NTNU
Norwegian University of
Science and Technology

Agility by Design: A Real Option Approach to Identify and Value Time-efficient Changes in Marine Systems

Carsten Christensen

Marine Technology
Submission date: June 2017
Supervisor: Bjørn Egil Asbjørnslett, IMT

Norwegian University of Science and Technology
Department of Marine Technology

NTNU
Norwegian University of
Science and Technology

Master Thesis in Marine Systems Design

Stud. techn. Carsten Christensen

Agility by Design: A Real Option Approach to Identify and Value Time-efficient Changes in Marine Systems

SPRING 2017

Background

To quickly adapt to changing market conditions in an efficient manner is crucial for any firm, and especially in volatile and capital intensive markets. Ocean engineering systems are typically operating in this context, and the speed of change for such systems could define important aspects for the systems overall performance. Uncertainty that affects the performance of such engineering systems could be anything from exogenous uncertainty as geopolitical events and nature catastrophes, to endogenous uncertainty like crack propagation in steel structure. Recent focus for many system designers have been to design flexible systems, that is able to adapt to changing market conditions, and hence increase the systems overall performance for its lifetime. In this context, agility represents the ability of a system to change quickly, and an investment lag is the time from the decision is made until the system has changed capabilities. All investments have lags to some degree, which is often disregarded in traditional real options analyses. For systems with relatively long investment lags, there is a need to better understand the impact of these lags, and how one can implement design solutions that in an efficient manner reduces the downside, while making the design ready to exploit potential upside.

Fall 2016, a project thesis named *Decision Support Under Uncertainty for Ocean Engineering Systems* was written by the author in collaboration with fellow student Morten Andreas Strøm. This can be seen as a introduction project for the master thesis, as it introduces general decision support framework, among other a basic introduction to real option framework. This master thesis is a natural continuation of this, by narrowing the focus towards real options and agility by design.

Objectives

The aim of this research is to enlighten the value of agility for an ocean engineering system operating in uncertain markets. There are two main objectives, *(i)* To value the agility by quantitative models and *(ii)* To identify design solutions that enables agility. By this one will identify real options, both in the system and on the operation of the system, and how they could reduce the investment lag. The approach to this work have been a mapping process between a value space and a design space.

Scope of work

The candidate should presumably cover the following main points

1. Present and discuss a real option framework, and its connections to relevant system engineering design features such as flexibility, changeability, path enablers, which again can be linked to identification of agility
2. Present and discuss a framework for quantifying the value of agility by
   (a) Time series analysis, literature and discussion, propose a stochastic model for simulation of market dynamics
   (b) Build models that investigate the option value of expansion as a function of investment lag.
3. Propose design solutions that increases the agility for an ocean engineering system
4. Discuss and conclude on the results

Modus Operandi

Professor Bjørn Egil Asbjørnslett will be the responsible supervisor at NTNU. The work shall follow the guidelines made by NTNU for thesis work. The workload shall correspond to 30 credits,which is 100% of one semester.

Limitations

The work was carried out from scratch, starting January 2017. The database from Clarkson Research have been used for market data. This have also been the main limitation, as longer time series of data, data from shipyards etc. could have been used in further analysis.

Preface

This thesis is the final part of the Master of Science degree in Marine Technology at the Norwegian University of Science and Technology, with specialisation in Marine Systems Design. The overall work load of the master thesis should be equivalent to 30 ECTS, and the thesis was written in its entirety during the spring of 2017.

The focus in the thesis have been on *Agility by Design*, i.e. how to design engineering systems such that agility could be enabled, which again will increase the systems performance. To identify and valuate this the author have taken a real option approach. This work could be seen as a continuation of the SIMOSYS project at NTNU, which focus on handling design stage risk and uncertainty in ocean engineering systems.

I am grateful to several people for help and guidance throughout the work process. First of all, I would like to thank my supervisor, professor Bjørn Egil Asbjørnslett for asking critical questions and keeping me on the right track, and co-supervisor PhD Candidate Carl Fredrik Rehn for all bright ideas, interesting discussions and digressions. Further, professor Stein Erik Fleten at NTNU, professor Roar Ådland at NHH and PhD Candidate Sigurd Pettersen at NTNU have given valuable guidance and input from their special fields. From the industry, Engebret Dahm from Thorvald Klaveness and Jo Ringheim from Arctic Securities have brought perspective of great value.

Trondheim, June 17, 2017

Summary

Agility by Design: A Real Option Approach to Identify and Value Time-efficient Changes in Marine Systems

Quickly adapting to changing market conditions is crucial for every firm, especially in volatile and capital intensive markets. These are two characteristics of the maritime industry. Incorporating flexibility in design have gathered an increased focus as means to cope with such a dynamic context. To be flexible is not always enough, partially because exploiting this flexibility causes a time delay. This time delay causes more uncertainty, which could make a good investment decision into a bad one. Hence, this master thesis investigates the contribution from investment lags in engineering systems by the following: *(i)* Structuring and presenting a real option framework for identification of possible design solutions that reduces investment lag *(ii)* Propose value models for system design changes that are exposed for investment lag *(iii)* Propose design solutions that limits the investment lag. For this, an elongation of a dry bulk vessel is a thorough example.

Agility represents the ability of a system to change quickly, and investment lag is the time from the decision is made until the system has changed capabilities. All investments have lags to some degree, which is often disregarded in traditional real options analyses. For systems with relatively long time lags, there is a need to better understand the impact of these investment lags. To identify design solutions that enables agility, a further separation in the real options framework has been proposed as a contribution to the existing literature. *On options* is seen as the superior option, which is the operational option *on* a projects future cash flow. This is often related to changes in value enabling variables, and as this is the conventional real option, there exist an established valuation framework for it. Further, *on* options are separated in two classes, *Built-in-Design options* and *Design Change options*. The former is multifunctionality that are implemented in the system from the initial design stage, the latter are options that make changes *in* the design, often referred to as *in options*, which comes with an investment lag due to off-hire when performing the design change. By this separation of *on* options, path enablers could be tied to real options.

Path enablers are features that enables easier change in value enabling variables, making it easier to exercise options. Design path enablers are design features that enables easier exercise of design change option, thereby reducing the investment lag and cost of exercise. Thus, Design Change options could be seen as operational path enablers, that enables change of operation, which by definition is an *on* options.

The relation between the option value of a capacity expansion/market entry, and the investment lag is defined to value agility. This gives a possible value for investment lag reducing path enablers. A design neutral capacity expansion in the dry bulk freight market is used as an illustrative case, and by introducing the investment lag as a parameter in the real option model, the value of a capacity expansion option could be considered as a function of investment lag. For this, the cost of investment lag is defined as the opportunity cost of operating in the market.

The analysis is conducted in several steps, by three models with increasing degree of complexity. Qualitative and quantitative time series analysis on dry bulk freight rates in the Capesize segment in the time span between 1990 and 2017 resulted in freight market replications for two of the models using the geometric Mean Reversion model, and the last with market rates and asset prices as correlated mean reversion paths. Then, by Monte Carlo simulation, a now-or-never investment analysis determines the value of agility by simulation of the projects cash flows, thereafter through including investment timing flexibility based on the Least Squares Monte Carlo algorithm, which gives the value of agility through an established option valuation framework. For this model two approaches were taken, one with correlated vessel values and freight rates, and one with vessel values as a value of underlying freight rates.

The option value reflects a premium of second hand vessel prices with different investment lags, and with no investment lag the maximum value will be respectively 147, 60 and 12.2 USD/dwt for the now-or-never approach, LSMC and LSMC and with correlated asset paths, which is reduced to 85 %, 65% and 55% of maximum value for an investment lag of 6 months. The results of the different models are quite consistent in their form, and the spread between the maximum value can be explained through different approaches and different underlying stochastic processes. The LSMC model with vessel values as function of freight rates is seen as the most realistic, as it includes investment timing flexibility and geometric Mean Reversion as underlying stochastic process for freight market dynamics.

Further, design path enablers for the illustrative case is proposed, an elongation of a dry bulk carrier which gives a capacity expansion. Design path enablers for this elongation is elements that make the vessel ready for elongation, an examples of this can be thickness of plates and visibility. As the design still water bending moment and wave bending moment is a function of L^3, a greater thickness is required. Further, the visibility of water surface shall not be obscured by more than 1xLOA forward of the bow. Hence, path enablers for an elongation from 150m to 200m could be to build the initially 150m long vessel with bottom plate thickness of 12mm instead of the required 11mm and a higher bridge. This will make the initial structure ready for 200m LOA.

By implementing design path enablers one increases the design freedom over the systems lifetime. In conventional design thinking, a design is often optimised for a base case. Though, by implementing design path enablers, one admit that the future is uncertain and partly unpredictable, and enables easier future design changes. This will increase the design freedom over the systems lifetime, which again is reflected by flexibility in operations at a strategic level. By implementing such design path enablers, together with Built-in design options, agility is enabled through design, thus, *Agility by Design*.

SAMMENDRAG

Rask og smidig tilpasning til endrede markedsforhold er avgjørende i alle industrier, særlig i volatile og kapitalintensive markeder. Dette er to kjennetegn ved den maritime industrien. System som opererer i en slik dynamisk kontekst, utsatt for usikkerhet, har sett økt fokus på fleksibelt design. Å være fleksibel er ikke alltid nok, delvis da utnyttelse av denne fleksibiliteten fører med seg tidsforsinkelse. Denne forsinkelsen gir økt usikkerhet, noe som kan gjøre en god inversteringsavgjørelse om til en dårlig. Derfor setter denne masteroppgaven fokus på bidraget fra investeringsforsinkelser til tekniske system med det følgende: *(i)* Presentere en strukturering av realopsjonsrammeverk for å identifisere mulige designløsninger som reduserer investeringsforsinkelser *(ii)* Foreslå kvantitative verdimodeller for systemendringer utsatt for investeringsforsinkelser *(iii)* Forslå designløsninger som begrenser investeringsforsinkelser. En forlengelse av et tørrbulkskip er valgt som hovedeksempel gjennom oppgaven.

Smidighet representerer et systems evne til å tilpasse seg raskt, og investeringsforsinkelse er tiden fra beslutningen er gjort til systemet har forandret evner. Alle investeringer har investeringsforsinkelser til en viss grad, noe som ofte blir ignorert i tradisjonelle realopsjonsmodeller. For systemer med relativt lange investeringsforsinkelser, er det behov for å bedre forstå effekten av disse. For å identifisere designløsninger som muliggjør smidighet, en ytterligere separasjon i realopsjonsrammeverket har blitt foreslått som bidrag til den eksisterende litteraturen. Realopsjoner *på* operasjonelle endringer er sett på som det overordnede alternativet, der en har opsjon på et prosjekts fremtidige kontantstrøm. Dette er ofte relatert til endringer i verdigivende variable, og et etablert rammeverk for verdsettelse eksisterer. Videre deler en *på*-opsjonen i to underliggende klasser, *Multifleksible opsjoner* og *Designendringsopsjoner*. Førstnevnte er multifunksjonalitet som er bygd inn i systemet i den initielle designfasen, sistnevnte er endringer som må gjøres *i* designet og krever ekstern hjelp. Dette er opsjoner som også gir en investeringsforsinkelse, da systemet må ut av operasjon for å gjøre endringer. Gjennom denne separasjonen, *muliggjørere*, som muligjør endringer *i* design og operasjon kan kobles mot realopsjoner.

Muliggjørere er funksjoner som muliggjør enklere endring av verdigivende variable, og som gjør det enklere å utøve realopsjoner. Design-muliggjørere er designfunksjoner som gir enklere utøvelse av Designendringsopsjoner, og dermed redusere investeringsforsinkelsen og kostnaden for utøvelse. Videre kan Designendringsopsjoner sees på som en operasjonsmuliggjører, som muliggjør endring av operasjon, som igjen av definisjon er en *på*-opsjon.

Forholdet mellom opsjonsverdien av en kapasitetsutvidelse/markedsinngang og investeringsforsinkelse er definert for å verdivurdere smidighet. Dette gir en mulig verdi for reduksjon av investeringsforsinkelser gjennom design-muliggjørere. En designnøytral kapasitetsutvidelse i markedet for tørrlastfrakt benyttes som illustrativt eksempel, og ved å innføre investeringsforsinkelsen som en parameter i realopsjonsmodellen kan verdien av en opsjon på kapasitetsutvidelse betraktes som en funksjon av investeringsforsinkelse. For dette er kostnaden ved investeringsforsinkelsen definert som en alternativkostnaden til å holde skipet i operasjon.

Den kvantitative analysen utføres i flere trinn, med tre modeller med økende grad av kompleksitet. Kvalitativ og kvantitativ tidsserieanalyse på fraktrater for Capesize-segmentet i

tidsperioden mellom 1990 og 2017 gir at varianter av Mean Reversion er videre brukt som stokastisk prosess, sammen med Monte Carlo-simulering. Først gjennom en nå-eller-aldri investeringsanalyse som bestemmer verdien av smidighet gjennom simulering av prosjektets fremtidige kontantstrømmer, deretter gjennom å inkludere investeringsfleksibilitet gjennom bruk av Least Squares Monte Carlo algoritmen. For denne modellen ble to ulike tilnærminger tatt, en der skipsverdier er en funksjon av stokastiske fraktrater, og en der skipsverdier og fraktrater er modellert som korrelerte Mean Reversion prosesser.

Opsjonsverdien gjenspeiler en premie på annenhånds skipsverdier med ulike investeringsforsinkelser, maksimumsverdien uten forsinkelse vil være henholdsvis 147, 60 og 12,2 USD/dwt for nå-eller-aldri tilnærming, LSMC og LSMC og med korrelerte prosesser. Denne verdien vil reduseres til 85%, 65% og 55% av maksimumsverdien for en investeringsforsinkelse på 6 måneder. Resultatene fra de ulike modellene er ganske konsistente i sin form og spredningen mellom maksimalverdien kan forklares gjennom ulike tilnærminger og ulike underliggende stokastiske prosesser. LSMC-modellen med skipsverdier som funksjon av fraktrater er sett på som den mest realistiske, da det inkluderer investeringsfleksibilitet og geometrisk Mean Reversion som underliggende stokastisk prosess for dynamikk i fraktmarked.

Videre er det foreslått design-muliggjørere for det illustrative eksempelet, en forlengelse av et tørrbulkskip som gir en kapasitetsutvidelse. Design-muliggjører for denne forlengelsen er elementer som gjør fartøyet klar for forlengelse, noe som kan være tykkelse på plater og restriksjoner for sikt. Ettersom designstillevannsbelastninger er en funksjon på L^3, kreves en større platetykkelse. Videre skal synligheten av vannoverflaten ikke skjules av mer enn 1xLOA framfor baugen. Derfor kan design-muliggjører for en forlengelse av LOA fra 150m til 200m være å bygge det initielle design, med LOA 150m, med bunnplatetykkelse på 12mm i stedet for den nødvendige 11mm, samt en høyere bro. Dette vil gjøre den opprinnelige strukturen klar for en LOA på 200m.

Ved å implementere design-muliggjørere øker designfriheten gjennom systemets levetid. I konvensjonell designtenking er et design ofte optimalisert for et scenario. Ved å implementere design-muliggjørere, innrømmer man at fremtiden er usikker og delvis upredikerbar, og muliggjør mer effektive designendringer i fremtiden. Dette vil øke designfriheten over systemets levetid, noe som igjen gjenspeiles av fleksibilitet i operasjoner på strategisk nivå. Ved å implementere slike design-muliggjørere, sammen med Multifleksible opsjoner, er smidighet muliggjort gjennom design, og dermed *Smidighet gjennom designløsninger*.

Contents

List of Figures

List of Tables

Buy when there's blood in the streets, even if the blood is your own.

Baron Rothschild

1 Introduction

1.1. Background

Uncertainty affects how successful an engineering system is in an economic, physical, technical and a regulatory context. To operate in this dynamic environment, changeability are essential in a systems design. Important life cycle properties for engineering systems such as *flexibility, agility, survivability* and *robustness*, often denote by the umbrella term *'ilities*, have seen increased research focus the last decade. Further,this master thesis work will focus on *agility*, how a system can change and adapt in a nimble and efficient manner. This ability is especially important in volatile and capital intensive markets. Ocean engineering systems are typically operating in this context, and several cases are considered to investigate how *agility* affects the system performance.

Many existing real world engineering systems are capable of changing, but in the end the question ends up with *What is the cost of changing? What is the time delay from decision to changed capability?*. An extreme example could be an airport. Given enough time we can melt the steel, and use it in the building of an oil rig. This is not a very efficient solution if you want a oil rig, but it still shows that all systems have a certain degree of flexibility. By addressing the aspect of time, and how this time affects the value of flexibility, one can map possible design solutions with it's value and investment lag.

In the literature *Investment lags* for real options can be seen as the time it takes for the transaction to be fulfilled, i.e. the time from the decision is made until the system have changed capabilities and is ready to exploit these. This lag, with some minor differences, is also denoted as *time-to-build, conversion lag, delivery lag, lead time.* All investments have lags to some degree, and these are often disregarded in traditional simplified analyses. For systems with relatively long time lags, operating in mature, but cyclical, market, there is a need to better understand the impact of these lags in the operation of the system and for the optimal exercise of real options.

In this context ocean engineering systems can be of high interest. E.g. oceanic bulk shipping, often seen as a "perfect market" with ship owners as price takers, and where capital intensive vessel often is bought with a delivery lag of 2 to 3 year. During this waiting time, markets can change from good to bad - or contrary. This rapid changes in markets have made many shipowner wealthy, but also given many an economic headache. Another example can be oil producing structures, where the profitability depends upon a highly uncertain oil price. The common thread for these systems is that they depend upon an uncontrollable source of uncertainty, exogenous uncertainty, and stakeholders have to adapt to the circumstances. And, with short period of high market rates, followed by longer periods of modest market rates, the ability to enter market fast is crucial.

All shipowners, independent if it is offshore supply market or deep sea shipping, have options that limits the downside, namely lay up or scrapping. While the uncertain environment often attracts negative attention, the potential upside that this uncertainty gives can often be forgotten. How could these rapid changes best be utilised? Many shipowners, with Mr. John Fredriksen as a good example, enjoys trust in the financial markets, and may in low markets raise equity to do mergers and acquisitions, and hence expand he's fleet.

This is in line with the thinking of Warren Buffet, which thinks of holding cash as an option to quickly move in the markets if good opportunity emerge[4].

Another approach can be *design options*, real options that makes it possible for the existing system to change capabilities post design phase, e.g. expand capacity and convert to other markets. Examples can be to initially build stronger structure for a bulk carrier, such as it will be possible with an elongation capacity expansion, or a offshore supply vessel with a moonpool, which makes it possible to retrofit it with a light intervention tower. All these are options that are costly, but makes the initial design easy to retrofit in an efficient manner. In this context, timing and investment lag is a key in the valuation of these design options, and their survivability.

1.2. Research question

The main objective for this thesis is to investigate what role agility plays and how this could be identified and valuate for an engineering system. Thus, the research questions will be:

> *How can we identify possible design solutions that will increase our agility?*
>
> *How can we value agility, i.e. how can a reduced investment lag be valued, and what is the value of investment lag?*

[4]Barron's http://www.barrons.com/articles/what-warren-buffett-likes-about-cash-1473286224 Accessed 6/5/2017

Traditional Investment Lag literature

Traditional surveys and papers states that increased uncertainty delays investment[Dixit, 1989, Pindyck, 1990]. Kydland and Prescott [1982] introduced and focused on the importance of time-to-build in their equilibrium real business cycle model, where time-to-build was *crucial* for the models fit, compared to standard adjustment-cost model. Construction projects and how they proceed is often adjustable with access to new information, and Majd and Pindyck [1987] investigate this by using contingent claims analysis for project with sequential irreversible investment outlays and maximum construction rates. Their findings suggest that time-to-build have greatest effects when uncertainty is greatest. Milne and Whalley [2000] continue this work, and find that long time-to-build reduce the investment thresholds, while Zhou [2000] incorporate Torbin Q in the model from Kydland and Prescott [1982], and shows that when time-to-build technology is accounted for, investments will have a positive autocorrelation.

The entry-exit model from Dixit [1989] is extended by Bar-Illan and Strange [1996] with a model where abandonment is not allowed. They find that investment lags lessen the prohibitive effect of uncertainty, and investment lag are closing the spread between the investment triggers. A particular interesting result is that for realistic values of uncertainty, the upper trigger price is lower under uncertainty than for a certain environment. This is further discussed by Sødal [2006], which argues that this is less likely then first proposed. Bar-Ilan [2000] extends the model from Dixit [1989] by allowing for abandonment, and finds that the investment policy is the same independent of investment lags. The intuition behind this is a neutralisation of cost and benefit of delay. Further extensions is presented by Bar-Ilan et al. [2002], which allow the model to investigate the critical economic factors that are involved, and further sticks to the conclusion that investment lags and uncertainty do not necessarily affects the investment policy in a negative way. These conclusions is much in line with the work presented by Aguerrevere [2003], which finds that an increase in uncertainty strengthen the incentives to expand capacity.

A common feature of the better part of traditional investment lag literature is that investment lag either lessen the prohibitive effect of uncertainty, lower the investment trigger, or suggest that decisions is independent of lag. But, a common feature of this literature is also the underlying stochastic processes, where many of them follows a Geometric Browninan motion, which will drift in a positive direction, and not capture the dynamics of cyclical market. This fact is also stated by Sødal [2006].

Lead time in supply chain

In the supply chain literature *lead time* can be seen as a parallel to investment lag. Blackburn [2012] values this lead time, and estimated the marginal value of time under predictable demand, and concludes that to cut down lead time is not cost effective, when cutting lead time imply producing in high-cost countries. With stochastic demand, De Treville et al. [2014] shows that the marginal value of time increases with demand volatility. In supply chain excellence the retailer Zara is a role model, and shows a high degree of *agility*, with short lead times combined with a flexible stock[Cachon and Swinney, 2011].

Maritime economics
Stopford [2009] separate the shipping market in four separate sub-markets, namely the newbuilding market, freight market, S&P and scrapping market. Sødal [2006] discuss the equilibrium model from Dixit [1989] with a discount factor approach. By a maritime case he also includes scrapping, investment lag and diminishing production capacity, and concludes that increased uncertainty can urge the investment when investment lag is incorporated. Investment lag in the maritime literature is synonymous with delivery lag, and Adland et al. [2006] and Adland and Jia [2015] incorporate this lag in an equilibrium model relating the four mentioned market. The latter suggest that, for bulk vessels, newbuildings and second hand vessels are substitutes if disregarding technological differences, except the time spread between revenue generating, and by this explain the lower volatility in newbuilding prices with the delivery lag, and newbuilding as a "future" contract. This is much in line with Strandenes [1984], which see newbuilding values as theexpected value of long run earnings, and second hand vessel values as a weighted average of short- and long term earnings. Kavussanos and Alizadeh [2002a] rejects that the efficient market hypothesis is valid for newbuilding and second hand ship values, due to a time varying risk premium. Greenwood and Hanson [2015] introduce a behavioural model to explain that second hand prices are way to volatile. Even though freight earnings shows mean reversion properties, shipowners are skewed in their expectations by exogenous demand shock, and partially ignores the investment activity by competitors. Though, to stay in spot market in the short term can be a way to obtain flexibility in responding to rapid changes in the current market situations, and hence a form of agility[Axarloglou et al., 2013]. Kalouptsidi [2014] investigate shipping industry investments, and shows that time-to-build decreases the total supply of vessels, and increases the investment volatility. [Adland and Jia, 2015] also reveals that the delivery lag for newbuildings is mostly determined by the yard capacity, and not the actual building time. An extreme event in that case was under the peak period in 2006-2008, where the delivery lag for newbuildings(dry bulk carrier) was between 3 and 4 years, while the building process was 11 months.

Continuous stochastic models of shipping rates have been subject to significant research, and mean reversion properties is proposed in several publications[Bjerksund and Ekern, 1995, Tvedt, 2003a, 1997, 2003b, Sødal et al., 2008, Taib, 2016, Joergensen and Giovanni, 2010, Koekebakker et al., 2006], contrary to many commodities prices that are assumed to follow a Geometric Brownian Motion. A state-of-the-art continuous stochastic model for shipping rates is presented by [Benth et al., 2015], which incorporate statistics like heavy-tailed returns, stochastic volatility and memory(AR-effects), effects that have been shown in empirical discrete-time literature.

Uncertainty in system engineering
For maritime systems, and all other engineering systems, uncertainty represents the elements and influences one do not have control of[Walton, 2002]. Maritime systems normally operates in a global, open market, and uncertainty is associated with both operational, regulatory, financial, technical, market, and Zuellig factors[?Strandenes, 1984, McManus and Hastings, 2006, Erikstad and Rehn, 2015]. In the thinking of Kolmogorov [1983] and Magee and de Weck [2004], maritime systems like bulk tankers and offshore vessels are considered as complex systems, and most of the design decisions that define the life cycle properties for an

engineering system is defined in the early design phase[Dierolf and Richter, 1989]. Traditional ship design like System-based ship design[Levander, 2012] and Set Based Design[Singer et al., 2009] have an approach with a fixed, static view of the design case and operations. This approach to design is criticised by Neufville and Scholtes [2011], which emphasises a more active design approach. In this context *Design for Changability*[Fricke and Schulz, 2005] and the focus on life cycle properties as flexibility, agility and adaptability('ilities) have received attention in system engineering literature like Beesemyer et al. [2012], De Weck et al. [2012], Ross et al. [2008a,b]. Response to this from the naval architecture community have been, among others, a deterministic optimisation formula[Erikstad et al., 2011], which optimises a design to match current and future contract demands, flexible strategies for compliance with emission regulation[Rehn et al., 2016], and the Accelerated Business Development process from Brett [2016].

To incorporate flexibility in systems is in many cases equivalent to implementing real options[Neufville, 2009]. Wang and Neufville [2004] divide options in to two overarching classes, namely *in* and *on* options. *On* options have the traditional thinking of financial options, but the underlying asset is the projects cash flow, e.g. a new vessel or a new airport runway, which can be valued in the option valuation framework that started with the disruptive work by Black and Scholes [1973]. *In* options can be seen as design options, and require technological insight for valuation, and is often handled by methods as Monte-Carlo simulation[Metropolis and Ulam, 1949]. This method have had increased popularity parallel to increasing computer power, and due to it's flexibility it is the favoured tool to analyse the performance of an engineering system exposed for uncertainty[Neufville and Scholtes, 2011, Mun, 2006]. Longstaff and E.S. [2001] introduced the Least squares Monte Carlo method to handle American-style options, which also have been used in real option cases, as valuing oilfield flexibility[Jafarizadeh and Bratvold, 2015] and electric storage[Bakke et al., 2016]. Though, closed form solutions have also been applied to maritime systems, in valuation of an combination carrier, where the price differential between wet and dry bulk market follows a mean reversion process[Sødal et al., 2008].

1.4. Structure of the report

The report is build up in three different parts, with a total of 9 chapters. Further, calculations and scripts will be found in appendices. The three main parts is

Introduction to *Agility by Design* which gives an introduction to design theory, system engineering, real options and its relation to changeability. Further, agility is defined and presented, and examples of agility in marine systems are presented. At last, the author defines *Agility by Design*.

Valuation of agility will consist of two parts, both focusing on the specific case. (i) how the market can be modelled and (ii) how a generic valuation of agility can be carried out. The first part consist of time series analysis of the dry bulk freight market, both quantitative and qualitative, and proposes a given stochastic process to replicate the market. The latter part introduces valuation models, and the proposed models for valuation of agility and its results

Design Solutions and authors remarks will build further on the illustrative case, by proposing design solutions that enables agility. Further, the author discuss the results and concludes.

Thus, by this structure, the mapping process from a value space to a design space is presented in the last two parts. This approach is graphically presented in figure 1.1.

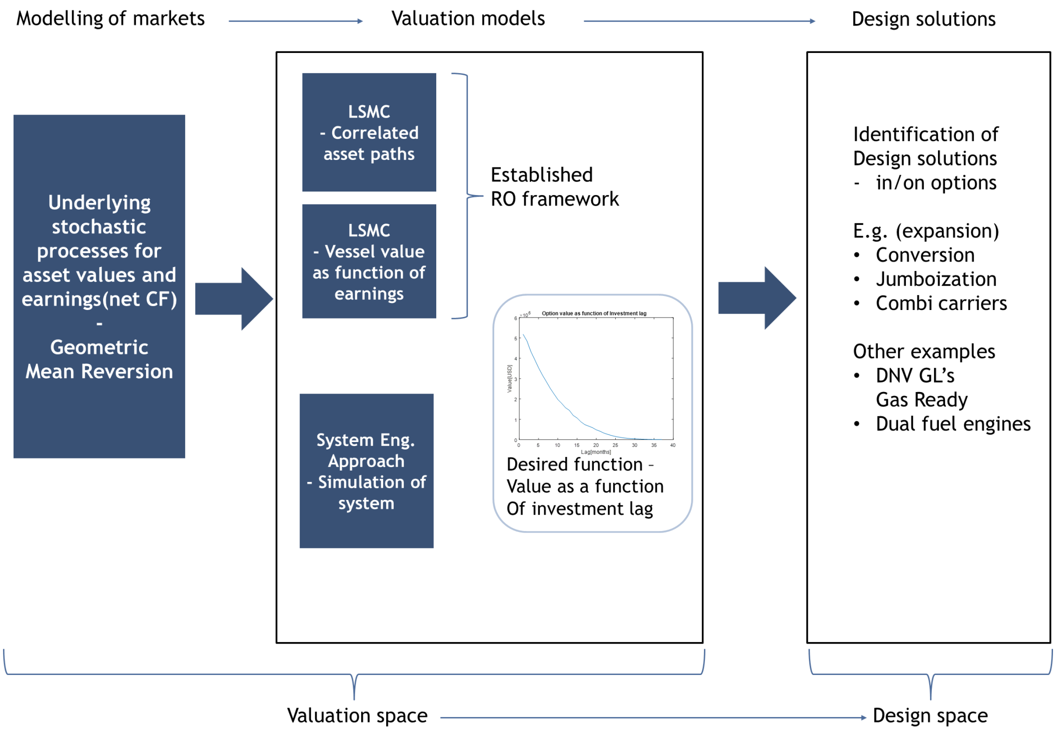


Figure 1.1: From value to design space

Part I - Introduction to *Agility by design*

In part I, an introduction to *Agility by Design* is presented. This consist of a general introduction to design and system engineering, before *Design for Changeability is presented* and tied to a real option framework. Thereafter, agility is introduced and defined, and identification of agility is presented.

2 Design Theory for Handling Uncertainty

In this section design theory is introduced, and further tied to changeability and real options. Path enablers is then introduced, and their connection to design and real options are presented.

2.1. Definitions of design

Design can be seen as a target directed process, but also open ended and with a need of creativity[Erikstad, 2015], with the purpose to create the plan and description of the product, rather than creating the product itself. According to ABET[5] engineering design can be defined as

> Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision making process (often iterative) in which the basic sciences, mathematics, and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing and evaluation.

The combination of approaches and skill set applied can be seen as an important key in a design phase. Another way to phrase this is to look at design as a mapping process from a performance space to a descriptive spaceCoyne [1990], Suh [1990]. By this, one will map from functional requirements in a functional domain to design parameters in a physical domain, such that the chosen design parameters satisfy the functional requirements. This can be exemplified in a maritime context with the design of an FPSO. Often, these have a minimum required free board, a functional requirement, which will be satisfied by adjusting the design parameter draft. An illustrative drawing of this is presented in figure 2.1. This is often an iterative process, with a feedback process as basis for redesigning.

[5] Accreditation Board for Engineering and Technology http://www.me.unlv.edu/Undergraduate/coursenotes/meg497/ABETdefinition.htm Accessed 11.04.2017

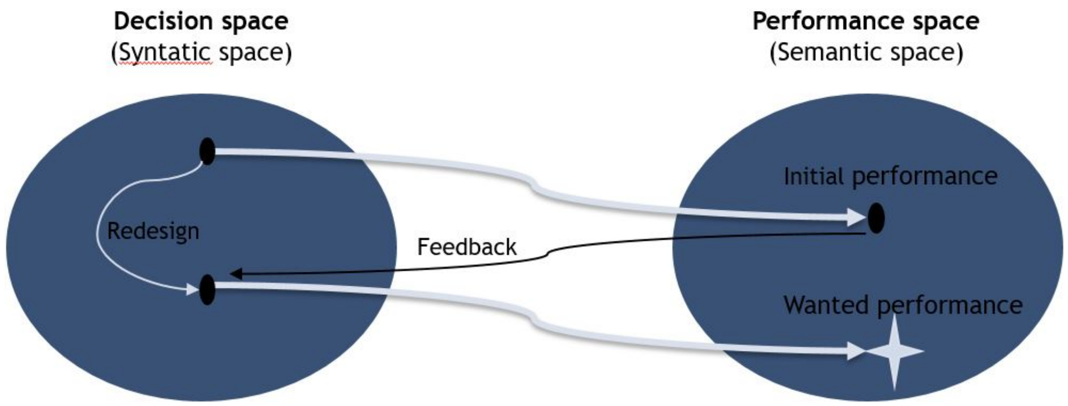


Figure 2.1: Generative method of design, adapted from Erikstad [2015]

Another approach, which will be followed in this thesis, is the mapping from a *value space* to a *design space*. With this in mind one approach the given need, and quantify it's value in monetary means, before obtaining possible design solutions to satisfy this need, within the cost of the obtained value. These processes can also be performed in a parallel way, ending in a decision space where evaluating costs and benefits, as presented in figure 2.2.

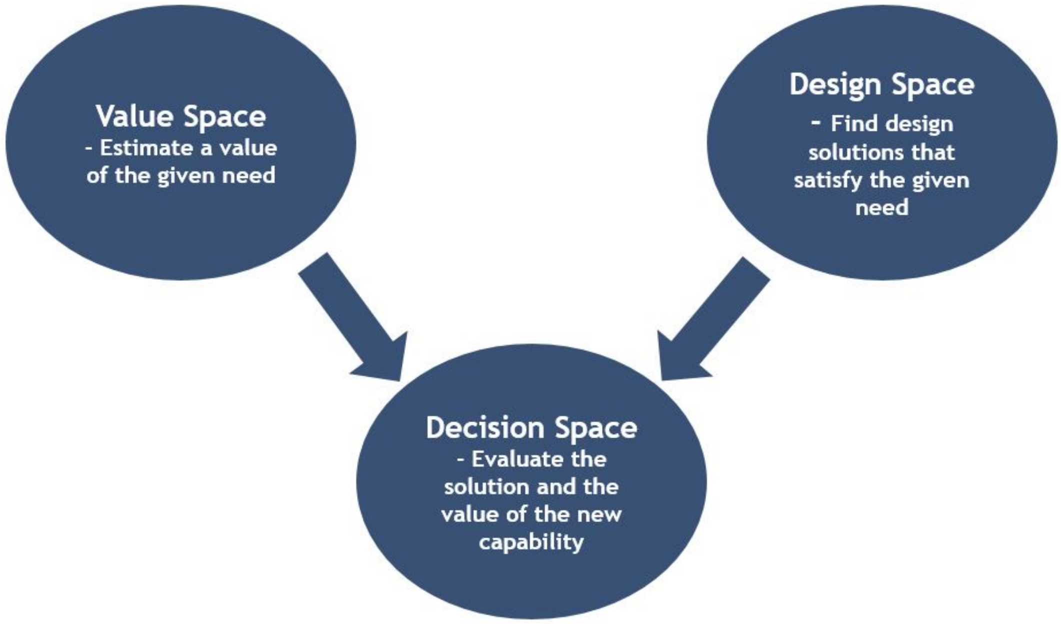


Figure 2.2: Combining a value space and design space to a decision space

2.2. System engineering and complexity

The complexity of a system have been related to the amount of information a system consist of[Kolmogorov, 1983]. This is in line with Magee and de Weck [2004], which consider the amount of unique elements in the system. According to the latter, marine systems like offshore vessels or vessels for deep sea shipping can be defined as complex engineering systems, since they satisfy the following: *(i) designed by humans (ii) significant human complexity (iii) significant technical complexity.* By an increased complexity there is also an increased uncertainty regarding the system, and the systems performance over it's lifetime[Skinner, 2009]. As a result of this a more active design approach have to be taken, and one approach to this is to implement flexibility in design[Neufville and Scholtes, 2011].

By takeing design thinking one step further one approaches the *system engineering* thinking. By this the systems complexity increases, due to an increased level of complexity the system should satisfy. As stated by INCOSE[6]

> Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.

In table 2.1 different degrees of design is exemplified, which show the relation between the complexity of the product and system engineering

Table 2.1: Design and engineering space[Erikstad, 2015]

	Product Design and Development	**Engineering Design**	**System Engineering**
Complexity of product	From everyday items to cars and more complex systems	Simple to advanced on technical systems. Focus engineering and technical systems	Large engineering projects. High complexity and expensive product/systems
Examples and types of products	Commercial products as Hair dryers, printers rollerblades,screwdrivers,cars	Machinery, production systems, technical systems	Building ships, planes or space missions
Customer focus	Mass production and commercial products	Specific, engineered products and products for mass production	Few customers, many stakeholders
Size of development teams	Small to Large	Small to Large	Large/Very Large

Hence, in a system engineering context the value space from figure 2.2 can be seen as a business domain, and the design space as an engineering domain, and these domains will combine to the decision space.

2.3. The importance of early phase design methodology

Early phase design can be defined as the phase where the main features of the system is determined, and high-level decisions is made about the technical and economical priorities[Erikstad, 1996]. Estimations by different sources in Dierolf and Richter [1989] suggest that 60 to 80% of the total life cycle cost is decided during this early phase, where the design freedom is at the top. Yet, a paradox in this early phase is the lack of *knowledge* about the design, and how this design will perform in an uncertain future, where all future design decisions is highly dependent on the initial design. This paradox is graphed in figure 2.3.

[6]International Council on Systems Engineering http://www.incose.org/AboutSE/WhatIsSE Accessed 11.04.2017

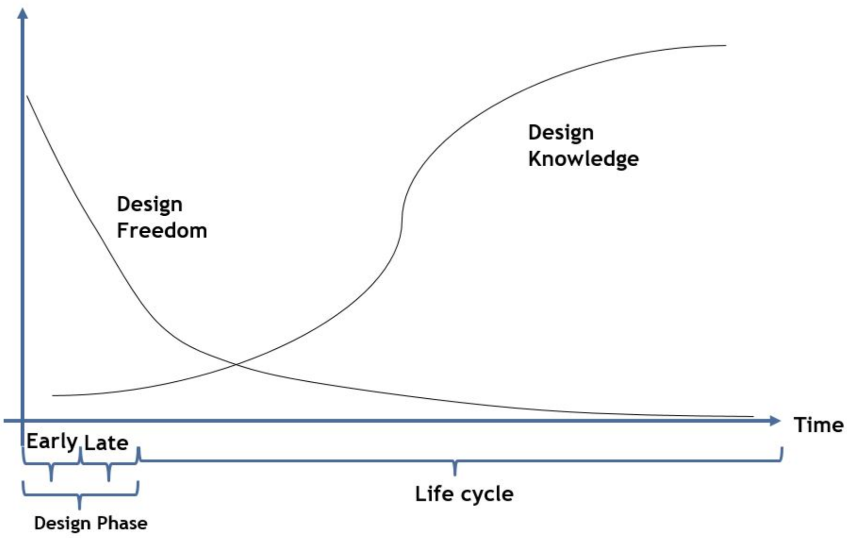


Figure 2.3: Knowledge and design freedom over design phase and life cycle[Erikstad, 2015]

This emphasises the importance of the early design phase, and how much this affects the total life cycle of the system. To increase the systems flexibility during its lifetime is a common goal for many system engineers due to the uncertain operational context, and a response to this can be to implement degrees of flexibility in the design phase.

2.4. Uncertainty and flexibility in design

From a system engineering perspective uncertainty can be defined *as the inability to quantify precisely; a distribution that reflects potential outcome*[Walton, 2002]. In other words, uncertainty represents things that one do not have control over. Lack of control are in many cases tied to downside risk, but uncertainty can also lead to upside possibilities, as emphasised by McManus and Hastings [2006], which also classifies uncertainty in the following overarching classes

Lack of knowledge is defined as *facts that are not know, or are known only imprecisely, that are needed to complete the system architecture in a rational way.* In early design stage, there are many of these uncertainties, and the system engineer must systematically reduce these uncertainties, at the appropriate time.

Lack of definition is defined as things about the system in question that have not been decided or specified. Lack of definition is a necessity in the context of not over-specifying design elements and "rush" in to the design spiral[7]. For example, in a conceptual design stage, one should not settle the vessels main dimensions at once. Instead, the designers should be more open minded and try different configurations to see how they meet the operational requirements.

[7] http://www.neely-chaulk.com/narciki/Design_spiral

where both classes have a certain degree of

- **Statistically characterised (random) variables/phenomena:** *Things that cannot always be known precisely, but which can be statistically characterised, or at least bounded.* Examples can be lifetime of equipment, weather and stock returns, which can be characterised by different statistical distributions.
- **Known Unknowns:** *Things that it is known are not known.* For example, the designer of an AHTS knows that he needs to know the required trust to pull a oil rig today, but he cannot know for certain the required pulling force for operations in 2025.
- **Unknown Unknowns:** a term used by, among others, former US Secretary of Defence Donald Rumsfeld to define events that we do not know we do not know. Due to these unknown unknowns, oil rigs are dimensioned with high margins, to be able to withstand some strange events that has never happened before and are impossible to predict.

Depending on how controllable the uncertainty is, Lin et al. [2013] distinguish between three classes of uncertainty. Endogenous uncertainties can actively be managed, hybrid uncertainties can to some extent be managed, while endogenous uncertainties cannot. Uncontrollable uncertainties like unknown unknowns, in close relation to Black/Grey Swan events[Taleb, 2008] are getting more and more focus, as the ability to handle and exploit such events can be crucial for companies[Thanopoulou and Strandenes, 2015]. An example of this could be the Fukushima disaster in March 2011, which made an upsurge in demand for LNG to Japan, and hence an increased demand for voyage miles and upsurge in freight rates, as shown in figure 2.4.

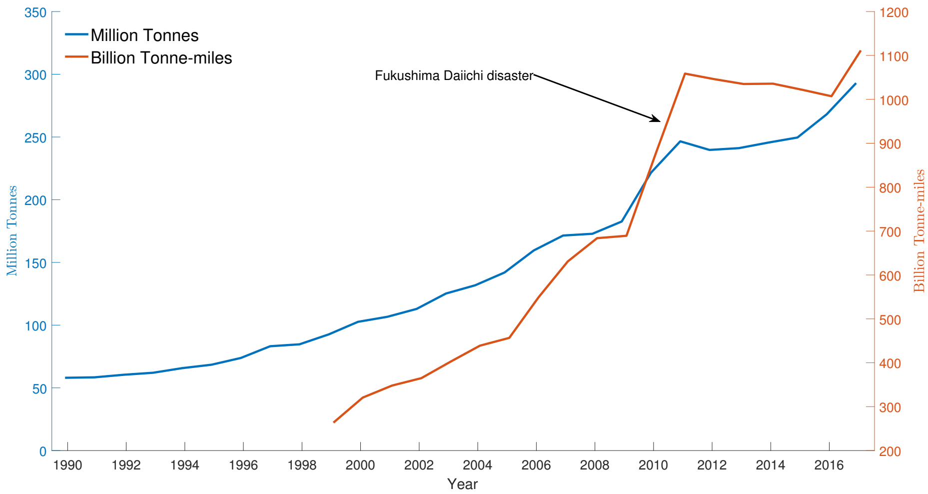


Figure 2.4: World Seaborne LNG trade before and after the Fukushima Daiichi disaster[Clarksons Research, 2017]

McManus and Hastings [2006] proceed and formalise the work by Neufville et al. [2004], and propose a framework to better exploit the possibilities uncertainty gives for an engineering system. They emphasise that uncertainty gives both an upside and downside, while conventional thinking have been to limit the downside. To be able to exploit these opportunities and mitigate the risks, the framework in figure 2.5 have been proposed, where the outcomes often is presented under the collective term *'ilities*, and that the design is *changeable* and *flexible*. Hence, by taking this approach, the system engineer admit that the future is uncertain and unpredictable, and rather focus on how to handle a range of scenarios by building flexible systems, instead of optimising the design after a point estimate.

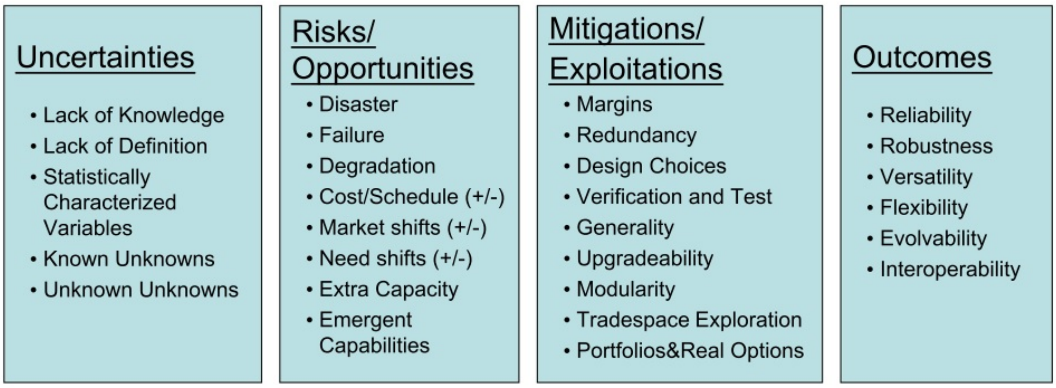


Figure 2.5: Framework for handling uncertainties and their effects[McManus and Hastings, 2006]

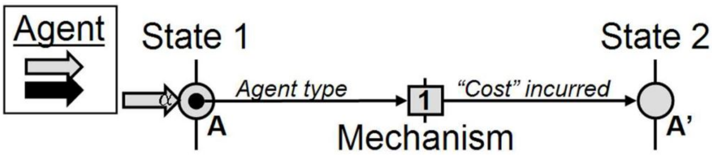
2.5. Changeability and real options

2.5.1. Definition and domains for changeability

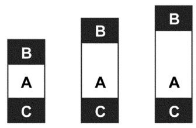
Changeability can be defined as the ability of a system to change design variables or modes of operation[De Weck et al., 2012, Fitzgerald, 2012], and serve as an umbrella term for the 'ilities from the framework presented in figure 2.5. Fricke and Schulz [2005] describes design for changeability as *architecting for system evolution*, and emphasises that implementing changeability for an engineering system can be beneficial if, among others, the complex system are competing in a dynamic marketplace, with a long life cycle. Ross et al. [2008b] see change as a state transition, where the effect of change can be seen as a change in capabilities, and the cost as time and effort. This is illustrated in figure 2.6a, where the mechanism is the physical transition that changes the state of the system and the agent is the force instigator for for the change to occur.

Design solutions to obtain changeability can, among others, be *Fabricate-to-Fit Modularity*, using standardised components/modules, which enables scalability to adjust to endogenous factors, as illustrated in figure 2.6b. This will be the same mechanism as capacity adjustments for a train, where an answer to increased transportation demand can be to add extra wagons to the train.

In Rehn et al. [2017e] the focus is to defines boundaries between dimensions of changeability, and a better understanding of a quantitative level of changeability. The two main dimensions of changeability is *time* and *cost*, where cost can be separated in carry cost and change cost. From a theoretical point of view, everything is changeable, e.g. an oil tanker can be scrapped and the steel could be used in an air plane, hence an oil tanker can change to an air plane. Though, this transformation will both be costly and take time, and hence a quantitative level of changeability for a change between the state *oil tanker* and *air plane* is



(a) Definition of change as a state transition[Ross et al., 2008b]



(b) Modularity [Fricke and Schulz, 2005]

Figure 2.6: Change transition and modularity

relatively low. The cost and time dimensions are illustrated for different industries in figure 2.7.

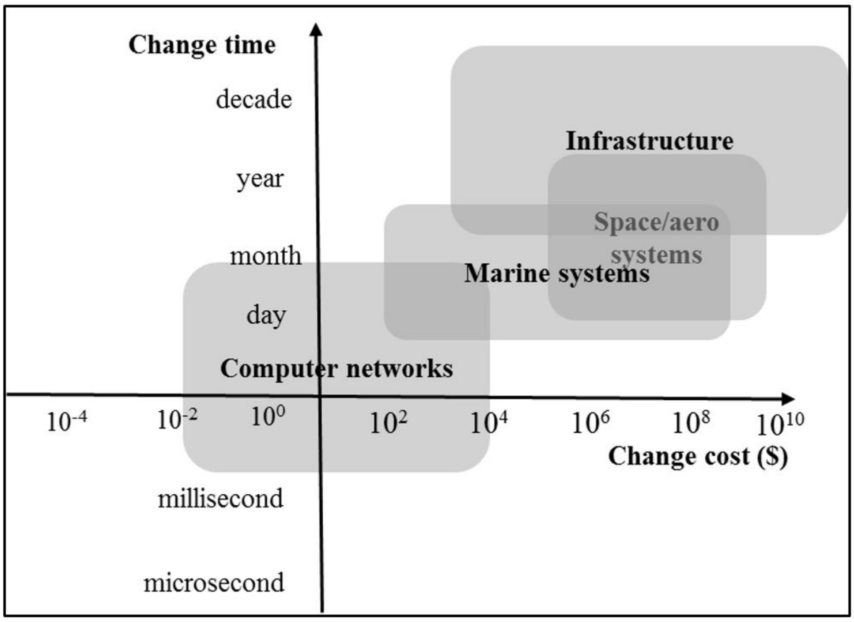


Figure 2.7: Cost and time dimensions for different industries[Rehn et al., 2017e]

Further, two reference domains for changeability is *design* and *operation*. These variables can either be discrete or continuous, such as the parameter *length* is a continuous design variable, and market is a discrete operational variable. Hence, the states to change between, as presented in figure 2.6a could either be **design variables** or **mode of operation**. Since a change in design variable gives a change in capabilities, a change in design variables will also give a change in operation, while a change in operation is not necessary a change in a design variable. A design change could for instance be an elongation for a dry bulk carrier, which makes it too long for the Panama channel, and have to established new trade routes in the Capesize segment and hence change operation.

2.5.2. Definition and classification for real options

To implement flexibility in design is equivalent to implement real options[Neufville, 2009], which gives the firm an option to await decisions until more information is available. Options that make changes *in* the design is often refereed to as *in* options[Neufville et al., 2004, Wang and Neufville, 2004]. These options consider design features, which separates them from conventional real option thinking, which threats technological aspects as a black box, and focus on change in operation mode which gives an option on the projects future cash flow. Such conventional real options can be thought of as real options *on* the systems. The overall objective of real options is to change the operation mode, and to change design is performed with the overall goal to change operation. Thus, the author see *Real options on system* as the superior option, and further separates this in two sub-classes, *Built-in Design options* and *Design Change options*, where the latter is the more typical *in* option. This hierarchy is presented in figure 2.8 and further described.

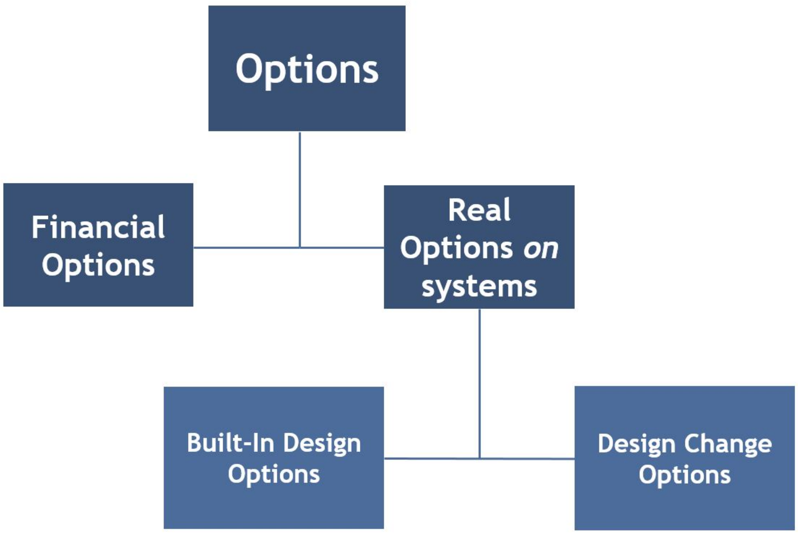


Figure 2.8: Classification of options

Built-in Design options is options implemented in design, such as the design itself can change operation and exercise option, without external influence. A common feature is that the option is multi-exercisable, and enables flexibility through the systems lifetime. This options have an initial cost to implement and hence a carry cost. Exercise cost could also occur, but these are normally lower than the implementation cost. Operation options could be thought of as *compound options*, since an exercise of the option will give a new option to switch, and so it follows on. As all designs have the option to abandon operation, this is also "built-in" together with entry/exit in the market. The latter options can though have "penalty" cost, and give a non-neglible investment lag. Examples from maritime industry and infrastructure could be:

- Combination carrier, which could switch between wet and dry bulk. The number of switches is unlimited, and the initial design consist of washing mechanism, hatch covers, pipelines and other necessary equipment to enable operability in both markets. Thus, there will both be a implementation cost, a carry cost and a exercise cost.

- Multi purpose vessel for offshore service. Many possible combinations but e.g. moonpool capacity and structural reinforcement make it capable of light well intervention, which can be utilised through equipment. Hence, implementation cost occurs in the construction, and exercise cost through equipment and change time.
- Dual fuel engines, engines that are able to burn both gaseous and liquid fuels. These engines often have higher implementation cost, but can without exercise cost change fuel and utilise spread in fuel prices. A carry cost can occur due to less efficiency[Babicz, 2015].
- Flexible airport terminal, which can be used for both domestic and international flights. For an airport, a given set of gates can be flexible between domestic and international flights, while the rest of the gates is specified for one of them. This flexibility will then handle the peak demand that could occur for different periods in each segment, e.g. in holyday periods more people will fly international than the rest of the year.

Design Change Options is options of design changes where the design need external influence to change and exercise the option. After exercising these options, the system have enabled new capabilities and can change operation mode. These options are normally single-exercise by nature, and the exercise cost is normally exceeding a possible initial cost. Examples from maritime industry and infrastructure could be

- Elongation/widening of vessels. This have been performed for vessels in different segments, and normally an extra midship section is inserted, as well as structural reinforcement. The option to perform this could be written by a yard, as this requires an extra midship section together with yard capacity. Vessels could in the design phase be equipped with structural reinforcement such as time in yard is reduced when exercising this option, however, this usually requires a higher initial cost.
- Conversion from burning marine distillate to LNG. This could be done throughout the lifetime of vessel, caused by e.g. new regulations or cost saving. In this context DNV GL's gas ready notation applies to vessels that *which during the new building phase are planned for and partly prepared for later conversion to liquefied natural gas (LNG) fuel.* This notation comes in certain level, but all are there to ensure a more effective conversion to LNG. By this notation there comes an initial cost as well as exercise cost for the final retrofit for compatibility with LNG. Another option with the same objective, to improve the operational profile of a vessel, is the flexible bulbous bow, which can change form and stay optimal for different transit speeds.
- Capacity expansion of an airport terminal, for instance to build out a new terminal or a new runway. This could be done throughout the operation period for the airport. Some airports are build with this in mind, i.e. there is dedicated space around where new runways could be built, and the terminals is planned such as they could be built as a natural expansion of the total airport.

2.5.3. Changeability as a design variable

Fricke and Schulz [2005] introduces *Design for Changeability(DfC)* as an overall system design variable, which tells about the degree of changeability. This variable can be described as a path enabler which enhance changeability, i.e. path enabler has the characteristic that it makes it easier to do changes in value enabling variables, and can be related both to the design and operation domain. Thus, it is a variable that makes changes happen more easily[Beesemyer et al., 2012, Ross et al., 2009]. There are many paths between two states, as illustrated in figure 2.9. As the overall objective in this case is to go from a small ship to a large ship, with an increased capacity, one can either change length, breadth or depth. Thus, one have three alternatives, which all have a different cost and time span. In this context a path enabler will be something that supports the change mechanism to increase size. For the ship there could be structural reinforcement which was implemented in the construction of the vessel, which makes the vessel ready for inserting a new midship section, without redesign and structural strengthening. This structural reinforcement are subject to an up front cost and a following carry cost, but will ensure an elongation to a lower cost and a shorter change time due to less work with the retrofitting.

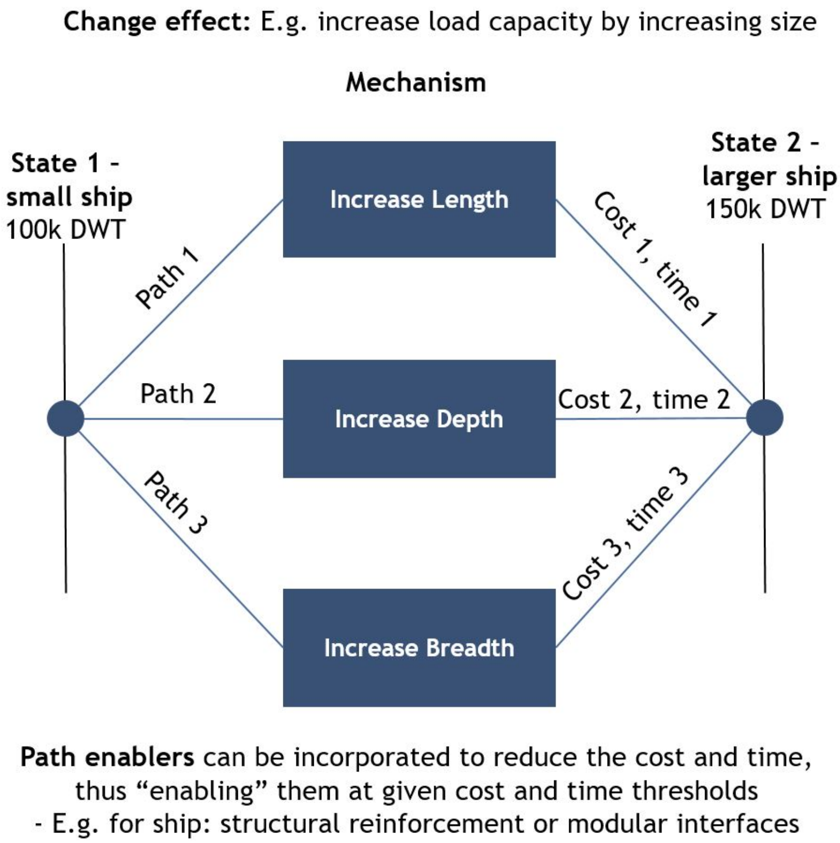


Figure 2.9: Changeability concept, adapted from[Rehn et al., 2017e]

Figure 2.10 map DfC variables and path enablers to a design hierarchy, and connects them to System Design Variables. This separates between *value enabling variables* and DfC level variable. The former is the variables that typically gives value, which are what the system will be paid for. Continuing the maritime context, a transportation vessel will be paid for the cargo it transports, thus *Deadweight tonne* will be the natural measure, which again is a function of the vessels main dimensions. An offshore vessel could be paid for its crane capacity, thus a value enabling variable for this could be *tonne*. *DfC level variables* are harder to fully describe and valuate, but can be related to the level of path enablers in the system, since the path enablers again supports changing the value enabling variables.

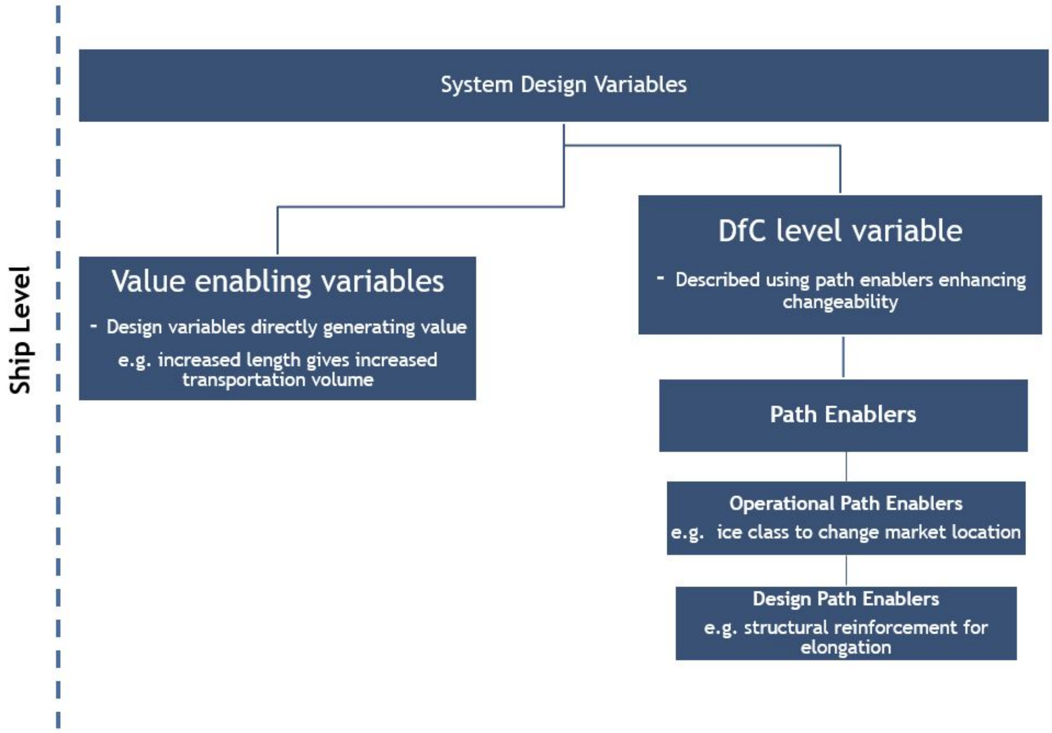


Figure 2.10: Hierarchy for path enablers, adapted from [Rehn et al., 2017e]

As described, change happens in either the design or the operation domain. Thus, it is also natural to separate path enablers in the design and operation domain. Continuing with operation as the dominating domain, design path enablers can be seen as a stepping stone for an operational path enabler, which again is a stepping stone for value enabling variables. For an operational path enabler it is not necessary to have an design path enabler, but a design path enabler will eventually become an operational path enabler. Thus, the path enablers could be seen in two levels, a low, structural design level, and a high, value focused level. This connection is presented in figure 2.11. Here, for an LNG tanker operating from the Yamal LNG plant in northern Russia, ice class could be an operational path enabler to change end market from EU to Asia, by sailing the Northeast passage. This could be fulfilled by external help from ice breakers as well, but ice class will *enable and support the change* *effect*, which is defined as changing operation mode through a market switch without change in design. On the other hand, a design path enabler could be, as mentioned, structural reinforcement which is built in to the initial design. This enables an easier change in length, as elongation also could be done without this structural reinforcement built in, but then to a higher cost and in a longer time than with structural reinforcement. Thus, the design path enabler will enable an easier change in design, which again is a stepping stone to change operation mode through capacity expansion.

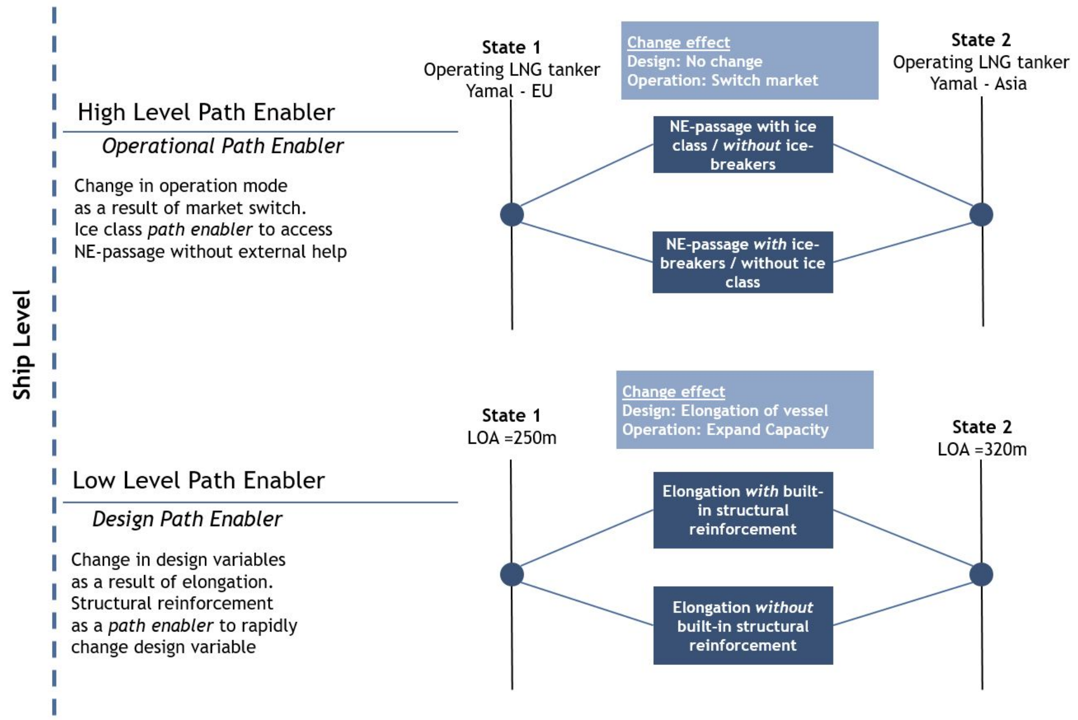


Figure 2.11: Operational and design path enablers

The relation between these levels of path enablers to the presented classification of design options is presented in figure 2.12 with typical real options. In this context, a strategic level is the superior, and the operation domain will affect both on a ship level and at the fleet level, while the design domain affects the ship level. Thus, from a strategic view, *on* options is the options to perform operational changes. Typical operational changes a shipowner can do is exemplified, with market switch, capacity expansion and lay-up.To be able to perform market switch or capacity expansion, design aspect has to be considered, and this could be exercised through either Design Change Options, or Built-in-design options, which in this context can be seen as operational path enablers. Typically examples for for market switch could be the Built-in-Design Option market switch capability which is characteristic for combination carrier, but this change could also be exercised through Design Change Options, such as retrofitting an platform supply vessel to a wind farm support vessel. To expand capacity, elongation could be a Design Change option, while a merchant vessel could be built to operate in a wide range of service speeds, and hence have a Built-in-design option to increase capacity be increasing speed. The last option, Lay-Up, is an option that, in this example, is not connected to the design domain. This is due to nature of Lay-Up, which is common for all systems, and is foremost a strategic decision, which do not need to connect either design changes or requires other built-in-functionality. But, degrees of Lay-Up exist, e.g. by using modularisation a vessel could change design to a "Lay-Up design", by stripping its equipment and utilise this in active systems.

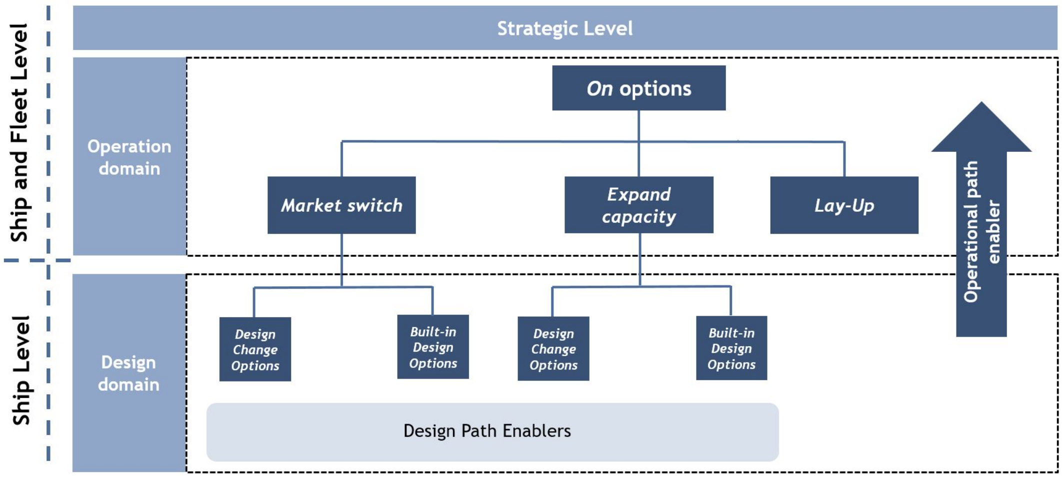


Figure 2.12: Options tied to path enablers

For illustrative manners, only three options was mentioned in figure 2.12. Example of more technical options can be technical operation profile changes. Built-in-Design Options for this could for instance be dual fuel engines or flexible bulbous bow, while the Design Change Options could be to retrofit the vessel with a new engine or a new bulbous bow. Though, all these do not necessarily give change in operations through change in contracts, markets etc., but can affect how a system is operated technically, which could affect the operating cost, ensure compliance with emission regulations etc.

As a foundation for the Design Change options is design path enablers. Most of the examples that was mentioned for Design Change Options, such as capacity expansion by elongation, could be performed with or without path enabler, as in the mentioned elongation case. Thus, a portfolio of design path enablers could be built in to the initial design.

According to the separation of real options, monetary valuation of all options could be found by valuation of *on* options, as this gives the valuation of change in operation, and could often be valued by established real option framework. Hence, a change in design could be valued by the change in operation, as a change in design is with a change in operation as objective. This statement is with a top-down approach for systems in commercial operation, as the valuation is based on the top objective, and the functionality is defined by its abilities valued in the open market, e.g. for an offshore construction vessel a design option is valued given the possibility for specific contracts.

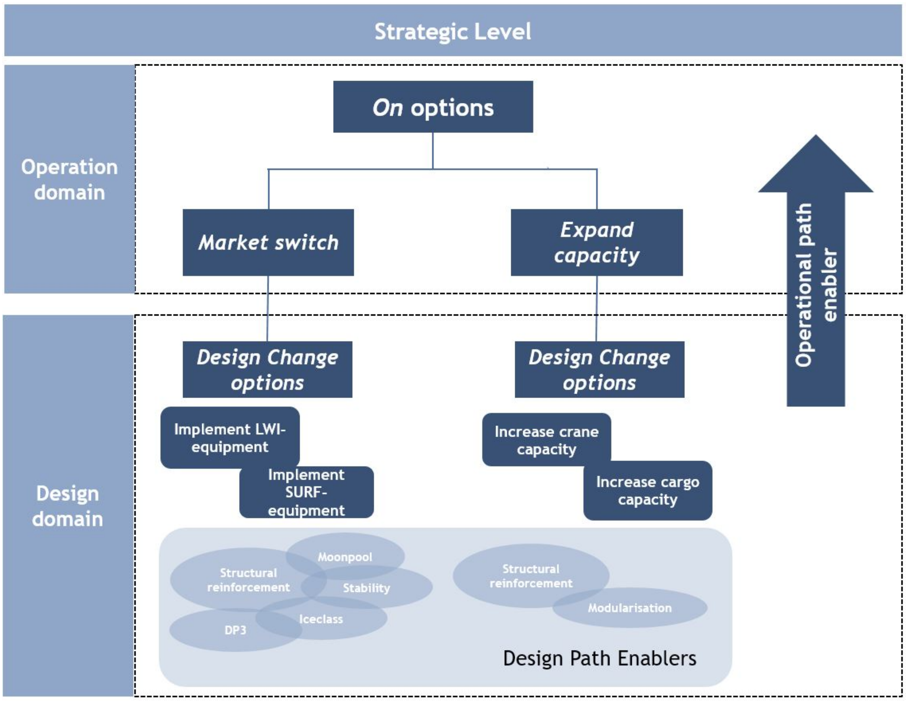


Figure 2.13: Options tied to path enablers for an OCV

Design Change options for an offshore construction vessel is exemplified in figure 2.13. An important point here is that some design path enablers can be common for several Design Change options, such as *structural reinforcement*, which could be necessary to implement a well intervention tower, but also for an increased crane capacity.

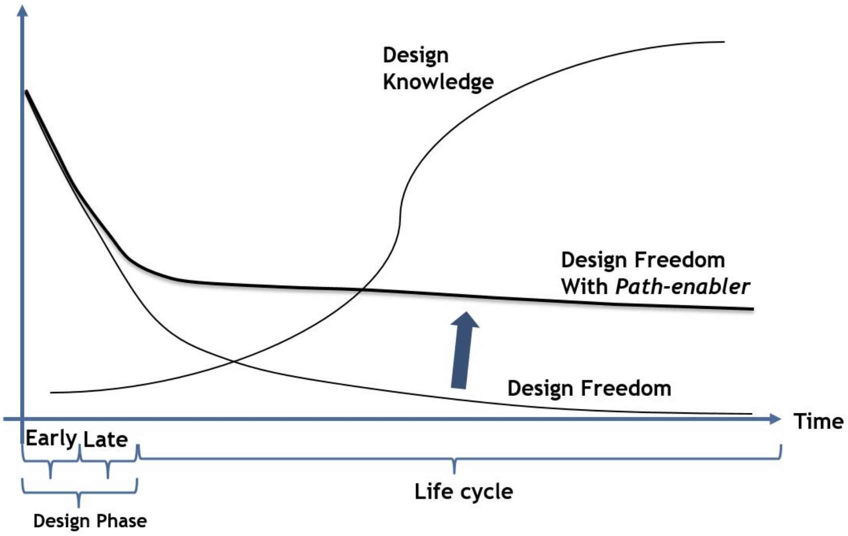


Figure 2.14: Increased design freedom over lifetime with path enablers

By implementing path enablers as variables in our total system, the system obtain a degree of changeability. This changeability will help the system to perform over its lifetime, operating in an uncertain environment. And, by this, the design freedom have increased compared to the conventional design thinking with a fixed design, as shown in figure 2.14.

3 Agility by Design

In this section agility is introduced and defined, and tied to investment lag. This is exemplified with cases from the maritime industry, and further agility is tied to real options, and Agility by Design is defined.

3.1. Definition of agility

The main focus in this thesis will be on *agility* and agile systems. This can be seen as an extension to the term *flexibility*. Fricke and Schulz [2005] defines agility and flexibility as

Flexibility is the property of a system that can be changed easily.

Agility is the property of a system that can be changed rapidly.

In other words, agile system have the option to change from a set of operational or design capabilities to a new set of capabilities in a quick and efficient way, without to large switching cost or rising complexity. The latter is common with flexibility, but agility now includes the aspect of response time, and the speed of the action. For systems operating in cyclical markets, where supply and demand is difficult to forecast, the ability to change fast can be crucial. Thus, agile system can have characteristics like flexibility in sense of capacity, functions and performance level, and the initial design can easily be modified[Haberfellner and de Weck, 2005].

In a business perspective, with the company as one strucural unit, Forrester research[8] defines business agility as *the quality that allows an enterprise to embrace market and operational changes as a matter of routine*. By this one think of the agility for the whole supply chain, so called *organisational agility*. [Sull, 2010] introduces the following separation of organisational agility, in line with research from McKinsey[9] and *ten pillars of organizational agility framework* by Farrell [2015].

Strategic agility can be summarised in three important principles.

- Probing for opportunities. This can be e.g. by M&A, introducing new products etc.
- Mitigating risk. By increased focus in risk management, due diligence etc.
- Staying in the game. Show patience and wait for big changes to happen, and chances to emerge

Operational agility is the organisation's ability to exploit revenue-enhancing and cost-cutting opportunities in a more rapid and efficient way than its competitors. These opportunities are hard to predict, but two important steps can be taken to increase the reaction time. *(i)* - to have systems that gather and share information that is needed to spot opportunities, and *(ii)* - to ensure that corporate priorities also is the individual objectives, hence the agility is taken from the board room and down to the floor.

[8] http://blogs.forrester.com/craig_le_clair/13-09-09-make_business_agility_a_key_corporate_attribute_it_could_be_what_saves_you accessed 18.05.2017

[9] http://www.mckinsey.com/business-functions/organization/our-insights/why-agility-pays accessed 18.05.2017

Portfolio agility is the agility that is required by companies with a diverse business portfolio. Allocating resources is the most important factor in this manner. It is often easy to invest as frontline employees spot new opportunities, while disinvestment and reallocating funds and human resources can be more difficult.

An agility which is not mentioned in this literature is *financial agility*. This agility can be seen as a necessity to ensure organisational agility, and is especially relevant in capital intensive industries like maritime industry. To have the possibility to be *strategic agile*, one need to have financial reserves, e.g. to stay in the game and wait for opportunities will burn cash and is necessary to be in position. Examples of this can be Warren Buffet, which sees cash as an option to move quickly if new opportunities emerge, or John Fredriksen's tanker company Frontline, which have the financial muscles to do M&A in cyclical downturns, when other shipowners are struggling to pay off their debt. A presentation of the described agility can be seen in figure 3.1, which suggest that financial agility is an extension to ensure organisational agility, and that *agility by design*, which will be discussed further, can contribute in all subsets of organisational agility.

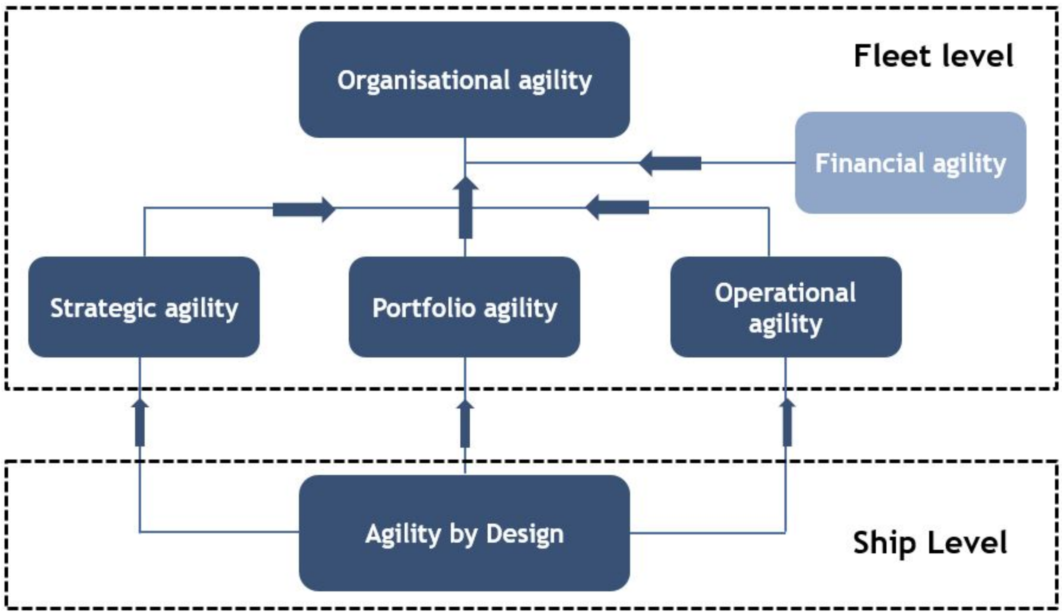


Figure 3.1: Organisational agility in maritime industry, partly adapted and extended from Sull [2010]

3.2. ***Agile system*** *engineering vs. agile* ***system engineering***

Haberfellner and de Weck [2005] emphasise that agility can built into the system engineering process, as well as the engineering system itself. To build agility in to the system engineering phase can be thought of as a parallel to organisational agility. This is typical for mature industries, which seeks to improve the process instead of innovate the product line, and by these have the possibility to rapidly satisfy new customer requirements. An example of this agility is the world largest retailer, Zara, which is known for it's *fast fashion*[Sull, 2010, Cachon and Swinney, 2011]. It's ability to spot emerging trends in fashion, and quickly serve it's main consumer, fashion-conscious young females from Europa, with the newest fashion. This have made them a supremacy in supply chain performance and strategic agility. Centralised production and design, extensive real time data collection, adjustment of 40 to 50% of retailers order during the season, small shipments and large inventory is some of the keys to this success story. On the other hand, agile systems is systems that have built-in flexibility, so that they can change capabilities in response to changing user demand during the systems lifetime. According to Haberfellner and de Weck [2005] this requires three elements

- that the system consist of a necessary amount of flexible elements, which allows it to be changed in an effective manner
- monitoring of external aspects to warrant necessary changes
- decision framework to assess cost and benefit of changing system state

Agility would be beneficial for much of the same systems that, as discussed in section 2.4, benefit from flexibility, and especially long lifecycles, significant switching cost and uncertainty in market demands make agility pay off[Haberfellner and de Weck, 2005]. These criterias are all satisfied by many maritime systems.

3.3. Investment lag and trend separation

Investment lag can be seen as the time it take for an transaction to be fulfilled, i.e. the time from the decision is made until the system have changed capabilities and is ready to exploit these. Investment projects with the following characteristics are projects that are exposed to investment lags, or the equivalent term, time-to-build[Majd and Pindyck, 1987]:

- Sequentially investment decisions and connected cash outlays
- Limited possibilities to adjust the construction progress, time-to-build occur
- The project will not have a positive cash flow until is fully completed

The investment lag will affect different markets differently. In figure 3.2 the electrical car brand Tesla shows and forecast an exponential growth rate for car deliveries. In this growth period the demand is higher than the possible supply, and the car makers expect to sell the same car for the same amount of money, nearly independent of time lag. Though, technological evolution is also rapid, and new technology eats up the value of older technology. These firms are typically in the development phase in figure 3.3, and the stock price of Tesla testify that Tesla is not priced as a normal car manufacter, but a technology company[10].

[10] http://nordic.businessinsider.com/tesla-stock-price-confusing-investors-2017-5?r=US&IR=T

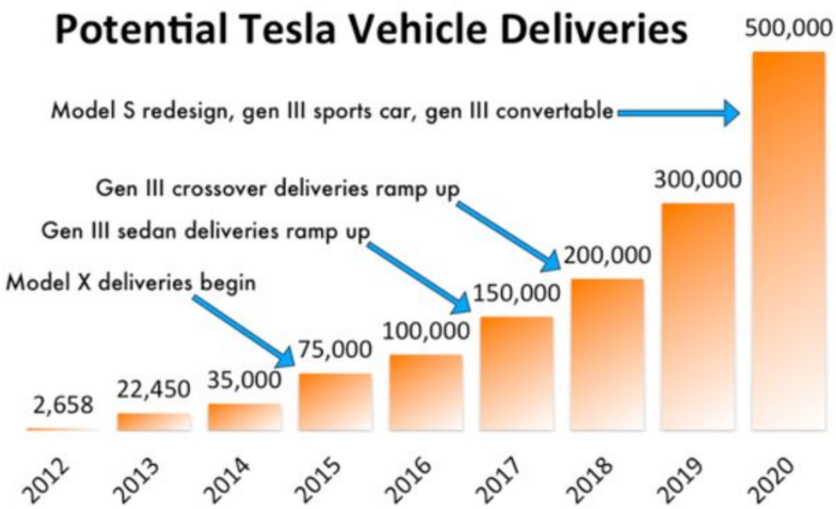


Figure 3.2: Growth industries - electrical cars from Tesla [11]

For mature industries like industrialised shipping an exponential growth rate is out of sight, and the focus is rather to keep a tight cost structure and stay in front of a slow evolution[Stopford, 2009]. The S-curve for market evolutions shows this, as seaborne shipping services is in a mature era, with a stabile market share. Such mature markets are also exposed for cyclicity in demand, and markets out of balance will again give cyclical prices and income. Thus, investment lag could here be the difference in utilising the periods with high rates, instead of entering with new capacity in a down turning market.

[11] Found from http://kirillklip.blogspot.no/2015/07/lithium-catalyst-tesla-model-s.html, and based on Tesla press releases

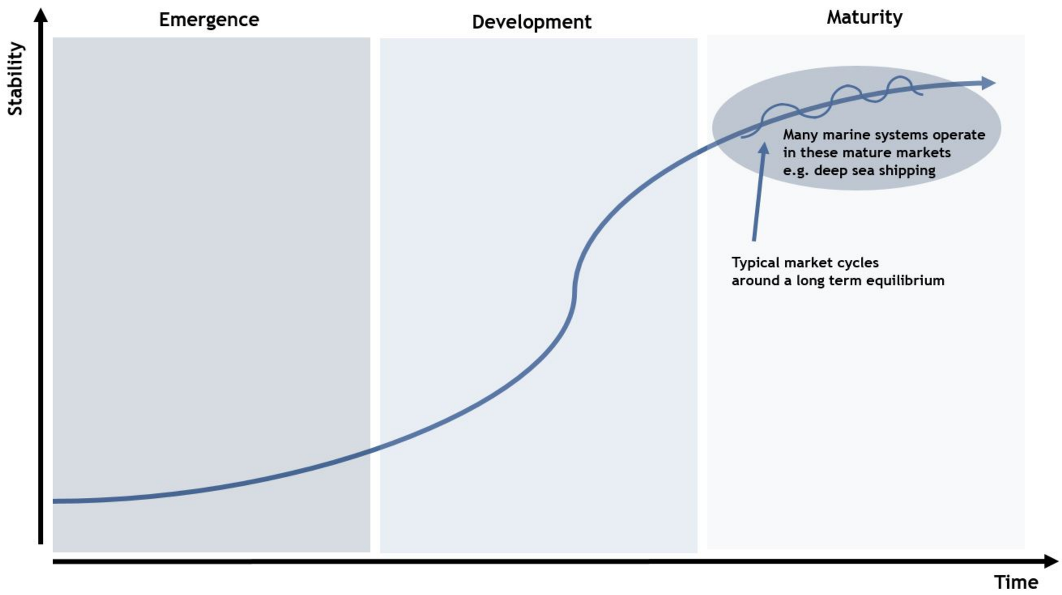


Figure 3.3: The S-curve for market evolution

3.4. Investment lag for maritime systems

Maritime systems, such as vessels, either designed for transport, offshore service or fishing, are built with a life cycle perspective of 20-30 years. Some of them are built to operate at fixed long term contract, and optimised for this, others operates in spot markets. Especially in transportation there is liquid markets for transportation of commodities that can be transported either as dry or wet. Many of these spot markets are affected by volatile rates, where shipowners are price takers in a highly competitive market. The spot rates are determined by the current demand for transport, which is fluctuating, while the supply side is relatively inelastic due to the slow scalability in vessel capacity. Neglecting conversions and other minor contribution, the supply side is restricted to entry by newbuildings and scrapping/lay up of vessel as exit. Thus, investment lag for newbuildings can be seen as the delivery lag from a vessel is ordered until delivery.

This delivery lag have been described by Adland and Jia [2015], which points out the fact that a great part of this delivery lag is determined by an uncertain waiting time for yard capacity and time slots in dry docks, while the building time it self can be seen as a fixed. This is shown in figure 3.4, where the delivery lag fluctuate between ~ 20 and ~ 46 months, while the building time is from 11 months for dry bulk, as the simplest vessel to build. From the plot one see that the delivery lag increased parallel with the ongoing super cycle in the shipping markets. Many vessels that was ordered during 2007-08 and first entered the market in 2011-2012, at a time when the market rates was only about 10% of the peak rates in the years before, and the scrapping age followed down as old vessels often had to high operation expenditures to be profitable, and a new upturn was not in sight.

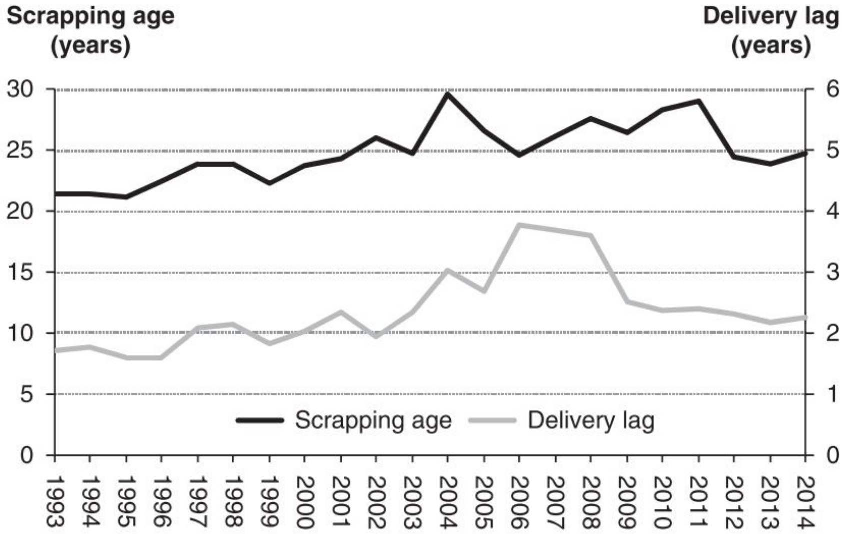


Figure 3.4: Delivery lag and scrapping age. Adland and Jia [2015] with data from Clarksons Research [2017]

In this context the delivery lag was crucial, with many shipowners ordering vessels with high leverage, and received the vessel when ship values was significantly lower at the investment decision. This can be seen as the big drawback with investment lags when the markets are uncertain, and the shipping industry and its cyclical market have been affected with this throughout its history. Thus, *agility* can, in a general perspective, be seen as the ability to decrease the investment lag of new projects or in Design Change options.

Though, the delivery of newbuildings can be seen as a question of timing, and the market evolution during this lag as out of control for the shipowner, new methods to enter market and grasp opportunities must be found, with focus on operational agility as well as the strategical agility. A simple and illustrative example of this investment case could be a shipowner which experience high markets, and the shipowners forecast gives up to 2 years before newbuildings have increased the total supply, and freight rates have reverted to a long term mean level. By this he want to expand capacity as fast as possible, and minimise his investment lag. A possibility is to expand through the second hand market and enter the market with new capacity and negligible investment lag. However, the high freight rates are reflected in second hand values, and the shipowner see this as a bad investment. This is also the case for a resale, and a newbuilding will have delivery after the rates have fallen back.

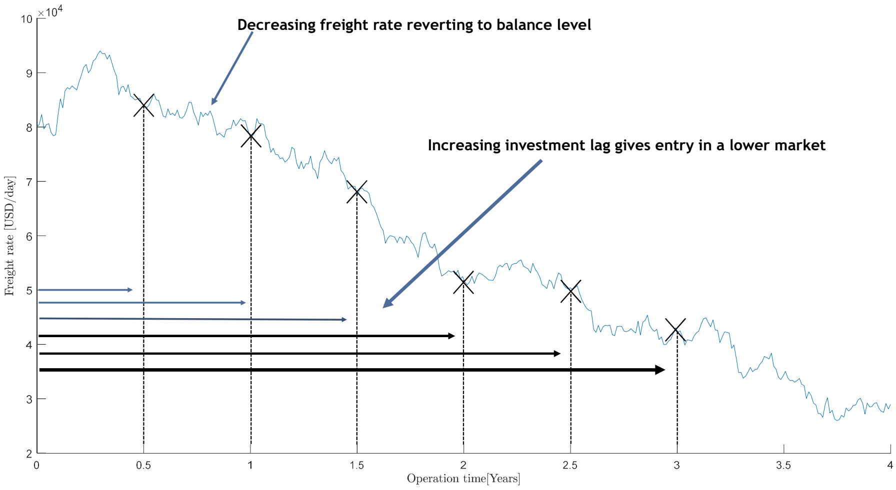


Figure 3.5: From a high market to a low

Thus, the waiting time for new capacity can be seen as the alternative cost of not staying in the market, and is defined by the cash flow from each capacity unit over time, $CF(t)$, which again is given by the freight rate less operational expenditures. Hence, the net present value of this will be the cost of investment lag(CIL)

$$CIL = \int_t^\tau e^{-rT} CF(t) \tag{3.1}$$

$$\tag{3.2}$$

where $\tau - t$ denotes the investment lag starting at the moment of decision t. Though, to be able to find options for capacity expansion between the investment lag for a second hand purchase and a newbuilding could then be crucial to be able to grasp such market opportunities, and benefit from this cyclicity.

An extreme example which test the operational agility is markets with high spikes and reverting properties, such as the spot market for AHTS, as shown in figure 3.6. To be able to utilise these spikes requires extreme agility, and many of these spikes is due to unforeseen demand that have to be satisfied in a short period of time, e.g. a rig that costs 500 000 USD/day will give a high willingness to pay if it could save days by faster relocation. Thus, it is also hard to plan to take these spikes, which often requires an agile fleet, with vessels off contract and ready to grasp such opportunities.

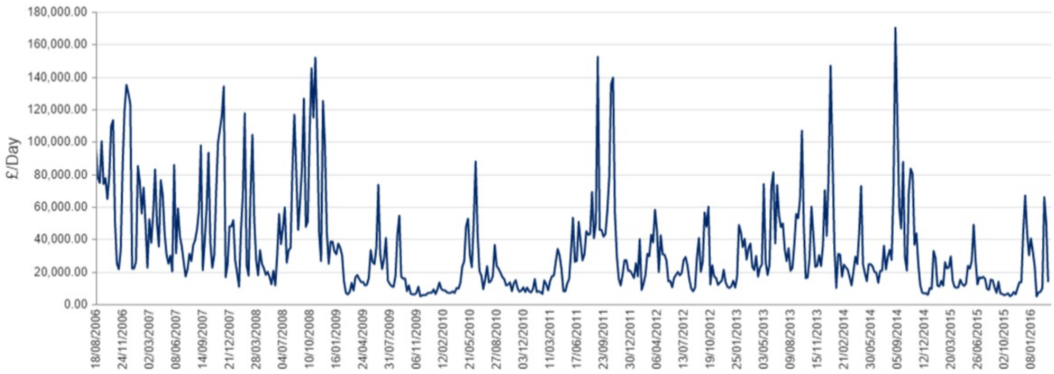


Figure 3.6: Spot rates for AHTS(+20k BHP) operating in the North Sea[Clarksons Research, 2017]

3.5. Examples of agility in marine systems

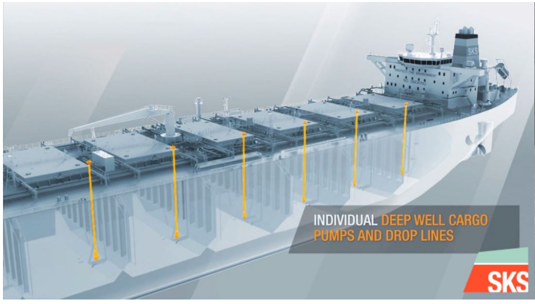
3.5.1. Built-in-design options

Operational options was introduce in section 2.5.2. For maritime systems they can be seen as underlying options which are built in to the design, and make possibilities for reversible changes in either design, function or capabilities. Typically, these changes are performed to exploit other markets and spreads, and they are all of value due to their ability to adapt to new markets fast, before an eventual spread are closed.

Market switching by Combination carrier

The combination carriers(OBO-carrier) are designed to be able to switch between dry and wet cargo, and by this operate in both markets. Thus, these carriers are able to exploit the price differential which can occur in these two markets and operate in one single market, or reduce the number of ballast voyages. The latter is the normal operation mode, by exploiting triangular routes, where two out of three legs is with cargo and one in ballast. To obtain routes like these one is often dependent on a mix of spot and long term charters, where the long term contracts require a certain degree of reliance in the shipowner to serve the route. By this, combination carriers is often ordered with a perspective of handling such triangular routes over its total lifetime, contrary to a speculation object which could be sold as a pure wet or dry carrier if one of these market booms and gives high second hand values[Thorvald Klaveness AS, 2017]. Yet, this leaves the shipowner with an added option value compared with a pure carrier, namely the option to switch markets if the price differential is advantageous, or the option to reduce ballast voyages. As noted, there are limited triangular routes, and historically there have been periods where the combination carrier capacity outgrew the market for such routes. This made both options less worthy, and the holding cost of these carriers made them unpopular[**?**].

Technically the combination carriers are not that different from conventional carriers. The cargo holds are equipped with high pressure cleaning systems, shown in figure 3.7b. Hydrocarbon sensors in all compartments ensures that the holds are cleaned, and water and oil will be separated in the washing process to prohibit oil spill.

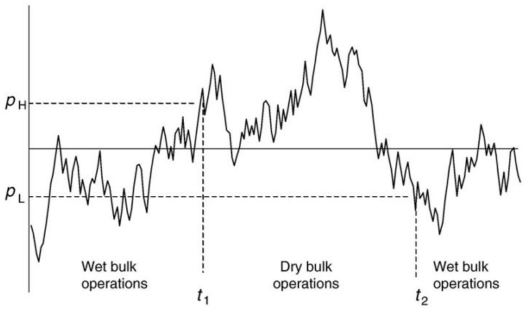


(a) Individual cargo holds

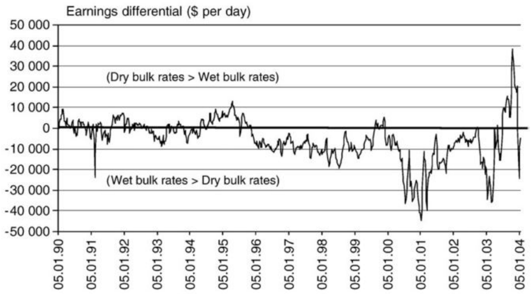
(b) High pressure washing systems

Figure 3.7: Captures from SKS's presentation of OBO carriers[SKS tankers, 2017]

Sødal et al. [2008] derives a valuation of a combination carrier's flexibility, by a standard entry-exit model with mean reverting price differential between the two markets. By this, there are underlying assumptions that the vessel only operate in one market a time, and change market according to given trigger prices with a negligible changing time between market.



(a) Price triggeres



(b) Historical price differential between wet and dry bulk rates

Figure 3.8: Examples of trigger prices and historical price differential[Sødal et al., 2008]

The assumption about negligible changing time between markets is an example of strategic agility, where one have a continuously latent and fully reversible option to change market. The degree and value of agility can hence be determined from the lag between a given price level is triggered and when the vessel is ready to exploit the alternative market. This lag can be due to technical aspects, such as cleaning and inspections before the vessel is ready to enter a new market, or ballast voyages to enter new route patterns. Thus, with the reverting property of the price differential, time lag can change a good switch to a worthless one. The price lag from figure 3.8a is modified, and the shaded region reflects a potential change time in figure 3.9. This change time will induce an opportunity cost defined by operation in the most profitable market.

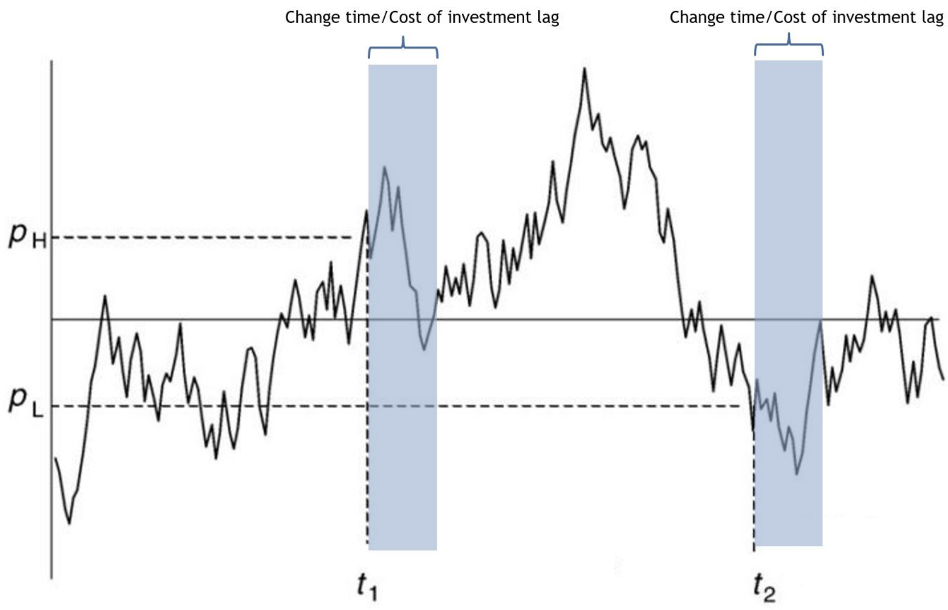


Figure 3.9: Price differential from Sødal et al. [2008] and cost of investment lag

Price triggers and investment lag have been discussed by the literature, and Sødal [2006] finds that price triggers will be the same for investment with or without investment lag when the price follows a geometric Brownian process. However, without making any conclusions about the price triggers, the intuition behind a higher changing time is a reduction in the switching value, which lessen the overall value of an combination carrier.

Market switching by Hoistable deck

The main segments in traditional RORO shipping are *High* & Heavy(H&H), *Pure Car Carrier*(PCC) and *Pure Car Truck Carrier*(PCTC). The difference between these markets are the deck heights, where the PCC have fixed deck height of 1.8m, which serve to ship a normal sedan, PCTC which can take an SUV, and H&H which have flexible decks for handling rolling cargo larger than a car. Even though these markets are closely linked, the freight rates can have deviations that could be exploited by a RORO vessel with hoistable decks, i.e. flexibility in the choice of market such as for an combination carrier. The choice of flexible or inflexible decks was discussed as an illustrative case by Erikstad and Rehn [2015], where Monte Carlo simulation of correlated mean reversion processes was used to represents possible price differential. The result is shown in figure 3.10 which gave a higher expected NPV of future cash flows for the flexible alternative.

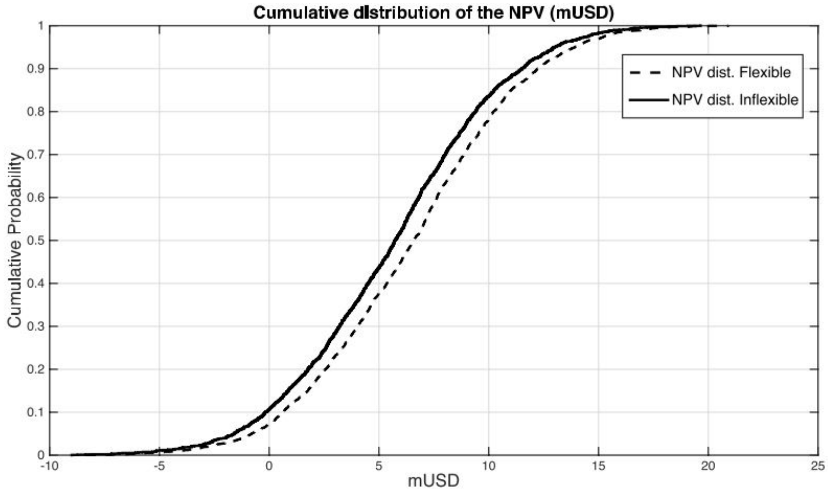


Figure 3.10: Cumulative distribution of the NPV(USDm) for flexible and inflexible decks[Erikstad and Rehn, 2015]

Thus, both the market switching case of an combination carrier, and market switching in the RORO-segments, represents strategic agility, where the importance is to exploit unbalance in markets, which gives greater price differential. Though, these differentials will eventually revert back. The faster and more agile the switch is, the more value gives the switching capabilities.

Other market switching examples in maritime industry

Another example of these price differentials in maritime industry could be fuel price differential between LNG and marine distillate, which could be exploited by Dual Fuel engines. Thus, this gives both an option to switch fuel due to cost, but also a value due to flexibility from sailing in areas with fuel and emission regulation. An example from the cruise industry and market switching could be the changing demand of luxury class cabins versus middle class cabins. An agile way to increase the flexibility for a given number of cabins in each vessel could be by functional modularity, and in a rapid way change the capacity in each cabin class after demand changes.

Design flexibility by Flexible Bulbous bow

For merchant vessels the bulbous bow is designed to reduce wave resistance, and optimised for the specific vessels design speed. The actual transit speed has the past years decreased according to slow steaming, and hence the bulb performance has been sub-optimal. An answer to this has been to retrofit the bulbous bow. Estimations of the payback period for such retrofits is about twelve months, which give indications of the huge potential for savings in fuel cost. A flexible and agile alternative to this is a flexible bulbous bow, which can adjust the geometric shape of the bulbous bow according to different operation profiles and transit speed[Leonhardsen, 2016].

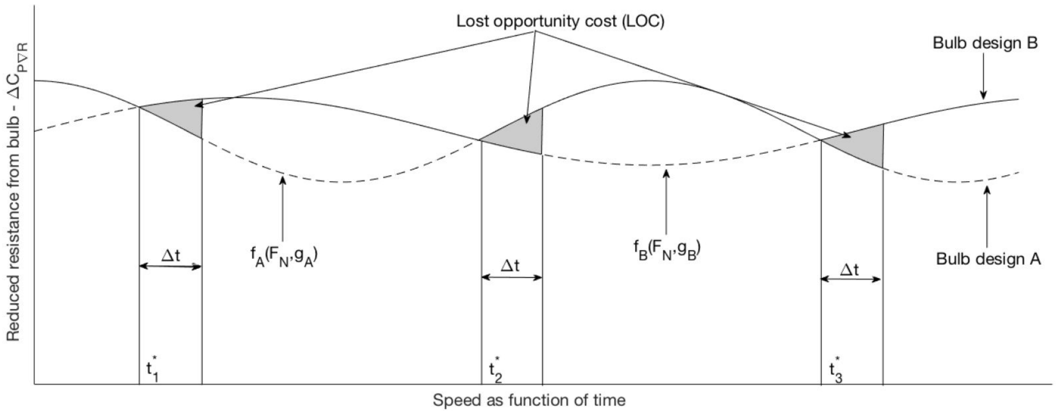


Figure 3.11: Lost opportunity cost due to time lag[Leonhardsen, 2016]

In the master thesis work presented by Leonhardsen [2016] the value of this flexible bulbous bulb have been investigated. Figure 3.11 shows the principle of operational agility in form of a rapid bulb change. The reduced resistance from the bulb is graphed at the vertical axis, i.e. the higher this is, the better is the bulb's performance. Thus, the performance of the bulb can be seen as a function of the Froude number and geometry. As one geometry is better performing than the other, an opportunity cost occur, and from this the changing time between the two geometries will give a lost opportunity cost.

3.5.2. Design Change options

Capacity expansion

Jumboisation of vessels is a way to increase a vessels capacity by either increasing the vessels length, breadth or depth. The normal approach is to split the vessel midship, and insert an extra midship section, shown by figure 3.12.

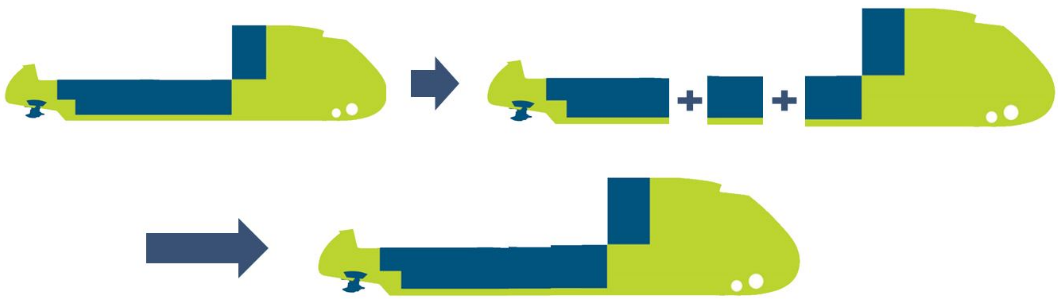


Figure 3.12: Elongation by inserting new midsection, adapted from Ebrahimi et al. [2015]

Jumboisation could also be performed by widening the breadth of vessels. This have been of special interest for container vessels, where the widening of the Panama channel have allowed larger vessels to cross. Examples of this can be the widening of three container ship from *MSC*, a widening concept from REEDEREI NSB, shown in figure 3.13. Further, a few examples of jumboisation is presented in table 3.1, and one see that there is a wide span both in segment and time of retrofit.

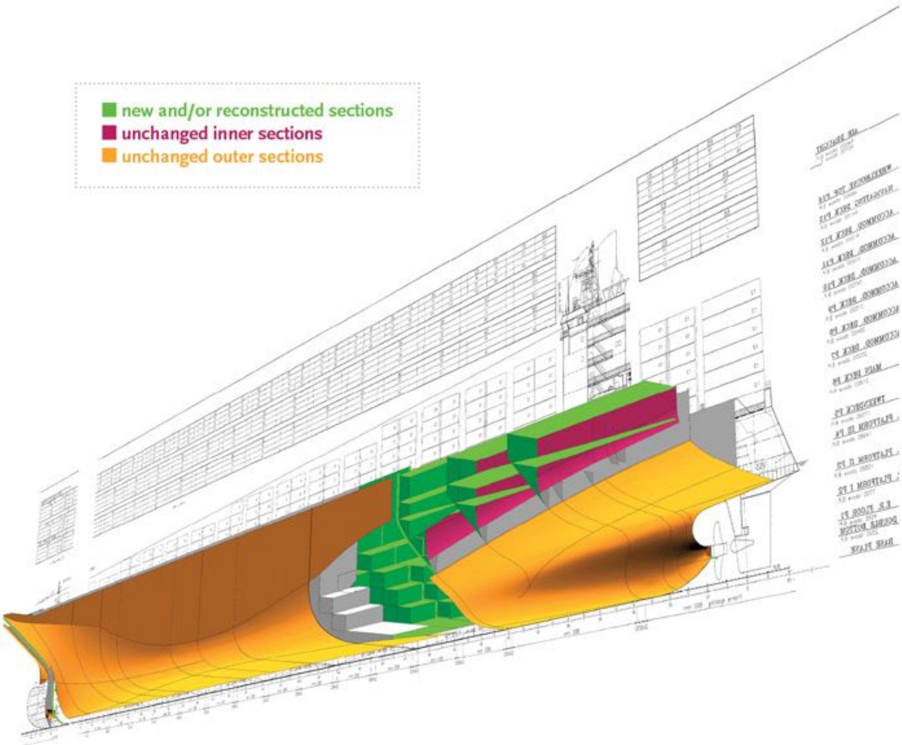


Figure 3.13: Jumboisation by widening [12]

Table 3.1: Examples of jumboisation of vessels [13]

Vessel	Type	Year Built	Retrofit Year	Jumboisation data
Costa Classica	Cruise	1991	2000	Fr LOA 704ft To LOA 870ft
Enchantment of Seas	Cruise	1998	2005	Fr LOA 915ft To LOA 992ft
Knock Nevis/Seawise Giant	ULCC	1979	1981	Fr 418,611 dwt To 564,763 dwt
MSC Geneva	Container vessel	2006	2015	4,860 TEU to 6,300 TEU
Hoegh Kyoto	Car Carrier	2005	2012	Fr LOA 615ft to LOA 652ft

Jumboisation can be seen as an alternative to capacity expansion by acquiring new vessels, hence an option of capacity expansion. To exercise this option there occur a change time

[12]http : / / www . reederei-nsb . de / en / knowledge / technical-nautical-services / widening-of-panmax-ships/accessed 14.05.2017
[13]http://www.20thcenturyliners.com/ol_stretched.htm accessed 14.05.2017
https://no.wikipedia.org/wiki/%C2%ABKnock_Nevis%C2%BB accessed 14.05.2017
http : / / gcaptain . com / innovative-containership-widening-project-completed-photos/ accessed 14.05.2017

for retrofitting the vessel, together with an exercise cost. The change time is normally less than the time it takes to acquire a newbulding, and more than acquiring a second hand vessel.

Conversion
Conversion of vessels from one ship class to another have been common, either it is for high-end offshore service vessel going from oil service to wind farm service, or a more simpler crude carrier to an ore carrier. Especially the latter was popular around 2008, when single hull VLCC was converted to large dry bulk carriers(VLOC), and can be seen as a permanent version of the combination carriers with only one change. In this context, a conversion normally have to take place in a yard, which requires a period off-hire. E.g. for an VLCC to work as a VLOC several structural changes have to be carried, such as tank holes to be cut out, which again require structural strengthening of the rest of the hull, given the loss in strength due to reduced deck plating and deck framing.

3.6. Path enablers to implement agility - Agility by Design

As seen, to be agile in cyclical markets can be crucial to utilise high markets, and through the ship level and subsystem level one can implement *Agility by Design*, which again gives a higher level agility, graphically presented in figure 3.14. In the maritime context, subsystems could be everything from engines and propellers to maintenance systems. By implementing design features that enables agile operational changes a general level of agility will be obtained.

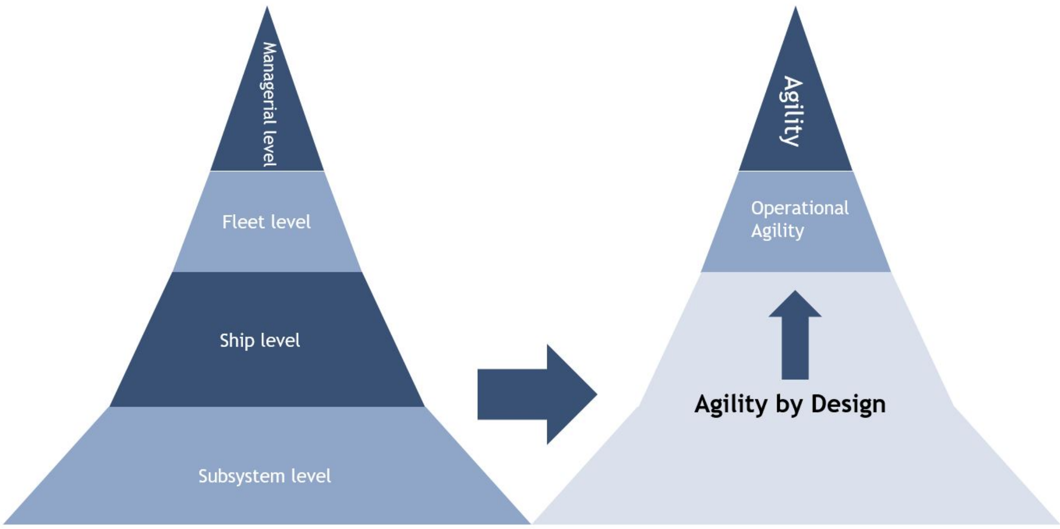


Figure 3.14: Agility in ship management

To implement this agility, there is two main contributors in Agility by Design, as graphically shown in figure 3.15 and described as:

Design Path Enablers , that enables a more efficient state transition in the design domain, and thus enables easier Design Change Options. Design Path Enablers can be built in to the initial design, to enable an easier and more time efficient change in design during the systems life time, hence increasing option value by limiting investment lag.

Built-in-Design Options , options that are built in to the initial design, and make the design itself enable agile changing in operational profile, rapidly market switch etc. This is options that are multi exercisable, and an exercise will again give a compound option of changing back to the initial market. This will represent a dynamic change opportunity.

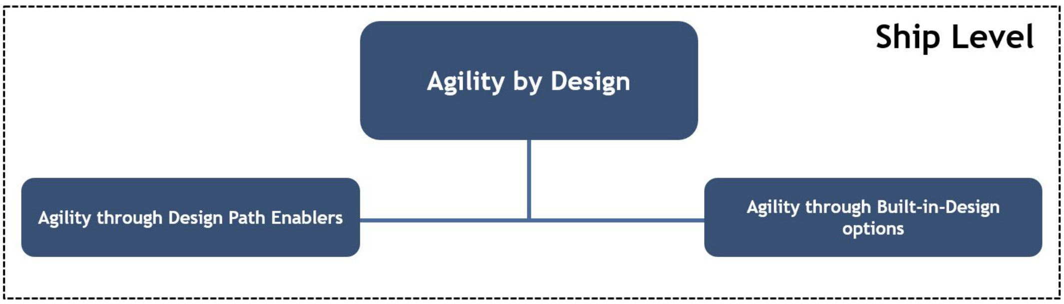


Figure 3.15: Agility by design

Thus, Agility by Design will affect the change time in the changeability framework, which is exemplified by the elongation case in figure 3.16. The axis will define discrete, independent barriers that an option will span, and by the path enabler for elongation the required change time is decreased but the assumed cost is fixed, while the elongation gives the same effect in a design and operation domain.

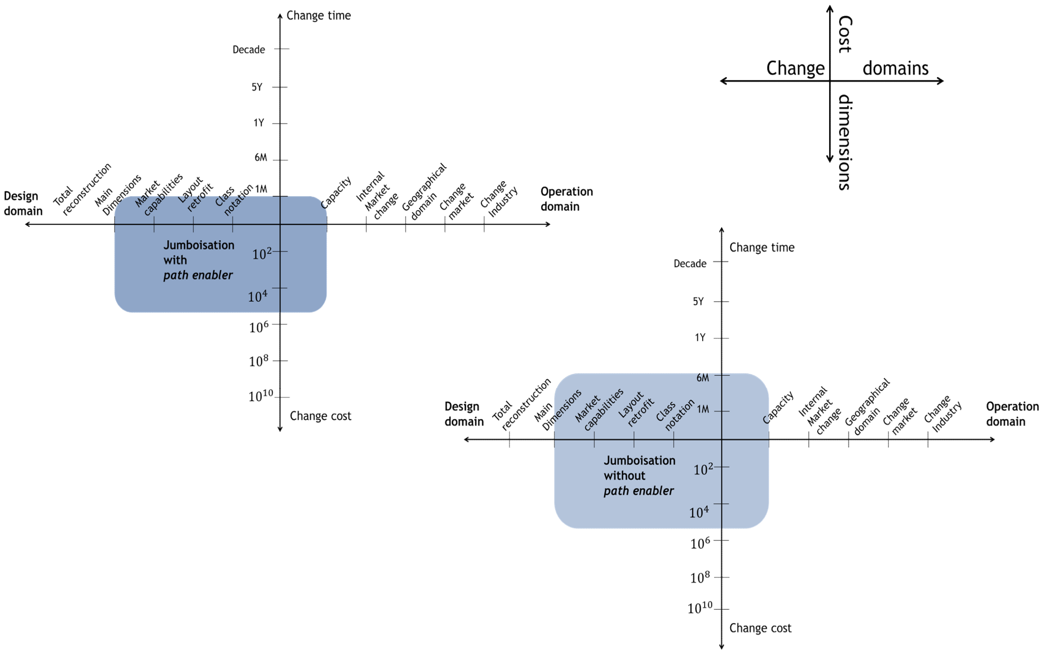


Figure 3.16: Discrete representation of the change option jumboisation and path enabler

Part II - Valuation of agility

In this second part a generic framework to value agility is proposed. The framework is built around the dry bulk market as an example, but will be applicable to other markets as well. In the first part stochastic processes is found to replicate the market, before this replication is applied in an option valuation framework where investment lag is included as a parameter.

4 Modelling of markets

In this section a stochastic process is proposed to further use in the real option valuation framework. For this, a general overview of market dynamics is presented, before time series analysis is performed.

4.1. Maritime economics

Seaborne transportation have been the main transport for cargo across continental landmasses in centuries, with air freight as only competitor the last decades. Thus, an extensive network of ports and sailing route for different cargo have been established, and in 2004 merchant shipping had an a total turnover of about 425 000 000 000 USD, which is about 30 % of the total turnover from marine activities[Stopford, 2009].

4.1.1. Organisation of shipping markets

The shipping market can be separated in four different sub-markets, the newbuilding market, the freight market, the sale and purchase market and the demolition market[Stopford, 2009]. Distinction could also be made between newbuilding and demolition market on the one hand, and the freight market and sale and purchase market on the other as "auxillary" markets to the former markets, which affects the total supply of transport services[Wijnolst et al., 1997]. These four markets and the interconnections are presented in figure 4.1. By this figure, the cash flows and assets flows through the overall market is graphically presented. Shipowners is the player that is involved in all the markets, and hence the centre of all four markets are the shipowning companies and their balance sheet, which describes their financial status and strength to act in the sub markets. The connection to the freight market is the main revenue contributor to the shipowners, as the sale and purchase market is a market between shipowners, and can be seen as zero-sum game from a general perspective. Thus, many of the traditional, often family owned, shipping companies do operate with the main strategy of securing stable cash flow from the freight markets, while other, less risk averse companies, operate in the sale and purchase market with intention to make easy money by timing the market, which can be seen as a asset play by "buying low and selling high".

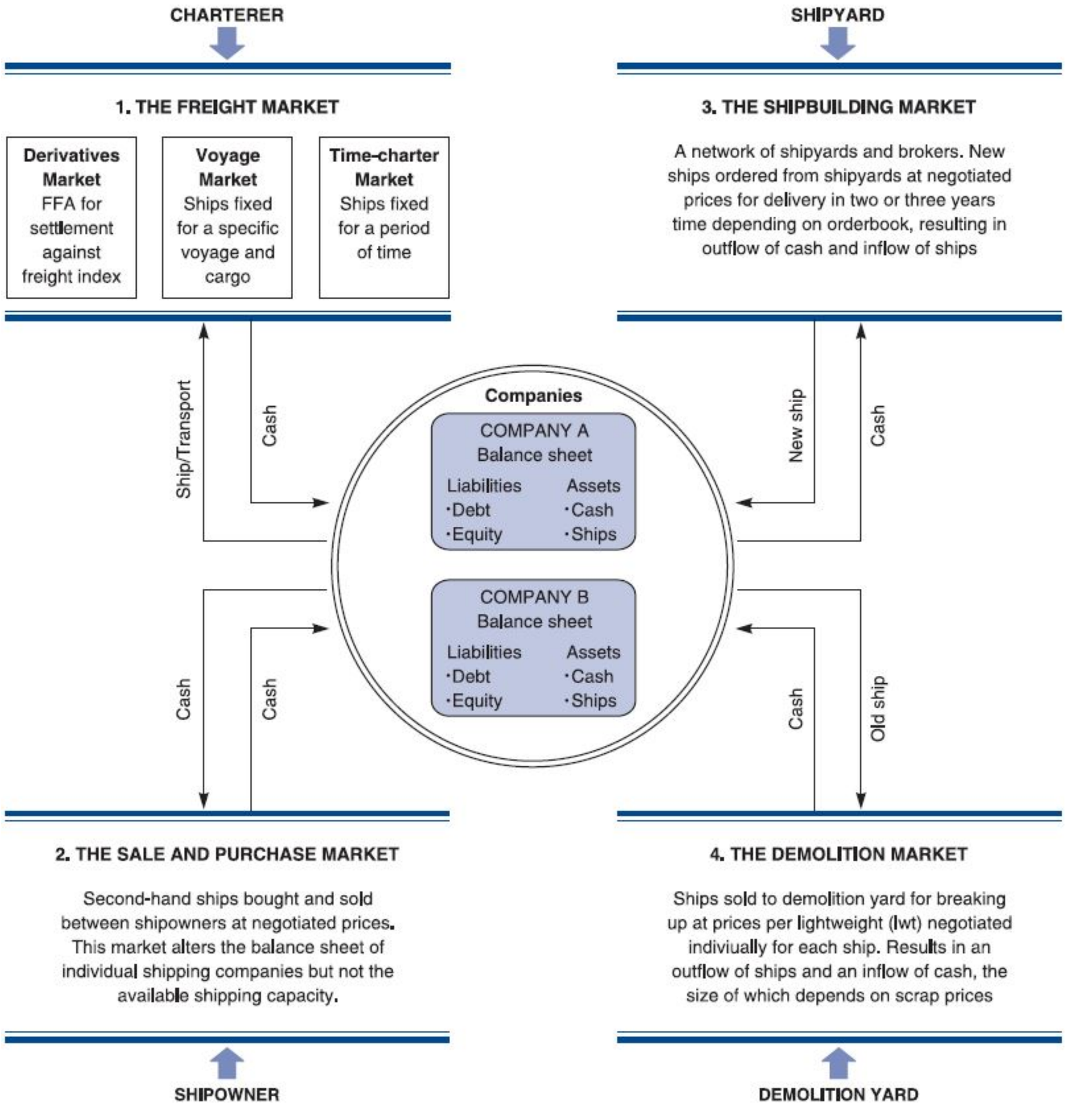


Figure 4.1: The four shipping market as presented by Stopford [2009]

Of the world merchant fleet, dry bulk carriers is the largest segment measured in gross tons. An overview of the total fleet of bulk vessel is presented in table 4.1.

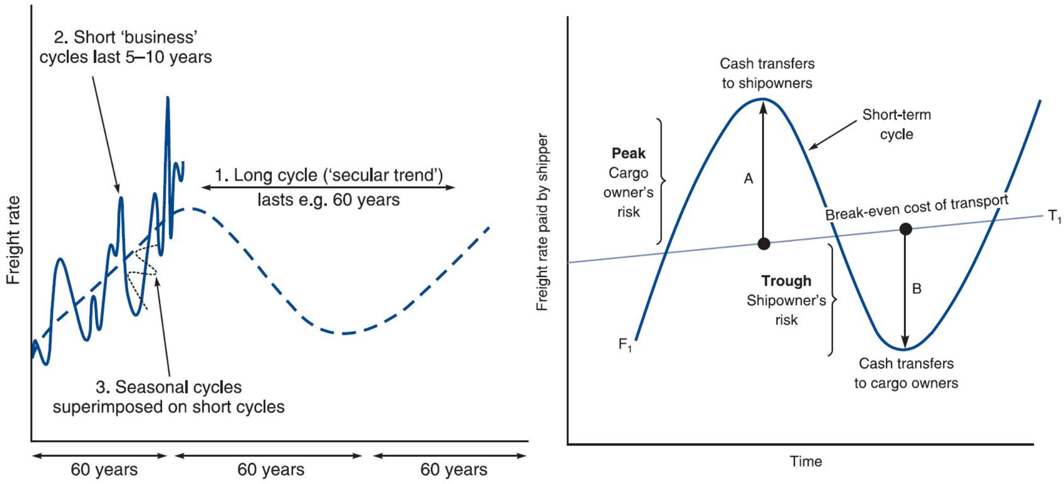
4.1.2. Shipping market cycles

Stopford [2009] introduces the shipping market as the *world's biggest poker poker game*, where the market cycles are the dealers and shipowners as players. These cycles can be observed from the freight rates, e.g. a Panamax operating in the spot market between the US Gulf and Rotterdam would in 1986 have net earnings of USD 1m, in 1989 USD 3.5, in 1992 USD 1.5m, in 1995 USD 2.5m and USD 16.5m in 2007. These cyclicity is not unique for the

Table 4.1: Overview of dry bulk carriers[Stopford, 2009]

Type	Size range[dwt]	Number of vessels	Total mill. dwt	Comment
Capesize	Over 100 000	738	125.7	Mainly carry ore and coal
Panamax	60-100 000	1453	106	Coal, grain few geared
Handymax	40-60 000	1547	74.1	Workhorse, mainly geared
Combination carrier		85	8.2	Oil/bulk/ore

shipping markets, and especially present ni mature, stabile markets,as presented in section 3.3. However, many economists look at the dry bulk freight market as an approximation to perfect markets, identified by identical, homogeneous products(transport), free entry and exit and fairly liquid markets, with about two trades of second hand vessels each working day[14].



(a) Seasonal, short and long cyclical components

(b) Key risk features of the shipping cycle

Figure 4.2: Shipping market cyclicity[Stopford, 2009]

The cycles can be divided in to three separate sub-cycles[Stopford, 2009], as shown in figure 4.2a. The overall trend can be seen as long cycles, which can last for several decades. Short business cycle can last for for about 5 to 10 years, and is often affected by events such as Black Swans, financial crises, rising economies etc. The last cycle is the seasonality that occurs in different markets due to regular events.

These cycles can be seen in the relation to the key risk features of the shipping cycle, presented in figure 4.2b, where the freight rates oscillats around the break even cost of transport. In a perfect market, this cost will be equivalent to the freight rates. Though, to be in such a condition there must be a perfect balance between supply and demand, which rarely is the case in shipping. Thus, in times with low freight rates shipowner subsidising

[14]Hermann Billung at HegnarTV 16.02.2017, http : / / www . hegnar . no / TV / video / ee771f9f-00080348-7bbebee8

cargo owners, as the freight rates are under the vessels break even rates, and vica versa with high freight markets. These properties can be seen as a reversion process, with freight rates reverting around a long term break even cost of transport.

4.2. Description of Data

For further analysis data from Clarksons Research [2017] have been utilised. The chosen data have been average earnings in the Cape Size segment in bulk shipping, as well as corresponding second hand value of 5y old Cape Size vessels and newbuilding in the time span 1990 - 2017. These earnings are estimated from voyage freight rates less voyage cost(bunker, port fees and total commission), and expressed as a average daily earning, $\frac{USD}{day}$. It is quoted at the end of each month, and hence reflect the average of each calender month. These earnings do not account for other operational expenditures(crew, insurance etc.)[Clarksons Research Services, 2014].

From the graphical representation the correlation between earnings and second hand value seems to be positive, which reflect the fact that the second hand vessel values is foremost a function of short term earnings, while newbuildings is seen as the value of long term earnings. This is also the reason why shipowners was willing to pay a premium for second hand ship over newbuildings at the boom in 2007/2008. The cyclicity of the market in the time span from 1990 to 2017 is first of all affected by this boom, and the dry bulk market have been through rough times especially post this boom, with the Baltic Dry Index reaching an historically low early 2016.

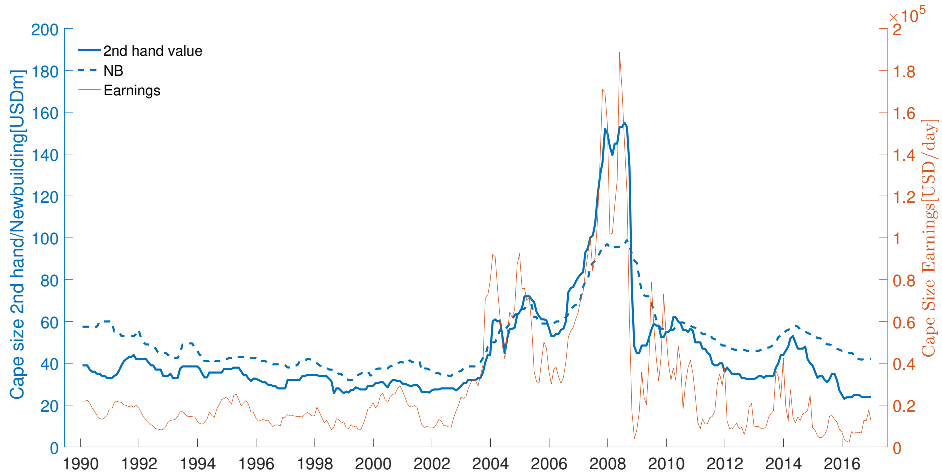


Figure 4.3: Cape Size asset values and earnings from 1990 to 2017[Clarksons Research, 2017]

A critic to this data set is the significant influence of the boom in 2007-2008, which have again directed to the down period in the time after. This will affect the following time series analysis, and we actually find that the distribution of returns are left-skewed and negative changes, which verify the negative overall market.

By observations, argumentation around capacity adjustment and former time series analysis of freight rates from the literature, mean reversion properties seems familiar. Though,

Table 4.2: Descriptive statistics, monthly data from Jan 1990 - Jan 2017

Statistic	**Datapoints**	**Mean**	**St. Dev.**	**Min**	**Max**
Cape Earnings[USD/day]	324	28 991	30306.62	2 287	188 643
5y Cape 2nd hand value[USDm]	324	44.98	25.48	23	155
Cape Newbuiding[USDm]	324	51.11	14.66	32	99

	Mean	**Kurtosis**	**Skewness**	**J-B Test**
ΔCape Earnings[USD/day]	-0.0018	8.13	-0.58	373.36
Δ5y Cape 2nd hand value[USDm]	-0.0015	30.18	-2.85	10385
ΔCape Newbuiding[USDm]	-0.00097	6.62	-0.41	186.512

Note: Δ = Log of changes

analysis of the presented data is performed for better understanding and basis for value models.

4.3. Normality and seasonality

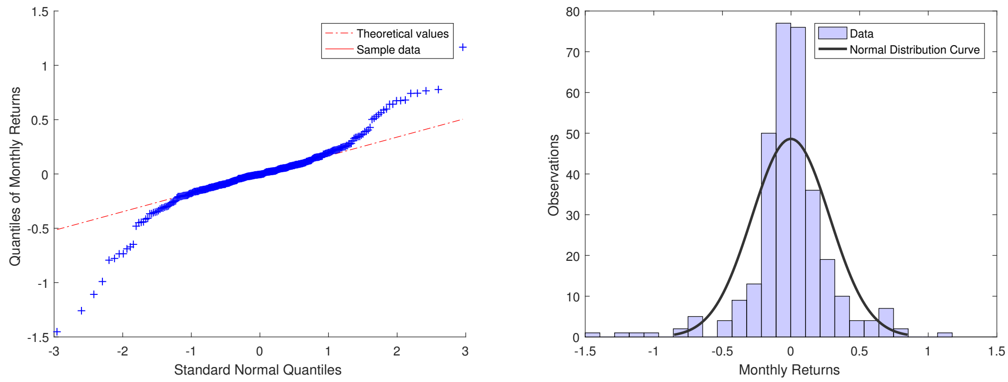
Earnings and prices are often assumed to be log-normally distributed[Black and Scholes, 1973], i.e. the change is normally distributed. This is contrary to time series that are affected by "jumps", which gives the distribution of return *fat tails*-properties. In other words, if the daily changes in prices is highly volatile, e.g. often have changes in absolute term of 3-4 % and higher, the distribution have a large number of more extreme observations than what will fit to a normal distribution.

To test for normality, the Jarque-Bera test[Jarque and Bera, 1980](J-B test) is performed for each time series, and the result is stated in table 4.2. The test indicators declines the hypothesis about normally distributed earnings, and all time series shows P-values of less than $\frac{1}{1000}$. This is in line with the plots in figure 4.4 of the historical freight rates. From the QQ-plot in figure 4.4a one can see that there will be extreme fluctuations, and both the left and right hand tail suggest higher probability to observe more extreme observations in changes than what is expected from a normal distribution. This is also seen from figure 4.4b, with its relatively long tails, and changes that are far away from fitting in to a normal distribution. Another curiosity is the large number of quite small changes, with high density around zero. This is also stated by the high kurtosis of 8.13. Thus, our data series suggest that there should be relatively high probability for extreme fluctuations, and that returns are non-Gaussian.

Kavussanos and Alizadeh [2002b] finds deterministic seasonaly in certain market segments in the tanker markets, while they in the dry bulk market[Kavussanos and Alizadeh, 2001] only finds seasonality at a very low level, and deny the existence of stochastic seasonality. This is supported by Benth et al. [2015], that neither find seasonal effect in logarithmic spot freight rates. Thus, this analysis proceed with the assumption of no seasonality in the data without testing our specific data.

4.4. Testing for mean reversion

Economic theory says that for certain asset prices the dynamics of mean reversion is natural[Dixit and Pindyck, 1994]. This is the case with shipping freight rates. Even if the prices in short term can fluctuate in one specific direction, the long run marginal cost will



(a) QQ-plot of changes

(b) Histogram of changes

Figure 4.4: Normality plots for historical freight rates

give a basis of mean reversion. If the rates are higher than this level, the market will attract new supply, which will enter the market until the prices have reverted back to balance. If the rates are lower than the marginal cost, supply will pull out of the market, and the supply level will decrease to balance.

4.4.1. Testing for stationary

To examine whether our data reverts to a long term mean level or not, we check for stationarity, which implies mean reversion properties. A time series is defined as stationary if it contain a constant mean, constant variance and constant auto-variance[Wei, 2007]. Hence, if the following holds for all t

$$E[x_t] = \mu \tag{4.1}$$

$$Var(x_t) = E[(x_t - \mu)(x_t - \mu)] = \sigma^2 \tag{4.2}$$

$$Cov(x_{t_2}, x_{t_1}) = E[(x_{t_2} - \mu)(x_{t_1} - \mu)] = \Omega_{t_2 - t_1}, \quad \forall t_2, t_1 \tag{4.3}$$

the process is stationary, i.e. the process is independent of time. To determine this the Augmented Dickey-Fuller test is performed on the time series. The test reveals if a time series variable have a unit root(hypothesis 0), which imply non-stationarity, or follows an autoregressive alternative that imply stationarity(alternative hypothesis). The result is presented in table 4.3, with stationary earnings and non-stationary vessel prices as conclusion. Thus, we proceed the modelling with fitting our data to a geometric Mean Reversion process, as in Tvedt [1997], where the geometric properties ensures non-negativity for the freight rates.

4.5. Estimating mean reversion parameters for simulation of earnings

An incremental change of a mean reversion process of its simplest form can be denoted by the stochastic differential equation

$$dX_t = \eta(\hat{x} - X_t)dt + \sigma dZ_t \tag{4.4}$$

Table 4.3: Results from test of stationarity

	ADF-test		
	Unit Root	$P > \|t\|$	**Conclusion**
Cape earnings	No	2.9%	$Stationary$
Cape 2^{nd} hand	Yes	31.5%	$Non - Stationary$
Cape Newbuilding	Yes	35.7%	$Non - Stationary$

Note: Calculations in Appendix B

and is know as the Ornstein-Uhlenbeck(OU) process[Dixit and Pindyck, 1994]. Here, η is the speed of reversion, $\hat{x}$ is the mean reverting level of x, σ is the standard deviation of the change, and dZ the Wiener increment defined by Equation 2.6 in Dixit and Pindyck [1994]. For a mean reversion process, the level of mean reverting will intuitively be the long term break even rate[Tvedt, 1997]. By Ito calculus the arithmetic level will be, for an level at time τ, and Z_t is a one dimensional Brownian motion defined at $[0 \leq s \leq t]$

$$X_t = e^{\eta(\tau-t)}x_t + \hat{x}(1 - e^{-\eta(\tau-t)}) + e^{-\eta(\tau-t)}\sigma \int_t^\tau e^{\eta s} dZ_s \quad (4.5)$$

Following the fact that the OU-process can take negativ values, and that shipowners are not likely to pay the charterer for taking its goods, a Geometric Mean Reversion would ensure non-negativity, as well as mean reversion properties and volatility proportional to the magnitude of x_t. This is in line with the argumentation from Tvedt [1997], which argues that the ship owner rather put the vessel in lay up than keeping it in operation with negative freight rates. The incremental change of this process can be given by the stochastic differential equation

$$dX_t = \eta(\hat{x} - ln(X_t))X_t dt + \sigma X_t dZ_t \quad (4.6)$$

Hence, the arithmetic level is

$$X_t = exp\Big\{e^{\eta(\tau-t)}ln(x_t) + (\hat{x} - \frac{\sigma^2}{2\eta})(1 - e^{-\eta(\tau-t)}) + e^{-\eta(\tau-t)}\sigma \int_t^\tau e^{\eta s} dZ_s\Big\} \quad (4.7)$$

A discrete version of equation 4.6, represented by equation 4.8, can further be used to estimate the mean reverting parameters[Rollins and Insley, 2005].

$$X_t = X_{t-1} + \eta(\hat{x} - X_{t-1}) + \sigma X_{t-1}\varepsilon_t \quad (4.8)$$

where $dt = 1$ and $\varepsilon \sim N(0,1)$, independent and identically distributed. Equation 4.8 can further be written as

$$R_t = -\eta + \frac{1}{X_{t-1}}\eta\hat{x} + \sigma\varepsilon_t \quad (4.9)$$

where R_t is defined as $R_t = \frac{X_t - X_{t-1}}{X_{t-1}}$, i.e. the percentage change from period $t-1$ to t. Hence, the parameters of the process can be estimated through the regression

$$R_t = \alpha + \beta\frac{1}{X_{t-1}} + e_t \quad (4.10)$$

where $\alpha = -\eta$, $\beta = \eta\hat{x}$ and $e_t = \sigma\varepsilon_t$[Rollins and Insley, 2005]. Thus, with our given data the following parameters for Geometric Mean Reversion is found.

Table 4.4: GMR parameters

Parameter	$\hat{x}$	η	σ
Cape Earnings	23284.4	0.0825	0.2972

Note: Calculations in Appendix C

4.6. Simulations of market

The simulations in figure 4.5 reflects the earnings, which is simulated with the parameters from table 4.4. 10 simulations is evolved, to better observe the dynamics from the simulation. One can see that 2-3 out of 10 simulations are going relatively higher than the rest which are reverting pretty calmly around the long term mean. The 3 simulations that are reflecting quite strong market also shows cyclicity, which is an important characteristic of shipping market[Stopford, 2009].

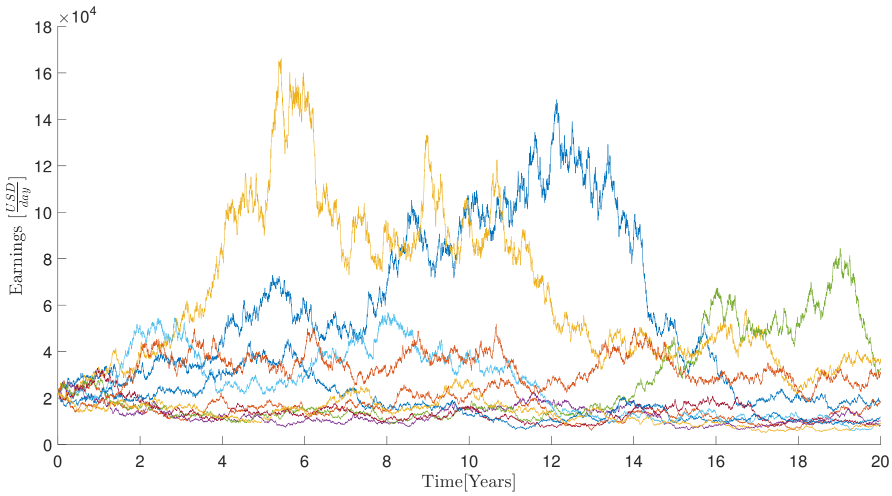


Figure 4.5: Simulations of daily earnings based on calibrated parameters and GMR-process.

Yet, a critic to the chosen GMR-process is the lack of "jump" in returns, which was present in the tests for normality in section 4.3. The GMR-process puts out normally distributed logarithmic changes, and hence do not account for the extreme fluctuations which was present in the data from 1990 to 2017.

4.7. Causality analysis - precedence between underlying earnings and asset values

To better understand the dynamics between underlying earnings and asset values, a pairwise causality analysis is performed between freight earnings and 2^{nd} hand vessel value.

According to the law of on price, the value of 2^{nd} hand vessels can be seen as equivalent to the expected net cash flow from operation. By this it is easy to assume that freight rates moves first, and asset values follow this movement. This can further be investigated by Granger causality analysis[Granger, 1969].

Granger causality is an econometric technique to determine the precedence between two time series, i.e. the causality relationship is based on that the cause happens before the effect, hence consist of unique information about the continuation of the effect. This is performed by using lagged variables in one time series, and by these trying to predict the other time series. In the test, the null hypothesis is the lagged values of time series x do not justify the variation in y. The results from the causality test is presented in table 4.5,

Table 4.5: Granger causality analysis

Hypothesis	$F_{statistic}$	$CV_{2.5\%}$	**Conclusion**
Earnings do not cause 2^{nd} hand value	31.80	3.73	Earnings do cause 2^{nd} hand value
2^{nd} hand value do not cause Earnings	9.97	3.73	2^{nd} hand value do cause Earnings

Note: Calculations in Appendix D

and shows how tight the interrelationship between 2^{nd} hand values and freight earnings is, as the conclusion is that both cause each other and are bi-directional. Even though the $F_{statistic}$ for *Earnings do cause 2^{nd} hand value* exceed the the $F_{statistic}$ for *2^{nd} hand value do cause Earnings*, any conclusions about the data will not be made and backed up by this test. Though, the result reflect the view from the professional shipping analyst community, which emphasise that there is no clear answer to this question. In some occasions the vessel values will move before the freight rates, as the expectations of freight rates rises. Other occasions, e.g. with demand shocks in the freight market, the rates will move quickly and there could be a lag before asset values moves[Arctic Securities AS, 2017]. Thus, as the causality test only consider the two time series, and not expectations in market, the results will be inconclusive.

5 Generic valuation of agility

In the following section the focus have been on option values of expansion/entry in a given market, and how this option values evolve according to a given investment lag, i.e. how agility affects the option value. All models are based on the time series analysis in the previous section, and hence reflect an expansion/entry in the bulk market. The models will, with other input data, also suit for other shipping markets. By these valuation methods the author value the option of expansion as an *on* option.

5.1. Real Option valuation versus valuation by NPV

The conventional way to evaluate capital budget decisions have been to apply discounted cash flow analysis, which carries out a net present value of the future free cash flow from the project. Thus, if this value is positive, the project is profitable, and hence attractive for investment. By this it relies on the assumption that forward cash flow can be forecast with high certainty. Another drawback with this method is the lack of capturing the potential upside in an investment, by discounting all future cash flow with a high discount rate, and hence only capture the potential downside. An example of such flexibility can be a fabric with adjustable production volume. Given a fixed demand, the fabric will produce a fixed volume, and the cash flow could be predicted. But, with an increased demand, the fabric could increasing its production, and increasing its profitability. In this context, where there are potential of great upside, real options valuation will be able to value this flexibility better than NPV-calculations[Harvard Business Review, 2017]. Another important aspect is that by applying real option theory, one admit that the future is uncertain. E.g. in a business affected by the oil price, managers ask the question: *What* ***could*** *happen with the oil price and what would it imply?*, instead of the point estimate approach where managers ask: *What will happen to the oil price?*[Dixit and Pindyck, 1994].

In figure 5.1 the complexity of real option valuation is graphically presented, and shows the elements that are accounted for in real option valuation versus conventional NPV-calculations.

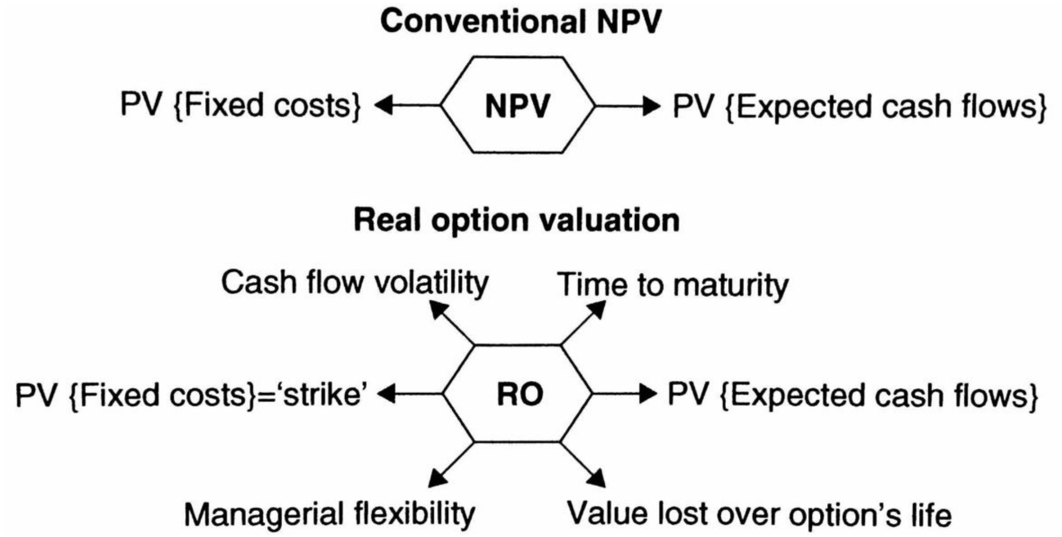


Figure 5.1: NPV vs. RO valuation[Cuthbertson and Nitzsche, 2001]

The framework for valuation of financial options is well established, and is built around the possibility of replicating the future payoffs by an combination of assets that are priced in the financial markets. By the principles of efficient markets and no-arbitrage, the fair price of an option will be the same as a replicating portfolio of traded assets. In the application of real options this assumption could be harder to justify, as most projects are unique and hard to replicate, as well as obtaining a fair market price for[Neufville and Scholtes, 2011].

According to the objective of valuating a flexibility, and how this changes with investment lag, the continuation will be through a real option framework. The models will follow two different paradigm, one that incorporates established financial option framework with basis in the least square Monte Carlo algortihm presented by Longstaff and E.S. [2001], and the other approach taking basis in the thoughts reflected by Neufville and Scholtes [2011], that take a system engineering approach to real option valuation with Monte Carlo Simulation.

5.2. Description of value

The objective value the models are proposing is the *option value of capacity expansion or market entry, given an investment lag.* This value is given as design neutral, and are solely based upon market values of Capesize vessels and Capesize earnings and hence determines a fair value. To generalise the option value further, the values are normalised to represent 1 capacity unit[dwt]. The option value is given per unit increase in dwt, which is a value enabling characteristic for typical merchant vessels as dry or wet bulk carriers. Thus, this option value represents the right, but not the obligation, to enter the market with one capacity unit. This option is possible to exercise during an expected vessel lifetime of 20 years, and can for instance represents the option value of expansion by elongation, newbuilding, conversion etc. The strike price of the option is set to be the same as the mean of the 2^{nd} hand values.

The overall valuation of the option can be seen as a two-stage procedure, which consist of

1. Determine the option value of expansion without investment lag, according to established framework for option valuation
2. Determine the cost of investment lag as a function of time, and adjust the option value found in (1)

Thus, the valuation will give an continuous value of the right to expand, given a range of investment lag. Valuation of the capacity expansion is quite straightforward, as it follows established procedures. To determine the cost of investment lag is more sophisticated in its way. The cost of investment lag/delivery lag follows the thinking from several articles about investment lag, such as the delivery lag cost in the shipping industry from Adland and Jia [2015] and cost of holding excess capacity in Bar-Ilan et al. [2002]. Hence, the cost of investment lag(CIL) is considered an alternative cost. Given the investment will happen some time in the future, the CIL will be the net present value of the free cash flow from operations from investment decision until operation start. The free cash flow from operations is determined by the uncertain freight rates, which is described through stochastic earnings, and a fixed operational cost. Further, the option holder is a price taker in the market, i.e. he will not affect the freight rates by increasing the total supply in the market. Thus, as the operation cost is assumed to be fixed, the alternative cost will increase with higher freight rates. The alternative cost could also be positive, i.e. in market conditions when the shipowner operate with higher operation cost than income. Thus, this could be written as:

$$CIL(t) = CF(t), \qquad \text{for t} \in [0, T] \tag{5.1}$$

and the net present value of the total present CIL over a given investment lag from time t to τ will then be

$$CIL = e^{-rt} \int_t^\tau CF(t)dt \tag{5.2}$$

where $CF(t) = Earnings(t) - \text{Operational Expenditures}$, r is the discount rate and earnings is represented by the Geometric Mean Reversion process from section 4.5:

$$Earnings(t) = exp\Big\{e^{\eta(\tau-t)}ln(x_t) + (\hat{x} - \frac{\sigma^2}{2\eta})(1 - e^{-\eta(\tau-t)}) + e^{-\eta(\tau-t)}\sigma \int_t^\tau e^{\eta s} dZ_s\Big\} \tag{5.3}$$

5.3. Discount rate

For the generic value models, a discount rate is calculated according to the Weighted Average Cost of Capital(WACC) Method, which considers the effect of leverage of the investment and hence accounts for the overall risk in the investment. In this case, the calculations is based on a common discount rate for the main stakeholder, which keeps an constant debt-to-equity ratio. Thus, the discount rate is calculated to be $r_{wacc} = 8\%$, under the assumption of an debt-ratio of 60%, a debt cost of capital of 2.3% and an equity cost of capital of 17.4%. Calculations to be found in Appendix A.

Since the discount rate partially can be defined as the premium one expect due to risk, Kalligeros [2006] argues that for an option to expand the two different states for the system should be discounted with a rate that reflects the increased capacity, which is exposed for a proportional increase in risk. Even though the following models is scaleble for capacity, it assumes a constant discount rate.

5.4. General value models

5.4.1. Monte Carlo principle

In the proposed models *Monte Carlo simulation* is the fundamental tool, which is expanded to satisfy the models need. MC-simulation can mathematically be described as a way to perform numerical integration of functions analytically unsolvable[Pidd, 2004]. Random numbers from a determined distribution is drawn, and hence the value function is simulated. The Monte Carlo principle is to do this a number of times, such as the law of large numbers makes a representative result. Thus, if option value V is a function of the underlying asset path S and the time to maturity, simulation of n possible asset paths are performed, the value will be the mean of the sampled paths, as denoted in equation 5.4.

$$V(S_0, t) = \frac{1}{n} e^{-rT} \sum_{i=1}^{n} V(S_T^i, T) \tag{5.4}$$

In the following models this is expanded to take in investment lag as a parameter. Thus, the same principle is applied, but now the value of the option will be a function of the asset path, time to maturity and investment lag denoted τ.

$$V(S_0, T, \tau) = \frac{1}{n} e^{-rT} \sum_{i=1}^{n} V(S_T^i, T, \tau) \tag{5.5}$$

To be able to obtain representativ results, all the results is based upon 10 000 simulations for each of the models.

5.4.2. System engineering approach - a now-or-never investment analysis

The system engineering approach(further also called SE-approach) is performed with inspiration from the simulation framework presented by Neufville and Scholtes [2011], which follows a straightforward approach to simulate the cash flow evolved from the engineering system for a given future, and discount it to a net present value. Hence, the performance of the system is simulated, one can by this obtain a value of the total project. The total project in this model is an entry in a freight market, and further adjust the value according to a given lag. The freight market is simulated with the stochastic process geometric Mean Reversion as earnings, with parameters calculated in section 4.4.1. The start state for each simulated path is drawn from the distribution of historical earnings, denoted $f(x)$, and the total process is presented in figure 5.2.

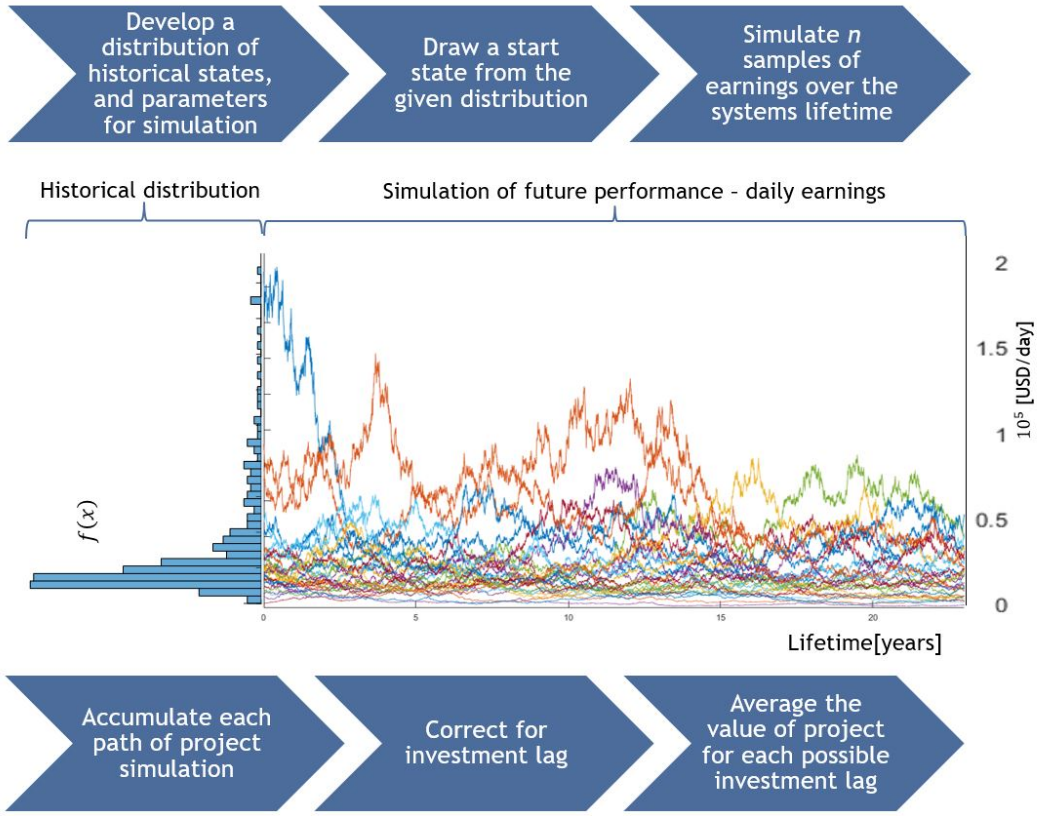


Figure 5.2: Simulation of system performance

From this one obtain a general option value of acquiring one capacity unit in time 0. To further adjust for the investment lag that can occur in t=*0*, the CIL is calculated from t=*0* to $t=\tau$ for each path. By this the capacity unit have a lifetime of 20 years from start time. Thus, for an investment lag of 3 years, this can be seen as changing the income from now, and 20 years ahead, since both systems, with or without 3 years lag, obtain the net earnings from year 3 to 20. In the figure 5.3 the investment lag is denoted Δt, which can be seen as the investment lag from 0 to maximum 3 years.

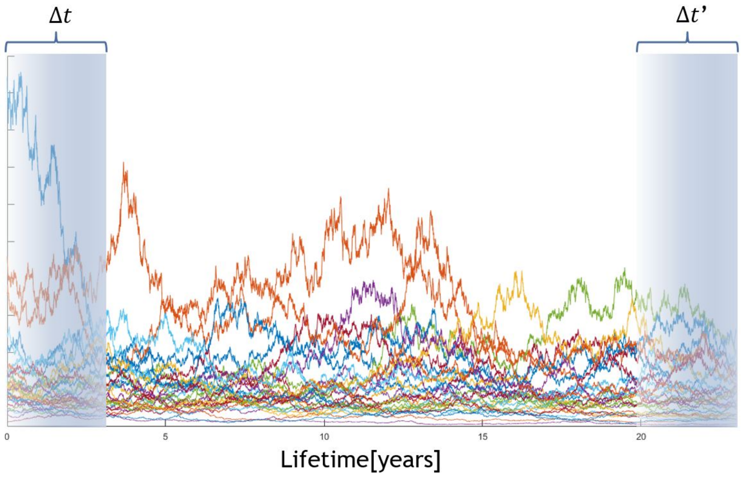
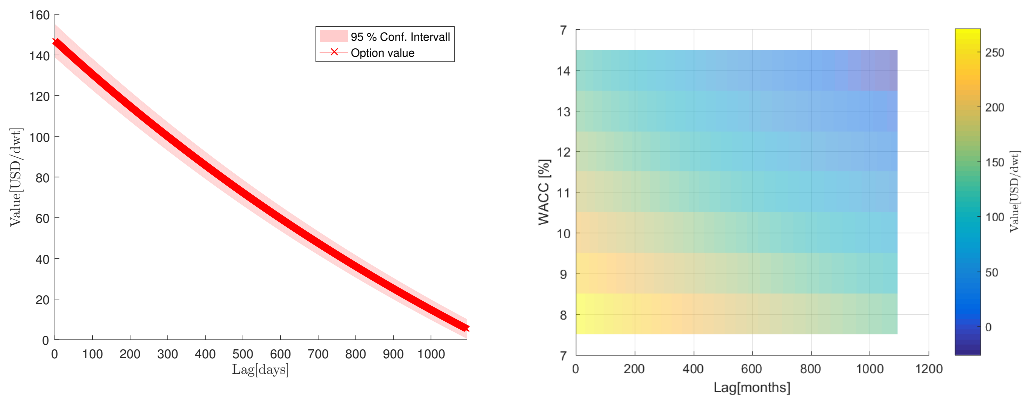


Figure 5.3: Investment lag from start of lifetime and

Δt and the shaded area represents the alternative cost CIL. The lag that occur will have the opportunity cost of net cash flow from this period of lag, but can extend its operation time with the same period, shown as $\Delta t'$. By this movement of cash flow from early to late, the time value of money will be the main determinator of how this option value will develop with investment lag. One see from figure 5.4a that the option value will have a decreasing value adjusted for investment lag. This is in line with the intuition, that with operation as the opportunity cost the option value will decrease, and the discounting factor could make be significant for the slope. To further investigate this, the sensitivity for the option value to the discount rate is presented in figure 5.4b, for discount rates from 8 to 14 %. From this, one can see that a ~40% increase in discount rate will give a ~40% reduction in option value, which confirms that the discount rate is crucial for this approach.



(a) Option value of 1dwt as function of time - $r_{discount} = 8\%$

(b) Sensitivity to discount rate

Figure 5.4: Option value from system engineering approach

As the model samples start states from the distribution of historical earnings, the start time for investment lag will be the same as if shipowners randomly picked their time to invest. This is not the fact in real life, but to put a fair price on an option this will be valid. Hence, the value will give an approximation of an option value which is an average option value of capacity expansion.

5.4.3. Least Squares Monte Carlo models - option values with investment timing flexibility

Least Squares Monte Carlo[Longstaff and E.S., 2001] was introduced as a way to price American style options with simulation. The American style allows for early exercise, contrary to it's European counterpart which only allows for exercise at maturity. Hence, when to exercise have to be determined by the decision maker, and valued by backward reduction[Chan and Wong, 2015].

The backward reduction method will for every possible exercise time compare the cash flow from the expected payoff from holding the option, to the immediate payoff given by exercise. Thus, in every step the expected payoff is calculated, which is conditional on the current state. This conditional expected payoff is modelled as a quadratic polynomial, where the coefficients is found by applying Least Square regression to the response variable(payoff) $Y_t e^{-r\Delta t}$ on to the explanatory variable(asset path) $S(t-1)$. This gives the regression line in equation 5.6, and the resulting formula in equation 5.7.

$$Y_t e^{-r\Delta t} = \hat{a_0} + \hat{a_1}[S(t-1)] + \hat{a_2}[S(t-1)]^2 + \varepsilon \tag{5.6}$$

$$E[Y_t e^{-r\Delta t}|S(t-1)] = a_0 + a_1[S(t-1)] + a_2[S(t-1)]^2 \tag{5.7}$$

where $\varepsilon \sim N(0,1)$, independent and identically distributed. Thus, the value of the option in state t, with K as exercise price

$$Y_t = \begin{cases} S(t+1) - K, & \text{if} \quad S(t+1) - K > E[Y_t e^{-r\Delta t}|S(t-1)] \\ Y_t e^{-r\Delta t}, & \text{otherwise} \end{cases} \tag{5.8}$$

An important feature in the models is the relation between second hand values and freight earnings. As mentioned earlier, the second hand vessel value can, according to the law of one price, be seen as the expected net cash flow from operation. Thus, a second hand vessel value will be equivalent to the project value in a real option framework, and a stock in financial options. Thus, the option value of one capacity unit $V(CF_0, t)$ for an initial cash flow CF_0 will be the cash flow over its lifetime from exercise time t to maturity time T, which can be written

$$V(CF_0, t) = \int_t^T CF(t)dt \tag{5.9}$$

which again will be equivalent to the value of one more capacity unit less the strike value

$$V_t = \begin{cases} P(t+1) - K, & \text{if} \quad P(t+1) - K > E[V_t e^{-r\Delta t}|P(t-1)] \\ V_t e^{-r\Delta t}, & \text{otherwise} \end{cases} \tag{5.10}$$

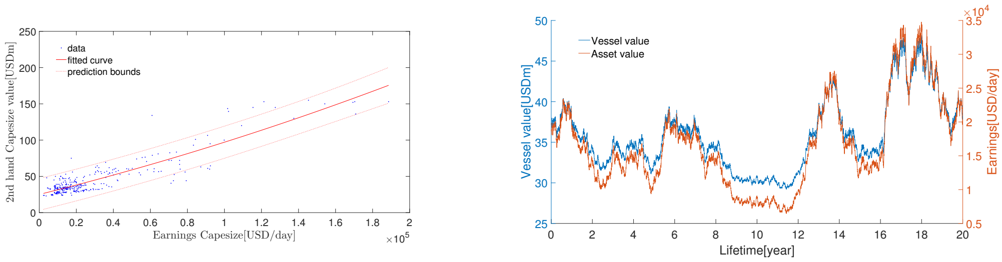
where $P(t)$ is the value of the capacity option, determined by the asset value less the CIL.

5.4.4. LSMC with asset prices as a function of earnings

In the first LSMC model the asset prices is generated as a function of earnings, where the earnings follow the Geometric Mean Reversion Process. To generate a model for asset value as a function of earnings, the average second hand value of capesize carriers is generated by the regression shown in figure 5.5a. This gives the 2^{nd} degree polynomial with R-square of 0.81.

$$\text{Vessel value}(x) = 8.7 \cdot 10^{-10}x^2 + 0.0006334x + 25.08 \quad [\text{USDm}] \tag{5.11}$$

Further, earnings are then simulated, and for each evolution of earnings a corresponding path for vessel value is evolved. In figure 5.5b one evolution is presented, and the close link between earnings and vessel value is seen.



(a) Regression of capesize value on capesize earnings

(b) One simulation path of earnings and corresponding vessel values

Figure 5.5: Relation between simulated earnings and vessel value

By this the earnings and vessel values have been determined, and one can further develop a corrected vessel value, which will be the vessel value in time t with delivery in time $t + \tau$, where τ was the period of investment lag. This is graphically presented in figure 5.6, where the corrected vessel value is given by the momentaneously asset value less the cumulative net cash flow from operation in the investment lag period, presented in equation 5.12

$$\text{Corrected asset value(t)} = \text{Asset value(t)} - e^{-rt}\int_t^\tau CF(t)dt \tag{5.12}$$

The dynamics between the asset value and the corrected asset value could be observed from figure 5.6. When the market freight rates are high, there will be a wide spread between asset values and corrected asset values, and this spread will narrow with lower freight rates, as the alternative cost is lower.

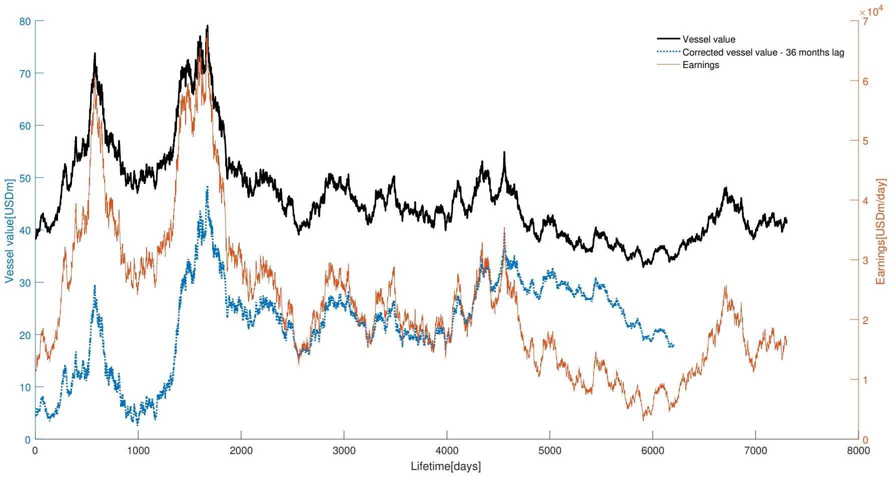


Figure 5.6: Asset values corrected for investment lag of 3 years

By this, the observed difference between asset value and corrected asset values are significant, and even though they are correlated, the asset values does not reflect the upcoming market changes. Instead of valuating an option on the asset it self, the valuation will be on the corrected values, which take the investment lag into account. By using the same simulation and correcting this over a continuous range of investment lag the option value as a function of investment lag is found, presented in figure 5.7

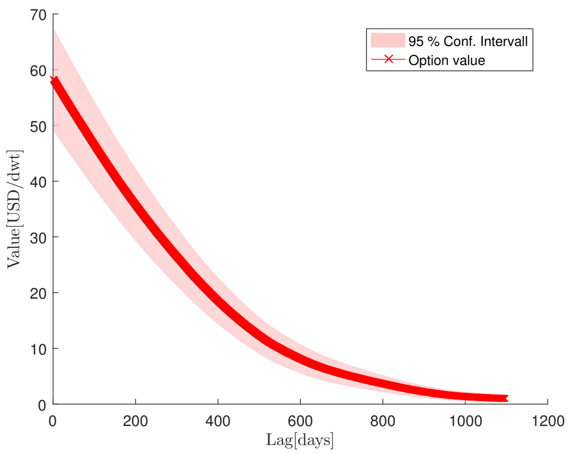


Figure 5.7: Option value of 1dwt as function of investment lag - asset values as function of earnings

This option value will represents the premium one is willing to pay for a capacity unit of dwt, compared to a three year delivery lag. The slope is significantly steeper in the start compared to the results from the system engineering approach, which can be seen as the value of timing and the freedom of exercise. Contrary to the system engineering approach, this model are able to predict and match the immediate value to the predicted value, and by this buying in low markets are possible. With this in mind there is even more important to limit the investment lag, and one see that the option value have lost nearly 50% of its value in about 200 days.

5.4.5. LSMC with asset prices and earnings as correlated process

Since the relationship and causality between earnings and asset values was unclear, a LSMC model with asset prices and earnings modelled as correlated Mean Reversion models was proposed. By modelling the processes with correlation, the relation between the underlying processes is related, but with randomness included. This is due to the procedure of simulating correlated paths, where the paths partly shares the same randomness through the noise variable ε. By this, the model do not take a stand in whether asset prices is a function of earnings or vica versa. The correlated paths, together with the corrected asset values is shown in figure 5.8. The process here is from a Mean Reversion process, and do not capture the cyclicity in the same way as the the Geometric version which was used in the first LSMC model. Yet, the paths is also here visually correlated, as the peaks correlates. The corrected vessel value is calculated as in equation 5.12.

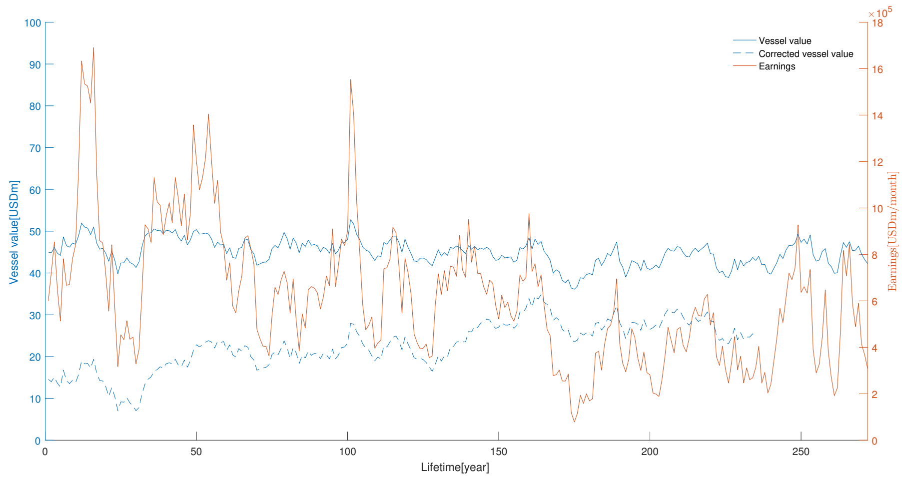


Figure 5.8: Asset prices and earnings as correlated processes, and corrected vessel value

The same algorithm for pricing the option is used, with corrected vessel values in the range of 0 to 36 months of investment lag as foundation for the valuation. The result is presented in figure 5.9.

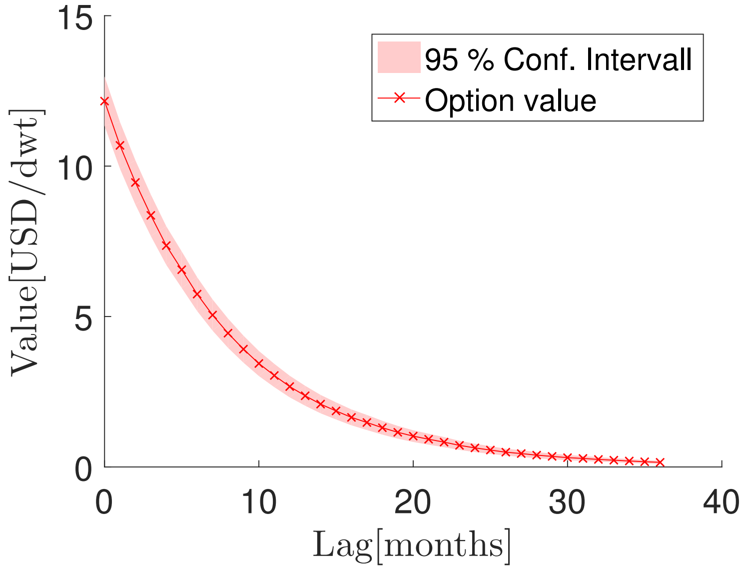
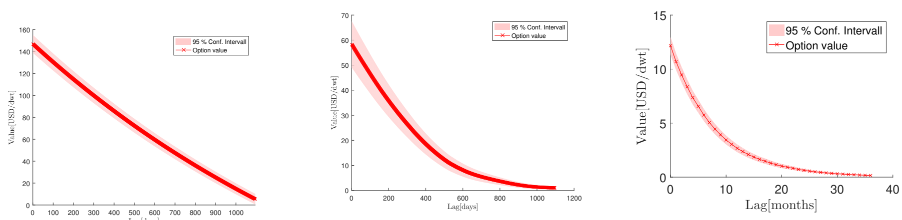


Figure 5.9: Option value of 1dwt as function of investment lag - correlated asset values and earnings

The shape of the function will be quite similar as the results from the first LSMC model, but the value is significantly. This is clearly due to the geometric properties of the first LSMC model, which reflects the possible upside better, by the evaluations seen in figure 4.5, which gives higher possible market states than the conventional mean reversion model. Thus, this reflect the normal approach to options, that the value increases with the underlying volatility.

5.5. Summary of results

In figure 5.10 the same results from the three models are graphed together, and the result is quite consistent, with a decreasing slope for all, allthough the LSMC model gives significantly steeper slope.



(a) SE - approach

(b) LSMC - asset value as function of earnings

(c) LSMC - correlated asset value and earnings

Figure 5.10: Option values as function of investment lag - summary

The intuitive reason behind the higher values from the SE-approach is that the option value is conditioned on exercise whether or not the option is "in the money". I.e. this option value is the added value due to earlier entry in the market, where it is assumed that it will operate independent of market rates. Thus, the operation can for some instances give a negative cash flow, but by this approach it will operate either way. This could also give a positive effect for the value, and the reason why the option value for the SE-approach will give a higher relative value than the other for longer lags, since negative evolutions will affect shorter investment lag more, due to the principle of discounting. This gives that negative evolutions makes a larger contribution to the option price for the SE-approach, while it do not affect the LSMC-approach, since out-of-money does not affect the price. Another positive effect for the SE-approach is the exercise price of this option. It is the same as for the other options, namely the mean of historical asset values, but the cost is partly taken up front, and partly discounted over a 20 years period, which will be a realistic way to finance expansions.

Table 5.1: Summary of results - option values as function of investment lag

	SE-approach	**LSMC**	**LSMC - correlated prices**
Maximal option value[USD/dwt]	147	60	12.2
Option value after 6 months	~ 85%	~ 65%	~ 55%
Option value after 12 months	~ 65%	~ 40%	~ 25%
Option value after 24 months	~ 32%	~ 12%	~ 5%
Option value after 36 months	~ 3%	~ 2%	~ 1%

Note: Option values given in % of initial option value

Part III - Design Solutions and Discussion

In this part design solutions to enable *Agility by Design* is proposed and exemplified, as well as the authors discussion and concluding remarks. The overall objective is to decrease the investment lag by implementing design solutions, hence make the overall design more agile. Graphically this could be seen in figure 5.11, where an increased investment lag of about 200 days gives a decrease in the option value of nearly 50%. Thus, the importance of limiting investment lag is crucial, and to reduce an investment lag for an capacity expansion with 200 days is something that could be possible with the correct design solutions.

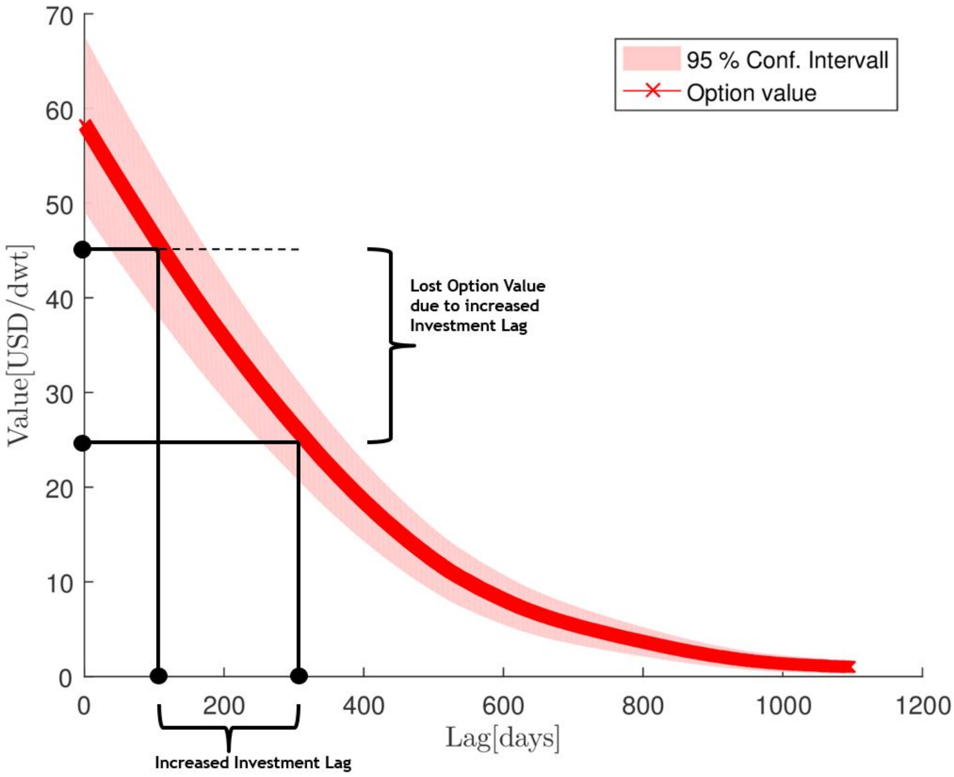


Figure 5.11: Loss of option value due to investment lag

6 Illustrative case - Capacity expansion by elongation

The concept of jumboisation have been discussed in section 3.5, and the further focus will be on elongation of a dry bulk carrier as an illustrative case to better present path enablers. This can be seen as a *Design Change Option*, and to increase an agile transition there is possible to implement *Design Path Enablers*. As the result from Part II and figure 5.11 shows, to reduce the transition time for such an elongation the investment lag is reduced, which will give an significant increase in the option value of capacity expansion. The following table presents a possible elongation for a dry bulk vessel, which also transfer the vessel from the Ultramax class to the Panamax class.

Table 6.1: Example elongation

	LOA[m]	**Beam[m]**	**Draught[m]**	**Capacity[dwt]**	**Cargo Holds**	**Ship Class**
Initial Design	195	32	13	60 000	5	Ultramax
Possible Design	225	32	13	74 000	6	Panamax

6.1. Path enabler for elongation

The practicalities with elongation is quite simple, as the ship is docked, split amidships and an extra, new midship section is inserted. The overall objective for the path enabler is to enable an easy elongation, i.e. when exercising the option to elongate there is as little as possible of work to do, and hence new capacity is ready to enter the market as fast as possible. There is no straight answer to what a path enabler for elongation is, as every functionality that will support and make it easier for the elongation to happen is a path enabler. The main focus from the authors perspective is that path enablers for elongation is foremost functionality that makes the initial design comply with rules for an elongated ship, e.g. a vessel with LOA of 200m, with an option to elongate to a LOA of 250m should be built in compliance with rules for the latter. This can be seen as a parallel to DNV GL's LNG-ready, only for elongation. Design question that should be answered in the initial design phase could then be

- Will the original machinery be sufficient after an elongation, or do this have to be changed?
- What is the loads the vessel should carry, and how much strength does it need?
- How will this change the weight, and the total resistance?
- Will there be compliance with stability requirements?
- Will there be compliance with the visibility?

Though, as these questions are answered, the physical exercise of the option will mainly be to insert the new midship section, as the technical concerns have been taken care of in the design phase.

6.2. Technical description of possible path enablers

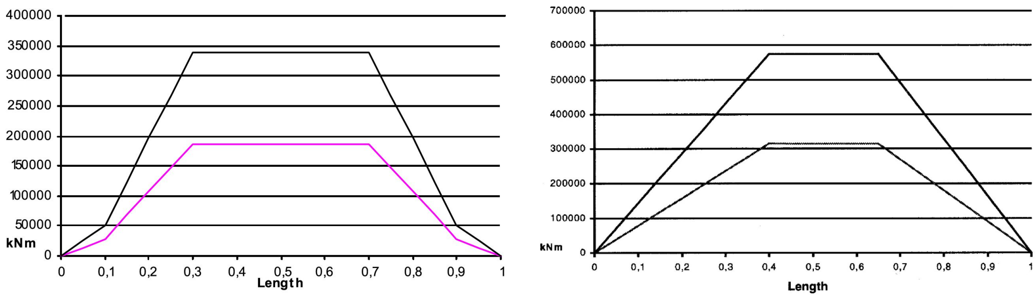
In the following two examples, path enablers are described, with the rules and guidelines from classification society DNV GL as basis. A common feature for both of the path enablers is to dimension a ship such that it is ready to be elongated, by dimension the ship for the possible elongated length, and build it with a shorter length.

6.2.1. Strength requirements

An elongation will, by the definition from DNV GL[DNV GL, 2016b], be a conversion, as it changes the main dimension of the vessel, as well as a change in carrying capacity and possible change of the ship type. Thus, the required scantlings for the new section should be in accordance with current rules for newbuildings, and the existing part of the vessel should comply with thickness requirements for newbuildings of same length. Further, the length will affect the design still water bending moments as well as design loads, increased sea pressure, bow impact, slamming and accelerations.

Longitudinal strength

A vessel can be idealised as a beam for the purpose of strength calculations, as the ratio between length and breadth is quite high[Amdahl, 2010]. Longitudinal strength for a vessel can then be determined by the still water bending moments and the wave bending moment, as well as shear forces. According to the rules from DNV GL, the design still water bending moment and wave bending moment is a function of L^3. This gives an increase of 90% for the still water bending moment with an increased length of 30%, and are shown in figure 6.1.



(a) Still water bending moments along normalised lenght, for L=100m and L=130m

(b) Wave bending moment along normalised length, for L=100m and L=130m

Figure 6.1: Example of relation between length and design moments

By this, the required scantlings for different lengths could be as proposed by table 6.2. Thus, a possible path enabler will be to build the hull with the required scantlings for the possible length, i.e. if the possible design is 200m long, while the initial design is 150m long, the initial scantlings will follow from the possible design length.

Table 6.2: Typical minimum thickness requirements for plates[DNV GL, 2013]

LOA[m]	**Bottom and sides[mm]**	**Keel[mm]**	**Strength Deck[mm]**	**Bottom decks[mm]**
150	11	14.5	8.5	9
200	12	17	9.5	10

Note: Corrosion addition not included

6.2.2. Visibility

For a vessel to go through the Panama Canal the rules for visibility are stricter than general rules. For the example elongation of bulk vessel, the requirements for the new

Panama Canal will be important. Thus, regarding the visibility from the conning positions, this shall for laden vessels be such as the view of water surface shall not be obscured by more than 1 x LOA forward of the bow, and for ballast 1.5 x LOA[DNV GL, 2016a].

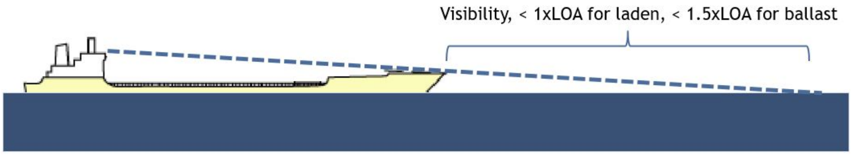


Figure 6.2: Visibility requirements according to DNV GL [2016a]

With this in mind, a path enabler will be to build the conning positions in compliance with the requirements for the possible design, which would imply a higher bridge.

6.3. Path enablers to increase agility - restricted by the fantasy

To be more agile by implementing path enablers have been exemplified through strength requirements and visibility restrictions, but only the fantasy set limits for what path enablers could be. The degree of agility, which the quantitative results reflects the value of, could be a future competitive advantage. For marine systems modularisation have been a response to this, and an infinitely flexible and agile ship could be made just by modules. Though, to e.g. have structural reinforcement that should satisfy requirements for vessel lengths from 50 to 250 m will intuitively be of high cost versus the utilisation, and a middle course could be a solution.

Design path enablers could also support the conversion process it self, which often can be a bottleneck. A supposition of this could be design path enablers that makes a dry bulk vessel ready to be elongated at sea, i.e. chopped in 2 and a midship section inserted at the middle, all while the vessel is floating in the sea. Bye this the process is being more agile, and the owner is not restricted by a shipyard, which could have significant waiting time in periods with high market rates, the periods when the value of agility is highest.

7 Discussion

Investment lag and mean reversion

Investment lag have been highly discussed in the literature, and a common feature of this litterateur is that geometric Brownian motion represents the value function in many of the cases. Different results is found, but Sødal [2006] summarises this quite straightforward by *"We also concluded that investment lags are not likely to have strong impact on investment in capital-intensive industry when prices are geometric Brownian"*. As seen in section 4, the prices, represented by the freight markets, for dry bulk shipping, are nowhere close to geometric Brownian, and highly cyclical. The intuition behind the statement that investment lag is *not* that important for markets that follows a geometric Brownian process is clear, since the prices will follow an overall trend upwards, and a lag will only delay a future income, an income which anyway will be positive, and most likely higher than at the exercise moment. This is not the case for markets with mean reversion trends, which follows cycles with higher peaks, followed by prices reverting to a mean level. In these markets the timing of investing, and the timing of entry in the market could be crucial, and due to this the author see market with mean reversion as much more influenced by investment lag.

Real Options and Changeability

To better understand and be able to identify possible design solutions to enable agility, real options from a system engineering perspective was further investigated. The literature in this field is still quite young, and a further separation was necessary to be able to understand the dynamics, and especially the connections between *changeability* and *real options on* and *in systems*.

A separation of *on* options in two classes was presented. There will be interconnection between these, and in some cases a continuous space between the two main *on* options. An example of this could be offshore multi purpose vessels that is ready for increased crane capacity, and only need to connect the crane to the vessel. It requires external equipment to fit the crane, but the crane itself could be a part of the initial design, and stored at shore if not in use. However, the purpose of this separation was to easier illustrate different options and their connections to design solutions.

In Agis et al. [2016], a final statement about offshore service vessels is: *In the end, the vessel should be profitable from a commercial perspective.* This is a statement that backs up the way of thinking in valuation of Design Change options for commercial systems. But, that all Design Change options could be valued by their respective change in operation is a statement is up for discussion. There is today no straightforward way and developed framework for valuation of these, and to only value them according to a monetary scale could be insufficient. This is dependent of among others, stakeholders perspective and their risk appetite, all though discount rates could scale possible gains to be measurable for different risk attitudes.

Approach

The overall approach in this thesis have to map between a value space and a design space. This have been performed by quantitative value models, followed by design solutions. This is performed, as it is, in the author's perspective, the natural way to approach new solutions and design. First by determining how much value the objective can give, which gives economic bounds for possible solutions, and then find possible design solutions for the objective.

Thus, a cost-benefit analysis can be performed to make the final decision.

The approach taken to model the market dynamics have been an in-depth statistical analysis, with the knowledge from an external view on the market. This is a so-called reduced form approach, where the modeller has the same information as the market. This is contrary to the structural models, that assume the same information as a firm's manager. By taking the reduced form approach the models do not take a stand in the supply and demand that determine the price, and rather base the future on historical relations. This approach is chosen to get a "fair" price in the valuation, as the valuation will be the same for all market participants.

The liquid market and easy access of market data was also one of the reasons why the dry bulk market was chosen. Due to this it was possible to make realistic simulations of the dry bulk freight markets, which again give a realistic result for the quantitative results. This is also due to the Monte Carlo approach, that secures great trade off between a large number of evolutions that reverting calmly around the long term mean and fewer evolutions that gives periods with more extreme return. This reflects the intuitive probability for the future, which most likely will give calm markets, but extreme events such as financial crises, wars and natural catastrophes could give periods with markets off balance. Together with the dynamics from the stochastic process, this made the models quite valid. The uncertainty that was accounted for by the models are mainly the freight rates. This can be seen as a aggregated uncertainty, as the freight rate uncertainty is a result of both endogenous and exogenous uncertainties. A natural extension here could be to include uncertainties in operational cost and finance cost, although this can in the real world be fixed by different types of hedging instruments and long contracts for crew and bunkers.

Results

For the case that have been presented, the value of entering the market can, to some degree, be seen by the Forward Freight Agreements(FFA). This is trade agreements between market participants for future pricing of trade contracts, and can reflect what a shipowner could make by entering the market today, and lock his earnings in up to the next five year. Though, the author argue that the proposed value of agility is not equivalent to FFAs. This is due to the nature of FFA, which is foremost an instrument used for hedging, and represents what market participant can lock future trades in to. Thus, the FFA will represent a future view, for participant that want to take down their risk. Thus, historically spot freight rates have given a premium over FFAs. The value of agility can, with this "risk premium" in mind, partly be seen as the value of entering a market that is almost impossible to forecast, and grasp opportunities faster, which is quite the opposite of locking in trades. Another point that divide the FFA from the presented results is the time span, as the option value of capacity expansion is valued over an assumed life time of the vessel. Another difference to the FFA will also be the added value for an decision maker with low response time to await more information than a decision maker with longer response time.

A drawback with the LSMC model is how it predicts, and how this affect the overall option value. The corrected value that is used will, straight after exercise, increase in value, until delivery date. This is due to a shorter delivery lag. As the corrected vessel value do not account for this, it is unknown how this will affect the model. But, as the simulation is performed over discrete time, for each day, the eventual underestimation should not be that significant, since a discounted prediction in day t will be matched against an actual value in day $t-1$.

Another drawback for the LSMC would be how the timing of exercise gives value. The model will not account for the restricted lifetime of the vessel directly, i.e. one assumes that the second hand value of the vessel will behave as the value of a 5 year old capesize the whole lifetime. This is partly adjusted, as the strike price is set to be the average of historical prices for 5 year old vessels.

Real world application
In the valuation, monetary value have been the only measure of value. By this one look away from technical performance, utilisation etc., though, for the illustrative case of a dry bulk vessel this is quite realistic. This is due to the simplicity of bulk vessels and its operation, contrary to e.g. an offshore service vessel, which shall fulfil demanding contract requirements and perform technically difficult tasks. Yet, an aspect that is not counted for in the real option valuation is the trust shipowners build up in the market, which can provide them with better contracts and agreements in poor market. The value models proposes an option value of expansion, and even if this is design neutral, the solutions to achieve this value is not, and some of them could affect shipowners trust in market. An example of this is the combination carriers. These are often operated in triangular routes, partly with long term charters, and a track record of market switching have to be build up to increase the confidence about correct handling of trades. If a shipowner invest in a fleet of combination carriers with asset play in its mind, it could loose trust in markets, and hence loose contracts for triangular routes. The capability of a combination carrier could then be worthless, and the upfront premium that is paid for a combination carrier over a dry bulk carrier is a sunk cost, affecting the overall balance sheet.

"Sticky" newbuilding prices have been a saying in the maritime market, and [Adland and Jia, 2015] argues that the relatively low volatility in newbuilding prices compared to second hand prices is due to delivery lag. This supports the option value that is found in the results, which can represents the premium a shipowner is willing to pay for a vessel with shorter delivery lag, over a vessel with 3 years lag. This again reflects the alternative cost of operating in the freight market, which in period with high rates could be quite high. This was especially the case during the peak period under the boom in 2007-2008, where 5 year old bulk carriers was bought with a premium over newbuildings with 3-4 year of delivery lag. This can not be compared 1:1 with the option value that is found in the result, as the latter only handles second hand value. However, the value of immediate entry is much in line with the value of agility that is found, and supports that for cyclical markets timing matters, which can be substituted by agile capacity adjustment.

Does investment lag amplify the cyclicity in shipping markets? Tvedt [2003b] tries to bridge the gap between equilibrium shipping market models and asset pricing, and states that *"adding time-to-build will most likely create even larger freight rate cycles"*. For certain markets, cyclicity and predictable cycles are indications of market efficiency. Shipowners sells transportation services or assistance to offshore energy production, these gods is not easy to store and sell the next day or year. In the example of spikes in the spot rates for anchor handling vessels a time window for both an available vessel and a rig that needs assistance has to match. Thus, agility can be seen as a way to increase the flexibility in these time windows for shipowners, and as more and more shipowners have available time windows to take mission, they will bid down the freight rate. Thus, it is rational to believe that investment lag as inelastic time windows amplifies cycles in the market, and shorter time lag for entering markets could reduce the amplitudes in the shipping cycles.

The focus in this thesis have been in bridging design and operation to increase agility, but something that have not been mentioned is portfolio thinking, and how this could increase the agility. For many shipowners this could an "easier" way to enable agility, and many do this today as well, as their fleet of vessels is operated in an agile way. This thinking could also be implemented in the offshore service markets, by e.g. flexible equipment that could be leased in to the shipowner, which will reduce its financial risk. This equipment could be used by several vessels, and combinations of equipment types could be put together for different contracts. By this, flexible vessels will also give an added flexibility to the fleet.

8 Conclusion

8.1. Concluding remarks

Even though the literature review reveals focus in investment lag, the greater part of this considers projects with demand and income modelled with an underlying upward trend. For mature market characterised by cyclicity this assumption is not valid. This thesis brings focus to agility and investment lags in these cyclical markets by (i) Investigating how investment lags affects design changes for engineering systems (ii) Investigating the value of efficient changes and reduced investment lag (iii) Proposes examples of design solutions to enable agility. The quantitative analysis was performed by Monte Carlo simulation, in a now-or-never investment analysis and further including investment timing by the use of the least squares Monte Carlo algorithm.

As an answer to the first research question, a contribution to bridging real option framework and changeability litterateur have been proposed. The author proposes that to identify design solutions which enables agility, one must identify Built-in design options and design path enablers. The former gives operational flexibility, the latter decreases the time it takes to do design changes. From this question, the author also structure real options in a new way, as operational *on* options is seen as the superior option, that again can be separated in different classes depending on the need of design changes. Thus, for commercial system, the author proposes that the value of design options *in* the system could be determined by the change in operation due to the design change, as operation will be the general objective of design changes.

Research question two have been answered by introducing the investment lag as a parameter in different models for valuation of real options, and the value of a capacity expansion option in the dry bulk freight market is further considered as a function of investment lag. The cost of investment lag is here defined as the opportunity cost of operating in the market. The investment lag is defined in the range from immediate change to a three years lag, and even an investment lag of 6 months will significantly reduce the option value of a capacity expansion, verifying the importance of agility in marine systems.

From research question two one see the value of agility, which again imply that possible design solutions to reduce investment lag must be of high interest. As example, fleet expansion usually relies on either newbuilding or acquisition in the second-hand market. A time lag of 2-3 years between a newbuilding order and the delivery of the vessel can, through the market uncertainty, change a good investment decision to a bad one. Second hand values can in many occasions be a substitute with closer delivery, and thus reduce the investment lags and uncertainty. In times with high markets the second hand values rises, and alternative solutions to this could for instance be combination carriers or conversions, which can enter the market with a relatively short investment lag. The latter is a typical *Built-in design option*, as capabality of changing fast is implemented in the initial design. Another possibility could be design changes like elongation of existing vessel, where design path enablers such as structural reinforcement will provide an efficient change in design and operational capabilities. Both Built-in design options and design path enablers will enable *Agility by Design*, and by implementing such design solutions a shipowner could change and evolve in a more time-efficient manner.

8.2. Further work

For design path enabler, only the fantasy set limits for what is possible. Thus, a further investigation into possible design path enablers for different vessels would increase the insight in this field. In this thesis a bulk vessel is used as an example, due to its simplicity and illustrative nature. An offshore vessel would maybe be even more relevant, as the possible operation space is wider. Maybe could also design path enabler be a middle course between the expensive multifunctional vessels and the specialised vessels, where path enablers are able to give a high degree of design freedom and flexibility through the systems life time, without taking to high up-front costs?

For the quantitative part, an even more in-depth analysis of statistical time series of different market and market segments could increase the knowledge about market dynamics, with a special focus on the speed of mean reversion. By knowing how quickly different markets returns to normal would give important knowledge to decision makers and system engineers, as the speed of action for a system should be faster than the speed of reversion for the market, to utilise rising opportunities. For this, it is also possible to extend the models, either by improve the underlying stochastic process by e.g. stochastic volatility and jump properties, or expand with multiple exercise of the option.

Valuation of Built-in Design options have not been performed in this thesis. These compound option have been valuated by both Erikstad and Rehn [2015] and Sødal et al. [2008] for market switch, by using a mean reverting process for price differential. Though, both assume negligible exercise cost and investment lag. This assumption could be questioned, and further research in the critical transaction between markets could be investigated. A parallel to this is how to agile move between contracts that have different requirements, such as a multipurpose offshore vessel that could operate in different sub markets of offshore service.

Further, a decision about implementing options should not to be based solely on monetary value. The option value presented in the result could be see as the maximum value, and assumes perfect markets for asset play. This is not always the case In the case of the elongation or conversion, an interesting aspect would be to investigate to which degree the shipowner gets the full monetary value of the option. A question one could rise is: *Will a shipowner that takes the vessel of market, and maybe change market, have trust in the markets if he wants to sign long term contracts in the future?*

At last, for the specific case of elongation a feasibility studies could be performed to get a more realistic view, which could result in a cost-benefit analysis whether building path enablers or not. This have not been in the scope of this thesis, and would require a solid analysis of, among others, resistance and required power.

References

Roar Adland and Haiying Jia. Shipping market integration: The case of sticky newbuilding prices. *Maritime Economics and Logistics*, 17(4):389–398, 2015.

Roar Adland, Haiying Jia, and Siri Strandenes. Asset Bubbles in Shipping? An Analysis of Recent History in the Drybulk Market. *Maritime Economics and Logistics*, 8(3):223–233, 2006. ISSN 14792931. doi: 10.1057/palgrave.mel.9100162.

Jose Jorge Garcia Agis, Sigurd Solheim Pettersen, Carl Fredrik Rehn, and Ali Ebrahimi. Handling commercial, operational and technical uncertainty in early stage offshore ship design. *2016 11th System of Systems Engineering Conference (SoSE)*, 2016. doi: 10.1109/sysose.2016.7542950.

F. L. Aguerrevere. Equilibrium Investment Strategies and Output Price Behavior: A Real-Options Approach. *Review of Financial Studies*, 16(4):1239–1272, 2003. ISSN 0893-9454. doi: 10.1093/rfs/hhg041. URL `http://rfs.oxfordjournals.org/cgi/doi/10.1093/rfs/hhg041`.

Jø rgen Amdahl. *Marin Teknikk 2: Konstruksjonsanalyse*. Institutt for Marin Teknikk, 2010.

Arctic Securities AS. Personal communication with shipping analyst, Jo K. Ringheim, 2017.

Kostas Axarloglou, Ilias Visvikis, and Stefanos Zarkos. The time dimension and value of flexibility in resource allocation: The case of the maritime industry. *Transportation Research Part E: Logistics and Transportation Review*, 52:35–48, 2013. ISSN 13665545. doi: 10.1016/j.tre.2012.11.010. URL `http://dx.doi.org/10.1016/j.tre.2012.11.010`.

Jan Babicz. *Wartsila encyclopedia of ship technology*. Wartsila Corporation, 2015.

I. Bakke, S.-E. Fleten, L.I. Hagfors, V. Hagspiel, B. Norheim, and S. Wogrin. Investment in electric energy storage under uncertainty: a real options approach. *Computational Management Science*, 13(3):483–500, 2016. ISSN 16196988 1619697X. doi: 10.1007/s10287-016-0256-3.

Avner Bar-Ilan. Investment with an arithmetic process and lags. *Managerial and Decision Economics*, 21(5): 203–206, 2000. ISSN 0143-6570. doi: 10.1002/mde.973. URL `http://doi.wiley.com/10.1002/mde.973`.

Avner Bar-Ilan, Agnès Sulem, and Alessandro Zanello. Time-to-build and capacity choice. *Journal of Economic Dynamics and Control*, 26(1):69–98, 2002. ISSN 01651889. doi: 10.1016/S0165-1889(00) 00018-X.

Avner Bar-Illan and William C Strange. Investment Lags. 58(3):531–537, 1996.

J. Clark Beesemyer, Adam M. Ross, and Donna H. Rhodes. An empirical investigation of system changes to frame links between design decisions and ilities. *Procedia Computer Science*, 8:31–38, 2012. ISSN 18770509. doi: 10.1016/j.procs.2012.01.010.

Fred Espen Benth, Steen Koekebakker, and Che Mohd Imran Che Taib. Stochastic dynamical modelling of spot freight rates. *IMA Journal of Management Mathematics*, 26(3):273–297, 2015. ISSN 14716798. doi: 10.1093/imaman/dpu001.

Peter Bjerksund and Steinar Ekern. Contingent claims evaluation for mean-reverting cash flows in shipping. *Real Options in Capital Investment, Models, Strategies, and Applications*, 1995.

Fischer Black and Myron Scholes. The pricing of options and corporate liabilities. *Journal of Political Economy*, 81(3):637–654, 1973. doi: 10.1086/260062.

Joseph Blackburn. Valuing time in supply chains: Establishing limits of time-based competition. *Journal of Operations Management*, 30(5):396–405, 2012. ISSN 02726963. doi: 10.1016/j.jom.2012.03.002. URL `http://dx.doi.org/10.1016/j.jom.2012.03.002`.

Per-Olaf Brett. *Design and development of specialised ships*. University Lecture at NTNU, 2016.

Gérard P. Cachon and Robert Swinney. The value of fast fashion: Quick response, enhanced design, and strategic consumer behavior. *Management Science*, 57(4):778–795, 2011. doi: 10.1287/mnsc.1100.1303.

Ngai Hang Chan and Hoi Ying Wong. *Simulation techniques in financial risk management*. Wiley, 2015.

Clarksons Research. Shipping Intelligence Network. 2017. URL `https://sin.clarksons.net/`.

Clarksons Research Services. Shipping Review & Outlook. (44), 2014.

Richard Coyne. *Knowledge-based design systems*. Addison-Wesley, 1990.

Keith Cuthbertson and Dirk Nitzsche. *Financial engineering derivatives and risk management*. John Wiley, 2001.

Suzanne De Treville, Isik Bicer, Valerie Chavez-Demoulin, Verena Hagspiel, Norman Schrhoff, Christophe Tasserit, and Stefan Wager. Valuing lead time. *Journal of Operations Management*, 32(6):337–346, 2014. ISSN 02726963. doi: 10.1016/j.jom.2014.06.002.

Olivier L De Weck, Adam M Ross, and Donna H Rhodes. Investigating Relationships and Semantic Sets amongst System Lifecycle Properties (Ilities). *Third International Engineering Systems Symposium CESUN 2012, Delft University of Technology, 18-20 June 2012*, (June):18–20, 2012.

D.A. Dierolf and K.J. Richter. Computer-aided group problem solving for unified life cycle engineering. *Institute for Defense Analysis, Alexandira, Virginia*, 1989.

Avinash K. Dixit. Entry and Exit Decisions under Uncertainty, 1989. ISSN 0022-3808. URL http://www.jstor.org/stable/1830458{%}5Cnhttp://www.journals.uchicago.edu/doi/abs/10.1086/261619.

Avinash K. Dixit and Robert S. Pindyck. *Investment under uncertainty.* Princeton University Press, 1994.

DNV GL. Classification notes, conversion of ships, 2013.

DNV GL. TECHNICAL AND REGULATORY NEWS No. 04/2016 – NEW REQUIREMENTS FOR PANAMA CANAL TRANSIT, 2016a.

DNV GL. Class Guideline, Conversion of ships - DVGL-CG-0156, 2016b.

Ali Ebrahimi, Per Olaf Brett, Jose J Garcia, Henrique M Gaspar, and Øyvind Kamsvåg. Better decision making to improve robustness of OCV designs. *Imdc 2015*, 3:1–13, 2015.

Stein Ove Erikstad. A decision support model for preliminary ship design. *PhD.Thesis, NTNU*, 1996.

Stein Ove Erikstad. Design Processes Objectives and Requirements. *Lecture in the course TMR4115 at NTNU*, 2015.

Stein Ove Erikstad and Carl Fredrik Rehn. Handling Uncertainty in Marine Systems Design - State-of-the-Art and Need for Research. *12th International Marine Design Conference 2015 Proceedings Volume 2 - 324* -, 2:324–342, 2015.

Stein Ove Erikstad, Kjetil Fagerholt, and Siri Solem. A Ship Design and Deployment Model for Non-Transport Vessels. *Ship Technology Research*, 58(3):4–13, 2011. ISSN 0937-7255. doi: 10.1179/str.2011.58.3.001.

Philip S E Farrell. Organizational Agility. *The Journal of Applied Business Research – March/April 2015*, 31(2):675, 2015. ISSN 15355535. doi: 10.1016/j.jala.2008.09.002.

Matthew Fitzgerald. Managing uncertainty in systems with a valuation apporach for strategic changeability. *MsC. Thesis, MIT*, 2012.

Ernst Fricke and Armin P. Schulz. Design for changeability (DfC): Principles to enable changes in systems throughout their entire lifecycle. *Systems Engineering*, 8(4):342–359, 2005. ISSN 10981241. doi: 10.1002/sys.20039.

C. W. J. Granger. Investigating causal relations by econometric models and cross-spectral methods. *Essays in Econometrics vol II: Collected Papers of Clive W. J. Granger*, page 31–47, 1969.

Robin Greenwood and Samuel G Hanson. WAVES IN SHIP PRICES AND INVESTMENT* Robin Greenwood and Samuel G. Hanson. pages 55–109, 2015. doi: 10.1093/qje/qju035.Advance.

Reinhard Haberfellner and Olivier de Weck. Agile SYSTEMS ENGINEERING versus AGILE SYSTEMS engineering. *INCOSE International Symposium*, 17(2):1–17, 2005. ISSN 23345837. doi: 10.1002/sys.

Harvard Business Review. Making real options really work, *accessed 25.05.2017*, 2017. URL https://hbr.org/2004/12/making-real-options-really-work.

Babak Jafarizadeh and Reidar Brumer Bratvold. Oil and Gas Exploration Valuation and the Value of Waiting. 2701(December), 2015. ISSN 15472701. doi: 10.1080/0013791X.2015.1045647.

Carlos M. Jarque and Anil K. Bera. Efficient tests for normality, homoscedasticity and serial independence of regression residuals. *Economics Letters*, 6(3):255–259, 1980. doi: 10.1016/0165-1765(80)90024-5.

Peter Loechte Joergensen and Domenico De Giovanni. Time charters with purchase options in shipping: Valuation and risk management. *Appl.Math. Finance*, 17:399–430, 2010. doi: 10.2139/ssrn.1336131.

Konstantinos Kalligeros. Platforms and Real Options in Large-scale Engineering Systems Design. *MIT PhD. thesis*, 2006.

Myrto Kalouptsidi. Time to build and fluctuations in bulk shipping. *American Economic Review*, 104(2): 564–608, 2014. ISSN 00028282. doi: 10.1257/aer.104.2.564.

Manolis G. Kavussanos and Amir H. Alizadeh. Seasonality patterns in dry bulk shipping spot and time charter freight rates. *Transportation Research Part E: Logistics and Transportation Review*, 37(6):443–467, 2001. doi: 10.1016/s1366-5545(01)00004-7.

Manolis G Kavussanos and Amir H Alizadeh. Efficient pricing of ships in the dry bulk sector of the shipping industry. *The flagship journal of international shipping and port research*, 29(3):303–330, 2002a. ISSN 0308-8839. doi: 10.1080/03088830210132588.

Manolis G. Kavussanos and Amir H. Alizadeh. Seasonality patterns in tanker spot freight rate markets. *Economic Modelling*, 19(5):747–782, 2002b. doi: 10.1016/s0264-9993(01)00078-5.

Steen Koekebakker, Roar Adland, and Sigbjø rn Sø dal. Are spot freight rates stationary? *Journal of Transport Economics and Policy*, 40(3):449–472, 2006. ISSN 00225258.

A N Kolmogorov. Combinatorial foundations of information theory and the calculus of probabilities. *Russian Mathematical Surveys*, 38(4):29–40, 1983. doi: 10.1070/rm1983v038n04abeh004203.

Finn E Kydland and Edward C Prescott. Time to Build and Aggregate Fluctuations. 50(6):1345–1370, 1982. ISSN 1098-6596. doi: 10.1017/CBO9781107415324.004.

Jon Hovem Leonhardsen. Flexible Bulbous Bows - Approaching the Value of Agile Bulbs in Uncertain Operating Conditions . *Project Thesis*, 2016.

Kai Levander. *System Based Ship Design*. SeaKey Naval Architecture, 2012.

Jijun Lin, Olivier de Weck, Richard de Neufville, and Howard K. Yue. Enhancing the value of offshore developments with flexible subsea tiebacks. *Journal of Petroleum Science and Engineering*, 102:73–83, 2013. ISSN 09204105. doi: 10.1016/j.petrol.2013.01.003. URL http://dx.doi.org/10.1016/j.petrol.2013.01.003.

F. A. Longstaff and Schwartz E.S. Valuing American options by simulation: a simple least-squares approach. *Review of Financial Studies*, 14(I):113–147, 2001. ISSN 14657368. doi: 10.1093/rfs/14.1.113. URL http://rfs.oxfordjournals.org/content/14/1/113.

C L Magee and O L de Weck. Complex System Classification. *Incose*, (March 2016):18, 2004. ISSN 23345837. doi: 10.1002/j.2334-5837.2004.tb00510.x.

Saman Majd and Robert S. Pindyck. Time to build, option value, and investment decisions. *Journal of Financial Economics*, 18(1):7–27, 1987. ISSN 0304405X. doi: 10.1016/0304-405X(87)90059-6.

Hugh McManus and Daniel Hastings. A framework for understanding uncertainty and its mitigation and exploitation in complex systems. *IEEE Engineering Management Review*, 34(3):81–94, 2006. ISSN 03608581. doi: 10.1109/EMR.2006.261384.

Nicholas Metropolis and S. Ulam. The Monte Carlo Method. *Journal of the American Statistical Association*, 44(247):335, 1949. doi: 10.2307/2280232.

Alistair Milne and Elizabeth Whalley. Time to build, option value, and investment decisions; a comment. *Journal of Financial Economics*, 56:325–332, 2000. ISSN 0304405X. doi: 10.1016/0304-405X(87)90059-6.

Johnathan Mun. Real Options Analysis versus Traditional DCF Valuation in Layman's Terms. *Managing Enterprise Risk: What the Electric Industry Experience Implies for Contemporary Business*, pages 75–106, 2006. ISSN 9780080449494. doi: 10.1016/B978-008044949-4/50039-8.

Richard De Neufville. Identifying real options to improve the design of engineering systems. *Real Options in Engineering Design, Operations, and Management*, page 75–98, 2009.

Richard De Neufville and Stefan Scholtes. *Flexibility in engineering design*. MIT Press, 2011.

Richard De Neufville, Olivier De Weck, Daniel Frey, Daniel Hastings, Richard Larson, and David Simchi-levi. Uncertainty Management for Engineering Systems Planning and Design. *Engineering Fracture Mechanics*, page 19, 2004. URL http://esd.mit.edu/symposium/pdfs/monograph/uncertainty.pdf.

Michael Pidd. Computer simulation in management science. page 328, 2004. ISSN 1747-7778. doi: 10.1057/palgrave.jos.4250005. URL http://eprints.lancs.ac.uk/47721/.

Robert S. Pindyck. Irreversibility, Uncertainty, and Investment. *Journal of Economic Literatur*, (March), 1990.

Rehn, Garcia, Pettersen, Brett, Erikstad, Asbjørnslett, Ross, Rhodes, and Hastings. Quantification of Changeability Level for Engineering Systems. Working paper, estimated publishing late 2017. 2017e.

Carl Fredrik Rehn, Annette Haugsdal, and Stein Ove Erikstad. Flexible strategies for maritime sulphur emission regulation compliance. 2016.

K. Rollins and M. Insley. On solving the multirotational timber harvesting problem with stochastic prices: A linear complementarity formulation. *American Journal of Agricultural Economics*, 87(August):735–755, 2005.

Adam Ross, Hugh Mcmanus, Donna Rhodes, Daniel Hastings, and Andrew Long. Responsive systems comparison method: Dynamic insights into designing a satellite radar system. *AIAA SPACE 2009 Conference Exposition*, 2009. doi: 10.2514/6.2009-6542.

Adam M Ross, Hugh L McManus, and Andrew Long. Responsive systems comparison method: Case study in assessing future designs in the presence of change. *AIAA SPACE 2008 Conference Exposition*, pages 1–9, 2008a. URL http://seari.mit.edu/documents/preprints/ROSS{_}AIAA08.pdf.

Adam M Ross, Donna H Rhodes, and Daniel E Hastings. Defining Changeability : Reconciling Flexibility , Adaptability , Scalability , Modifiability , and Robustness for Maintaining System Life cycle Value. 11 (3):246–262, 2008b. ISSN 23345837. doi: 10.1002/sys.

David J. Singer, Norbert Doerry, and Michael E. Buckley. What is set-based design? *Naval Engineers Journal*, 121(4):31–43, 2009. doi: 10.1111/j.1559-3584.2009.00226.x.

David C. Skinner. *Introduction to decision analysis: a practitioner's guide to improving decision quality*. Probabilistic Publishing, 2009.

SKS tankers. Presentation videos, 2017. URL http://skstankers.com/vide-presentations.

Sigbjørn Sødal. Entry and exit decisions based on a discount factor approach. *Journal of Economic Dynamics and Control*, 30(11):1963–1986, 2006. ISSN 01651889. doi: 10.1016/j.jedc.2005.06.011.

Sigbjørn Sødal, Steen Koekebakker, and Roar Aadland. Market switching in shipping - A real option model applied to the valuation of combination carriers. *Review of Financial Economics*, 17(3):183–203, 2008. ISSN 10583300. doi: 10.1016/j.rfe.2007.04.001.

Martin Stopford. *Maritime Economics*. Taylor & Francis, Abingdon, UK, 2009.

Siri Strandenes. Price Determination in the Time Charter and Second Hand Markets. *Discussion Paper 05/84, Norwegian School of Economics and Business Administration: Bergen, Norway*, (May), 1984.

Nam P. Suh. *The principles of design*. Oxford Univ. Pr., 1990.

Donald Sull. Competing through organizational agility. *McKinsey Quarterly*, (1), 2010. URL http://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=47918197&site=ehost-live.

Che Mohd Imran Che Taib. Forward pricing in the shipping freight market. *Japan Journal of Industrial and Applied Mathematics*, 33(1):3–23, 2016. ISSN 1868937X. doi: 10.1007/s13160-015-0204-6.

Nassim Nicholas Taleb. *The impact of the highly improbable*. Penguin Books Ltd, 2008.

H. Thanopoulou and S. Strandenes. Uncertainty and long term forecasts in shipping: A theoretical framework. *Statewide Agricultural Land Use Baseline 2015*, 1(1):1–17, 2015. ISSN 1098-6596. doi: 10.1017/CBO9781107415324.004.

Thorvald Klaveness AS. Personal communication with head of combination carriers, Engebret Dahm, 2017.

Jostein Tvedt. Valuation of VLCCs under income uncertainty. *Maritime Policy & Management*, 24(2): 159–174, 1997. ISSN 0308-8839. doi: 10.1080/03088839700000067.

Jostein Tvedt. A new perspective on price dynamics of the dry bulk market. *Maritime Policy & Management*, 30(3):221–230, 2003a. ISSN 0308-8839. doi: 10.1080/0308883032000133413.

Jostein Tvedt. Shipping market models and the specification of freight rate processes. *Maritime Economics and Logistics*, 5(4):327–346, 2003b. ISSN 1388-1973.

M. Walton. Managing uncertainty in space systems conceptual design using portfolio theory. *Ph.D. thesis, MIT*, 2002.

Tao Wang and Richard De Neufville. Building Real Options into Physical Systems with Stochastic Mixed-Integer Programming. *Options*, pages 1–35, 2004.

William W. S. Wei. *Time series analysis: univariate and multivariate methods*. Pearson Addison Wesley, 2007.

Niko Wijnolst, Tor Wergeland, and Frans A. J. Waals. *Shipping*. Delft Univ. Press, 1997.

Chunsheng Zhou. Time-to-build and investment. 82(May):273–282, 2000.

Appendix A Discount rate

Year	Yearly average, 5 y gov. bond	OSEBX Yearly Return	Excess return
2015	0,99 %	5,3%	4 %
2014	1,82 %	3,4%	2 %
2013	1,93 %	21,9%	20 %
2012	1,59 %	14,7%	13 %
2011	2,56 %	-10,7%	-13 %
2010	2,83 %	18,0%	15 %
2009	3,33 %	70,4%	67 %
2008	4,43 %	-52,8%	-57 %
2007	4,77 %	13,7%	9 %
2006	3,90 %	33,6%	30 %
2005	3,27 %	41,0%	38 %
2004	3,61 %	37,2%	34 %
2003	4,58 %	47,0%	42 %
2002	6,36 %	-30,2%	-37 %
2001	6,31 %	-15,2%	-22 %
2000	6,38 %	12,3%	6 %
Average	3,7%	13,1%	9,4%
Risk free rate	0,94 %		
Expected market return	**10,38 %**		

Cost of capital			
Beta	Risk free rate	Expected market return	Equity Cost of capital
1,74	0,94 %	10,38 %	17,4%

Cost of Debt			
	NIBOR 6M(10.12.2016)	Risk Premium	Debt Cost of Capital
	1,29 %	1,00 %	2,29 %

Market/Company Inputs	
Corporate tax	-
Debt	-
Equity	-
Debt Ratio	60 %
Equity Ratio	40 %

WACC	8%

Appendix B Time serie analysis

```
% This script is used to test the time series
% written for MatLab
% Requires data of cape earnings, 2nd. h value and NB

% Test of data
% Data
load('cape_earnings')
load('cape_2ndh')
load('cape_nb')

% ADF-test
% https://se.mathworks.com/help/econ/adftest.html
[h,pValue,stat,cValue,reg] = adftest(cape_earnings);
[h,pValue,stat,cValue,reg] = adftest(cape_2ndh);
[h,pValue,stat,cValue,reg] = adftest(cape_nb);

% Normality
l_cape_earnings=log(cape_earnings);
l_cape_2ndh=log(cape_2ndh);
l_cape_nb=log(cape_nb);

q=price2ret(cape_earnings);
w=price2ret(cape_2ndh);
r=price2ret(cape_nb);

% JB-test
% https://se.mathworks.com/help/stats/jbtest.html
[h,p,jbstat,critval]=jbtest(q)
[h,p,jbstat,critval]=jbtest(w)
[h,p,jbstat,critval]=jbtest(r)

% Properties
snitt_q=mean(q);
snitt_w=mean(w);
snitt_r=mean(r);
kurt_q=kurtosis(q);
kurt_w=kurtosis(w);
kurt_r=kurtosis(r);
skew_q=skewness(q);
skew_w=skewness(w);
skew_r=skewness(r);
```

Appendix C Estimation of mean reversion parameters

```
# This is the script used to estimate parameters for
# Geometric Mean reversion written for R
# Requires data file of Capesize histoical earnings

# GOU
library('readxl')
Average_Capesize_Long_Run_Historical_Earnings <- ...
     read_excel("C:/Users/Carsten/Dropbox/Skule/Master Thesis/Clarkson ...
     Data/Average Capesize Long Run Historical Earnings.xlsx")
x = Average_Capesize_Long_Run_Historical_Earnings$X__1
y=x[6:332]
z=as.numeric(gsub(" ", "", y))
price = ts(z,start=1990, Δt=1/12)


#function to calculate R_{t}, the sequence of percentage price changes
pct.diff = function(price){
PCT = rep(0,length(price))
d = diff(price)
for(t in 1:length(price)){
  PCT[t] = d[t]/price[t]
}
PCT = PCT[-length(PCT)]
return(PCT)
}
#####

R = pct.diff(price)
Z = 1/price[-327]
#regression equation to find the parametervalues
summary(lm(R ¬ Z))
```

Appendix D Causality test

```
% Chandler Lutz, UCR 2009
% Questions/Comments: chandler.lutz@email.ucr.edu
% $Revision: 1.0.0 $  $Date: 09/30/2009 $
% $Revision: 1.0.1 $  $Date: 10/20/2009 $
% $Revision: 1.0.2 $  $Date: 03/18/2009 $

% References:
% [1] Granger, C.W.J., 1969. "Investigating causal relations by econometric
%     models and cross-spectral methods". Econometrica 37 (3), 424  438.

% Acknowledgements:
%   I would like to thank Mads Dyrholm for his helpful comments and
%   suggestions


%%%%%%%%%%%%% Test of Granger causality
%% Data
% load('cape_earnings')
% load('cape_2ndh')

%%
function [F,c_v] = granger_cause(x,y,alpha,max_lag)
% [F,c_v] = granger_cause(x,y,alpha,max_lag)
% Granger Causality test
% Does Y Granger Cause X?
%
% User-Specified Inputs:
%   x -- A column vector of data
%   y -- A column vector of data
%   alpha -- the significance level specified by the user
%   max_lag -- the maximum number of lags to be considered
% User-requested Output:
%   F -- The value of the F-statistic
%   c_v -- The critical value from the F-distribution
%
% The lag length selection is chosen using the Bayesian information
% Criterion
% Note that if F > c_v we reject the null hypothesis that y does not
% Granger Cause x



%Make sure x & y are the same length
if (length(x) ≠ length(y))
    error('x and y must be the same length');
end

%Make sure x is a column vector
[a,b] = size(x);
if (b>a)
    %x is a row vector -- fix this
    x = x';
end

%Make sure y is a column vector
```

```
[a,b] = size(y);
if (b>a)
    %y is a row vector -- fix this
    y = y';
end



%Make sure max_lag is ≥ 1
if max_lag < 1
    error('max_lag must be greater than or equal to one');
end

%First find the proper model specification using the Bayesian Information
%Criterion for the number of lags of x

T = length(x);

BIC = zeros(max_lag,1);

%Specify a matrix for the restricted RSS
RSS_R = zeros(max_lag,1);

i = 1;
while i ≤ max_lag
    ystar = x(i+1:T,:);
    xstar = [ones(T-i,1) zeros(T-i,i)];
    %Populate the xstar matrix with the corresponding vectors of lags
    j = 1;
    while j ≤ i
        xstar(:,j+1) = x(i+1-j:T-j);
        j = j+1;
    end
    %Apply the regress function. b = betahat, bint corresponds to the 95%
    %confidence intervals for the regression coefficients and r = residuals
    [b,bint,r] = regress(ystar,xstar);

    %Find the bayesian information criterion
    BIC(i,:) = T*log(r'*r/T) + (i+1)*log(T);

    %Put the restricted residual sum of squares in the RSS_R vector
    RSS_R(i,:) = r'*r;

    i = i+1;

end

[dummy,x_lag] = min(BIC);

%First find the proper model specification using the Bayesian Information
%Criterion for the number of lags of y

BIC = zeros(max_lag,1);

%Specify a matrix for the unrestricted RSS
RSS_U = zeros(max_lag,1);

i = 1;
while i ≤ max_lag
```

```
    ystar = x(i+x_lag+1:T,:);
    xstar = [ones(T-(i+x_lag),1) zeros(T-(i+x_lag),x_lag+i)];
    %Populate the xstar matrix with the corresponding vectors of lags of x
    j = 1;
    while j ≤ x_lag
        xstar(:,j+1) = x(i+x_lag+1-j:T-j,:);
        j = j+1;
    end
    %Populate the xstar matrix with the corresponding vectors of lags of y
    j = 1;
    while j ≤ i
        xstar(:,x_lag+j+1) = y(i+x_lag+1-j:T-j,:);
        j = j+1;
    end
    %Apply the regress function. b = betahat, bint corresponds to the 95%
    %confidence intervals for the regression coefficients and r = residuals
    [b,bint,r] = regress(ystar,xstar);

    %Find the bayesian information criterion
    BIC(i,:) = T*log(r'*r/T) + (i+1)*log(T);

    RSS_U(i,:) = r'*r;

    i = i+1;

end

[dummy,y_lag] =min(BIC)

%The numerator of the F-statistic
F_num = ((RSS_R(x_lag,:) - RSS_U(y_lag,:))/y_lag);

%The denominator of the F-statistic
F_den = RSS_U(y_lag,:)/(T-(x_lag+y_lag+1));

%The F-Statistic
F = F_num/F_den

c_v = finv(1-alpha,y_lag,(T-(x_lag+y_lag+1)))



end
```

Appendix E LSMC model with correlated asset values and freight rates

Requires *base_ script.m*, *sim_ correlatedOU.m* and the LSMC model, *LSMC_ modified.m*

Appendix E.1. base_ script.m

```
%%%%%%%%%%%%  Base script       %%%%%%%%%%%%%%%%%%%%%%%

clear all
clc

% Data
load('cape_earnings')
load('cape_2ndh')

% Run simulation
run('sim_correlatedOU');


siz=size(vessel_prices);

% Define possible lags - months
lags = [0:1:36];           % [months]
max = length(lags);
K=mean(cape_2ndh)*10^6;                    % strike
S0=mean(cape_2ndh)*10^6;                   % Initial value of vessel
option_values=[];
exercise_time=zeros(siz(1)-max,siz(2),max);
r=0.08;
conf=zeros(NumTrials,max);


    for i = 1:max
        rng(1);
        vessel_corrected = zeros(siz(1)-max,siz(2));
     % Adjust each value function(vessel_price) with corresponding ...
         correction value

        for k = 1:siz(2)
            for j = 1:(siz(1)-max)
                correction_value = cumsum(spot_prices(j:j+lags(i),k));
                vessel_corrected(j,k) = vessel_prices(j,k) - ...
                    correction_value(end);
            end
        end


    % Option valuation


    [Price,ExTime,cc] = LSMC_modified(S0,K,r,vessel_corrected,NumTrials);

    option_values(i)=Price;
    conf(:,i)=cc;
end
```

Appendix E.2. sim_correlatedOU.m

```
%%% Simulation of correlated OU process
% Settlement date
Settle = '01-Jun-1990';
% Maturity Date
Maturity = '01-Jun-2013';
% Actual/Actual basis
Basis = 0;
% Monthly cape earnings
cape_earnings=cape_earnings*30;

% Roughly
% all values
% Initial log
X0 = [log(mean(cape_2ndh)*10^6) log(mean(cape_earnings))]';
% Volatility of log(price)
Sigma = [0.647 0; 0 0.2790];
% Number of trials in the Monte Carlo simulation
NumTrials = 10000;
% Number of periods (monthly)  (days/[days/month])
NumPeriods = floor(daysdif(Settle, Maturity, Basis)/31);
% Montly timestep
dt = 1/NumPeriods;
% Mean reversion speed of log(price)
Kappa = [0.0102 0; 0 0.065];
% Mean reversion level of log(price)
Theta = [log(mean(cape_2ndh)*10^6) log(mean(cape_earnings))]';
% Correlation
korr= [1 0.8987; 0.8987 1];
% Create HWV object
hwvobj = hwv(Kappa, Theta, Sigma, 'StartState', X0, 'Correlation', korr)

% Set random number generator seed
%savedState = rng(0, 'twister');
% Simulate gas prices
[Paths, Times] = hwvobj.simBySolution(NumPeriods, 'NTRIALS', NumTrials, ...
    'DeltaTime', dt);
Paths = squeeze(exp(Paths));


str=size(Paths);
vessel_prices=zeros(str(1),str(3));
for j = 1:str(3)
    for i = 1:str(1)
        vessel_prices(i,j)=Paths(i,1,j);
    end
end

% Less monthly OPEX
spot_prices=zeros(str(1),str(3));
for j = 1:str(3)
    for i = 1:str(1)
        spot_prices(i,j)=Paths(i,2,j)-270000;
    end
end
```

Appendix F LSMC model with asset values as function of earnings

Requires *base_script_det_gmr.m*, *det_shipvalue_gmr* and the LSMC model, *LSMC_modified.m*

Appendix F.1. base_script_det_gmr.m

```
%%%% Base script - with ship value as a function of rate
clear all
clc


load('cape_earnings')
load('cape_2ndh')

run('det_shipvalue_gmr');
siz=size(vessel_prices);
% Define possible lags - days
lags = [0:1:1095];            % [days]
max = length(lags);
K=mean(cape_2ndh)*10^6;
S0=mean(cape_2ndh)*10^6;                    % Initial value of vessel
option_values=[];
r=0.08;
        for i = 1:max

        vessel_corrected = zeros(siz(1)-max,siz(2));
        % Adjust each value function(vessel_price) with corresponding corr ...
            value

            for k = 1:siz(2)
                for j = 1:(siz(1)-max)
                    correction_value = cumsum(spot_prices(j:j+lags(i),k));
                    vessel_corrected(j,k) = vessel_prices(j,k) - ...
                        correction_value(end);
                end
            end


         % Option valuation

        [Price,ExTime] = LSMC_modified(S0,K,r,vessel_corrected,NumTrials);
%

         option_values(i)=Price;

end
```

Appendix F.2. det_shipvalue_gmr.m

```
%% Determinsitic function of ship values based on earnings
% Data processing
% Average Capesize Long Run Historical Earnings USD/day avg monthly
% Capesize 5 Year Old Secondhand Prices (Long Run Historical Series)
% $ million

% Fit: '2nd cape value'.
[xData, yData] = prepareCurveData( cape_earnings, cape_2ndh );

% Set up fittype and options.
ft = fittype( 'poly2' );

% Fit model to data.
[fitresult, gof] = fit( xData, yData, ft );

% Plot fit with data.
figure(1)
h = plot( fitresult, xData, yData, 'predobs' );
xlabel('Earnings Capesize[USD/day]','interpreter','latex')
ylabel('2nd hand Capesize value[USDm]','interpreter','latex')


%% Simulation of vessel earnings


mu = log(23285.42);                   % Reverting level
n=1000;                           %   # of sim.
NumTrials=1000;
th = 0.0825;                      %Speed of mean reversion
sig = 0.2972;                    % Daily volatility
years=20;
dt = 1/365;
t = 0:dt:years;                  % Time vector
x0 = 23285.42;
rng(1);                          % Set random seed
W = zeros(1,length(t));          % Allocate integrated W vector
Z=zeros(length(t),n);
for j=1:n
        for i = 1:length(t)-1
            W(i+1) = W(i)+sqrt(exp(2*th*t(i+1))-exp(2*th*t(i)))*randn;
        end
        % Draw starting point from historical dist. of earnings
        x0=cape_earnings(floor(rand*324)+1);
        ex = exp(-th*t);
        x = exp(log(x0)*ex+(mu-0.5*(sig^2/th))*(1-ex)+sig*ex.*W/sqrt(2*th));
        Z(:,j)=x;
        figure(2);
        hold on
        plot(t,x);
end

ylabel('Net Cash Flow [$\frac{USD}{day}$]','interpreter','latex')
xlabel('Operation time[Years]', 'interpreter','latex')
Paths=Z;

% Less opex and assume layup = 0 cost, rather than negative CF
```

```
size_path = size(Paths);
spot_prices=zeros(size(Paths));
for j = 1:size_path(2)
    for i = 1:size_path(1)
        spot_prices(i,j)=Paths(i,j)-7000;
        if spot_prices(i,j)≤0
            spot_prices(i,j) = 0;
        end
    end
end

% Vessel prices and regression formula
vessel_prices=zeros(size(Z));
for i = 1:size_path(2)
   vessel_prices(:,i)=fitresult(Z(:,i))*10^6;
end
```

Appendix G LSCM model

```
% Adapted and modified, from ...
    https://se.mathworks.com/matlabcentral/fileexchange/
% 16476-pricing-american-options

function [Price,ExTime,cc] = LSMC_modified(S0,K,r,vessel_corrected,NumTrials)
% Inputs:
%   S0       Initial asset price
%   K        Strike Price
%   r        Interest rate
%   T        Time to maturity of option

str_corr = size(vessel_corrected);
N = str_corr(1);
dt = 1;
t=0:1:N;
ExTime = zeros(N,NumTrials);


CF = zeros(str_corr); % Cash flow matrix

% Only positive cash flows
for kk=1:str_corr(2)
    if (vessel_corrected(end,kk) - K) < 0
        CF(end,kk) = 0;
    else CF(end,kk) = vessel_corrected(end,kk)-K;
    end
end

for ii = size(vessel_corrected)-1:-1:2
    Idx = find(vessel_corrected(ii,:) > K); % Find paths that are in the ...
        money at time ii
    X = vessel_corrected(ii,Idx)';
    X1 = X/S0;
    Y = CF(ii+1,Idx)'*exp(-r*dt); % Discounted cashflow. OBS, sjekk ...
        diskonterinsrente opp mot      diskontere hver m ned
    R = [ ones(size(X1)) (1-X1) 1/2*(2-4*X1-X1.^2)];
    a = R\Y;                         % Linear regression step
    C = R*a;                         % Cash flows as predicted by the model
    Jdx = find(X-K > C)';
    nIdx = setdiff((1:NumTrials),Idx(Jdx));
    CF(ii,Idx(Jdx)) = X(Jdx)-K;
    ExTime(ii,Idx(Jdx)) = ii;
    CF(ii,nIdx) = exp(-r*dt)*CF(ii+1,nIdx);
end

Price = mean(CF(2,:))*exp(-r*dt);
cc = CF(2,:)*exp(-r*dt);
end
```

Appendix H System engineering simulation

```
%%% System engineering
clear all
clc

% Data
load('cape_earnings')
load('cape_2ndh')
opex=7000;      % OpEx [$/day]

mu = log(23285.42);              %Reverting level
n=1000;                        % # of sim.
th = 0.0825;                    %Speed of mean reversion
sig = 0.2972;                  % Daily volatility
years=23;
dt = 1/365;
t = 0:dt:years;               % Time vector
rng(1);                  % Set random seed
W = zeros(1,length(t)); % Allocate integrated W vector
Z=zeros(length(t),n);
for j=1:n
        for i = 1:length(t)-1
            W(i+1) = W(i)+sqrt(exp(2*th*t(i+1))-exp(2*th*t(i)))*randn;
        end
        % Draw startpoint from hist distribution
        x0=cape_earnings(floor(rand*324)+1);
        ex = exp(-th*t);
    x = exp(log(x0)*ex+(mu-0.5*(sig^2/th))*(1-ex)+sig*ex.*W/sqrt(2*th))-opex;
    Z(:,j)=x;
    figure(1);
    hold on
    plot(t,x);
    xlim([0 23])
end


wacc=[0.075:0.01:0.15];
max_lag=1095;
option_2d=zeros(length(wacc),max_lag);

% Underlying processes - vessel_prices / spot_prices
for w=1:length(wacc)
    % For sensitivity analysis
    r = wacc(w);
    %%% Discounting
    NPV_cf=zeros((length(t)),n);
    for i = 1:n
        for j = 1:(length(t))
            NPV_cf(j,i) = Z(j,i)*exp(-(dt*j)*r);
        end
    end

    % Accumulates cashflow over lifetime
    akkumulert = cumsum(NPV_cf,1);
    akumulert_profit = akkumulert((length(t)),:);
            % Max. # of days, investment lag
```

```
    conf=zeros(n,max_lag);
    Q = [];
    lagged_profit = [];

    for j = 1:max_lag
        for i =1:n
            Q(i) = akkumulert(7301+j,i) - akkumulert(j,i);
        end
        conf(:,j)=Q;
        lagged_profit(j)=mean(Q);
        option_2d(w,j)=mean(Q);
    end
end
```