously the development of new subsea fields has contracted pipe-laying vessels for hundreds of kilometres. But recently, with the drop in the oil price a new competition has started among the actors, where cost efficiency is in focus. Still the increasing demand for energy and the declining resources, forces the petroleum production into deeper and harsher waters. This creates demands for improved technology and equipment on the vessels performing these operations, and an increased focus on multifunctionality has developed.

## 1.1 OBJECT

The object of this thesis is to find the value of owning a Multipurpose Offshore Construction Vessel (MOCV) by applying the Black-Scholes Option Pricing Model (BS OPM). The problem considers a MOCV holding the option to transform into an OSCV, WIV or Pipe Laying Vessel (PLV). The thesis aims to discuss what the economic benefit of owning one MOCV is instead of three separate vessels. The thesis also seeks to identify and price the underlying assets necessary for the design of each vessel type.

## 1.2 LITERATURE STUDY

Real Options (RO) were apparently used in ancient Greece as the story of Thales, narrated by Aristotle, tells us. Thales speculated that the coming olive harvest would be record-breaking, therefore he made a prepayment to the field owner for the right (but not obligation) to rent the olive pressing factory for a predetermined price for the rest of the season. As it turned out Thales' prediction were correct and the olive harvest rose. He then sublet the facility for a much higher price. (Copeland & Antikarov, 2001)

In 1973, Fischer Black and Myron Scholes presented a new financial analytical tool, the Black-Scholes Option Pricing Model (BS OPM), in their article on pricing of options and corporate liabilities. By assuming ideal conditions and no arbitrage, their formula was revolutionary since it was solvable by using only observable variables. Knowledge about the expected return of the stock was not required. In an extension of the formula, Merton (1973) showed how the BS OPM still applied even when the risk-free interest is stochastic, the stock pays dividends and the option is exercisable prior to expiration. In an article on exchanging assets, Margrabe (1978) developed a formula for the value of the option to exchange one risky asset for another. His formula grew from the Black-Scholes formula and Merton's extension of it. Geske (1979) used the Black-Scholes formula to derive a method for valuing compound options with non-constant returns on the stock price, where the volatility is a function of the stock price. Geske argued that for compound options, the volatility cannot be assumed constant because they depend on the stock price or on the value of the firm.

The concept of option pricing has its origin from finance theory, but it has been adapted to engineering systems since the 1990s by numerous economists and researchers. The term *Real Options* was coined by Stewart Myers (1977). It was used to value non-financial or "real" investments with learning and flexibility. In conjunction with the project thesis done prior to this thesis, a literature study was conducted, where I looked into the use of Real Options in projects. The examples found are included in this sub-section:

The bridge over the Tagus River in Lisbon is an example of the use of Real Options. The bridge was originally built stronger than necessary, so that an extra level could be added in the future. During the 1990s the option of the second level was exercised (Gesner & Jardim, 1998).

Kulatilaka (1993) used Real Options to value flexible steam boilers that can switch between using residual fuel oil and natural gas. In the analysis the author found that the flexible boiler has a value exceeding the initial investment of purchasing it, meaning that the initial investment of buying the dual boiler should be made.

While solving a problem quite similar to the one assessed in this study, Gregor (2003) used a Real Options approach to value flexibility in the ship design for the United States Navy vessels. In his thesis he evaluated three different hull options and compared them to a single hull approach. Based on Gregor's results from the Monte Carlo simulation, it can be concluded that the value of any design combination would be preferred over preparing for only one hull.

A Real Options approach was used in an architectural project by Greden and Glicksman (2004). They developed a Real Options model to determine the value of the option to convert an apartment into an office space. The time at which the investment can be made is American and the option of renovation is a call option. A Binomial Option Pricing Model (BOPM) was used to determine how much it would be worth to invest in such a space.

Cruz and Zavoni (2005) used Real Options to evaluate maintenance for offshore jacket platforms in a paper presented at the 24th International Conference on Offshore Mechanics and Arctic Engineering. In this study, a platform was subjected to fatigue and damage, and different maintenance options were evaluated. Similar to our case, the option is a European call option, since the exercise date is when the structure fails. Hence, the project is valued by using the Black-Scholes method. The results of their empirical work show that the project using Real Options on maintenance has a greater value than when using the traditional Net Present Value (NPV) approach. Their discovery could make a great difference in future decision making about maintenance strategies for other structures.

Scoltes and Wang (2006) evaluated the size of a garage space by using the spread-sheet method. This process looks into the Net Present Values by comparing future revenues and expenses of the garage space. The case is studying a space where structural reinforcements make future addition of parking levels possible as the population grows. They seek to find the value of the American call option that is to expand the garage at any time before the expiration of the project.

Greden, Glicksman and Betanzos (2006) used a Real Options Analysis (ROA) to evaluate risk and opportunity of natural ventilation. This was done by looking into a building designed for natural ventilation with the American call option to install mechanical cooling in the future. They are interested in valuing the cost savings by using the option-based ventilation system, rather than installing a completely new system in an already built house. By describing future stock prices as Geometric Brownian Motion, and using binomial lattices the option is priced when the volatility is known in a market without arbitrage.

## 1.3 THE STRUCTURE OF THE THESIS

The first chapter has presented an introduction to the theme of Real Options and flexible ship design, including a literature study of Real Options used in engineering practice. Chapter 2 is an introduction to the problem that will be solved in this thesis. The first section of the chapter provides a study of the vessel types included in the MOCV. It covers the vessel type's main tasks, operations, deck equipment and market situation. The design areas that could benefit from applying Real Options are identified. The second part of Chapter 2 is a description of the current offshore market and an explanation of the limitations of the case study.

In Chapter 3 the Real Options methodology is explained, and its general properties, principles, pros, and cons are described. Different methods for valuing Real Options are presented and compared to the Black-Scholes method, which is used in this analysis. A thorough explanation of the Black-Scholes method is included in this section. Chapter 4 is a validation of the assumptions and decisions made regarding the implementation of the data into the Black-Scholes analysis. In Chapter 5 the results of the analysis are presented and explained. Finally the results and sources of errors are discussed in

Chapter 6. Chapter 7 contains concluding remarks and recommendations for further work, followed by references and appendixes.

# 2 PROBLEM DESCRIPTIONS

## 2.1 OFFSHORE SUPPORT VESSELS

Offshore Support Vessels (OSV) transport large modules or piping systems to install them at the seabed and then connect them between the processing unit and the ocean surface. The vessels can also be used for inspection, maintenance, repair and decommissioning of subsea installations. For the analysis in this thesis, it has been chosen to look deeper into the three OSV types: Offshore Subsea Construction Vessels (OSCV), Well Intervention Vessels (WIV) and Pipe Laying Vessels (PLV). The following sub-chapters will elaborate on the common deck equipment and ship systems on these vessel types. A lot of this information was found by studying the specifications of other similar vessels, and in Appendix D, a list of the relevant vessels and their specifications can be seen.

### 2.1.1 Offshore Subsea Construction Vessels

The Offshore Subsea Construction Vessel is designed to perform various tasks, such as inspection, maintenance and repair to more heavy operations like lifting and installation. The vessel has customers from both the oil and gas industry and the green energy market. The vessel's stakeholders are mainly the owner and the operator of the ship, but also the charterer, supplier, classification society, design company and the government. These interested parties have various performance expectations for the vessel, and the spider web in Figure 2.7 illustrates the most important ones. The diagram shows that the deck area on the vessel is of importance; the deck is mainly used for transportation of large modules that are going to be installed. Further the Dynamic Positioning (DP) system is crucial to maintain a high level of position accuracy and good station keeping during the operations. Another important design feature is the offshore crane, where the main considerations are the crane type, capacity and its location on deck. The vessel's tasks and operations are also dependent on ROV support and a large crew. OSCVs are often categorized based on the vessel's crane size and loading area, making the definition of high-end and low-end less obvious.

Nearly all offshore cranes are currently installed with Active Heave Compensating (AHC) systems that can withstand wave motions so that the module's vertical position relative to land does not change even in high waves. For an OSCV the crane type is typically a Knuckle Boom Crane (KBC) with AHC. These cranes have the same moving pattern as an excavator: they transform power through a momentum that makes them extremely heavy, and can weigh up to 150 tons. The crane rests on a pedestal that transfers forces and momentum into the hull through the decks. When the crane is in operation and the boom, with the attached load, is rotated out to the ship's side, the stability of the vessel is maintained by a ballasting system. Ballast tanks are filled with water on the opposite ship's side of the crane, this way the rolling motion is kept to a minimum.

The OSCV's ability to operate in deeper waters require a longer crane wire, and therefore also a bigger and heavier winch. There are several possibilities to where the crane winch can be located. For bigger cranes, the winch is usually installed on or under the deck, whereas smaller cranes have an elevated winch attached on the top of the crane pedestal. This is illustrated in Figure 2.1 and Figure 2.2. Although the reference vessel, Island Performer, has its crane winch installed under the deck, in this case we have assumed that the winch is elevated.

Almost all the new OSCVs have capacity to launch and operate Remotely Operated Vehicles (ROV). This comes from an increased focus on deep-water subsea installations with different support requirements than conventional oilrigs. The ROVs enable safer access into deeper waters, and facilitate the assignments in areas where divers cannot reach. The ROV is equipped with visibility or recording abilities, and is launched from a heave compensated handling system through the moonpool or from auxiliary side systems. The illustration in Figure 2.10 shows an example of a deck arrangement for this vessel type.

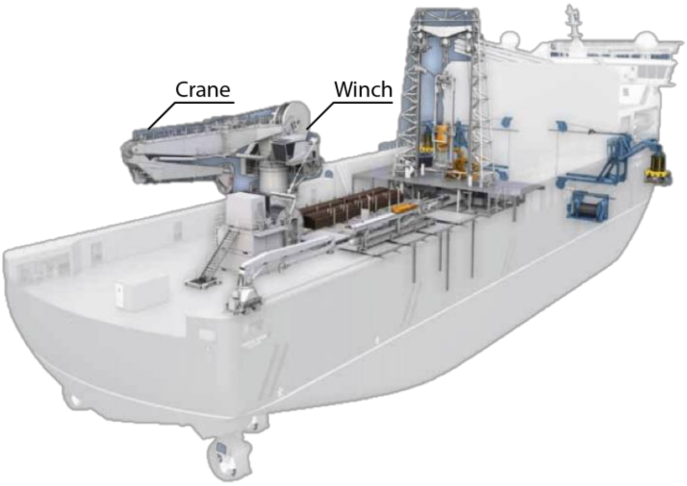

Figure 2.1: OSCV with Elevated Crane Winch. (Roll's Royce)

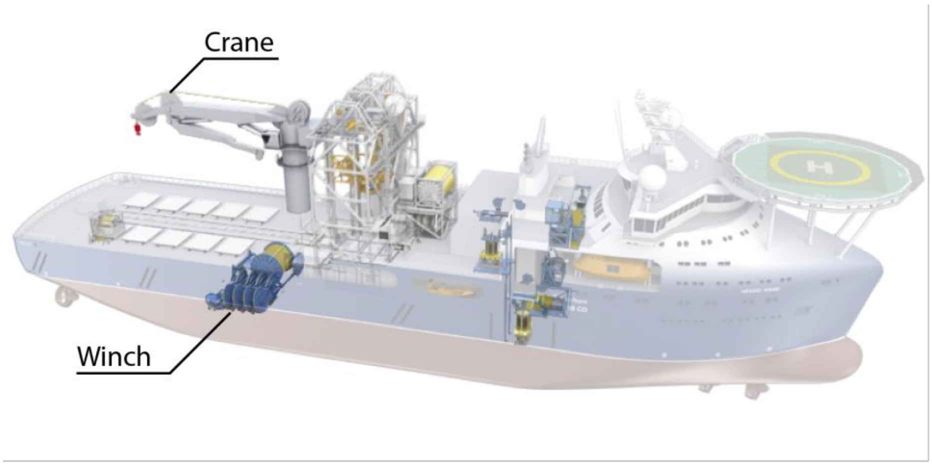

Figure 2.2: OSCV with Crane Winch Installed under Deck. (Roll's Royce)

### 2.1.2 Well Intervention Vessels

Well Intervention Vessels are mainly used to extend the lifetime of the well, by performing inspection, maintenance, repair and construction work on the wells. From the spider web in Figure 2.8 we can see that cargo capacity is of high importance. This is because mud and brine are directly involved in the maintenance work on the wells and need to be transported on-board the WIV in tanks. The DP system is also crucial in well intervention because of the danger of oil spills if the well is penetrated without precision.

Well Intervention Vessels are equipped with a Module Handling Tower (MHT) located above a centred moonpool. The tower supports wire lines, which are used to lift and lower the modules into the water, and a cursor frame to guide the hook and prevent horizontal displacement of the modules inside the tower. The WIV we will be looking into is a monohull vessel, which commonly uses Riserless Light Well Intervention (RLWI). RLWI is done by installing downhole tools into the well, under full pressure, using a Subsea Intervention Lubricator (SIL). A SIL is a single trip system that accesses the subsea wells. This method reduces the operational costs by 40-60% from conventional drill rigs (FMC, 2014). On deck there is a skidding system transporting the modules to and from the crane, the moonpool and the ROV hangar. The moonpool can be closed using a door structure enabling the skidding rails to continue over the closed doors. Other deck equipment include offshore crane(s) and ROVs, often used for visual support. Figure 2.11 and Figure 2.12 show the deck arrangement on a Well Intervention Vessel seen from above and from the starboard side. From the study presented in Appendix D it is observed that most WIVs today are performing Riserless Light Well Intervention consisting of bore-hole surveys, fluid displacement, sand washing, zonal isolation etc.

A subsea well can have a lifetime of more than 50 years, and well services are often needed within five years of production. Well intervention can be performed when there is reduced pressure in the wells, increased water or sand production. It is mostly oil wells that have the greatest need for intervention. Figure 2.3 from Zijderveld et al. (2012) shows how the demand for well intervention services in ultra-deep water is growing, and there are several reasons as to why well intervention is growing more important. Production is moving into deeper waters, and the days of “easy oil” are over. The amount of subsea installations is increasing. There is also a large aging generation of subsea wells, especially in the North Sea. Due to the fall in oil prices, operators seek to extend economic production for as long as possible, resulting in a change in the intervention market. Operators are striving to ensure economic rates for mature wells and maintenance work is done to assure durability. This is the result of a period of uncertainty, where maintenance of existing wells is more economically viable than to invest in new projects. Therefore, there is a strong demand for Well Intervention Vessels, which are more cost efficient than traditional drilling rigs. However, one of the threats to the Well Intervention Vessel is precisely the rigs, as they can offer a wider range of operations. Another challenge is the falling oil price, which causes the oil companies to cut back, but still, maintenance and repair are good investments to economically extend the production. (Angell, 2015)

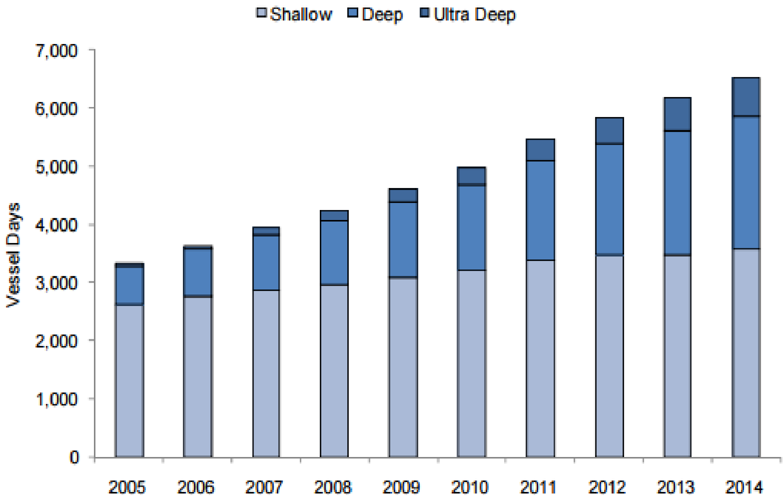

Figure 2.3: Global Well Intervention Demand by Water Depth.(Infield Systems Ltd.)

### 2.1.3 Pipe Laying Vessels

A pipe-laying vessel (PLV) is a construction vessel used for installation of subsea infrastructure. As illustrated in Figure 2.4 there are different methods to install pipelines on the seabed: S-lay, J-lay, Flex-lay and Reel-lay. S-laying is suitable for installation of rigid to concrete covered pipes. When using the S-lay method, the pipes leave the vessel at the stern from a nearly horizontal stinger, which guides the pipes down into the water with the right angle. The S notation describes the form of the pipes as they are being lowered. The welding of the pipes can be done at several stations at a time for the S-lay method, resulting in a high production rate. However, in deeper water the method will force the pipelines to overbend and cause large tensions on the pipes as they leave the vessel, therefore the S-lay method is not recommended in deep waters. The J-lay, Flex-lay and Reel-lay methods are more common for deep-water operations. J-laying is utilized for laying rigid pipes, which are more sensitive to fatigue than flexible pipes. When using the J-lay method, the pipes leave the vessel from a vertical stinger, rather than a horizontal, which will cause less stress on the pipes. As an effect of laying pipes vertically, the pipes now form a J as they touch the seabed. The J-lay method only allows for one welding station, therefore the method has a reduced lay rate compared to the S-lay method.

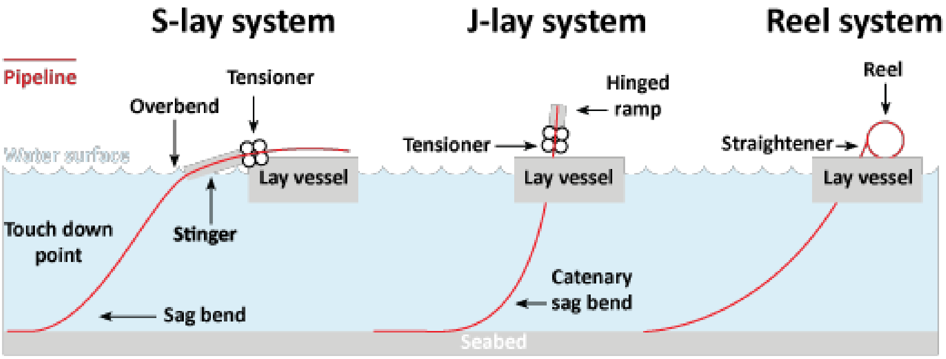

Figure 2.4: Illustration of Pipe Laying Methods. (Inspired by Luslier. Modified by Author)

A Vertical Lay Tower (VLT) is suitable for J-laying, flex-laying and reel-laying. When using reel-laying, all the welding and coating is done onshore and the pipes are transported offshore on large reels ready for submerging. Since all the welding is done onshore during the non-critical vessel time, reel-laying gives a high production rate. A separate barge can also transport the reels offshore where a heavy lifting crane will lift the reels onto the PLV. This requires a large crane capacity (2500t) on the PLV. In Appendix D we can see that some of the PLVs have such cranes with capacity to lift the reels on-board the vessel. In flex-laying and reel-laying, the pipes are spooled from the carousel or the reel, and then guided over a chute or a wheel at the top of the VLT and lead by the tensioners into the water. Since the pipes are bent around the reel and the chute, fatigue sensitive pipes are not suitable for this type of transportation and installation, thus flexible flow lines and risers are installed using this method.

In order to facilitate the transformation between pipe laying equipment and well intervention equipment, it is decided that a flex-lay system with a moonpool located behind the accommodation area will be more compatible. This is also in accordance to the design of the reference vessel, Island Performer. A traditional flex-lay system consists of a storage system often located below deck and a loading system from the storage to the pipe laying system. Most of the new PLVs are combinable between flex-lay, reel-lay and J-lay. Figure 2.13 shows the deck arrangement for a conventional flex-laying PLV. Since the main task of the PLV is to lay pipes along a planned route while moving slowly, the accuracy of the DP system is operationally crucial. Other important factors for the PLV are accommodation for the large crew on-board, crane capacity and ROV support. Figure 2.9 shows the most important performance expectations for a PLV.

### 2.1.4 Multifunctional Offshore Construction Vessel

The Multipurpose Offshore Construction Vessel (MOCV) is designed with flexibility as a main attribute. It will have the opportunity to clear the deck from equipment, and install new deck equipment when the market demand indicates it to be necessary. The MOCV is a commitment to the deep-water construction market, and it can potentially be further customized to meet the client's individual requirements.

With a unique understanding of the operational market and the client's needs, the advantage of the MOCV is its probability to win contracts for offshore operations. As a shipowner it is important to establish an overview of the market segments with the highest utilisation rates and revenue yields. It is then important to obtain a fleet of vessels and gain information about when to expand or exit markets to maximise profits. The MOCV's main task will be subsea construction, installation, inspection, repair and maintenance work. Further the vessel will be built with the option of performing well intervention or pipe lying as secondary tasks, and can therefore be expected to benefit from the economy of scale. This means that when a new contract is available on the market, the probability that the MOCV is qualified for the task is three times higher than for an OSCV, WIV or PLV alone. This is due to the vessel's flexible operability, and its suitability to enter multiple market segments in the subsea industry. The most important goal for a vessel owner is of course to have his vessels under a contract at all times and to avoid situations where one or several of the vessels are laid-up. The MOCV is a way to invest in a vessel with a higher likelihood of not being laid-up. Bram Lambregts (2013), Marketing and Sales Manager at Ulstein Sea of Solutions, says "*what is unique with the MOCV is that it is developed for coping with future requirements in mind".* The vessel is adaptable to the swings in the market.

When studying the MOCV it is important to understand the relations between the different operational modes. What needs to be done when switching from one vessel type to another, and back? The adjustments from vessel type A to type B may not be the same as from type B to type A. This will be shown in the matrix in Table 2.1 below. The table is listing the necessary adjustments to be made when switching from one market to another, and it shows how the change from, for example, an OSCV to a WIV is not the same as from WIV back to OSCV.

Table 2.1: Necessary Adjustments between Vessel Types. (Compiled by Author)

| To<br>From | OSCV | WIV | PLV |
|---|---|---|---|
| **OSCV** | *No change required* | • Mobilize MHT<br>• Mobilize skidding system<br>• Open moonpool | • Mobilize VHT<br>• Mobilize Carousel under deck<br>• Open moonpool |
| **WIV** | • Demobilize MHT<br>• Demobilize skidding system<br>• Close moonpool | *No change required* | • Demobilize MHT<br>• Demobilize skidding system<br>• Mobilize VHT<br>• Mobilize Carousel under deck |
| **PLV** | • Demobilize VHT<br>• Demobilize Carousel<br>• Close moonpool | • Demobilize VHT<br>• Demobilize Carousel<br>• Mobilize MHT<br>• Mobilize skidding system | *No change required* |

## 2.2 MARKET DESCRIPTION

As onshore and shallow water oil productions continue to decline, more of the future oil investment will be in deep waters. Four regions where subsea operations are performed in ultra-deep waters are South America, West Africa, Australia and the Gulf of Mexico. Since Australia is relatively new to the subsea market, there are few vessels operating in this area and the market is not fully developed. The connection between the other three regions is called “The Golden Triangle”, which links Brazil, Angola/Nigeria and the Gulf of Mexico. The first leg of the Golden Triangle is Brazil’s pre-salt field where Petrobras is playing a huge role. One of the only oil producing fields in the US who plan to expand production is the Gulf of Mexico. And in Africa a growing economy and numerous new findings cause for great potential. Africa has prepared to spend around $60billion on deep-water spendings, while Brazil and Mexico are following with nearly $30 billion each (Gue, 2009).

The investments in Exploration and Production (E&P) of petroleum are mostly of long term. Managerial and/or operational decisions are normal, and the projects have a high irreversibility. The market is under conditions of economic and technical uncertainty, such as: oil prices, the hire rates, costs and equipment reliability. Historically the offshore industry has experienced many booms, and in good periods it is common for shipowners to reinvest their profits into new vessels to expand their fleet. The problems only occur when the market switches and there is a sudden oversupply, which was exactly the case when the market dropped in the second half of 2014. To make a long story short, the oil price fell because of an oversupply in the oil market when the USA started producing shale oil and was no longer importing as much oil as before. Simultaneously the good period from 2002-2009 resulted in an increase in the development of new fields, and Saudi-Arabia is maintaining a high production rate even with low oil prices. This can have coherence with wanting to reduce the growth in the American shale oil industry and put economic pressure on competitive countries. Although some companies want to expand their business by benefitting from historically low asset and building prices, most banks are unwilling to take more risk and lend money to new high-margin projects. Downscaling and down payment of loans, rather than making new investments will therefore probably dominate the following years. In the market report from RS Platou published in July 2014, predictions of high and stable oil prices for the following years were made (Platou, 2014). This is proof that market developments are difficult to foresee. Still, with shifting markets and a declining oil price, the need for flexible investments is important. Given the recent drop in oil prices, one might assume that all the involved producers and companies will fall along with the oil price, but companies with knowledge on weathering volatile markets are more trusted and supported by banks and investors who are interested in the energy market (Lorusso, 2014).

Despite the low oil price over the past year, a report from British Petroleum shows that the demand for energy will grow by 41% between 2012 and 2035. With the industrializing and electrification of the non-OECD countries, "*the decade between 2002-2012 recorded the greatest ever increase of energy consumption over any ten year period, which most likely will not be surpassed in the future*" (BP, 2014). It is reported that 95% of the growth is represented by the non-OECD. Especially China and India, who represent the main growth contributors. The total world energy production will also increase with a rate of 1.5% from 2012-2035, and the growth includes all regions except Europe. (BP, 2014)

However, other challenges are also facing the oil and gas industry such as the increased awareness of climate changes. This will affect the use of oil and gas since it is being challenged by substitutes. Today the fastest growing fuel is in renewables, followed by nuclear and hydro-electric power. Fossil fuels have the least growth, and among them gas is the fastest growing fuel, while oil and coal have the slowest growth, as can be seen in Figure 2.5 from BP (2014).

The supply-demand ratio will also create changes in the trading relationships between the regions. There is a great amount of unconventional oil and gas being produced in North America, causing the region to switch from being a net importer to a net exporter by 2018, and Asia will by 2035 contribute to 70% of inter-regional net imports. (BP, 2014)

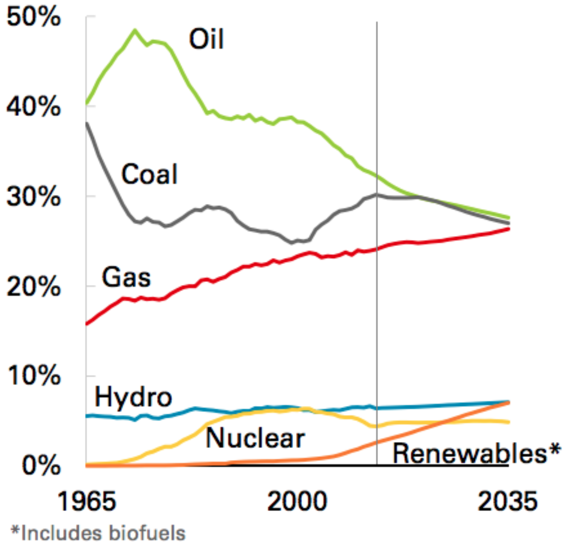

Figure 2.5: Shares of Primary Energy. (BP, 2014)

OSVs are important tools in Exploration and Production (E&P) of offshore oil and gas fields, rigs, platforms and FPSOs. Therefore the oil price and the production of oil and gas play a vigorous part in the Offshore Support Vessel industry. The E&P process in the oil and gas industry is the first period of a long value chain of producing petroleum for our everyday use. Within the E&P process are four phases: Exploration, Development, Production and Decommissioning, and different vessel types are required in the four stages. This is shown in Table 2.2 below. During the first stage, the exploration stage, the common task is searching for hydrocarbons. Important vessels in the exploration phase are seismic vessels, Anchor Handling Tug Supply (AHTS), Platform Supply Vessels (PSV) and barges. When a prominently large field of hydrocarbons is found the development phase can commence, involving installation of subsea wells and infrastructure. These tasks require dive support vessels, OSCVs, PLVs and pipelay barges. The production phase can start when oil and gas is ready to be extracted from the wells. Further the oil and gas is processed, stored and transported from the field. Important vessels are AHTS, PSV, crew boats, utility vessels and subsea support vessels such as WIVs. The final stage, the decommissioning phase is initiated when the field no longer can provide economic benefits. Decommissioning consist of plugging the wells and removing the production installations. The required vessels for this stage are naturally the same as for the development phase (Yeo, 2010).

Based on the information in Table 2.2 we are able to say something about the duration of the tasks performed by the different vessels in each phase. The period lengths from this table will be used as an underlying argument for the choice of contract lengths in Chapter 4.1. The table also shows how affected the vessels are by the oil price. This can be helpful in later chapters when the volatility of the income opportunities is discussed.

Table 2.2: Exploration and Production in Oil and Gas. (Pareto Research, Modified by Author)

| | **Exploration** | **Development** | **Production** | **Decommissioning** |
|---|---|---|---|---|
| **Period** | 1-3 years | 2-4 years | 5-50+ years | Upon oilfield depletion |
| **Sensitivity to oil price** | High | Medium | High oil price extends lifespan of oilfield | High oil price defers decommissioning |
| **OSVs deployed** | | OSCV<br>PLV | OSCV<br>WIV | OSCV |

## 2.3 CASE DESCRIPTION

As mentioned in the objective, this thesis is a Real Options Analysis to find the value of a Multipurpose Offshore Construction Vessel compared to owning several single purpose vessels. Consider an OSCV with an initial building cost of 107 mUSD (E Sandvik, 2015, pers. comm., 24 April) and a service life of 20 years. Initial building cost includes hull structure, machinery, accommodation, reinforced moonpool area, deck equipment such as offshore cranes, ROV capacity and installation of the equipment. The vessel has the option of transforming into a PLV or WIV subject to contract requirements. The vessel is initially constructed as an OSCV, because the deck equipment on an OSCV, such as cranes and ROV capacity, is a common denominator between the three vessel types. A 250t Knuckle Boom Crane with AHC is chosen and there will be an ROV hangar in the deck house on the starboard side. Further it is necessary in both well intervention and pipe lying with a closable moonpool with the typical dimensions 8x8 meters. The deck structure around the moonpool needs reinforcement to be able to support the heavy equipment used, such as the Module Handling Tower (300tons) and the Vertical Lay System (250tons). It is also essential to have enough space under deck for a carousel (2500tons). The deck equipment on OSVs commonly only need to be provided with electricity from the ship. The machinery itself is located inside the equipment. The chosen dimensions and capacities are selected from a reference vessel, the Island Performer, designed and built by Ulstein. Table 2.3 summarizes the deck equipment chosen for the case analysis.

Figure 2.6 shows an example of the periods of the vessels lifetime and the options it holds. The initial deck arrangement will be optimized for tasks related to the OSCV. At expiration of the first contract, the owner has the option to switch the vessel into a PLV or WIV. The option holder can also decide to keep the vessel as an OSCV. The figure shows how the vessel will be built and operated as an OSCV the first period. This is illustrated with a single node. From the end of the node a line is drawn which leads to three new nodes. This line represents the length of which the vessel will operate as an OSCV. The end of the line represents the end of the contract where the vessel owner has to make a final decision about what contract type to take in the next phase and thus what vessel type to retrofit the vessel into. The rest of the figure follows the same principle. In the analysis, the contract lengths will vary based on the vessel type and what a typical duration of the performed tasks can be, but the lines in the figure have the same length for graphical simplicity. The intention of this study is to evaluate each node and find the value of holding the options to switch, by using the Black-Scholes formula.

The case is limited from the following boundaries:

- At the time t=0, the vessel will be completed as an OSCV, and the following first period it operates as an OSCV
- At the time t=T, the owner has the option to switch to a different vessel type
- The vessel can enter into the OSCV, WIV or PLV markets
- Each of the three markets have different contract lengths
- Each contract represents a period in the analysis
- The analysis only addresses the first four periods of the vessel's lifetime

Table 2.3: Deck Equipment on Vessel Types. (Island Performer)

| **Vessel Type** | OSCV | WIV | PLV |
|---|---|---|---|
| **Deck Equipment** | 250t KBC | 300t MHT<br>100t Skidding System | 250t VLS<br>2500t Carousel |

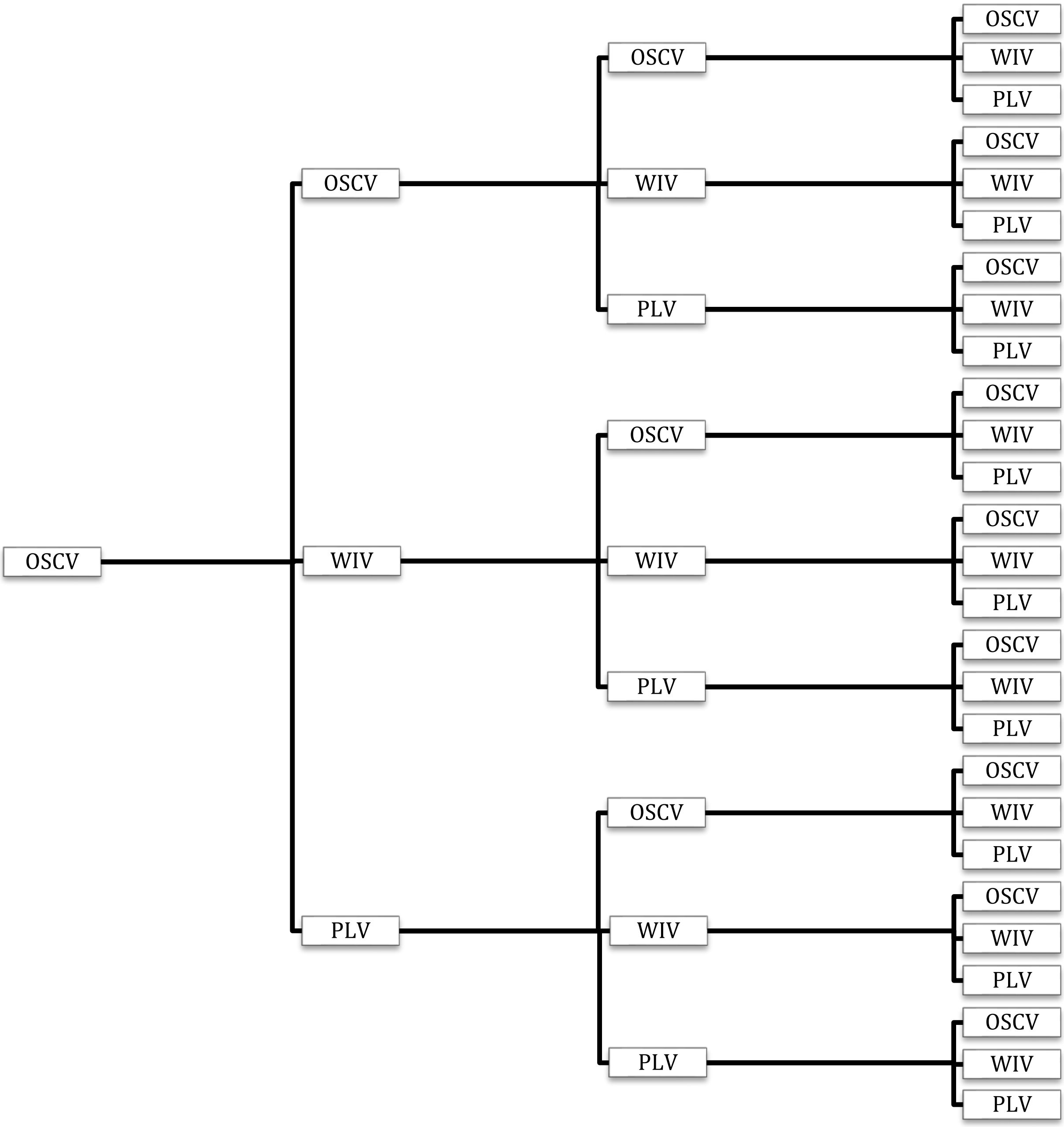

Figure 2.6: First Four Periods of Vessel Lifetime. (Compiled by Author)

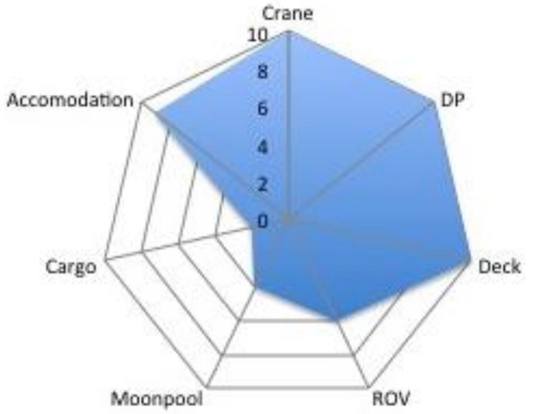

Figure 2.7: OSCV Performance Expectations.
(Inspired by ABD Lecture, Ulstein. Modified by Author)

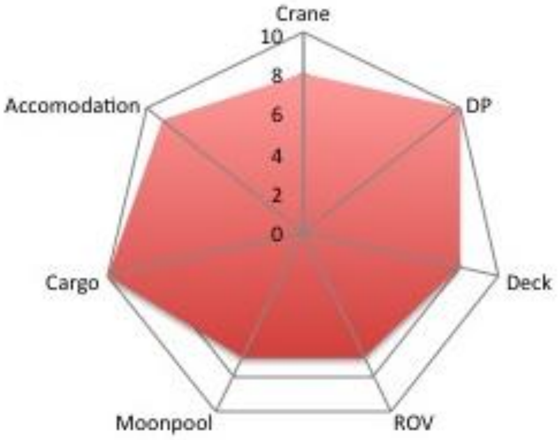

Figure 2.8: WIV Performance Expectations.
(Inspired by ABD Lecture, Ulstein. Modified by Author)

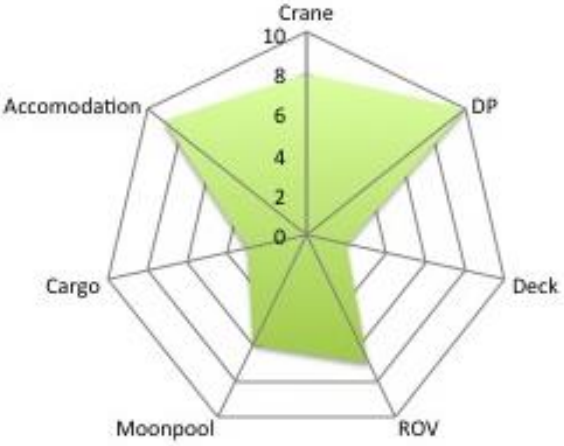

Figure 2.9: PLV Performance Expectations.
(Inspired by ABD Lecture, Ulstein. Modified by Author)

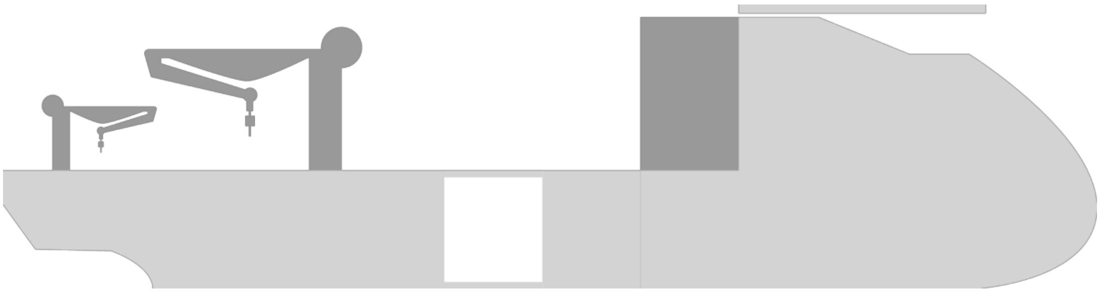

Figure 2.10: Deck Arrangement on OSCV. (Inspired by ABD Lecture, Ulstein. Modified by Author)

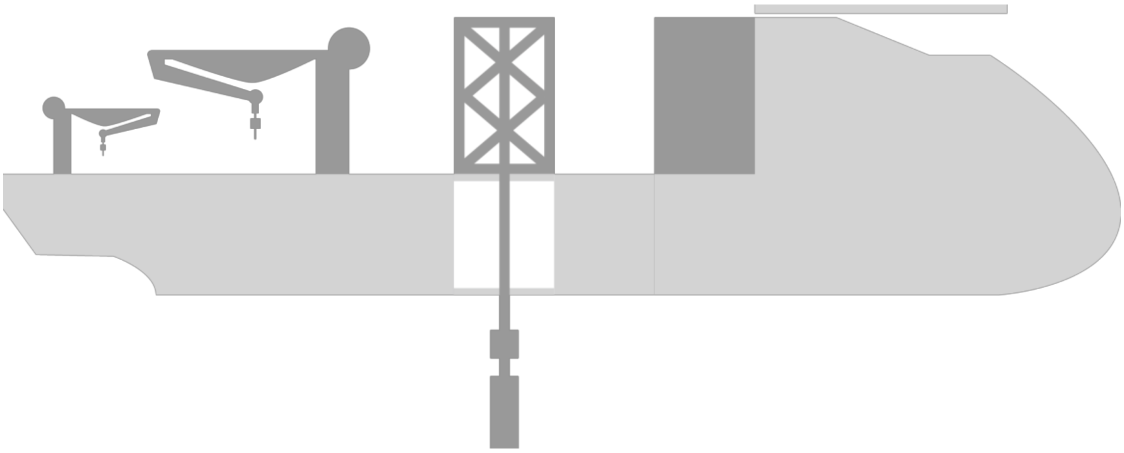

Figure 2.11: Deck Arrangement on WIV. (Inspired by ABD Lecture, Ulstein. Modified by Author)

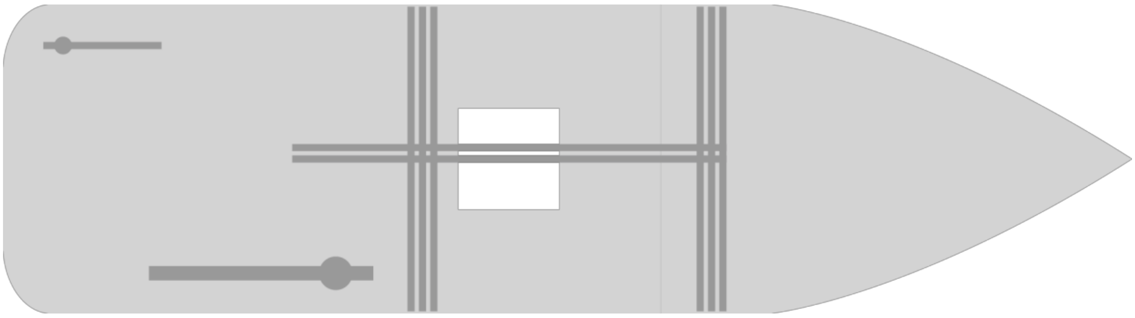

Figure 2.12: Deck Arrangement on WIV. (Inspired by ABD Lecture, Ulstein. Modified by Author)

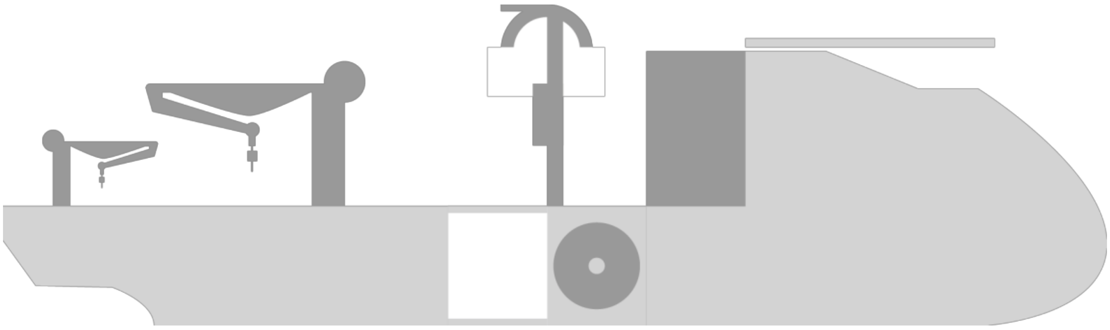

Figure 2.13: Deck Arrangement on PLV. (Inspired by ABD Lecture, Ulstein. Modified by Author

# 3 REAL OPTIONS

It is said that: *"50% of the value of Real Options is simply thinking about it. Another 25% comes from generating the models and getting the right numbers, and the remaining 25% of the value of Real Options is explaining the results to the person beside you, or to yourself"* (Leggio, 2006).

Each project holds countless numbers of possibilities of expansion, waiting, switching or abandoning. The systems we value are so complex that during their engineering and creation, more options are possible than the human mind can fathom. In Real Options thinking we ask ourselves what would happen if we begin to think down a new path. What options will be available for us and what can we gain by holding these options? The very first and toughest step to take when entering into this thinking path is to identify the existing Real Options in the investment already in the Research and Development (R&D) stage. After this the actual valuation analysis can begin.

## 3.1 INTRODUCTION TO REAL OPTIONS

To analyse and determine an option value, we must first define the concept of Real Options (RO). A Real Option is the right, but not obligation, to undertake some business decision such as buying or selling an asset. Real Options refer to physical assets, like equipment, in contrast to options defined as financial instruments (Investopedia, 2015). All projects can be expanded, delayed, sped up or abandoned. A Real Options Analysis (ROA) is not just an equation or a formula, but it is a method used to value these choices by using different pricing techniques (Wijst, 2010).

In Figure 3.1 the basic structure of Real Options is illustrated in a decision tree by Adner and Levinthal (2002). The decision tree is organized as follows: In the first stage an option is purchased by investing an initial amount of money. This gives the option holder the opportunities, such as choosing between assets, or whether or not to expand a project. In the second stage the option value has changed due to external influence, which affect the decision since it is based on the expected outcomes. Finally, based on the acquired information the option holder choses to either invest or to abandon the project in the last stage. If abandoned the option holder loses the initial investment, if exercised he can gain profits from the assets acquired.

In decision tree analyses there exists a forecast of the future outcomes. This is often represented by a probability of a particular event happening, which can be dependent on past events happening. Forecasting these probabilities is a challenging task and the trees can grow quite large and complex. However, many decisions can benefit from using a decision tree because of its ability to take into account the possible changes in the parameters, such as the volatility.

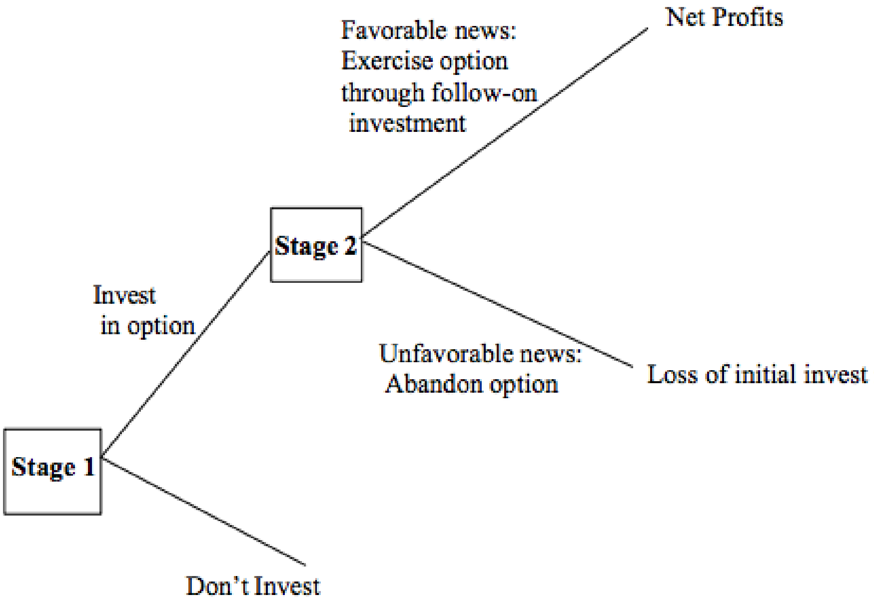

Figure 3.1: The Basic Structure of Real Options. (Adner & Levinthal, 2012)

### 3.1.1 Terminology

In this section a brief overview of the most important terms within Real Options theory is presented with definitions from Howell et al. (2001) and Black and Scholes (1973).

A *put option* gives the owner the right to sell an asset, as opposed to a *call option*, which is an asset that can be bought. Further, an *American option* can be exercised at any time before the expiration date of the option, while the exercise time of a *European option* is fixed to a certain time. American options usually have higher values than similar European options because of their greater optionality. The price that is paid for an option is called the *strike price* or the *exercise price* (Black & Scholes, 1973). A *Bermudan option* can be exercised only on predetermined dates, either at the expiration date, or on specific dates before the expiration date. A Bermudan option is commonly valued using the swaption method. In this thesis we are valuing European call options. The background for this will be further explained in Chapter 4.

The *option holder* is in the position of holding the rights to buying or selling the option, while the *option writer* has the obligation to sell or buy the option to/from the option holder. The date when an option expires is called the *expiration date* or the *time to maturity*. For European options the time at which the option can be exercised is at this particular date (Howel et al. 2001). In Real Options the time to maturity can be as long as decades depending on contract times, equipment lifetime etc., while financial options are traded much faster, within months. In this case the option holder is the owner of the Multipurpose Offshore Construction Vessel, the option writer is the supplier of the prospective deck equipment, and the expiration date of the option is when a contract expires and the vessel is in need of a new assignment.

The *underlying asset* can be sold and bought as a remedy to enter into different markets (Howel et al. 2001). In this study the deck equipment is considered the underlying asset. This will also be further explained in Chapter 4. The value of the underlying asset is financially called the *stock price*, but what it really represents is the highest amount someone is willing to pay for the stock, or the lowest amount that it can be bought for. The Net Present Value (NPV) of the potential investment represents the stock price.
The *volatility* is a critical parameter for option pricing models, as it is a measure for the fluctuation of the return of an asset over time. The volatility is usually expressed as a percentage where a high volatility implies a risky security (Investopedia, 2015b). The volatility is the logarithmic return of the stock price. And one can use the historic volatility of the stock to determine the future volatility.

The *initial investment* or the *option premium* is essential when owning call or put options, and serves as a platform for a company to extend further into market opportunities. The initial investment is what gives us the opportunity to install new equipment after the vessel has been built, and is therefore the most important investment made in order to realize the Multipurpose Offshore Construction Vessel. From Chapter 2.1 we learned that for the MOCV the pre-investment is in the strengthening of the deck to support large deck equipment, arrange space under the deck for cargo and pipes, the installation of the moonpool and the costs related to this. In the Black-Scholes formula this cost is not included, but the knowledge of its existence is still important.

To invest *long* in a company is to buy a stock, with the expectation that the asset value will increase. The opposite is a *short* investment, which is defined as the sale of a borrowed security with the expectation that the asset value will decrease. For example if you want to invest in a company with better numbers than their competitor, you go long on the company, and short on their competitor. If the industry you invested in goes up, you profit from the long and lose on the short. If the industry goes down, you lose money on the long and make money on the short. This is called *hedging,* an investment made to limit the risk of another investment. A common example of a hedge is insurance.

### 3.1.2 Types of Options

There exists different types of options and they turn up at different stages of an investment. From Brealey et al. (2006), Amram and Kulatilaka (1999) and Trigeorgis (1996) some of the most relevant option types are selected:

The option of *waiting to invest* is useful when a project might turn more profitable in the future. Under some conditions it can prove to be more valuable when deferring to invest when immediate cash flow is low, rather than to commit to invest. Waiting to invest also enables the holder to learn more about the market trends and developments (Brealey et al., 2006). To halt further investment is to *abandon* or *exit* a project. Abandoning can often leave other options valueless. In our example abandoning the project would be to sell the vessel.

We have *timing and switching options* that should be exercised when the demand for a certain product rises. As an example, the owner of a Pipe Laying Vessel notices a drop in the market while the Offshore Wind Turbine market is constantly growing, the timing for doing a switch between these markets would then be perfect if he already owns the option. Further, a *growth option* is when a business is expanded. An Offshore Subsea Construction vessel with a 150 ton crane could get more contracts with a bigger crane, and holding the option of installing such a crane is a growth option. The option to add flexibility to an investment can be done by for example using shipbuilding yards in different continents so that productions can be regulated by the demand, exchange rates and production costs in the different continents. This is called a *flexibility option.* In many examples of RO, these option types exist simultaneously and it is therefore important to identity all the options a project holds (Amram & Kulatilaka, 1999).

Wang & de Neufville (2005) stated that there is a difference between Real Options “on” projects and “in” projects. The main difference is that when using Real Options “on” projects the physical system is treated as a “black box”. To contrast, Real Options “in” systems are where the design features are considered in the project. Real Options “in” systems require that the analyst has a good knowledge about the technology that is being worked with. This is because there is little available data for these types of options compared to the RO “on” projects. Another reason is because the equipment can be complex and have numerous options or limitations that need to be regarded in the project. This thesis is an example of RO being used “in” projects, and many other examples are presented in the literature study such as the parking garage case or the office space case.

### 3.1.3 Real Options in Our Everyday Life

The Real Options way of thinking is quite similar to the way we make decisions in our everyday life: we wait until the uncertainty is resolved to be able to make a safer choice. A relevant example of the modern use of Real Options is when an oil company buys the drilling rights for a piece of land, they are buying an option with the right to extract oil that can be exercised when they can gain profit from it. Although oil prices vary all the time and at the moment being quite low, the possibility of making a profit from the oil prices going up again is worth having.

A common example of Real Options is the leasing of cars or equipment with the option to buy at the end of the leasing period. Typically these agreements have a predefined lease time and exercise price in the contract. The decision to buy the car or not is often made at the expiration time of the leasing, like a European call option. Another example of options in our life is insurance. We pay a small annual premium to protect us from potential economic losses. The amount of money we get in return is equal to the size of the damage minus the deductible. The payoff from buying insurance resembles an American put option.

## 3.2 VALUATION OF REAL OPTIONS

The process of valuing Real Options is one of the most difficult in strategic management and R&D. The RO approach solves problems that the traditional Discounted Cash Flow (DCF) method and Net Present Value (NPV) method fail to do.  Some of the pioneers in financial Options thinking were Fisher Black and Myron C. Scholes who invented the Black-Scholes Option Pricing Model (BS OPM) in the seventies, which is an important method for valuing European call options. Some years later John Cox, Steve Ross, and Mark Rubenstein developed the Binomial Option-Pricing Model (BOPM) for the valuation of American options. In this chapter, the traditional NPV and DCF methods will be presented with a discussion of their weaknesses, together with a brief summary of the BOPM and Monte Carlo Simulation and a more detailed explanation of the Black-Scholes method.

### 3.2.1 Net Present Value

A traditional method to value investments is with the Net Present Value (NPV). The NPV is a formula representing the difference between the present values of cash inflows and outflows, and is used in capital budgeting to determine whether an investment or a project will turn out profitable. The method uses the future cash inflow with regards to inflation and returns over the years of the project. If the NPV is negative the project should be abandoned, but considered if the opposite occurs. The challenge with the NPV analysis is that it undervalues the option, as the risk-adjusted discount rate is not properly identified, and the fact that the project's risk is different at each decision point is not considered. Therefore the NPV is not suited to value flexibility in a project, because it assumes that the investment has to be done fully now or never, even if the project can still hold options for development (de Neufville & Scholtes, 2011; Trigeorgis, 1996). In Real Options Analyses we sometimes invest in projects with a negative NPV, when this investment generates new options. These can be options to expand productions, and/or generate valuable new information and options. ROA can also recommend to postpone projects with positive NPV (option to wait and see) (Dias, 2004).

### 3.2.2 Discounted Cash Flow

Similarly, the Discounted Cash Flow (DCF) method also tends to undervalue the R&D projects. The method was developed by Irvin Fisher to evaluate financial investments and decisions to invest in real assets. There is an increased risk from abandoning and an increased potential from expanding and delaying. The DCF method fails to capture the implications of this, and is thus best used for valuing short-term projects with low uncertainty. The method undertakes no flexibility to make decisions during the project lifetime, and future decisions are fixed at the outset (Damodaran, 2007; de Neufville & Scholtes, 2011).

### 3.2.3 The Binomial Option Pricing Method

The most important tool for valuing American options is the Binomial Option Pricing Method. BOPM creates a periodic view of the stock price and the option value, and is performed by creating a simple spread sheet. Binomial option pricing is based on a no-arbitrage assumption, which means that the market is efficient, and investors will earn the risk-free rate of return. The process of solving the binomial method is quite similar to using decision trees with "discrete-time" (lattice based) steps, where the stock price is considered logarithmic.  The value of the asset can go in two directions, up or down with the probability of $p$ and $1-p$. In the BOPM, the up and down factors, and the probabilities can be found by using the asset's volatility and the risk-free rate. The option value is found eventually by solving the tree backwards by multiplying each state with the risk-neutral probability and discounted with the risk-free interest rate.

### 3.2.4 Monte Carlo Simulation

For complex problems of Real Options, where analytical or tree building methods are too time consuming to perform, the Monte Carlo method is often used instead. The Monte Carlo method simulates the possible value of an asset over a time period by drawing random numbers from the probability distributions to recreate the asset behaviour. By using a computer to repeat numerous simulations, a distribution of the option payoffs is obtained. The average of these payoffs is then discounted back to determine the present value of the Real Option (de Neufville & Scholtes, 2011).

### 3.2.5 The Black-Scholes Method

***Introduction to the Black-Scholes Method***

The probability distribution of the option price and the risk-free rate are two factors which are not directly observable, but they are both necessary in order to discount the future probable payoffs of the option. Fischer Black and Myron Scholes created the Black-Scholes formula to resolve this major problem in valuating options.

In the development of their formula, Black and Scholes defined these assumptions regarding the stock and option:

1. *"The short-term interest rate is known and is constant through time*
2. *The stock price follows a random walk in continuous time with a variance rate proportional to the square of the stock price. Thus the distribution of possible stock prices at the end of any finite interval is lognormal. The variance rate of the return on the stock is constant.*
3. *The stock pays no dividends or other distributions.*
4. *The option is "European," that is, it can only be exercised at maturity.*
5. *There are no transaction costs in buying or selling the stock or the option.*
6. *It is possible to borrow any fraction of the price of a security to buy it or to hold it, at the short-term interest rate.*
7. *There are no penalties to short selling. A seller who does not own a security will simply accept the price of the security from a buyer, and will agree to settle with the buyer on some future date by paying him an amount equal to the price of the security on that date."* (Black & Scholes, 1973)

The assumptions listed above tell us that the option value depends on the stock price and other known constants. It is therefore possible to create a hedge where we invest long in the stock, and short in the option. The hedge value will thus only depend on the time period where we are hedging, and not on the stock price. This is useful because it guarantees a return on the hedge. (Black & Scoles, 1973)

The explanation to this is because the stock price follows a continuous random walk also called a Geometric Brownian Motion (GBM). A GBM is a continuous-time stochastic process where the logarithm of the randomly varying stock price follows a Brownian motion with drift. Therefore the return of the stock is varying constantly, and the covariance between the return of the hedge and the stock is zero. Thus, the return of the hedge does not depend on the stock value.

***Explanation of the Formula***

The Black-Scholes option pricing formula, showed in Equation 3.1-3.3, gives the value of a call option for a non-dividend paying stock, where C(S,t) is the European call option value.

$$C(S,t) = N(d_1)S - N(d_2)Ke^{-r \cdot T} \tag{3.1}$$

$$d_1 = \frac{1}{\sigma\sqrt{T}}[\ln\left(\frac{S}{K}\right) - (r + \frac{\sigma^2}{2})T] \tag{3.2}$$

$$d_2 = \frac{1}{\sigma\sqrt{T}}\left[\ln\left(\frac{S}{K}\right) - \left(r - \frac{\sigma^2}{2}\right)T\right] = d_1 - \sigma\sqrt{T} \tag{3.3}$$

Where:

S = Stock price, or price of the underlying asset
K = Strike price, or exercise price of the call
T = Time to maturity of the option, given in fractions of one year
$\sigma$ = Volatility of the stock price
r = Annual risk-free rate of return in decimal form

Equation 3.1 states that the option call value is the difference between the stock and the strike price. If the value of the stock price is less than the strike price at expiration the option will be out-of-the money, and the call option value will be set to zero. In these cases the buyer will most likely not exercise the option. However, if the stock price is higher than the strike price, the option is in-the-money, and the call option value equals the difference between them. Call options are usually exercised when the option is in-the-money.

The values N($d_1$) and N($d_2$) are probabilities from the standard normal distribution function. The values for $d_1$ and $d_2$ are used to calculate the probabilities that the stock price will be a certain number of standard deviations above or below the standardized mean at expiration. One can say that N($d_2$) is the risk-neutral probability that the stock price is higher or equal to the strike price at the expiration, and N($d_1$) is the probability of how far into the money the stock price will be if, and only if, the option expires in the money. The number N($d_1$) can also be called the hedge ratio, which tells how much the option price changes if the stock price changes with a small amount (Gitman et al, 2010).

The factor $e^{-rT}$ is multiplied with the strike price because we are valuing a call that has not yet happened. This means that the strike price that is going to be paid in order to buy the call option will not be paid until the expiration date, and we must therefore discount the strike price to present value.

In the formulas the volatility is always multiplied by the square root of the time. This is because the stock follows a random walk, which means that the width of the distribution increases with time. So the probability that the asset price is further away from the initial price also increases with time. The square root of the time is used because asset prices that change in opposite directions will cancel each other out.

Notice that the return of the stock price is not a factor in neither of the Equations 3.1-3.3, thus the option value is not depending on the return of the stock, only on the stock price itself, and it is therefore risk neutral. It is also noticeable that the time to maturity $T$-$t$ is only multiplied by the risk-free rate $r$ or the volatility $\sigma$, therefore an extended time to maturity will affect the option value in the same way an increase in $r$ or $\sigma$ will.

### ***What Influences the Option Value?***

There exists a positive relation between the stock price and the option value, which is illustrated in Figure 3.2. The stippled line A represents the maximum value of the option, and line B the minimum. In the figure the strike price is set to \$20, which is also the continuous parallel difference between the lines A and B. This is because the maximum value of the option (A) cannot be more than the stock, and the minimum value of the option (B) cannot be less than the stock price minus the exercise price ($20). (Black & Scoles, 1973)

The dotted lines $T_1$, $T_2$ and $T_3$ represent the values of the options for successively shorter maturity times. If the date of expiration for an option is in a long time, the value of the option is close to the price of the stock. However, if the expiration date is close, the option value is the stock price minus the exercise price, or zero if negative. If the stock price does not change, the option value normally reduces when the expiration date is close. (Black & Scoles, 1973)

The option value as a function of the stock price is characteristically represented by a convex curve, and since it is below 45°, the option is more volatile than the stock. This means that a small change in the stock price gives a larger change in the option value. Or that the rate of variation in the option is higher than the stock rate of variation. This can be proven from the Equation 3.1 showing how the option value is dependent on the stock price.

As a result of the market demand and supply, the stock price of an investment vary each day. If there are many vessels of the same type available on the market and the demand for these vessels are lower than the supply, the price will go down. Conversely, if the demand for a vessel type is higher than the amount of unchartered vessels the stock price goes up. Therefore Real Options can sometimes be referred to as a set of strategic options where the decision is triggered by market-priced risk.

The oil price is an example of market-priced risk because it is valued by future contracts. By securing their position in trading, assets with market-priced risk can reshape their risk. The ability of Real Options is to give this uncertainty a positive value. (Amram & Kulatilaka, 2000)

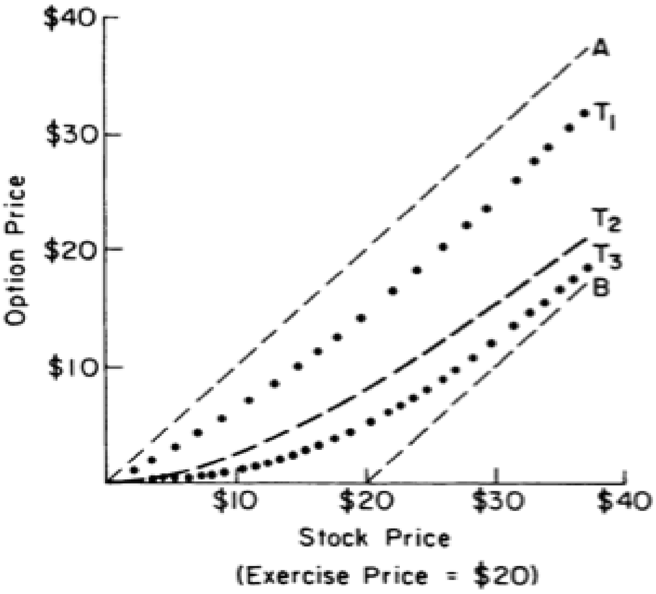

Figure 3.2: The Relationship between Option Value and Stock Price. (Black & Scoles, 1973)

From Brealey et al (2006) and Trigeorgis (1996) it can be summarized how the different factors influence the European option value. A high asset price or a low exercise price give a more valuable option. If payment of the exercise price is delayed until the expiration date and the interest rate is high, this is quite valuable. If the stock price is higher than the exercise price the option is valuable. The option value rises with the volatility of the stock price. And finally, options with a longer time to maturity are according to the BS OPM more valuable than short-term options. This is because the possibility of a higher stock price increases with a longer period of time. In a long-term call option there will be more time for an event to occur and make the option go in-the-money. In reality a bad news events can make the option be worth less, but the option value is limited down by zero whereas the upside is limited and this is captured with the Black Scholes formula.

## 3.3 CHALLENGES WITH REAL OPTIONS

It is exciting that a Real Options Analysis can place a value to the question "what if", but options are challenging to value when the underlying asset is non-liquid such as property, manufacturing equipment, oilrigs, offshore vessels and commodities. A Real Options Analysis often uses a decision tree to show different scenarios that can occur and a value is given to the probability rate of each scenario. The problem is that an estimation of the future is impossible to do with certainty and the probabilities are pulled out of thin air. However, other valuation methods (DCF, NPV) have the same problem when estimating the risk-free rate and the expected cash flow of a project.

Real Options shall not be used when there are no options at all, although this is almost never the case. When the level of uncertainty is low or the consequences of the uncertainty can be ignored, Real Options theory is not useful. Apart from this almost all projects are subject to option valuation.

Some of the statistical data such as the volatility, are difficult to implement to engineering. Even if the ROA is performed thoroughly and assumptions are carefully made, the results are based on assumptions that are difficult to explain, since the technique is optimized for financial assets. Because Real Option models use more complex tools like stochastic processes and optimization under uncertainty, the results can be difficult to present to a boss or manager who is responsible for the project.

# 4 USING THE BLACK-SCHOLES METHOD TO VALUE THE MOCV

Primarily it is important to justify the choice of method namely the Black-Scholes method. Black-Scholes is a method used for valuing European call options. It must therefore be explained as to why the option in this problem is European and why it is a call option. As described in Chapter 2.3, the ship owner has the option of entering into a new market by changing the equipment on the vessel. Since this can only be done at the expiration date of the current contract and not before, the option cannot be American. The option can in reality be exercised after the expiration date. However, there is a cost to keep the vessel idle, without contract. So, in this thesis I consider that at the first contract expiration the owner has an immediate decision to make: ether to invest in upgrading the vessel or not. If not, the owner will get a new contract with the same type of vessel (continue unchanged). Hence, the nature of this application points to a European option style. To argue that the option is a call, it should be mentioned that in order for the ship owner to perform the switch, he must buy the new equipment or pay an amount for installation, so there is a payment that needs to be made in order to exercise the option. Or you can say that the asset has to be bought. If this was a put option, the owner would earn money from selling an asset. Thus, the aforementioned explains why the option is a European call option and the choice of method is verified.

In the following sub-chapters, the Real Options theory from Chapter 3.2.5 will be applied to find a value to the pre-investment of creating a MOCV. In order to perform the ROA we need to obtain some market data that will be used in the Black-Scholes formula. Some of the data, such as the volatility and the strike price are difficult to find and must be drawn from a comparison of many references. This chapter gives an explanation of all the assumptions and input data used in the analysis.

## 4.1 TIME TO MATURITY

In the Black-Scholes formula the time to maturity of the option is required. This value represents the time period the option owner has to decide whether to exercise it or not. In our analysis, this is the time window the investors have to decide what equipment type will secure the vessel the safest future, whether a change of deck equipment can be more profitable or to continue unchanged. The expiration date is assumed to be the date of which the current contract expires. As an example, when switching from an OSCV to a PLV, we want to know the value of switching to a PLV after the OSCV contract has expired, and the available time we have to justify this choice is the time left of our current contract. Therefore the time to maturity in the model is assumed to be the contract length of the previous phase.

For the different vessel types it has been chosen varying contract lengths. This is decided based on Table 2.2 in Chapter 2.2, showing the typical length of the periods under which the vessels are usually contracted. The OSCV is utilized in many of the stages of Exploration and Production for oil and gas fields, such as development, production and decommissioning. This means that the vessel has a high likelihood of being requested. However, the tasks performed by this vessel type are not long-term. The OSCV can typically be chartered out in the spot market in the North Sea. Thus, the contract length for the vessel type is here set as one year. Of course the contract length varies based on the task the vessel will be performing, the extent of the operation and how many modules to be installed.

A pipe-laying vessel is mostly used during the development phase of oil and gas fields. Supported by Table 2.2, this phase take between 2-4 years, depending on the size of the field and the complexity of the piping system. Therefore, in this analysis, a pipe-laying contract is assumed 3 years in duration. The Well Intervention Vessel is contracted based on immediate requirements during the production phase of the well, which can stretch from 5-50+ years (see Table 2.2). Therefore the vessel has more variable contract durations. Since a field can consist of numerous wells, and the intervention work on each well can be quite time consuming, the contract length used in this analysis is 5 years. The contract durations are presented in Table 4.1.

Table 4.1: Contract Lengths for each Vessel Type

| Vessel Type | Contract Length [years] |
|---|---|
| OSCV | 1 |
| WIV | 5 |
| PLV | 3 |

During one year the total amount of operational days is 365 minus days in off-hire. The off-hire period depends on the vessel's need for repairs, dry-docking and surveys, and is highly undesirable as it often occurs unscheduled. During this time the charterer is not required to pay for the vessel. It is assumed that without severe problems or drastic need for maintenance we can set an average amount of off-hire days for Offshore Support Vessels to 2 days (SIEM, 2014). Resulting in 363 operational days per year, which will become useful for the calculation of the stock price in the next section.

## 4.2 THE STOCK PRICE

In this analysis it is assumed that the stock price is represented by the daily hire rate of the vessel multiplied by the amount of days in the contract, and several explanations for this exist. In finance, the stock price is the value of which you can sell a stock. Another way to see it is that the stock price is the potential income one can earn from selling the stock. When chartering out a ship, the potential income comes from the vessel's daily hire rate. This rate is a result of the operational region, the time (month and year), what type of contract it is etc., and they can be represented as an average yearly value. Because the Black-Scholes formula requires the current value of the stock, the charter rates used for this analysis are taken from 2015. Table 4.2 shows the daily hire rates for the three vessel types and their associated stock prices. In Appendix C, the full calculations of the stock prices are included. The hire rates are gathered from personal communication with Ulstein, and they are for vessels operating in the North Sea based on long to medium term contracts.

Table 4.2: Daily Hire Rate and Stock Price. (JJG Agis, 2015, pers. comm,. 28 April)

| Vessel Type | Daily Hire Rate, 2015 [$] | Stock Price [$] |
|---|---|---|
| OSCV | 75 000 | 27 225 000 |
| WIV | 243 000 | 441 045 000 |
| PLV | 203 000 | 221 067 000 |

## 4.3 THE STRIKE PRICE

The strike price is defined as the price paid to exercise the option, or the cost of purchasing the underlying asset. In this thesis we are valuing the option of switching markets by switching the deck equipment on our vessel, and the deck equipment can be referred to as the underlying asset. The strike price represents the cost related to transforming the vessel from one phase to another. This cost is dependent on various factors, but the most dominant expense is the cost of acquiring the deck equipment. Further, an additional cost for mobilization and demobilization of the equipment is included. The installation cost consists of the man-hours and the use of equipment required to perform the installation, such as cranes. Since the vessel is prepared for the additional deck equipment, further modifications to support the equipment and engage it with the rest of the vessel are not included. Supported by these assumptions, the installation cost is set as 10% of the equipment cost (JJG Agis, 2015, pers. comm., 28 April). When removing the equipment the same procedure is followed, thus the cost of demobilizing is also assumed to be 10% of the equipment cost. The chosen type and dimensions of the deck equipment for each vessel type is explained in Chapter 2 and the costs of buying the deck equipment are listed in Table 4.3. The equipment costs are gathered from personal communication with NOV.

Table 4.3: Equipment Costs and Strike Price. (D Hoy, 2015, pers. comm., 28 April)

| Vessel Type | Equipment | Equipment Cost | Total Equipment Cost |
|---|---|---|---|
| OSCV | 250t KBC | 9.6 mUSD | 9.6 mUSD |
| WIV | 300t MHT | 25 mUSD | 25 mUSD |
| | 100t Skidding System | 1 mUSD | |
| PLV | 250t VLS | 16 mUSD | 21.5 mUSD |
| | 2500t Carousel | 5.5 mUSD | |

The strike price is also affected by the decision of whether to sell the used equipment or store it, or buy the new equipment or to rent it. This is solved in the analysis by assuming that the first time the vessel will undergo a change into a new vessel type, the shipowner will have to acquire all the necessary equipment, but once it is bought the equipment can be stored for future periods. The next time the vessel will operate with this particular equipment it will only be necessary to transport the equipment from the storage and do the installation at the dock. This is implemented in the calculations by calculating different stock prices based on what operational modes the vessel has been in before.

When switching from an OSCV mode the only change is to add new equipment, and no equipment will need to be removed. If the vessel takes on a new OSCV contract without changing, the strike price is 0 and the option has not been exercised. However, if the option is exercised the strike price is calculated as the cost of the new equipment plus an additional 10% covering the installation, plus the 10% additional cost of removing the previous equipment, if there is any. Formula 4.1 shows the calculation of the strike price the first time new equipment is mobilized. The second time this particular equipment will be utilized, the strike price only includes removal of the previous equipment, if there is any, and installation of the new equipment. This is shown in Formula 4.2. The cost of storage is neglected.

If the equipment is being demobilized for the last time, because it is not going to be used anymore, or the end of the vessel's lifetime is approaching, the equipment can be sold in the second hand market. The second hand sale price for this type of equipment can be estimated equally as the sale of a used car; with a 10% discount for each year since it was built (D Hoy, 2014, pers. comm., 10 December). This is shown in formula 4.3. In the analysis, the income from selling the equipment is not included because then the strike price would be negative which the Black-Scholes formula cannot handle. Therefore the potential earnings are included in the discussion of the value of the call option in Chapter 6.

$$K_1 = Prev. Equipment\ Cost \cdot 0{,}1 + New\ Equipment\ Cost \cdot 1{,}1 \qquad (4.1)$$

$$K_2 = Prev. Equipment\ Cost \cdot 0{,}1 + New\ Equipment\ Cost \cdot 0{,}1 \qquad (4.2)$$

$$K_3 = Equipment\ Cost \cdot 0{,}9^{years\ in\ use} \qquad (4.3)$$

Based on the Equations 4.1 and 4.2, and the arguments for when they should yield, different strike prices have been calculated for almost every scenario in the decision tree. These are presented in Table 4.4 and Table 4.5. The actual calculations are shown in Appendix F.

Table 4.4: Strike Price when Switching. Cost of New Equipment Included

| To<br>From | OSCV | WIV | PLV |
|---|---|---|---|
| **OSCV** | 0 | 27 500 000 | 23 650 000 |
| **WIV** | 2 500 000 | 0 | 26 150 000 |
| **PLV** | 2 150 000 | 29 650 000 | 0 |

Table 4.5: Strike Price when Switching. Cost of New Equipment Excluded

| To<br>From | OSCV | WIV | PLV |
|---|---|---|---|
| **OSCV** | 0 | 2 500 000 | 2 150 000 |
| **WIV** | 2 500 000 | 0 | 4 650 000 |
| **PLV** | 2 150 000 | 4 650 000 | 0 |

## 4.4 THE VOLATILITY

In the Black-Scholes formula, the volatility is defined as the fluctuation of the stock price over time. By looking at the historical change in the stock price, one can derive the historical volatility of it. The historical volatility can therefore be explained as the past behaviour of the stock, and be used to predict the future of the price. In excel the volatility is found by creating a simple table listing the previous stock prices in a constant time frame. By using Formula 4.4, the change between one stock price and the previous is calculated as a decimal. Since the volatility is related to standard deviation, or how much the prices differ from the mean, it is calculated by finding the standard deviation of all the change rates found for each vessel type.

$$Change = \frac{Stock\ Price}{Previous\ Stock\ Price} - 1 \tag{4.4}$$

The historical volatility of the stock price is represented by the volatility of the daily hire rates for the vessel types from 2012-2015. This can be justified because the stock price is proportional to the daily hire rate. So the volatility of the stock price would be the same as the volatility of the daily hire rate. The historical daily hire rates are presented in Table 4.6 and the calculated volatilities for each vessel type in Table 4.7. A complete calculation of the volatilities is added to Appendix B.

The Black-Scholes formula requires the annual volatility of the stock price. When the volatility was calculated, the input had a time frame of one year; therefore the output is the annualized volatility. However, if the input had been, for example monthly, the results would need further calculations to be converted into annualized historical volatility.

Table 4.6: Daily Hire Rate [USD]. (JJG Agis 2015, pers. comm., 28 April)

| **Vessel Type** | **2012** | **2013** | **2014** | **2015** |
|---|---|---|---|---|
| OSCV | 105.000 | 106.667 | 100.000 | 75.000 |
| WIV | 277.000 | 246.667 | 309.000 | 243.000 |
| PLV | 150.000 | 203.333 | 242.125 | 203.000 |

Table 4.7: Calculated Annual Historical Volatility for each Vessel Type

| **Vessel Type** | **Volatility** |
|---|---|
| OSCV | 0,14 |
| WIV | 0,24 |
| PLV | 0,26 |

## 4.5 THE RISK-FREE RATE OF RETURN

The risk-free rate of return or risk-free interest rate is the theoretical rate of return from an investment without risk. The rate is the expected interest from a risk-free investment over a specific time period. It is common to base the interest rate on government bonds, because they are the safest investments one can make (Johansen et al., 2013). The risk-free rate can be expressed as a ten-year rate or sometimes a five-year rate. From a market survey answered by the members of the Norwegian Society of Financial Analysts

(NFF) most respondents utilize the ten-year bond as the risk-free rate. It has therefore been chosen to utilize the ten-year risk-free rate of a government bond from 2014 found from a report by PWC on the Norwegian risk premium (PWC, 2014). The interest rate was given as 48% for a ten-year bond, but the Black-Scholes formula requires the rate to be annual, so to convert the ten-year rate from 48% the tenth root of the number was used. The yearly interest rate became 1.47%, and was implemented in the formula as the decimal 0.0147.

# 5 RESULTS

Based on the assumptions and decisions made in Chapter 4, the Black-Scholes analysis was implemented in Excel for all switching options. The main results from the case analysis will be presented in this chapter; this includes the call option value for each node in the decision tree. When applying the Black-Scholes formula obtain the value C, representing the value of the European call option. For visual simplicity the results will be presented in three separate tables, representing the first three options and their following three options. The total structure of the decision tree is equal to Figure 2.6 in Chapter 2.3.

Figure 5.1 represents the option values of the vessel's opportunities if the next contract after the initial OSCV contract is another OSCV contract. In other words, if the option is not exercised. Towards the end of the second period operating as an OSCV the figure shows the option values for the next three alternatives, and from the next nodes there are three new opportunities with each their own value. Figure 5.2 shows the option values if the first contract the vessel takes on is within well intervention. Similar to Figure 5.1 the following nodes give the values of the three possible choices, and the next three choices after that. Figure 5.3 shows the values if the option of switching to PLV is exercised at the first expiration date.

In Table 5.1 and Table 5.2 the same results are presented, but in matrix form. The tables illustrate the values of switching between different operational modes. Table 5.1 shows the option values in the scenario where the new equipment has to be acquired before switching, while Table 5.2 represent option values when the equipment is already bought and stored for use. It is noticeable that the option values of all scenarios where switching to an OSCV are the same in both of the tables. This is because no new deck equipment has to be acquired when switching from one of the other vessel types to an OSCV. Another observation is that the values of not exercising the option - going from one vessel type to the same vessel type in the table – cannot calculated by the BS OPM. This is because when no change is made the strike price is zero. The BS OPM does not comply with a strike price equal to zero because it would force the model to divide by zero. In these scenarios the option is delayed for the next period. The rest of the values will always be higher in Table 5.2. As explained in Chapter 4.3, this is because the strike prices were calculated differently based on whether or not the new equipment had to be bought or not. When the equipment has already been stored from previous periods the strike price is lower and thus the total option value becomes higher.

The main discovery from the results is that to invest in a multifunctional vessel is valuable. This can be seen because all the call option values C, in the figures 5.1-5.3 and the tables 5.1-5.2 are strictly positive. From Equation 3.1 in Chapter 3.2.5 we know that in order for C to be positive, the stock price has to be higher than the strike price, which means that the potential income from exercising the option is more than the cost of exercising the option. Another variable that can justify this observation is the value $N(d_2)$, which is defined in Chapter 3.2.5 as the probability that the stock price is higher than the strike price at expiration. When using the BS OPM, an option will usually be exercised at expiration if the stock price is higher than the strike price. Thus, $N(d_2)$ actually represents the probability of the option being exercised at expiration. From Appendix H it can be seen that for almost all scenarios, $N(d_2)$ has the value 1, which means that the probability of exercising is 100%. The value $N(d_1)$, representing how far into the money the stock price will be if, and only if, the option expires in the money, is also always equal to 1. Meaning that the stock is 100% into the money at expiration. The only occurrences where these values are not 1, with a three decimal approximation, is when the vessel retrofits into a PLV for the first time after it has been operating as a WIV. The reason for the option value being lower in these scenarios might be because the stock price for the PLV is a lot lower than for a WIV, while the strike prices are quite close. Also the deck equipment for the PLV will have to be bought and installed, at the same time as the expensive WIV equipment has to be demobilized. The strike price between this particular switch is among the highest in the analysis. Therefore the value of exercising the option of switching between a WIV and a PLV when the strike price is at its highest is lower than for the other switching options.

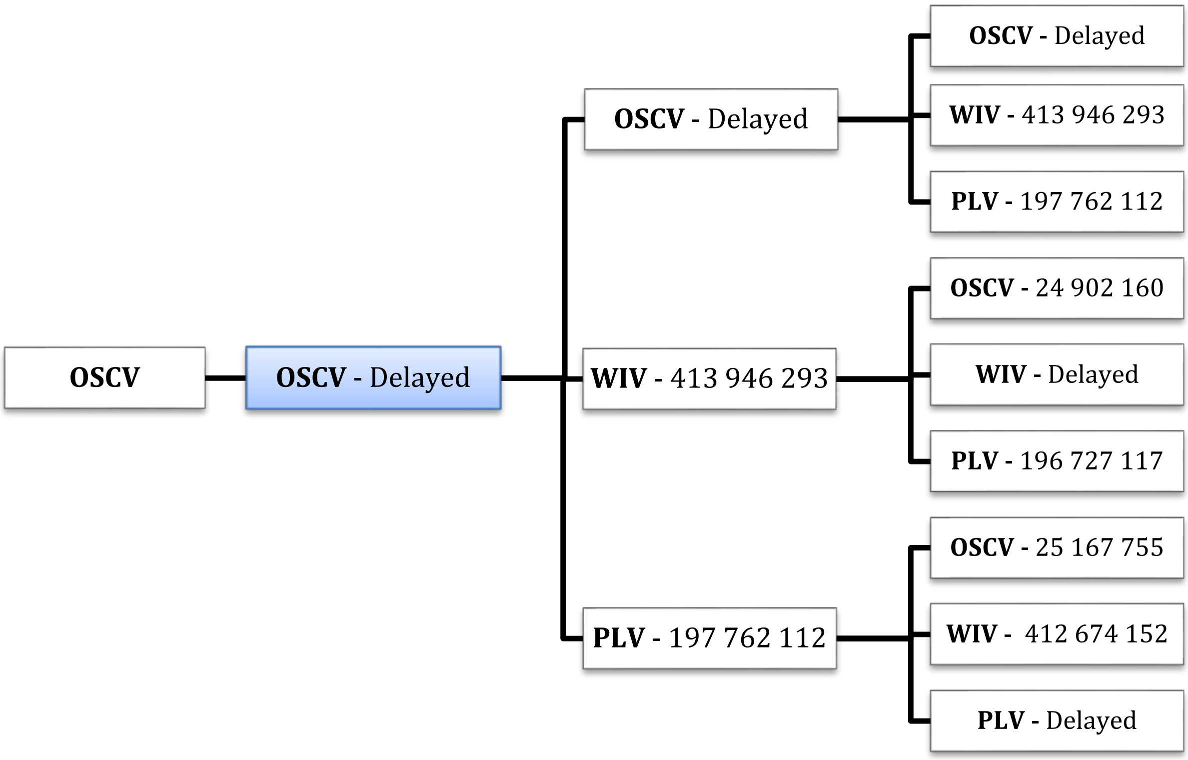

Figure 5.1: Results if the Option is not Exercised at the first Decision Node

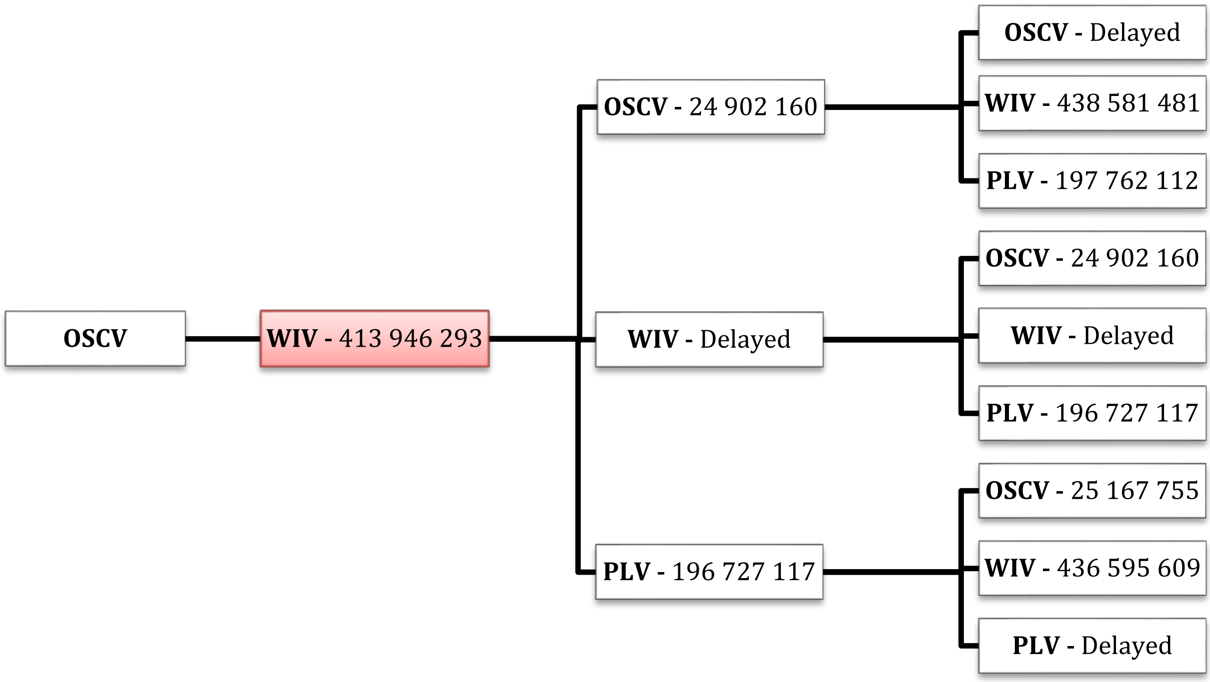

Figure 5.2: Results if the Option of Switching to a WIV is Exercised at the first Decision Node

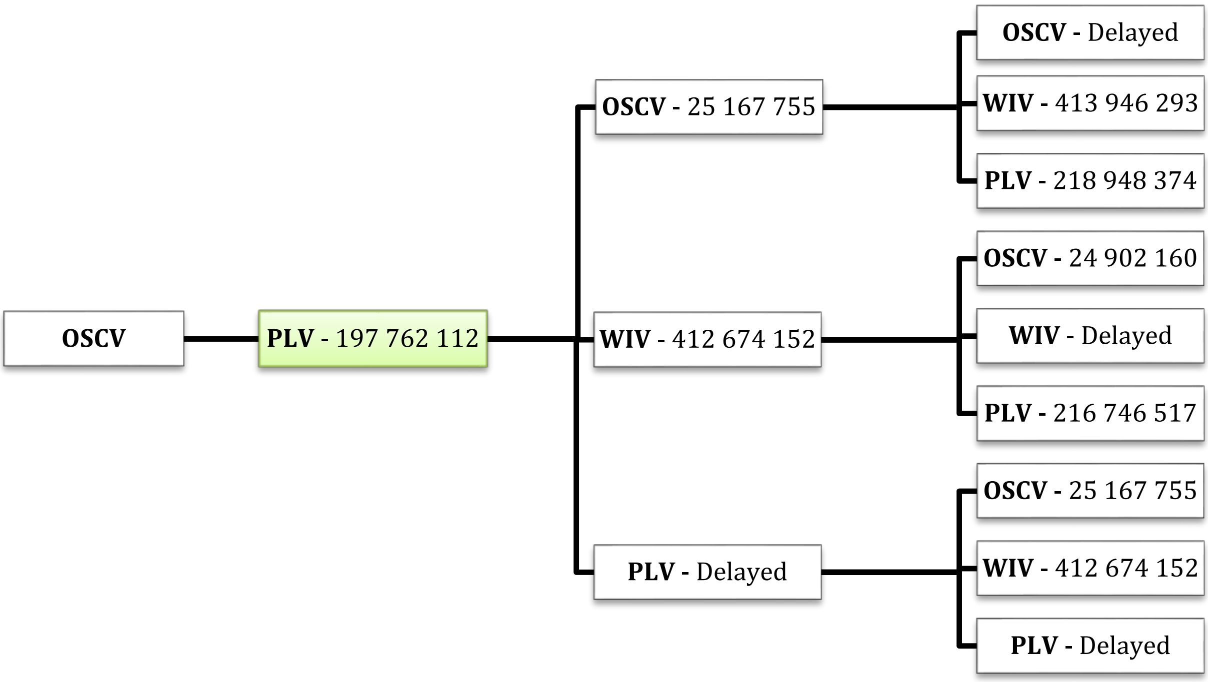

Figure 5.3: Results if the Option of Switching to a PLV is Exercised at the first Decision Node

Table 5.1: Value of Switching between Vessel Types. Equipment Cost Included

| To<br>From | OSCV | WIV | PLV |
|---|---|---|---|
| **OSCV** | - | 413 946 293 | 197 762 112 |
| **WIV** | 24 902 160 | - | 196 727 117 |
| **PLV** | 25 167 755 | 412 674 152 | - |

Table 5.2: Value of Switching between Vessel Types. Equipment Cost Excluded

| To<br>From | OSCV | WIV | PLV |
|---|---|---|---|
| **OSCV** | - | 438 581 481 | 218 948 374 |
| **WIV** | 24 902 160 | - | 216 746 517 |
| **PLV** | 25 167 755 | 436 595 609 | - |

# 6 DISCUSSION

Certainly, there have been many assumptions that make these results less exact. This chapter is a discussion of the assumptions and choices made in relation to the analysis, and the challenges faced when analysing Real Options.

## 6.1 DISCUSSION OF THE INPUT DATA

Each and every decision regarding the input parameters in the analysis contributed somehow to the final results. In this subsection each assumption will be evaluated, and the consequences of their deviation from reality will be discussed. Before we begin it is important to list up how a change in one of the different variables will affect the call option value, which is listed in Table 6.1.

Table 6.1: Determinants of the Call Option Value (Gitman et al., 2010)

| An Increase in… | Will cause the Call Option Value to… |
|---|---|
| Time to maturity | Increases |
| Stock price | Increase |
| Strike price | Decreases |
| Volatility | Increase |
| Risk free rate of return | Increases |

### 6.1.1 Discussion of the Time to Maturity

In Chapter 4.1 it was justified that the time to maturity, T should be set equal to the contract length of the previous operational phase. This is a good estimation for the model, but in reality the decision time can be estimated in many different ways based on various arguments. There can be high competition among companies to get a contract that is highly attractive in the market. This requires extensive preparation and planning from each rivalling company in order to convince the customer. Thus, the planning time is increased, and the time to maturity of the option is also increased. Based on what is stated in Table 6.1 this would increase the option value.

It is also a common fact that the complexity and the length of the operation described in the contract will demand a longer preparation time from the shipping company. Thus, a contract over five years requires a longer planning time than one of three years. This means that an assignment for a well intervention task following an OSCV contract can be in planning even before the OSCV contract has begun. Following this argument, the time to maturity used in the model is too short, which results in an option value that is lower than it should be. If the analysis was performed with these considerations in mind, and the times to maturity of each option were set equal or proportional to the contract duration of the new vessel type, this would have affected the results.

### 6.1.2 Discussion of the Stock Price

The seven assumptions underlying the stock price in the Black-Scholes model were first presented in Chapter 3.2.5. In this subsection, the assumptions will be investigated to determine if they can be justified. In the Black-Scholes formula, the stock price is assumed to follow a random-walk behaviour. This is based on the presumption that buyers invest rationally, which means that they act self-interested and with economic profit in mind. The asset value is estimated based on future expectations, which can be forecasted from existing information, and it changes when new information is available. When the forecast of the future stock price is favourable investors rush to buy the asset before the value jumps down. The Black-Scholes model also assumes that the market is efficient, meaning that the price will be adjusted quickly with new information, and investors cannot "beat the market". This is because all investors do thorough research on each stock before making decisions. The big question is therefore: can the offshore vessel charter market be described as efficient? If so, the assumptions in the Black-Scholes model will be entirely accurate. But this is not a simple question, and it is an issue to which economists have devoted a lot of time and effort.

If the freight market is inefficient the profit can be maximized by wisely switching from one market to another, like entering the spot market or locking in the time charter rates. According to Karakitsos and Varnavides (2014) consultants must "*instantly learn all new information, absorb its implications for profit opportunity or loss and react instantly to take advantage of it*" for a market to be efficient. But this is not possible in a realistic market, as many investors do not act upon the new information, because they do not appreciate its implication or they are not prepared to take the risk. There are many factors affecting this subject. Like how the risk can be measured and adjusted. Can anyone have control over all available information that can change the market, and how does someone know what information is relevant? In some cases investors are not in the market long enough to be aware of the changes. Or secret data can be discovered by snooping or looking hard enough for it. Therefore Karakitsos and Varnavides describe the market as inefficient in the short run, but not necessarily in the long run. However, in reality if the market can be beaten, there is no obvious way to do so, and market movements are difficult to foresee. During the Greek financial crisis in 2010 the demand fell short of the supply, and many ship owners did not act on the information by locking in the time charter rates. If the market had been efficient this decision would not have had an economic impact, but since the market can be observed as inefficient during short time periods, the owners that did lock in the charter rates benefited from it.

The initial assumption of a random walk behaviour of the stock price can also be discussed. An article by MacKinlay and Lo (1988) states that there exists a low correlation between the prices on a short basis and a slightly stronger correlation over the long term. Our stock price was implemented into the calculations with yearly intervals. In finance, one year is considered to be a long time period and there will thus exist a correlation between the values. The final results are most likely affected by the error related to this assumption.

Another assumption regarding the stock price in the Black-Scholes method is that the stock price does not pay dividends, which is not compatible to the real world. A way of adjusting this in the formula is to subtract the discounted value of the future dividend from the stock price, but this is neglected in this analysis. If the dividends had been included in the calculations, it would have resulted in a lower stock price and thus a lower call value, which is supported by Table 6.1.

The stock is also assumed to follow a lognormal distribution. The difference between lognormal and normal distribution is that the tail of the lognormal function is longer, which allows for stock prices between zero and infinity. The lognormal distribution also assumes that the stock can only drop by a 100%, but it can rise by more than 100%

(Hodley, 2015). In reality, dramatic movements in the market affect the stock price by making their tails shorter than the lognormal. Measuring the degree to which the real asset price differs from the lognormal distribution can prevent the errors from the lognormal assumption.

### 6.1.3 Discussion of the Strike Price

The strike price, representing the price at which the option can be exercised, is implemented in this analysis as an approximation of the total cost of switching from one vessel type to another. The strike price affects the results so that a lower strike price increases the option value. In Chapter 4.3 the content of this cost was verified as the cost of purchasing the new equipment, plus the cost of installing the equipment and demobilizing the old equipment. The installation and demobilizing cost was assumed 10% of the equipment cost. However, it is problematic to give a mutual estimate for all equipment types. Some equipment can be considered cheap to purchase, but it can be quite complicated to install, while other equipment may be expensive, but the mobilization procedure can be quite simple and fast. Despite that, with errors and omissions accepted a 10% assumption is valid.

When performing the actual retrofitting from one vessel type to another, the vessel will be in off-hire during the time this process will take place. The potentially lost income from days in off-hire is neglected from the strike price. This is because it is assumed that when the vessel is dry-docked and the deck equipment is demobilized/mobilized, the vessel will already be unchartered, and it will not be under a specific contract. In the absence of the off-hire contribution, the strike price is lower in the analysis than what it should be in real life. Based on Table 6.1 this makes the calculated option value somewhat higher than the realistic value.

It is assumed that after the period where an equipment type is used for the last time, the equipment can be sold with a 10% discount for each year since it has been fabricated. Although the income from selling the used equipment is part of the transformation phase between the vessel types, the earning contribution cannot be included in the strike price of this call option because it will in some cases result in a negative strike price. This is not compatible with the Black-Scholes formula. Mathematically, because it we will be trying to find the natural logarithm of a negative value, which is not possible. It also coincides with the original definition of holding a call option. The option holder has the right, but not obligation to exercise the option at the expiration date, but if exercising the option gives an income, then no matter the stock price, the owner would exercise the option with a negative strike price. Therefore the sales income is presented additionally in the results as an extra potential income and not used in the calculations.

In the demobilization of the equipment needed for well intervention it can be beneficial to keep some lengths of the skidding system, especially in the areas around the ROV hangar. The ROVs are helpful in the other operational modes as well, and the skidding rails in the hangar area would not obstruct other operations. In the analysis it is assumed that after operating as a Well Intervention Vessel, all the purchased equipment such as MHT and all lengths of the skidding system is removed upon the switch. By not removing parts of the skidding system the strike price could have been lower resulting in a higher call option value. There is also some other small, but necessary equipment that were not included in the strike price, like the cargo tanks for mud and brine on the WIV. By including these, the actual strike price would have been higher, making the call value lower.

### 6.1.4 Discussion of the Volatility

The most significant assumption regarding the volatility in the Black-Scholes formula is that it is constant over time. This might be true over a short time, but never for a longer period. Figure 6.1 shows how the daily hire rate for the three different vessels has changed over the past three years, which is a relatively short time period compared to the vessel's total lifetime of 20 years. Still, during this short period of time it is observable that the rates change drastically. The constant volatility that was implemented in the BS OPM would therefore differ from the non-constant volatility that could have been used instead. In some advanced option-valuation methods, like the one presented by Geske (1979) a non-constant volatility is generated by a stochastic process, which could have been done in this analysis to simulate more realistic non-constant volatilities over time. The results would become somewhat different and more realistic if this method was used.

Another interesting observation to discuss regarding the volatilities is shown by comparing Figure 6.1 and Figure 6.2. Figure 6.2 shows that from 2013 to 2014 the oil price dropped almost 60%. The figure also shows the oil price over the last decade. Since we calculated the volatility of the stock price by looking at its change over the last three years, we will use the same time period for calculating the volatility of the oil price. By using the same method as in Chapter 4.4 to calculate the volatility of the oil price we discover that the volatility is 0.25 for the last three years. The Excel calculations are shown in detail in Appendix E. As a reminder, the volatilities of the stock prices for the OSCV, WIV and PLV were calculated in Chapter 4.4 as 0.14, 0.24 and 0.26. This means that in the case of the WIV and PLV the stocks change proportionally to the oil price from 2012 to 2015. However, the volatility of the OSCV is much lower than for the oil price.

An initial thought was that the volatility of the oil price could be used in the analysis as a good approximation to the volatility of the stock price. If this had been done in the analysis, the option values for the WIV and PLV would not have differed much, but the option value of the OSCV would have ended up too high. It was therefore wise to use different volatilities for the different vessel types as was done eventually in this analysis. This enables the method to evaluate each vessel type separately and discover their differences.

It can be also interesting to look into the physical factors causing the OSCV's volatility to not be equal to the other vessel types', and why it is not equal to the volatility of the oil price. It can have something to do with the fact that the OSCV is not as dependent on the oil and gas industry as the other two vessel types. For example the vessel can be utilized in construction and maintenance of wind turbine fields and other offshore tasks. Table 2.2 shows how the OSCV is needed in three of four phases in Research and Development of oil and gas. The table also shows how the different phases are affected by the oil price. Another reason for the dissimilarity between the volatilities could have been the way the volatility was calculated that caused an error. Still it can be seen from Figure 6.1 that the span in the change of the hire rates is bigger for WIV and PLV than OSCV. Based on this it should be correct that OSCV has a lower volatility.

It is of importance to mention that the volatility does not consider negative changes in the stock price, because it uses the absolute value of the change. In the Black-Scholes formula a higher volatility gives a higher call option value, regardless of whether the volatility represents a rise or decline in the stock price. The Black-Scholes formula does not consider that stock prices can go down the same way that for example the Binomial Option Pricing Model (BOPM) does. As explained in Chapter 3.2.3, the BOPM uses a binomial lattice tree to look into the chances of the stock price going up by a factor u, or down with the factor d. The factors u and d are calculated from the volatility. By using the binomial lattice tree it analyses all the possible directions the stock price can move in and correct for the volatility only being positive, which the Black-Scholes model doesn't. Although the BOPM considers rising and declining in the stock price, this problem could not have been solved by using the BOPM. This is because the option is not American as it can only by exercised at the expiration, and not at any time before the expiration like the BOPM suggests.

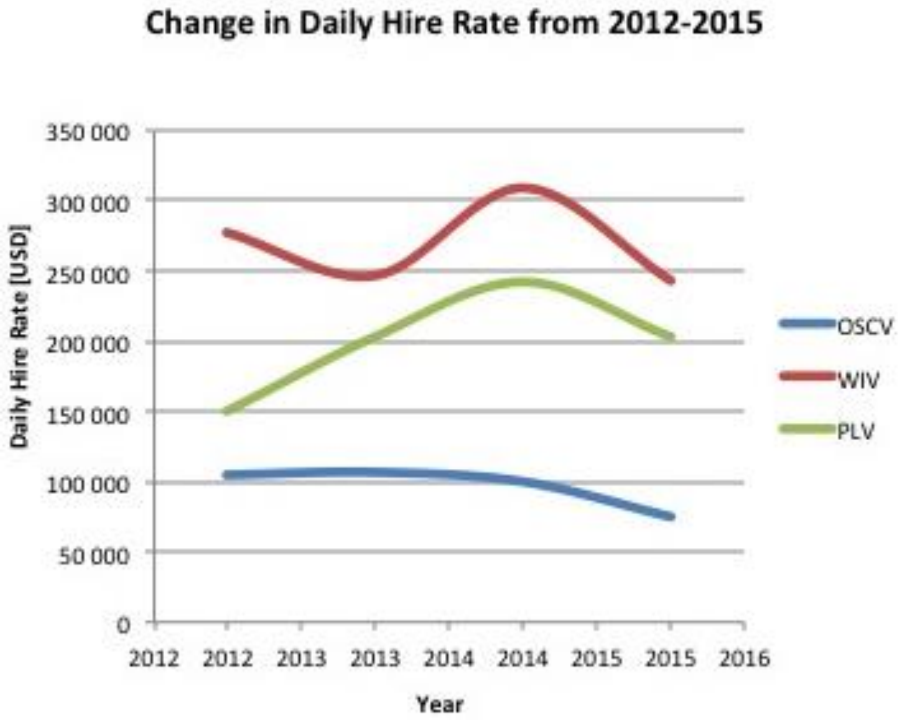

Figure 6.1: Change in Daily Hire Rate from 2012 - 2015. (Compiled by Author)

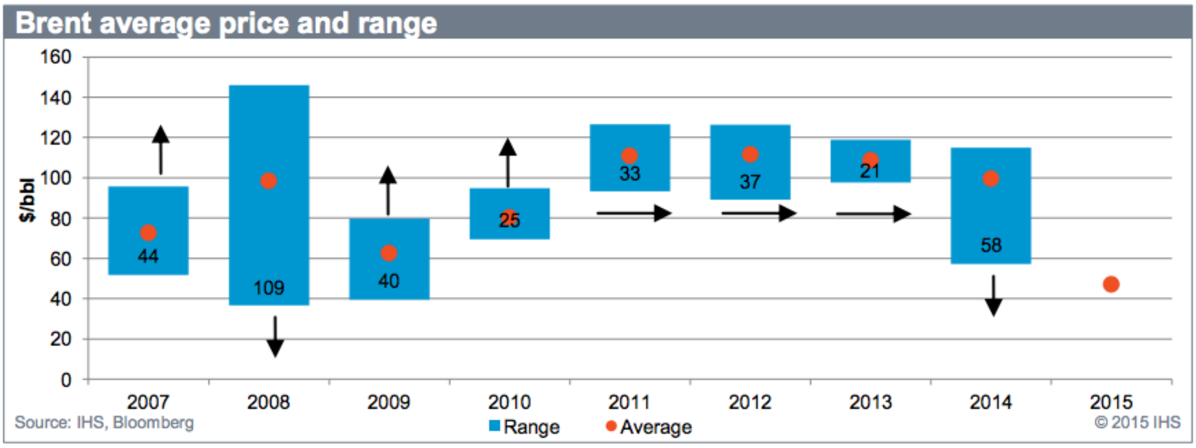

Figure 6.2: Brent Average Price and Range. (Victor, 2015)

### 6.1.5 Discussion of the Risk-Free Rate of Return

The value of the risk-free rate of return is dependent on the development in the market and is not constant in time, or directly observable in the market, therefore different market surveys can give varying rates. The last years the market has been irregularly volatile and characterized as highly uncertain. This has resulted in a risk-free rate at historically low values. The numbers used in this analysis are from 2014, but the numbers from 2015 might be even lower because of recent changes in the economy. By using the rate from 2015 the results would thus have been lower. In this analysis, the ten-year bond was used, but the five-year bond gives a higher risk-free rate than the ten-year. If the five-year bond had been used instead the results would have been higher. Since there are many different ways of choosing the risk-free rate, there follows a level of error in the results.

## 6.2 DISCUSSION OF THE RESULTS

Based on the results presented in Chapter 5 it has been established that the option value is positive for all nodes. A factor that has not been considered in the calculations is the initial investment of building the MOCV. It is understandable that the OSCV with a reinforced moonpool area is more expensive to build than a conventional OSCV. In Table 6.2 the building costs of each vessel type is listed, estimated based on the vessel specifications and equipment capacities presented in Chapter 2.3. The numbers were obtained from personal communication with Wärtsïla, and the values were converted from NOK to USD by using the currency rate 0.134 (April 24th 2015). From the table it can be seen that the difference in building costs between the multipurpose OSCV and the conventional OSCV is 13 mUSD. Thus, the necessary extra investment that has to be made in order to build the MOCV is 13mUSD. Or one can say that for the price of 13 mUSD the owner buys the right to retrofit the vessel into three different vessels. Since the initial investment is not considered in the Black-Scholes analysis, we must evaluate the implication of it ourselves. Now if any of the option values had been below the initial investment we would not have gained less then what we initially invested in the project. Luckily the lowest option value in our results is 24 902 160 mUSD, which is above 13 mUSD. So the lowest profit we could obtain is the difference between the lowest option value and the investment, which is approximately 12 mUSD. This occurs when switching from a WIV to an OSCV. The reason that this particular scenario gives the lowest option value is somewhat because of the low stock price for the OSCV. And because when switching from a WIV, there is a cost for demobilizing the expensive deck equipment of the WIV.

The numbers presented in Table 6.2 apply to vessels built at Norwegian shipyards. The building cost of a vessel is of course not constant in time. Factors affecting the cost can include the priority of the client, quality of the project, choice of materials, market conditions, legislative restrictions, where the vessel is being built and many more. When the building cost is low it will economically be wise to buy the vessel and operate it, and when the cost is high, it can be clever to use one of the already existing vessels in the fleet and operate it. In a good market where the utilization rate is higher for offshore vessels, it is more profitable to own several vessels that can be in operation simultaneously. In a market like today where numerous vessels are laid up, a vessel owner with many vessels will have made a large investment in a fleet that gives low revenue. Had the owner invested in a flexible vessel instead of three single purpose vessels, this would have provided a safer income and contracting opportunities for the vessel. Although a multipurpose vessel is a bigger investment than one single purpose vessel, it is safer with regard to securing employment in several potential markets. In addition, a fleet of three single purpose vessels is more costly than one MOCV, which can be seen from Table 6.2.

Table 6.2: Building Costs. (E. Sandvik 2015, pers. comm., 24 April)

| **Vessel Type** | **Building Cost** |
|---|---|
| OSCV Conventional | 94 mUSD |

| | |
|---|---|
| OSCV Reinforced | 107 mUSD |
| WIV | 134 mUSD |
| PLV | 127 mUSD |

The payback period for a multipurpose vessel will depend on the state the vessel operates in, the Operating Expense (OPEX) and the hire rates. If the vessel is not operated by the owner, the OPEX includes manning cost (Scandinavian crew, not technical personnel), maintenance and repair cost, stores and supplies cost, insurance cost and management cost. The amount of years in operation it would take to earn the total investment for each vessel type can be calculated from Equation 6.1. From this it has been discovered that the longest payback period is if the vessel operates as an OSCV for five and a half years. The shortest payback time is if the vessel performs well intervention for one year and eight months. While for a PLV it would take one year and eleven months to regain the investment.

$$PaybackYears = \frac{BuildingCost\ [USD]}{HireRate[USD/Day] - OPEX[USD/Day]} \cdot \frac{1}{365} [{}^{year}/_{days}] \qquad (6.1)$$

Table 6.3: OPEX and Hire Rate. (JJG. Agis 2015, pers. comm., 21 May)

| **Vessel Type** | **Building Cost [mUSD]** | **Hire Rate[USD/Day]** | **OPEX [USD/Day]** | **Payback Period [Years]** |
|---|---|---|---|---|
| OSCV | 107 | 75 000 | 22 000 | 5,5 |
| WIV | 134 | 243 000 | 27 000 | 1,7 |
| PLV | 127 | 203 000 | 24 000 | 1,9 |

The vessel owner has the opportunity to profit from selling the used deck equipment. It is assumed that this equipment can be sold with a 10% discount for each year since it was produced. By using the costs of new equipment presented in Chapter 4.3, we obtain the graphs in Figure 6.3. The graph shows how the price of the deck equipment decrease with time and converge towards 2 mUSD at the end of the vessel's lifetime. As explained in Chapter 4.3 this potential income was not included in the calculations of the option value, but it is important to consider in the overall picture.

From the discussion of the input parameters in this chapter, we know that the results have errors and deviations. Since Real Options is relatively new in engineering practice, many errors occur when financially-based approaches are used in practice. Many deviations have been discovered and discussed earlier in this chapter. Probably, many more sources of errors exist that have been missed here. Since there is no available data available from previous analyses of this particular multipurpose vessel, the results cannot be compared to previous or similar work.

It has been chosen to use the BS OPM in four stages of the service time to clearly see the economic benefit of storing the equipment for future periods. And this is shown in Table 5.1 and Table 5.2. It can be seen that the biggest amount of money one can save by doing this is about 25 mUSD, which is in the case of switching from OSCV to WIV. This is a 5.6% increase in option value. Although the actual price of storing the equipment has been neglected the results demonstrate the increase in value.

Although it looks like WIV is the most profitable operational mode, it is difficult to give a recommendation of what operational mode is most preferred and when it should be used. The results clearly show that the WIV mode always gives the highest option value, followed by the PLV and lastly the OSCV. This is because WIV hire rates usually exceed hire rates for OSCV and PLV to compensate for the complexity of the vessel and the higher building cost. Since the stock price is calculated based on the hire rates, the stock price of the WIV will always be greater than for OSCV and PLV. Also, in Chapter 4.2 it was explained that the stock prices were calculated by multiplying the daily hire rates for each type with the amount of days in the contracts of each vessel type. Since it was assumed that the operational modes would have different contract lengths with the WIV having the longest of 5 years, the stock prices of the vessel types are multiplied with a different number of years. This makes a huge difference in the results as the stock price of the WIV is, for example, 5 times higher than for the OSCV. Therefore it becomes unrealistic to compare the vessel types to each other based on the results. The results also underscore the already known fact that a longer contract is more valuable. However, had the time to maturity of the options been given a mutual value, for example 3 years, for each of the cases, the option values would have been closer to each other in value, but from Appendix J it can be seen that the WIV still gives the highest value.

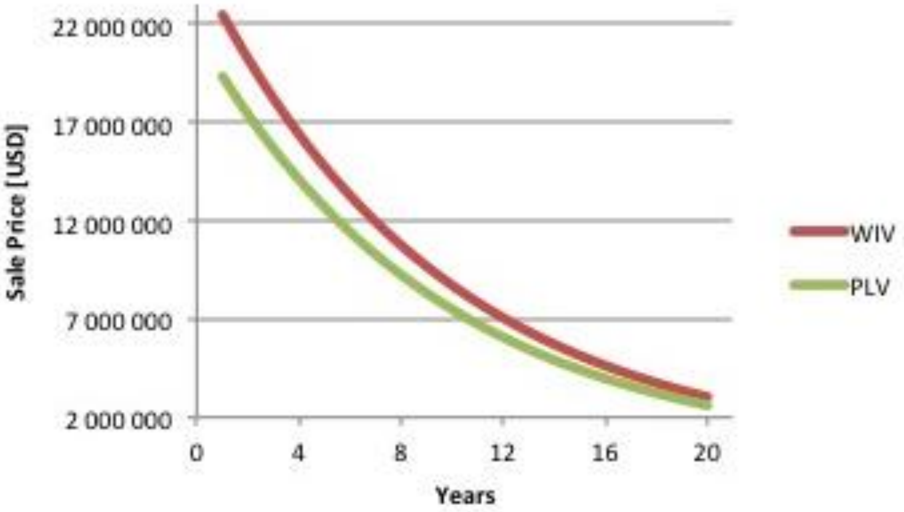

Figure 6.3: Sale Prices for WIV and PLV Equipment. (Compiled by Author)

# 7 CONCLUSION

In this thesis we have evaluated the value of a Multipurpose Offshore Construction Vessel. A Real Options approach has been used to solve the problem because of its insight into handling uncertainty and flexibility. Using Real Options and adding flexibility to a design allows it to be reshaped with time, when the market is more predictable. By using the Black-Scholes Option Pricing Model we have estimated the values of switching between different operational modes.

In a bad market, such as the one we are experiencing today, many ship owners are left with vessels in lay-up. A Multipurpose Offshore Construction Vessel can serve as a work platform where switching deck equipment can enable the vessel to enter different markets. In the discussion it was said that the vessel charter market can be observed as inefficient in the short-run. This means that by acting rationally ship owners can gain profits by switching vessel types. From the results obtained in this study, one can see that the value of owning a MOCV is positive. Although it has been difficult to justify many of the assumptions that have contributed to the final results, the study has shown that by using a Real Options approach one can determine the value of flexible ship design. Though Real Options is more commonly used to value financial instruments, the results show that the shipping sector can win over the uncertainties of the future by investing in flexibility in projects.

Albert Einstein said that *"In the middle of difficulty lies opportunity".* Difficult markets often work as a wakeup call to invoke experimentation in engineering. They make options available, and new knowledge forces adjustments over time. Real Options thinking is an efficient tool when valuing risk and uncertainty since it actually becomes more valuable when uncertainty is high. The method is betting on market volatility, and that one will eventually require a plan B. Although the Real Options method has its weaknesses, it has revolutionized investors' way of handling companies as it forces the option holder to consider hidden assets as business opportunity. It is risky to bet too much on uncertainty, but it is also a mistake to forget all about it.

## FURTHER WORK

Future applications of Real Options in ship design could be to value the option of creating a flexible vessel able to operate in both the fishing and the offshore construction industry. It would be interesting to identify vessels with similar performance expectations and create a mutual design platform combining these. An example of a concept to consider is a combination between a fishing trawler and an Anchor Handling Tug Supply.

Extensions of this problem can be made by performing the analysis with more sets of data to compare the results. The volatility could have been calculated over a longer time period, or it could have been implemented as a non-constant in the model, like Geske (1979) suggested in his work. It could also be interesting to compare the Net Present Values of the flexible project to a traditional inflexible design.

The problem has been solved by applying the Black-Scholes Option Pricing Model into Excel. Matlab could have been used to check the validity of the method or to create a more interactive model that could be used by others later.

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## APPENDIX A – PROBLEM DESCRIPTION

### Master Thesis in Marine Systems Design
### For Stud. Techn. Tara Jahangiry

### "Valuing Flexibility in Ship Design: A Real Options Approach"
### Spring 2015

#### Background

Today's construction vessels are usually built with a specific deck equipment type, and operate throughout their entire lifetime with this particular equipment. In a competitive industry the equipment composition and performance area of a vessel can be crucial to signing a contract with an operator, due to changing marked demands.

For the future generation of construction vessels, a new trend is being more and more popular that enables the vessel to change deck equipment during the vessel's lifetime. This change is dependent on available contracts and market demand. This requires a ship design where the deck structure is prepared to support different equipment types, and implies a large deck area with high deck strength and sufficient space under deck. It also includes a lay up for installation of different deck equipment used on offshore vessels, such as of offshore- and deck cranes, winches, pipelay spread, flex lay tower, carousels, ROV hangars, moon pool, diving bell etc. A Real Options approach can be used to find a value of a multipurpose vessel that owns the options of switching between vessel types.

#### Objective

The object of this thesis is to evaluate the value of the Multipurpose Offshore Construction Vessel (MOCV), using the Black-Scholes Option Pricing Model (BS OPM). The problem considers a MOCV holding the option to transform into an OSCV, WIV or Pipe Laying Vessel (PLV). The thesis aims to discuss what the economic benefit of owning one MOCV is instead of three separate vessels. The thesis also seeks to identify and price the underlying assets necessary for the design of each vessel type.

## Tasks

The candidate should presumably cover the following main points:

1. An introduction to illustrate the general properties, principles, pros, and cons of using Real Options Analysis.
2. Describe and discuss alternative strategies for a flexible ship design with focus on modifiable deck equipment to handle uncertainties in the market.
3. Do a market assessment of the current state and development trends of today's offshore marked.
4. Identify the most important results from (2) and (3) and use them as main parameters to perform a case study using Real Options Analysis.

## General

In the thesis the candidate shall present her personal contribution to the resolution of a problem within the scope of the thesis work. Theories and conclusions should be based on a relevant methodological foundation that through mathematical derivations and/or logical reasoning identify the various steps in the deduction. The candidate should utilize the existing possibilities for obtaining relevant literature.

The thesis should be organized in a rational manner to give a clear statement of assumptions, data, results, assessments, and conclusions. The text should be brief and to the point, with a clear language. Telegraphic language should be avoided.

The thesis shall contain the following elements: A text defining the scope, preface, list of contents, summary, main body of thesis, conclusions with recommendations for further work, list of symbols and acronyms, reference and (optional) appendices. All figures, tables and equations shall be numerated.

The supervisor may require that the candidate, in an early stage of the work, present a written plan for the completion of the work. The original contribution of the candidate and material taken from other sources shall be clearly defined. Work from other sources shall be properly referenced using an acknowledged referencing system.

## Deliverable

- The thesis shall be submitted in two (2) copies:
- Signed by the candidate
- The text defining the scope included
- In bound volume(s)
- Drawings and/or computer prints that cannot be bound should be organized in a separate folder.
- The bound volume shall be accompanied by a CD or DVD containing the written thesis in Word or PDF format. In case computer programs have been made as part of the thesis work, the source code shall be included. In case of experimental work, the experimental results shall be included in a suitable electronic format.

**Main supervisor:** Bjørn Egil Asbjørnslett
**Deadline:** 10.06.2015

## APPENDIX B – CALCULATION OF VOLATILITY OF STOCK PRICE

Volatility of Stock Price of OSCV

| Year | Daily Hire Rate [USD] | Change | Volatility |
|---|---|---|---|
| **2012** | OSCV2012 | | |
| **2013** | OSCV2013 | =OSCV2013/OSCV2012-1 | |
| **2014** | OSCV2014 | =OSCV2014/OSCV2013-1 | |
| **2015** | OSCV2015 | =OSCV2015/OSCV2014-1 | =STDAV(Change1:Change3) |

Volatility of Stock Price of WIV

| Year | Daily Hire Rate [USD] | Change | Volatility |
|---|---|---|---|
| **2012** | WIV2012 | | |
| **2013** | WIV2013 | =WIV2013/WIV2012-1 | |
| **2014** | WIV2014 | =WIV2014/WIV2013-1 | |
| **2015** | WIV2015 | =WIV2015/WIV2014-1 | =STDAV(Change1:Change3) |

Volatility of Stock Price of PLV

| Year | Daily Hire Rate [USD] | Change | Volatility |
|---|---|---|---|
| **2012** | PLV2012 | | |
| **2013** | PLV2013 | =PLV2013/PLV2012-1 | |
| **2014** | PLV2014 | =PLV2014/PLV2013-1 | |
| **2015** | PLV2015 | =PLV2015/PLV2014-1 | =STDAV(Change1:Change3) |

## APPENDIX C – CALCULATION OF STOCK PRICE

Calculation of stock price, S for OSCV under a contract with a length of 1 year:

$$\mathrm{S(OSCV)} = 75\ 000\,\frac{\mathrm{USD}}{\mathrm{Day}} \cdot 363[\mathrm{Days}] \cdot 1[\mathrm{Year}] = \underline{27\ 375\ 000\ \mathrm{USD}}$$

Calculation of stock price, S for WIV under a contract with a length of 5 year:

$$\mathrm{S(WIV)} = 243\ 000\,\frac{\mathrm{USD}}{\mathrm{Day}} \cdot 363[\mathrm{Days}] \cdot 5[\mathrm{Year}] = \underline{443\ 475\ 000\ \mathrm{USD}}$$

Calculation of stock price, S for PLV under a contract with a length of 3 year:

$$\mathrm{S(PLV)} = 203\ 000\,\frac{\mathrm{USD}}{\mathrm{Day}} \cdot 363[\mathrm{Days}] \cdot 3[\mathrm{Year}] = \underline{222\ 285\ 000\ \mathrm{USD}}$$

## APPENDIX D – OSCV, WIV, PLV AND MOCV FLEET OVERVIEW

**Offshore Subsea Construction Vessel (OSCV)**

| Built | Name | Dimensions L, B, D [m] | Operational Depth [m] | Crane Capacity [t] |
|---|---|---|---|---|
| 2003 | Boa Deep C | 119 x 27 x 12 | 2000 | 250 |
| 2006 | Normand Installer | 124 x 28 x11 | 2500 | 250 |
| 2007 | Boa Sub C | 138 x 30 x 11 | 3000 | 400 |
| 2008 | Siem TBN | 121 x 22 x 9 | 3000 | 250 |
| 2010 | Skandi Aker | 157 x 27 x 12 | 1000 | 400 |
| 2010 | Aker Wayfarer | 157 x 27 x 12 | 1000 | 400 |
| 2011 | Skandi Skansen | 107 x 24 x 19 | 2500 | 250 |
| 2011 | Polar Queen | 110 x 20 x 10 | 2000 | 150 |
| 2013 | Rem Installer | 108 x 22 x 9 | 650 | 250 |
| 2013 | Siem Daya 2 | 121 x 22 x 9 | 3000 | 250 |
| 2013 | Siem Daya 1 | 121 x 22 x 9 | 3000 | 250 |
| 2014 | Siem Stingray | 120 x 23 x 9 | 3000 | 250 |
| 2014 | Siem Spearfish | 120 x 23 x 9 | 3000 | 250 |
| 2014 | Rem Ocean | 108 x 22 x 9 | 2000 | 150 |
| 2014 | Olympic Boa | 93 x 19 x 7 | 650 | 250 |
| 2014 | Polar Onyx | 130 x 25 x 7 | 3000 | 250 |
| 2016 | Salt 304 | 150 x 27 x 12 | 3000 | 400 |

**Well Intervention Vessels (WIV)**

| Built | Name | Dimensions [m] | Moonpool [m] | Offshore Crane | MHT [t] | Skidding [t] |
|---|---|---|---|---|---|---|
| 2004 | Island Frontier | 106 x 21 | 7.2 x 7.2 | 130t | 70 | |
| 2008 | Island Constructor, RLWI | 120 x 25 x 10 | 8.1 x 8.1 | 150t, 2500m | 300 | 100, 60 |
| 2008 | Skandi Constructor, RLWI | 120 x 25 x 10 | 8.0 x 8.0 | 150t, 2500m | 150 | |
| 2008 | Island Wellserver, LWI | 116 x 25 | 7.8 x 7.8 | 150t | 100 | |
| 2009 | Skandi Santos | 121 x 23 x 9 | 7.2 x 7.2 | 250t, 1000m | 125 | 125 |
| 2010 | Aker Wayfarer | 157 x 27 x 12 | 7.2 x 7.2 | 400t, 3000m | 125 | 125, 60 |
| 2010 | Skandi Aker, RLWI | 157 x 27 x 12 | 7.2 x 7.2 | 400t, 1000m | 450 | 100, 60 |
| 2011 | Island Intervention, RLWI | 120 x 25 x 10 | 8.0 x 8.0 | 150t, 2500m | 150 | 100, 60 |
| 2014 | Island Performer, LWI | 130 x 25 x 10 | 8.0 x 8.0 | 25t | 300 | 100, 60 |

**Pipe Laying Vessel (PLV)**

| Built | Name | Dimensions [m] | Moonpool [m] | Offshore Crane | Pipelay Method | VLS [t] | Carousel [t] |
|---|---|---|---|---|---|---|---|
| 1980 | Deep Constructor | 126 x 25 x 11 | 8.0 x 8.0 | 300t, 1570m | Reel-lay | 270 | 2000 |
| 1997 | Seven Eagle | 139 x 29 x 7 | | 250t | Flex-lay | 90 | 1200 |
| 2001 | Seven Mar | 145 x 27 x 13 | | 300t, 2000m | Tiltable Flex-lay | 340 | 2 x 1600 |
| 2008 | Seven Seas | 153 x 28 x 8 | 7.5 x 8.5 | 400t | J and Flex-lay | 400 (J) 430 (f) | 1390 (aft) + 1510 (fwd) |
| 2008 | Skandi Seven | 121 x 23 x 9 | 7.2 x 7.7 | 250t, 2500m | Flex-lay | 110 | 300 |
| 2008 | Skandi Acergy | 157 x 27 x 12 | 7.2 x 7.2 | 400t, 3000m | Flex-lay | 125 | 3000 |
| 2010 | Seven Pacific | 134 x 24 x 10 | 7.5 x 7.0 | 250t | Flex-lay | 260 | 2 x 1250 |
| 2012 | Seven Borealis | 182 x 46 x 16 | | 5000t 6000m | J and S-lay | 937 (J) 600 (S) | 2800 |
| 2014 | Polar Onyx | 130 x 25 x 7 | 8.0 x 8.0 | 250t, 3000m | Flex-lay | 275 | 2000 |
| 2016 | Salt 304 | 150 x 27 x 12 | 7.2 x 7.2 | 400t, 3000m | Flex-lay | 150 | 3000 |
| 2016 | Seven Arctic | 162 x 32 x 14 | 7.2 x 7.7 | 900t, 3000m | Flex-ley | 325 | 7000 |

**Multipurpose Offshore Construction Vessel (MOCV)**

| Built | Name | Dimensions [m] | Operability | Offshore Crane | Moonpool [m] | MHT [t] | Skidding [t] | VLS [t] | Carousel [t] |
|---|---|---|---|---|---|---|---|---|---|
| 2009 | Skandi Santos | 121 x 23 x 9 | OSCV, WIV | 250t, 1000m | 7.2 x 7.2 | 125 | 125 | | |
| 2010 | Skandi Aker | 157 x 27 x 12 | OSCV, WIV | 400t, 3000m | 7.2 x 7.2 | 100 | 100 | | |
| 2010 | Aker Wayfarer | 157 x 27 x 12 | OSCV, WIV | 400t, 3000m | 7.2 x 7.2 | 125 | 125, 60 | | |
| 2013 | Siem Daya 1 | 121 x 22 x 9 | OSCV, PLV, WIV | 250t, 3000m | 7.2 x 7.2 | 60 | | 130 | |
| 2014 | Island Performer | 130 x 25 x 10 | OSCV, PLV, WIV | 250t | 8.0 x 8.0 | 300 | 100, 60 | 250 | 2500t |
| 2014 | Rem Ocean | 108 x 22 x 9 | OSCV, WIV | 150t, 2000m | 7.2 x 7.2 | 40 | | | |
| 2015 | Toisa's MOCV | 150 x 32 x 13 | OSCV, PLV | 900t, 3500m | 8.0 x 8.0 | | | 550 | 2 x 2500t |
| 2016 | Salt 304 | 150 x 27 x 12 | OSCV, PLV | 400t, 3000m | 7.2 x 7.2 | | | 150 | 3000 |
| - | Deepwater Enabler | 160 x 32 x 13 | OSCV, PLV, WIV | 800t, 3500m | 8.4 x 8.4 | | | 550 | 3500 |
| 2014 | North Sea Giant | 161 x 30 x 11 | OCV, PLV, WIV | 400t, 3000m | 7.2 x 7.2 | 270 | | 270 | 2000 |

## APPENDIX E – CALCULATION OF VOLATILITY OF OIL PRICE

| | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|
| **Brent Price** | Brent2012 | Brent2013 | Brent2014 | Brent2015 |
| **Change** | | =Brent2013/Brent2012-1 | =Brent2014/Brent2013-1 | =Brent2015/Brent2014-1 |
| **Volatility** | | | | =STDAV(Change1:Change3) |

## APPENDIX F – CALCULATION OF STRIKE PRICE

| Vessel Type | Equipment Price |
|---|---|
| **OSCV** | 0,001 |
| **WIV** | 25000000 |
| **PLV** | 21500000 |

| **Period: 0** | | **1** | | **2** | | **3** | |
|---|---|---|---|---|---|---|---|
| | | | | | | **OSCV** | 0 |
| | | | | **OSCV** | 0 | **WIV** | =EqWIV*1,1 |
| | | | | | | **PLV** | =EqPLV*1,1 |
| | | | | | | **OSCV** | =EqWIV*0,1 |
| | | **OSCV** | 0 | **WIV** | =EqWIV*1,1 | **WIV** | 0 |
| | | | | | | **PLV** | =EqWIV*0,1+EqPLV*1,1 |
| | | | | | | **OSCV** | =EqPLV*0,1 |
| | | | | **PLV** | =EqPLV*1,1 | **WIV** | =EqPLV*0,1+EqWIV*1,1 |
| | | | | | | **PLV** | 0 |
| | | | | | | **OSCV** | 0 |
| | | | | **OSCV** | =EqWIV*0,1 | **WIV** | =EqWIV*1,1 |
| | | | | | | **PLV** | =EqPLV*1,1 |
| | | | | | | **OSCV** | =EqWIV*0,1 |
| **OSCV** | | **WIV** | =EqWIV*1,1 | **WIV** | 0 | **WIV** | 0 |
| | | | | | | **PLV** | =EqWIV*0,1+EqPLV*1,1 |
| | | | | | | **OSCV** | =EqPLV*0,1 |
| | | | | **PLV** | =EqWIV*0,1+EqPLV*1,1 | **WIV** | =EqPLV*0,1+EqWIV*0,1 |
| | | | | | | **PLV** | 0 |
| | | | | | | **OSCV** | 0 |
| | | | | **OSCV** | =EqPLV*0,1 | **WIV** | =EqWIV*1,1 |
| | | | | | | **PLV** | =EqPLV*0,1 |
| | | | | | | **OSCV** | =EqWIV*0,1 |
| | | **PLV** | =EqPLV*1,1 | **WIV** | =EqPLV*0,1+EqWIV*1,1 | **WIV** | 0 |
| | | | | | | **PLV** | =EqWIV*0,1+EqPLV*0,1 |
| | | | | | | **OSCV** | =EqPLV*0,1 |
| | | | | **PLV** | 0 | **WIV** | =EqPLV*0,1+EqWIV*1,1 |
| | | | | | | **PLV** | 0 |

## APPENDIX G – CUMULATIVE STATISTICAL VALUES

| **Period: 0** | | **Period: 1** | | | **Period: 3** | | |
|---|---|---|---|---|---|---|---|
| | | | | | **OSCV** | Delayed | |
| | | **OSCV** | Delayed | | **WIV** | d1 = 11,155 | d2 = 10,910 |
| | | | | | **PLV** | d1 = 8,273 | d2 = 8,009 |
| | | | | | **OSCV** | d1 = 7,423 | d2 = 7,118 |
| **OSCV** | Delayed | **WIV** | d1 = 11,155 | d2 = 10,910 | **WIV** | Delayed | |
| | | | | | **PLV** | d1 = 3,194 | d2 = 2,603 |
| | | | | | **OSCV** | d1 = 10,424 | d2 = 10,187 |
| | | **PLV** | d1 = 8,273 | d2 = 8,009 | **WIV** | d1 = 6,052 | d2 = 5,628 |
| | | | | | **PLV** | Delayed | |
| | | | | | **OSCV** | Delayed | |
| | | **OSCV** | d1 = 7,423 | d2 = 7,118 | **WIV** | d1 = 20,952 | d2 = 20,707 |
| | | | | | **PLV** | d1 = 8,273 | d2 = 8,009 |
| | | | | | **OSCV** | d1 = 7,423 | d2 = 7,118 |
| **WIV** | | **WIV** | Delayed | | **WIV** | Delayed | |
| d1 = | 11,155 | | | | **PLV** | d1 = 3,194 | d2 = 2,603 |
| d2 = | 10,910 | | | | **OSCV** | d1 = 10,424 | d2 = 10,187 |
| | | **PLV** | d1 = 3,194 | d2 = 2,603 | **WIV** | d1 = 10,422 | d2 = 9,998 |
| | | | | | **PLV** | Delayed | |
| | | | | | **OSCV** | Delayed | |
| | | **OSCV** | d1 = 10,424 | d2 = 10,187 | **WIV** | d1 = 11,155 | d2 = 10,910 |
| | | | | | **PLV** | d1 = 17,349 | d2 = 17,085 |
| | | | | | **OSCV** | d1 = 7,423 | d2 = 6,876 |
| **PLV** | | **WIV** | d1 = 6,052 | d2 = 5,628 | **WIV** | Delayed | |
| d1 = | 8,273 | | | | **PLV** | d1 = 6,117 | d2 = 5,526 |
| d2 = | 8,009 | | | | **OSCV** | d1 = 10,424 | d2 = 10,187 |
| | | **PLV** | Delayed | | **WIV** | d1 = 6,052 | d2 = 5,628 |
| | | | | | **PLV** | Delayed | |

## APPENDIX H – CUMULATIVE NORMAL PROBABILITIES

| **Period: 0** | | **Period: 1** | | | | | **Period: 3** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | **OSCV** | Delayed | | | |
| | | **OSCV** | Delayed | | | | **WIV** | N(d1) = | 1,000 | N(d2) = | 1,000 |
| | | | | | | | **PLV** | N(d1) = | 1,000 | N(d2) = | 1,000 |
| | | | | | | | **OSCV** | N(d1) = | 1,000 | N(d2) = | 1,000 |
| **OSCV** | Delayed | **WIV** | N(d1) = | 1,000 | N(d2) = | 1,000 | **WIV** | Delayed | | | |
| | | | | | | | **PLV** | N(d1) = | 0,999 | N(d2) = | 0,995 |
| | | | | | | | **OSCV** | N(d1) = | 1,000 | N(d2) = | 1,000 |
| | | **PLV** | N(d1) = | 1,000 | N(d2) = | 1,000 | **WIV** | N(d1) = | 1,000 | N(d2) = | 1,000 |
| | | | | | | | **PLV** | Delayed | | | |
| | | | | | | | **OSCV** | Delayed | | | |
| | | **OSCV** | N(d1) = | 1,000 | N(d2) = | 1,000 | **WIV** | N(d1) = | 1,000 | N(d2) = | 1,000 |
| | | | | | | | **PLV** | N(d1) = | 1,000 | N(d2) = | 1,000 |
| | | | | | | | **OSCV** | N(d1) = | 1,000 | N(d2) = | 1,000 |
| **WIV** | | **WIV** | Delayed | | | | **WIV** | Delayed | | | |
| N(d1) = | 1,000 | | | | | | **PLV** | N(d1) = | 0,999 | N(d2) = | 0,995 |
| N(d2) = | 1,000 | | | | | | **OSCV** | N(d1) = | 1,000 | N(d2) = | 1,000 |
| | | **PLV** | N(d1) = | 0,995 | N(d2) = | 0,995 | **WIV** | N(d1) = | 1,000 | N(d2) = | 1,000 |
| | | | | | | | **PLV** | Delayed | | | |
| | | | | | | | **OSCV** | Delayed | | | |
| | | **OSCV** | N(d1) = | 1,000 | N(d2) = | 1,000 | **WIV** | N(d1) = | 1,000 | N(d2) = | 1,000 |
| | | | | | | | **PLV** | N(d1) = | 1,000 | N(d2) = | 1,000 |
| | | | | | | | **OSCV** | N(d1) = | 1,000 | N(d2) = | 1,000 |
| **PLV** | | **WIV** | N(d1) = | 1,000 | N(d2) = | 1,000 | **WIV** | Delayed | | | |
| N(d1) = | 1,000 | | | | | | **PLV** | N(d1) = | 1,000 | N(d2) = | 1,000 |
| N(d2) = | 1,000 | | | | | | **OSCV** | N(d1) = | 1,000 | N(d2) = | 1,000 |
| | | **PLV** | Delayed | | | | **WIV** | N(d1) = | 1,000 | N(d2) = | 1,000 |
| | | | | | | | **PLV** | Delayed | | | |

## APPENDIX I – CALL OPTION VALUE FROM EXCEL

| **Period: 0** | **1** | | **2** | | **3** | |
|---|---|---|---|---|---|---|
| | | | | | **OSCV** | Delayed |
| | | | **OSCV** | Delayed | **WIV** | 413 946 293 |
| | | | | | **PLV** | 197 762 112 |
| | | | | | **OSCV** | 24 902 160 |
| | **OSCV** | Delayed | **WIV** | 413 946 293 | **WIV** | Delayed |
| | | | | | **PLV** | 196 727 117 |
| | | | | | **OSCV** | 25 167 755 |
| | | | **PLV** | 197 762 112 | **WIV** | 412 674 152 |
| | | | | | **PLV** | Delayed |
| | | | | | **OSCV** | Delayed |
| | | | **OSCV** | 24 902 160 | **WIV** | 438 581 481 |
| | | | | | **PLV** | 197 762 112 |
| | | | | | **OSCV** | 24 902 160 |
| **OSCV** | **WIV** | 413 946 293 | **WIV** | Delayed | **WIV** | Delayed |
| | | | | | **PLV** | 196 727 117 |
| | | | | | **OSCV** | 25 167 755 |
| | | | **PLV** | 196 727 117 | **WIV** | 436 595 609 |
| | | | | | **PLV** | Delayed |
| | | | | | **OSCV** | Delayed |
| | | | **OSCV** | 25 167 755 | **WIV** | 413 946 293 |
| | | | | | **PLV** | 218 948 374 |
| | | | | | **OSCV** | 24 902 160 |
| | **PLV** | 197 762 112 | **WIV** | 412 674 152 | **WIV** | Delayed |
| | | | | | **PLV** | 216 746 517 |
| | | | | | **OSCV** | 25 167 755 |
| | | | **PLV** | Delayed | **WIV** | 412 674 152 |
| | | | | | **PLV** | Delayed |

## APPENDIX J – CALL OPTION VALUE WHEN T=3

| Period: 0 | 1 | | 2 | | 3 | |
|---|---|---|---|---|---|---|
| | | | | | **OSCV** | Delayed |
| | | | **OSCV** | Delayed | **WIV** | 262 720 121 |
| | | | | | **PLV** | 200 090 968 |
| | | | | | **OSCV** | 79 457 699 |
| | **OSCV** | Delayed | **WIV** | 240 236 640 | **WIV** | Delayed |
| | | | | | **PLV** | 197 873 066 |
| | | | | | **OSCV** | 79 768 121 |
| | | | **PLV** | 200 090 968 | **WIV** | 238 329 695 |
| | | | | | **PLV** | Delayed |
| | | | | | **OSCV** | Delayed |
| | | | **OSCV** | 79 457 699 | **WIV** | 262 409 699 |
| | | | | | **PLV** | 200 090 968 |
| | | | | | **OSCV** | 79 457 699 |
| **OSCV** | **WIV** | 240 236 640 | **WIV** | Delayed | **WIV** | Delayed |
| | | | | | **PLV** | 197 873 066 |
| | | | | | **OSCV** | 79 768 121 |
| | | | **PLV** | 197 873 066 | **WIV** | 260 502 820 |
| | | | | | **PLV** | Delayed |
| | | | | | **OSCV** | Delayed |
| | | | **OSCV** | 79 768 121 | **WIV** | 240 236 640 |
| | | | | | **PLV** | 219 160 121 |
| | | | | | **OSCV** | 79 457 699 |
| | **PLV** | 200 090 968 | **WIV** | 238 329 695 | **WIV** | Delayed |
| | | | | | **PLV** | 216 942 820 |
| | | | | | **OSCV** | 79 768 121 |
| | | | **PLV** | Delayed | **WIV** | 238 329 695 |
| | | | | | **PLV** | Delayed |