NTNU – Trondheim
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Using Epoch Era Analysis in the Design of the Next Generation Offshore Subsea Construction Vessels

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"Using Epoch Era Analysis in the Design of the Next Generation Offshore Subsea Construction Vessels"

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Background

High oil prices have spurred the development of subsea oil and gas fields. These fields are increasingly developed using offshore subsea construction vessels (OSCVs) providing both a flexible and a cost efficient solution for marginal fields. In addition, as the number of subsea wells increase in number, there is a growing need for well maintenance and intervention services, increasingly using light, riserless technologies.

The design of a new OSCV should combine an optimization of the first likely mission, while still taking into account additional functionality and performance capabilities in order to meet future requirements and changes in an uncertain future operating context. Such uncertainties may include increased/decreased oil prices, stricter environmental regulations, the availability of new and more cost-efficient technologies and possible new (arctic) offshore fields. To prepare for these uncertainties and to avoid making a particular design losing its competitiveness early on, design solutions related to flexibility, robustness, and adaptability should be assessed accordingly.

Overall aim and focus

Thus, the overall objective is to investigate the plausibility of an Epoch-Era Analysis (EEA) and whether it can deliver sustained value to stakeholders over time in a complex, uncertain and changing operating context, and, additionally, how to evaluate and interpret the results of such an analysis. As a basis for the EEA, a concise analysis of the current OSCV market and inherent development trends should also be provided to ensure realistic input parameters.

Scope and main activities

The candidate should presumably cover the following main points:

1. *A simplified introduction case to illustrate the general properties, principles, pros, and cons of utilizing Epoch-Era Analysis.*

2. *Describe and discuss alternative strategies for providing flexible design solutions with improved capabilities for handling uncertainty into this market.*

3. *Provide a concise market analysis of the current state and development trends of today's OSCV market.*

4. *Identify the most important results from (3) and use them as main parameters to perform an illustrative case study utilizing Epoch-Era Analysis.*

Modus operandi

At NTNU, Professor Stein Ove Erikstad will be the responsible supervisor. The candidate will work closely with Ulstein International during the thesis. The contact person at Ulstein International will be Dr. Per Olaf Brett.

To the extent that the candidate will use data and material from Ulstein International that they consider sensitive, this must be presented in the thesis in an aggregated/anonymized form that is acceptable to Ulstein International.

The work shall follow the guidelines given by NTNU for the MSc Thesis work. The workload shall be in accordance with 30 ECTS, corresponding to 100% of one semester.

Stein Ove Erikstad
Professor/Responsible Advisor

PREFACE

This thesis is part of a M.Sc. degree in Marine Technology – Marine Systems Design, involving a collaboration between the Norwegian University of Science and Technology and Ulstein International during the spring of 2014. The work load is equivalent to 30 ECTS and has focused on the applications of Epoch-Era Analysis and its benefits during conceptual ship design.

The main objective has been to develop the framework on which this type of analysis is built and consequently perform such an analysis with realistic inputs in order to illustrate potential benefits. As very little research has been performed on the utilization of Epoch-Era Analysis in ship design, the original scope was aimed at including a genuine industrial scenario, however it quickly became apparent that because of the lack of research and virtually no available software to directly implement such scenarios in, the necessary tools would have to be developed manually. This required not only a significant amount of work, but also high level of programming capabilities, which impeded the intended scope.

I would like to thank my supervisor Stein Ove Erikstad for agreeing to the proposed topic and providing valuable insights underway. Especially, I would like to thank Henrique Gaspar of HiALS who has provided continuous support and invaluable help at times when it was most needed. Finally, I would also like to thank Dr. Per Olaf Brett for his comments, and pointing out important industrial aspects along the way.

Trondheim, June 8 - 2014

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ABSTRACT

This thesis examines the plausibility of using Epoch-Era Analysis during conceptual design of the next generation offshore subsea construction vessels (OSCV). Spurred by high oil prices and a decreasing level of accessible carbon resources, OSCVs have to a larger degree become qualified as flexible and cost efficient solutions for marginal fields. The reduction of “easy” oil has led to a push towards harsher regions, at deeper operational depths and farther from shore. Consequently, the market and technology is in constant development continuously leading to new requirements, regulations and legislation being imposed, affecting the ship building process.

Facing these challenges, designers are expected to account for broader, multi-faceted future scenarios, while simultaneously improving performance and decreasing cost. Leading to an exorbitant amount of information needing to be incorporated and accounted for, future uncertainty increases exponentially the further one looks. Coupled with a widespread tendency many owners have of optimizing designs to the initial obtainable contract, the impact of future uncertainties on earning capability and cost, have to a certain degree been neglected because of its difficulty to model.

This work utilizes a comprehensive Epoch-Era Analysis in an attempt to highlight the benefits especially present in complicated and highly uncertain scenarios. A developed segment of code was used to create the foundation data, which is further analyzed in Tableau.

The resulting analysis yields favorable results in terms of illustrating the potential Epoch-Era Analysis has as a tool to decompose complicated information and turning it into valuable insights for stakeholders to evaluate, inherently making communication with designers much clearer and unambiguous. Key aspects include the ability of revealing and defining which features and capabilities stakeholders actually value, and by further evaluating all possible design solutions accordingly, attractive cost-benefit ratios and the most profitable future scenarios can be identified. Adding constraints to the analysis also enabled a coherent mapping of which possible designs are applicable to probable future scenarios, in conjunction with any requirements being imposed.

The results imply that the use of Epoch-Era Analysis during conceptual design can most certainly provide invaluable acumen with an inherent capability of increasing stakeholders' confidence in their final choice of design. This increased level of confidence also simplifies their message to the designer, making it much easier to interpret and accordingly optimize the vessel. Through the use of this analysis exogenous circumstances such as technology or market developments otherwise difficult to capture, can be deconstructed and taken into consideration through a more factual perspective leading to lesser risk and higher value.

SAMMENDRAG

Denne masteroppgaven tar for seg I hvilken grad bruk av Epoch-Era Analyse er plausibel under design av den neste generasjons subsea konstruksjonsfartøy (OSCV). Tatt i betraktning at høye oljepriser og avtakende nivåer av lett tilgjengelig karbonressurser, har OSCVer blitt kvalifiserte som både fleksible og kostnadseffektive løsninger i forbindelse med marginale felt. Reduksjonen av "lett" tilgjengelig olje har ført til et push mot mer værharde regioner, dypere farvann og lengre avstander fra kysten. Som følge er markedet og teknologien i konstant bevegelse, noe som følger til nye krav, reguleringer og lovgivninger som kan påvirke skipsbyggingsprosessen.

For å møte disse utfordringene ventes det at designerne tar i betraktning et bredere perspektiv for fremtidige scenarier, samtidig som funksjonalitet og ytelse skal forbedres, og kostnadene minkes. Dette fører til en enorm mengde informasjon som må være inkludert og inkorporert, samtidig som den fremtidige usikkerheten øker jo mer fremtidsrettet en er. I forbindelse med en velkjent tendens mange skipseiere har til å optimalisere et skip mot den første tilgjengelige kontrakten, er effekten av fremtidig usikkerhet vedrørende mulig profitt og kostnader, tradisjonelt sett til en viss grad blitt neglisjert.

Dette verket tar i bruk Epoch-Era Analyse for å illustrere mulige fordeler som spesielt er tilstede under komplekse og høyst usikre forhold. Det har blitt utviklet en rekke kodesnutter som genererer datagrunnlaget for videre analyse som igjen blir evaluert av et program som heter Tableau.

Resultatene av analysen viser et fremragende potensiale denne metoden har for å både forenkle sofistikert og kompleks informasjon, så vel som å konvertere denne informasjonen til verdifull innsikt. Interessehavere kan ta denne informasjonen i betraktning i et mye tidligere stadie og dermed tydeliggjøre sine ønsker og mål, noe som direkte gagner designeren ved simplifisert kommunikasjon og et klarere rammeverk å jobbe innenfor. Nøkkelaspekt inkluderer muligheten til å avsløre og definere hvilke funksjoner og kapabiliteter interessehaverne *egentlig* verdsetter. Som følge kan alle mulige designløsninger evalueres deretter, samtidig som de mest profitable scenariene kan identifiseres og de beste kost-nytte relasjonene funnet. Ved å i tillegg legge på en rekke

føringer kan en også direkte identifisere hvilke design som vil yte best og tjene mest penger under bestemte forhold i takt med fremtidige forventninger.

Resultatene impliserer at bruken av Epoch-Era Analyse under konseptuelt design kan gi betraktelige mengder av merverdi til involverte parter. Høyere grad av forståelse for uklare fremtidige situasjoner, og i hvilken grad slike hendelser vil påvirke gitte design er en sentral fordel som ikke bare bidrar til interessentenes grad av klarhet og tilhørende sikkerhet i sitt valg, men det gjør også jobben til designeren betraktelig lettere ved økt forståelse av hendelseskonsekvenser og et tydeligere rammeverk å jobbe innenfor. Bruken av denne type analyse gir en også muligheten til å modellere eksogene omstendigheter, som for eksempel mulige endringer i markedet eller teknologiske fremskritt som ellers ville være veldig vanskelig å fange essensen av. I konklusjon vil denne metoden bistå til å redusere risiko og øke verdi.

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1 INTRODUCTION & BACKGROUND

"Uncertainty is different from vagueness in that whereas the latter involves the intrinsic indeterminacy of certain terms, the former is concerned with the limitations in our knowledge." (Galton, 2009)

A competitive ship-building industry has an objective to swiftly deliver high quality, complex and customized ships to the global market. Upholding this objective in practice entails an exorbitant number of challenges impacting the design task. And if there is one thing we can be certain of, it would be that the scope and range of future design scenarios, created by the wake of this constant stream of challenges, is uncertain. When designing highly complex offshore vessels, knowing exactly which contexts and scenarios to design for would benefit the designer tremendously. Not only because of the possibility of optimizing potential solutions to a fixed context, but also having the ability of excluding irrelevant variables and parameters that otherwise could impact several aspects of the final product.

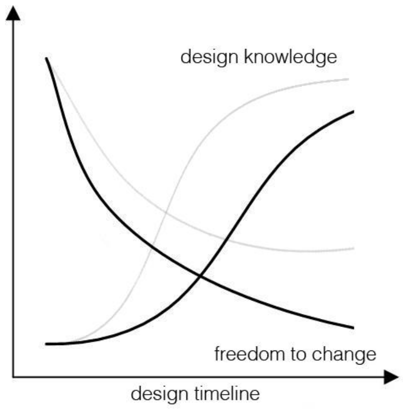


Figure 1 - Design Knowledge vs. Time. Based on (Erikstad, 1996)

In reality, the everlasting flow of information obtained from sources such as stakeholder preferences, performance tests or market analyses, are being utilized to the best of the designers ability by delimiting, partitioning, and employing common reasoning as frequently as possible. The efficiency in which this is performed and interests upheld, can arguably be labeled as relatively inadequate. As such, the object of an efficient design task is to create knowledge as early as possible, without compromising too much freedom as illustrated in Figure 1. Alternatively speaking, maximum flexibility is warranted in order to improve upon vessel parameters and increase performance, while still being able to swiftly acquire detailed knowledge pertinent to vital decision making.

The multi-stakeholder dialogue between owner, operator and designer during early stages is an essential technique in order to verify and mature reasoning pertinent to choice of solution, which methods and tools to use, and how to implement them. This demands a particularly high throughput and density of complex information. Gaspar (2013) highlights the importance of managing relevant information through decomposition and encapsulation, allowing important aspects of the total information flow to be interpreted and utilized in a better way. It is here that Epoch-Era Analysis (EEA) truly becomes useful by effectively mapping all possible interests and design possibilities, combining them with value-oriented assumptions ultimately creating an immense range of potential future scenarios and predicting which affects the consequences will have on their designs. By method of elimination one can very swiftly converge towards plausible solutions giving the expected amount of value to all parties involved and at the same time map different lifecycle scenarios corresponding to a *"what would happen if"* questionnaire of sorts.

One of the key difficulties of implementing changeability in design is the justification of extra costs upon inclusion, as this unavoidably results in either extended periods of development or additional technology requirements. The benefits of changeability are also rendered moot by review in a static context, leading towards a logical favouring of more passively robust systems (Boehm et al., 2013). The EEA framework provides the means with which to instinctively and systematically analyse a system's performance over time and across different contexts. The method was designed to highlight the effects time and context have on system value in a natural and intuitive way. By modelling all possible exogenous circumstances according to a set of predefined designs, lifecycles can be generated, which inherently enables the analysis of value delivery over time for systems under the influence of indeterminate operating conditions.

1.1 Introducing Subsea Construction & the Current Market

The offshore subsea construction market is a market in constant development. A continuing shift towards increased production on the seabed has played a huge role in shaping which directions the industry aims their technological development efforts. As a result, developments and innovations have become so complex in nature that potential effects of one decision could propagate through the rest of the architecture in ways previously not encountered by the designer, in turn, causing large degrees of uncertainty during the conceptual design phase. As opposed to the general engineering thought process of optimizing a design, which directly infers certainty, design flexibility must be invoked to hedge against uncertain changes. The opposite could potentially sub-optimize the result as requirements change when the market fluctuates.

1.1.1 What Defines Subsea?

Construction work under the ocean surface is most often driven by oilfield developments. These developments are divided into several different phases which here will be defined by (1) survey or seismic operations, (2) construction, (3) production, (4) inspection, maintenance and repair (IMR), and (5) De-commissioning. The relevant phases for the scope of this project are production, construction, and IMR, which further can be characterized by operations requiring lifting capabilities to and from the seabed, excavation, trenching of cables and pipeline, installation of flexibles, dredging functions and ROV launching for purposes such as touch down monitoring or site surveys, or well intervention and workover services (Dokkum and Koenen-Loos, 2013). More specifically, terms such as pipeline routing/support, well development/abandonment, flowline and manifold installation and subsea tie-ins are central topics for this development phase. Furthermore, typical capabilities of vessels in this segment consist of relatively large accommodation capacities, helidecks, flat aft work-decks, active heave compensated cranes, moonpools, and sometimes also diving facilities.

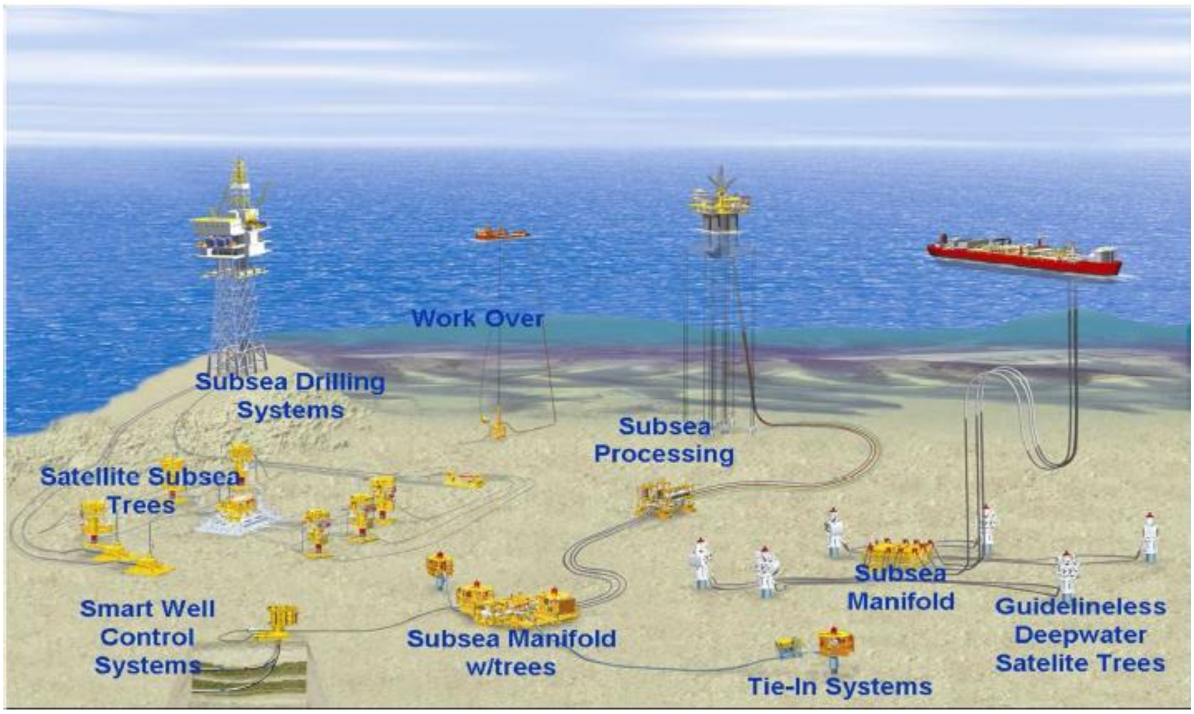


Figure 2 - Subsea Operations (Husby and Søgård, 2011)

As depicted in Figure 2, most subsea operations involve the use of a subsea structure; all of which are driven by the subsea well. The first subsea well was completed by Shell in the Gulf of Mexico in 1961. Since, 140 were operational in 1978, 2404 by 2005 and by the year 2009 an additional 3200 were forecasted to be installed by 2013 (Husby and Søgård, 2011). In other words, there has been an exponential growth of subsea work since the mid-1970s because these types of wells not only can be placed outside the effective drilling reach of existing platforms, but they can be installed faster than the construction time for a platform and they enable less expensive platforms to be installed if flowlines rather than casing risers are tied back to the surface, reducing the platform load.

1.1.2 General Subsea Market at a Glance

Exploration and production (E&P) spending for the oil and gas industry has seen an enormous growth over the past decade, increasing at a compound annual growth rate (CAGR) of 14% from 2000 to 2011 (Mathisen, 2012) and driving a high number of oil and gas discoveries, especially in deepwater regions where subsea development is of high interest.

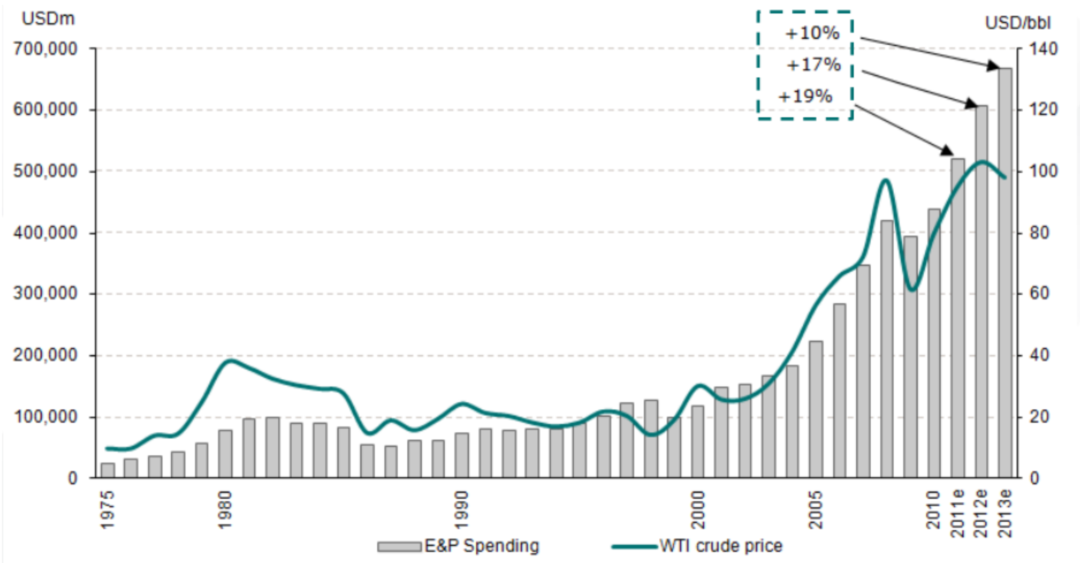


Figure 3 - Expected E&P Spending (Kreutz, 2012)

The high E&P spending is further spurred by oil price estimates above $100/b, which enables large companies in the industry by supplying them with enough leverage to support such investments. According to OPEC's general secretary Lawler (2013) this level is sustainable both from a producer and a consumer standing point which would support Carnegies' oil price estimates in Figure 4.

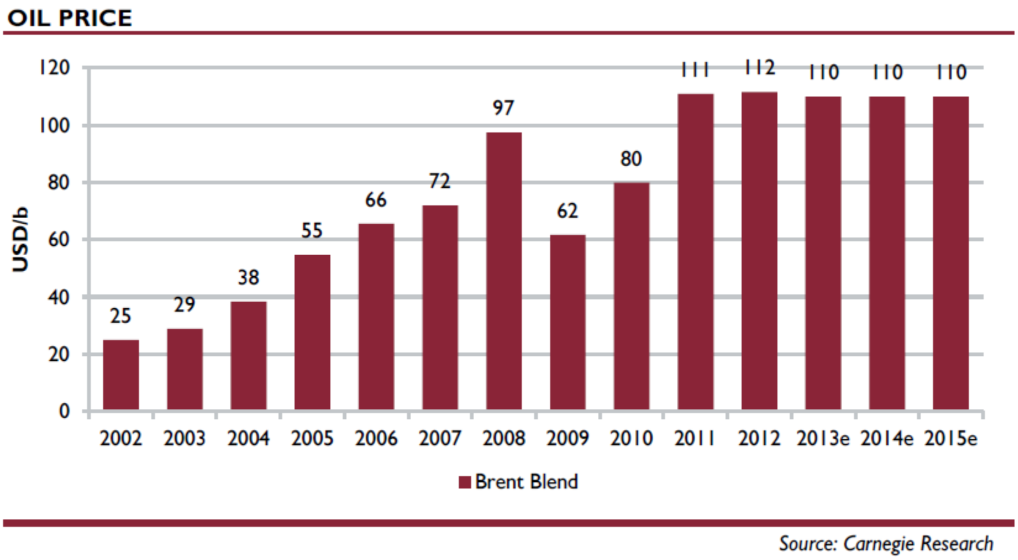


Figure 4 - Oil Price Estimates (Gaard et al., 2013)

Figure 5 illustrates at which rate and amount subsea hubs spending and production is forecasted to grow towards 2020.

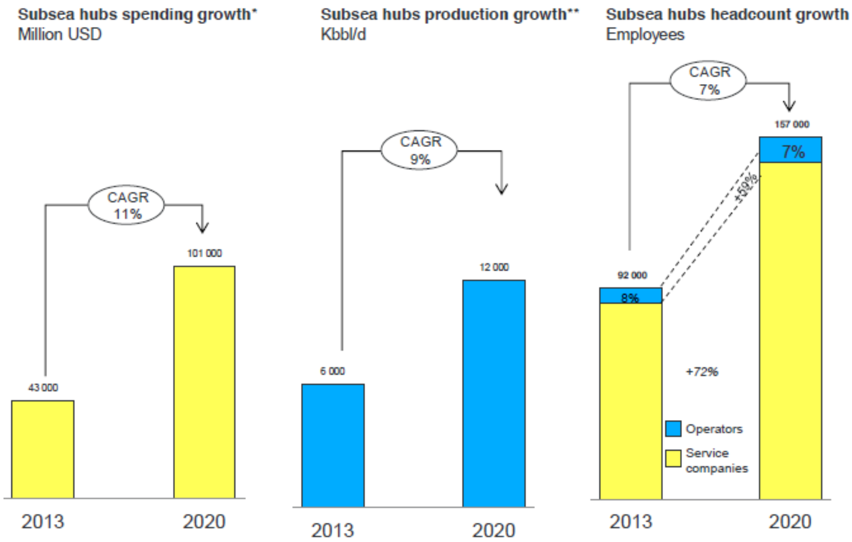


Figure 5 – Expected CAGR Growth Towards 2020 (Rystad Energy, 2013)

Field development is a key driver of the subsea construction market. INTSOK's annual market report from 2012 states that the number of rig deliveries came to a halt after the financial crisis, but has since 2010 picked up speed reaching a peak in 2013 with 70 delivered rigs. Already, there are more than 150 rigs under construction or under firm orders towards 2017. This supports the statement of increased E&P spending and illuminates the bright future this market currently is enjoying. However, the continuation of market growth is highly dependent on new acreage being awarded and specifically, for the subsea construction segment, new acreage should preferably be located in deeper waters, where a combination of floating production units and vast subsea structures are required. These areas are currently dominated by Brazil, Gulf of Mexico and West Africa. Other emerging regions applicable to subsea construction are East Africa, Australia, the Mediterranean and some areas surrounding Indonesia.

1.1.3 Why Subsea?

As previously mentioned the subsea construction market is comprised of many different aspects and components, but the main market drivers for this area can be segmented into three categories: (1) ultra-deepwater (UDW); (2) increased oil recovery (IOR); and (3) inspection, maintenance and repair (IMR). UDW combined with harsh environments pose a risk for oil companies in terms of higher degree of difficulty, which requires extra training and competence. Additional challenges include more stringent HSE requirements to protect workers as well as increased technological demands, both of which drive the development of new equipment that has yet to be proven or qualified to a satisfactory degree. IOR is a result of seismic and technological developments creating new ways of extracting larger and larger quantities from reservoirs previously thought to be unreachable. This has prolonged the production time significantly for many wells previously planned to be de-commissioned up to several decades ago. The prolonged lifecycle of oilfields has also been a key actor, spurring the need for more and more advanced and economically feasible ways of performing IMR operations.

Nevertheless, however certain market drivers are divided or categorized, the main goal will always be profitability. The key differentiator between our current status and a few decades ago are the technological developments, which have enabled cost efficient recovery of oil and gas from deeper reserves in deeper waters further from shore. When this option, in addition, has proven to be feasible at lower cost than many other platform concepts, the industry's growth is secured as long as they can continue to do so.

1.2 The Contribution of Epoch-Era Analysis & the Role of Uncertainty

A monumental challenge in the field of conceptual ship design is the abundance of uncertainty aspects, inherently affecting the quality, robustness, and flexibility of produced designs for different future contexts. Such aspects directly influence the parameters and constraints under which a new design is considered, and not being able to properly interpret those means that the produced design is less probable to succeed in the future.

> *"Current valuations in naval ship design tend to focus on valuing a point designed product. Although there have been efforts to more completely explore the design space for the optimal solution, the optimal solution is based on a fixed set of requirements and preferences. In addition, optimization infers certainty. There is no way in the current system to value adding flexibility to the design, since under certainty, flexibility has no value."* (Gregor, 2003).

As Jeffrey Gregor states above, there is no value in proposing a flexible design when requirements are certain. OSCVs are constantly tasked with a wide-spanned variety of missions, each with varying requirements regarding functionalities and capabilities, and all of them are subject to change over time as technology evolves; climate changes; oil prices vary; political agendas are altered; regulations are appended; and environmental considerations become more stringent. These factors all contribute towards an increased amount of uncertainty, and are just a few of potentially infinitely many others, undoubtedly affecting not only the future utility of current vessels, but also the manner in which future designs are able to cope with a continuous leveraging between flexibility, utility and profitability. By employing the use of Epoch-Era Analysis, such circumstances can (to a degree) be accounted for so that the best possible design, providing value to all involved parties for the duration of its lifetime, can be identified and opted for.

Historically ships rarely fulfill the exact purpose for which they were built because the contract opportunities and mission requirements often change due to their expected long service life. As a result, it has become more and more difficult for designers to keep up with the increasing degree of complexity characteristic to mission requirements and at the same time anticipate the vessels future operating scenarios in order to successfully uphold an adequate utility rate over many years of service.

What all of the uncertainties discussed in this thesis have in common, are that they are imposed as a result of future actions and thusly stand as part of a chronological series. This pertains to the *temporal* aspect, meaning changes over time during a systems lifespan. Epoch-Era Analysis aims to decompose this temporal aspect into isolated and more comprehensible chunks, each exhibiting the capability to model cause and effect of any exogenous circumstance. Theoretically, this enables stakeholders to more efficiently narrow the scope of the design's predicted purpose, consequently increasing the agility with which designers can fulfill it.

It is however important to note that for the purpose of this type of analysis, the scope of uncertainty is limited to what can be deemed as *plausible assumptions*. Meaning a potential scenario involving a coup d'état would presumably fall outside the range of reasonable assumptions and subsequently the scope of this analysis.

Moreover, there is a clear need for development of design methods that can incorporate increased levels of flexibility, robustness, agility and adaptability to not only eliminate superfluous costs during development, but also in order to increase customer satisfaction and value by introducing the ability of handling several types of missions with a single vessel in an efficient manner. This thesis aims to illustrate the most prominent benefits of using Epoch-Era Analysis when attempting to mitigate the consequences of uncertainty in ship design.

Following chapters will introduce the concept of Epoch-Era Analysis and illustrate briefly through a simple case how some of the aforementioned factors can be incorporated. An overview of uncertainty-mitigation methods and how Epoch-Era Analysis complements such methods will also be provided, as well as a comprehensive market analysis serving as basis for the inputs of the final case assessment.

2 INTRODUCTION TO EPOCH-ERA ANALYSIS

This chapter will introduce the concept of Epoch-Era Analysis and provide a very simple example of how it can be used to illustrate the methodology and why it can be an extremely beneficial analysis when used specifically in conceptual ship design. However, to understand what an Epoch-Era Analysis is used for and which benefits and challenges the method poses, an introductory paragraph about the underlying context of this type of analysis is provided in order to allow the reader a more holistic understanding.

Historically, system design is targeted towards a given set of objectives and optimizes them in a given context. For systems that are meant to be capable of delivering value to stakeholders while continuously mitigating risk in fluctuating markets, this method no longer is able to keep up because of the fact that an optimization problem infers certainty. In fact, Carlson and Doyle (2000) suggest that overly optimized designs are quite susceptible to value degradation in the face of varying objectives or contexts. Also regarding the exorbitant amount of complexity inherent in advanced OSCVs and how their systems interact with alterations caused by sudden demands in newer capabilities, it is clear that a method able to model huge amounts of changing variables over time in different contexts is desirable.

Epoch-Era Analysis is an approach aiming to provide visualization and a structured way of representing the temporal aspect of system complexity, i.e. the modeling of plausible alternate future contexts. The full lifecycle of a system is referred to as an *era*, which further can be decomposed into *epochs*. For the duration of a single epoch the context and value expectations are both static, but altering these variables in line with the emergence of alternative scenarios provides the possibility of continuously adapting the system in order to sustain value. Value is here defined by Ross and Rhodes (2008) definition of a moving measure of success as defined individually by system stakeholders and in this sense includes not only technical performance or operational environment, but also stakeholder sets, expectations, available resources, competition and any other exogenous factors that affect perceived value of the system. By utilizing this technique, the ultimate goal is to generate knowledge about tradeoffs, compromises, risks in a development project, and allowing designers and stakeholders to communicate more effectively (Ross et al., 2009).

2.1 FRAMEWORK SURROUNDING THE ANALYSIS

In order to diminish non-quantifiable information and handle aspects of complexity in an efficient manner, Gaspar et al. (2012b) propose the use of the Responsive Systems Comparison (RSC) as a framework surrounding Epoch-Era Analysis. RSC proposes a methodology of handling complexity by decomposing and encapsulating necessary information defining the system, and aims to generate knowledge about tradeoffs, compromises, risks and identifying concepts that are value robust. This chapter will use the RSC methodology as a baseline in order to explain the various aspects of building an Epoch-Era Analysis through describing and discussing each of the processes illustrated in the flowchart below (see Figure 6). Additionally, each process will be highlighted during each correlating section of the illustrative example later on.

Value-driving context definition: identify overall problem/needs statement. This process aims to figure out what the overall value proposition for a design will be. Also taken into consideration should be main constraints, which contexts the design is to operate in and which stakeholders to include. In other words, this initial process should clearly define what the problem is, why it is important, who cares about it, and which types of value are required for a solution to be considered satisfactory over its lifespan.

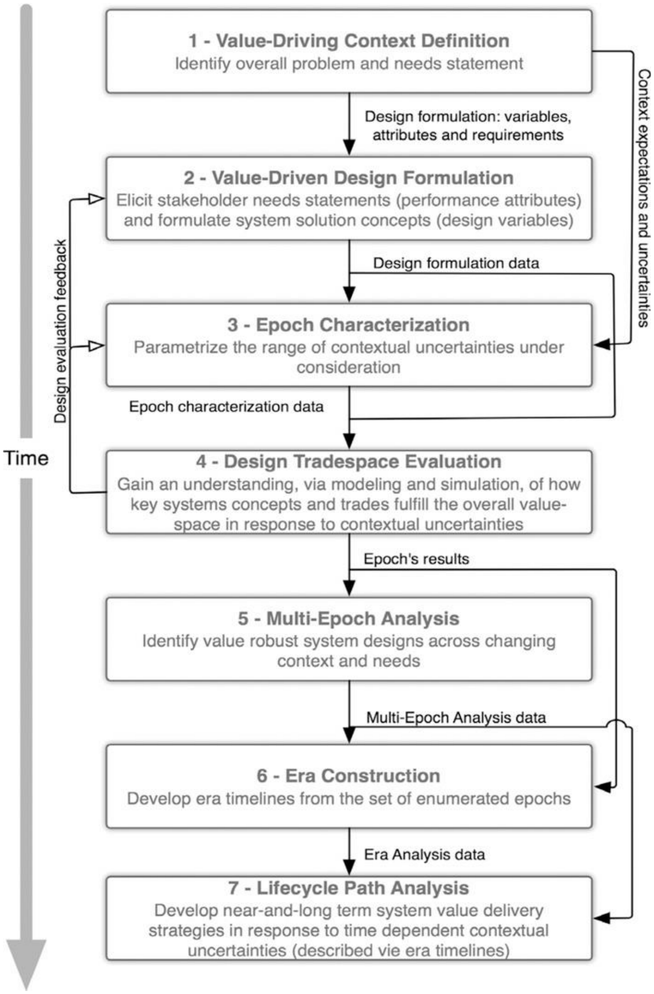


Figure 6 - RSC Methodology (Gaspar et al., 2012b)

Value-driving design formulation: elicit stakeholders' needs statements (performance attributes) and formulate system solution concepts (design variables). It is during this process that the previously defined high-level requirements are broken down into objectives by attributes and variables. The system mission, structure and main performance attributes should be included herein. Firstly, in order to handle both behavioral and perceptual value during this process, a quantification of performance attributes is recommended to include a range based on stakeholders' preferences. This directly reflects the perception of what is acceptable and not in the eyes of the stakeholder. Secondly, the structural aspect should be decomposed into associated design variables driving the stakeholder's expressed attributes. Simply put, this provides the basic mapping between form and function - a basic information design problem.

Epoch characterization: parameterize the range of contextual shifts/uncertainties (epochs) under consideration. This process is about defining which parameters constitute future certain or uncertain contexts. These parameters are called epoch variables and have units, ranges, and discretization levels to provide a mapping between context and vessel performance. Such variables can be comprised of emission requirements, class regulations, operational water depths, or oil prices just to name a few, and at a single static point in time (a snapshot) create a vector of epoch variables, or an epoch.

Design tradespace evaluation: gain an understanding, via modeling and simulation, of how key system concepts and trades (design variables) fulfill overall value space (performance attributes) in response to contextual elements (epochs). During this process each of the proposed design alternatives are evaluated for instance in terms of attributes, utilities and cost. The main function here is to decompose the structural aspect in order to better understand the design space. Typical evaluations include scatter plots of utility versus cost of all designs per epoch, regression analysis, and various optimization methods.

Multiepoch analysis: identify value robust system designs across changing contexts and needs. From the previous process emerges a conceivably large amount of data, which needs to be understood in order to pose any sort of value to stakeholders or designers. This process initiates the organization of data so that the most robust designs can be identified either by accounting for expectations and stakeholder preferences, or performing extensive epoch space searches. Roberts et al. (2009) present techniques such as tradespace yield, distribution of attributes, Pareto Set for a single epoch, and Pareto Trace across epochs. The challenge here is not necessarily locating the best performing design, but making sure that the definition of "best" is aptly represented in the value functions in the previous processes so that the result correlates with each stakeholder’s perception of value.

Era construction: develop era timelines from the set of enumerated epochs. As previously mentioned an era is constructed from several epochs, but since a single era represents one specific possible lifecycle certain consistency rules such as continuity and appropriate technology evolution, must be obeyed.

Lifecycle path analysis: develop near- and long-term system value delivery strategies in response to time-dependent contextual elements (described through era timelines). This last process enables the designers to understand the implications of possible shifts in eras in terms of modification costs and benefits to sustain value over time. This is done by first defining which design variables can be changed during the operational lifecycle given a cost. The result must then be analyzed based on the stakeholders' value-driven context definition established early on.

2.2 Epoch-Era Example Illustrated Through RSC-Methodology

In order to fully understand the concept and scope of a simple Epoch-Era Analysis (EEA) a simple yet illustrating example of an offshore vessel will here be discussed within the proposed RSC framework. This example will utilize an overly simplified case for an OSV operating a fixed mission type and the variables and parameters will not represent a complete picture of an actual realistic scenario. It will, however, suffice in order to illustrate some of the most prominent benefits and challenges of performing an EEA. It is also important to note that this is not a definitive or closed method. The RSC framework is used to handle the flow of information, but the method as a whole can be expanded to include other possibilities such as real options (value of designing a vessel with an easily accessible option of adding or altering functionality at a later stage in the vessels lifecycle, see chapter 3.4.2 for more), or other simple changeability analyses (considering changes in design over time). Additionally, it is important to keep in mind that the underlying motivation for utilizing the EEA method is to better mitigate arising challenges associated with increasing levels of complexity.

2.2.1 Value-Driving Context Definition

In order to sufficiently simplify this introduction the design problem is here limited to a single mission type and the only varying context variables (epoch-variables) will be the place in which they operate in and whether or not the area is regulated as an emission control area (ECA). Each contract is considered a mission to take place in one of the specified regions, which either is regulated as an ECA, or not. To supplement the amount of epoch variables almost bordering towards banality, some assumptions have been made to slightly increase the complexity, which will be further explained during the design formulation in the next subsection.

The value driving design question is thusly to which degree the ship owner wishes to target specific geographic regions and if the vessel should be ECA compliant or not.

2.2.2 Value-Driving Design Formulation

It is during this phase that the basic mapping between form and function takes place. In other words, the general requirements generated in the holistic context definition of the previous subsection are to be broken down so that the stakeholders' objectives can be quantified based on their needs.

Normally, the mapping between form and function requires intrinsic knowledge of the design process, but in our case, because the high-level requirements are discrete and only related to aspects with minimal influence to major design alterations, the stakeholder's desired performance attributes are in no need of a range of acceptable levels. The resulting attributes require only a yes or no answer as opposed to, for instance, an interval of acceptable availability levels or the range of an acceptable cargo area. As a result, the tradespace evaluation will only be able to determine whether a given design is applicable or not and as such cannot quantify the value of the resulting design on a continuous scale to give us a more complete picture.

Design Variables			
Variable	**Unit**	**Range**	**Levels**
Ice Class	Class	yes/no	2
X-bow	Bow Shape	yes/no	2
ECA	Control	yes/no	2
		Design Space	8

Table 1 - Design Variables

Table 1 shows the chosen design variables for this case. Each variable has been chosen to specifically impact at least one of the epoch variables that are to be presented in the next subsection. The number of variables has been kept to a minimum in order to keep this introduction example as simple as possible.

2.2.3 Epoch Characterization

This phase of the RSC methodology takes all external factors that can potentially have an impact on possible contracts into account. Figure 7 illustrates how the contextual aspect can be affected by external factors and some of the most common variables.

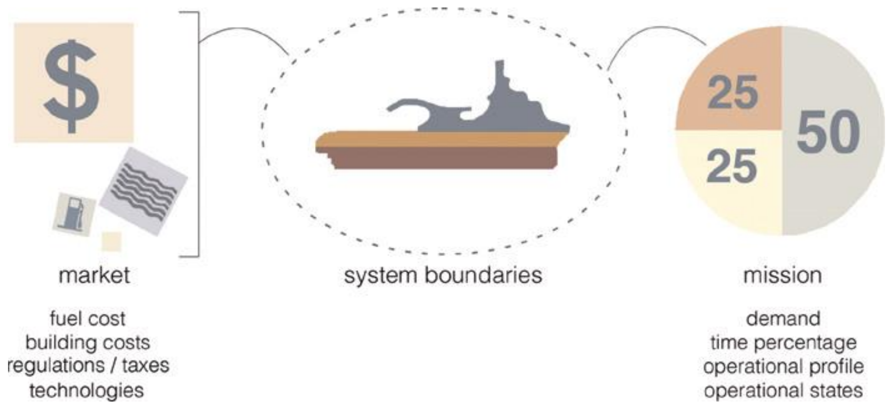


Figure 7 - Contextual Aspects (Gaspar et al., 2012b)

Table 2 shows the epoch variables that this case will be subject to. These are simply based on popular offshore regions which each infer different capability requirements. The chosen regions are Brazil, the North Sea, and the Arctic. The assumptions, or inferred capability requirements, consist of the North Sea having a larger impact on fuel consumption caused by harsher weather conditions, and that in order to operate in the Arctic region the vessel must have a sufficient ice-class which also will increase fuel consumption by way of added weight inherently increasing hull resistance. Brazil is assumed to have no specific impact on either fuel consumption or hull requirements.

Epoch Variables			
Category	**Unit**	**Range**	**Levels**
Place	Field	Brazil (no waves)	3
		North Sea (waves - +10% fuel)	
		Arctic (ice)	
Environ.	Control	None	2
		ECA (must comply)	
		Epoch Space	6

Table 2 - Epoch Variables

An additional category of environment has also been added in order to supplement the contract detail with an element based purely on stakeholder interest and probability as opposed to requirements set by region, which directly can affect a design's performance. By adding this variable, the value of a design will fluctuate according to the stakeholder's interests. This is to illustrate the effect of perspective contrary to structurally optimized designs. In other words, even though a design is structurally optimized to be a *better* vessel, another vessel could potentially create higher value for a customer who *thinks* he will not need an ECA-compliant design, for instance. To illustrate this phenomena some numbers from the Epoch Analysis performed at a later phase have here been included to create a perception based value distribution shown in Figure 8.

#	All Designs	No ECA	No Arctic
1	32%	63%	48%
2	45%	90%	43%
3	33%	66%	50%
4	47%	93%	45%
5	63%	63%	95%
6	93%	90%	90%
7	66%	66%	100%
8	90%	93%	86%

Figure 8 – Perspective Based Value

As can be seen from the figure above design #5 and #7 show large variations in value according to whether the owner would like to incorporate arctic capabilities in the vessel or not. The method regarding how these values are calculated will be presented in the next subsection.

2.2.4 Design Tradespace Evaluation

The objective of this phase is to evaluate the design space for each possible epoch through various methods of modeling or simulations. This is done to ensure that the designs in question are evaluated in accordance with specific mission requirements. In this case, the mission requirements are overly simplistic purposefully in order to properly separate each phase within the RSC methodology, and convey each of their corresponding values. By defining a single mission, only varying by geographical location and emission requirements, the amount of technical intricacy is reduced to an almost banal state. Nevertheless, decisions can still be modeled and simultaneously related to real life applications.

In order to evaluate the limited number of possible designs over the few defined epoch variables in this case, a set of assumptions have been made in order to quantify a few additional measures of performance. In addition to requiring ECA-compliant or ice-classed vessels in order to travel to ECA-controlled and arctic areas respectively, rough estimates of fuel costs and capital expenditures (CAPEX) have been added. The assumptions for the epoch variables have been mentioned earlier and are listed in parenthesis in Table 2. Regarding expenditures the capital cost for each design variable has been assumed as 100% for a design with no additional capabilities (see design #1 in Table 3). For each additional capability, i.e., ice-class, X-Bow and ECA, one can add 20%, 5%, and 20% respectively to the total CAPEX.

Regarding fuel consumption, it is assumed that the X-Bow will reduce consumption by 10% in harsh wave conditions, i.e. the North Sea, and being ice-classed will add 10%.

Design space				
#	Ice	X-Bow	ECA	CAPEX
1	-	-	-	100%
2	√	-	-	120%
3	-	√	-	105%
4	√	√	-	125%
5	-	-	√	120%
6	√	-	√	140%
7	-	√	√	125%
8	√	√	√	145%

Table 3 - Design Space

Epoch Space		
#	Field	Control
A	Brazil	None
B	Brazil	ECA
C	North Sea	None
D	North Sea	ECA
E	Arctic	None
F	Arctic	ECA

Table 4 - Epoch Space

Following the logic of each design (Table 3) across the range of possible epochs (Table 4) and at the same time considering the underlying assumptions, the Epoch Analysis is created (Table 5).

Revenue						
#	A	B	C	D	E	F
1	100%	0%	90%	0%	0%	0%
2	90%	0%	81%	0%	100%	0%
3	100%	0%	99%	0%	0%	0%
4	90%	0%	89%	0%	100%	0%
5	100%	100%	90%	90%	0%	0%
6	90%	90%	81%	81%	100%	100%
7	100%	100%	99%	99%	0%	0%
8	90%	90%	89%	89%	100%	100%

Table 5 - Epoch Analysis

Design #1 performing in epoch A is the benchmark because there are no additional costs for capabilities or requirements from epoch variables. Because this fulfills all requirements, the revenue of this specific design-epoch combination is rated at 100%. In addition, because the North Sea is assumed to increase fuel consumption by 10%, the revenue can never be higher than 100% unless the value function is altered. Cells containing 0% are not applicable because they do not fulfill needed requirements such as ice-class for arctic travels or ECA-compliance.

2.2.5 Multiepoch Analysis

It is during this phase that the identification of the best designs according to the value function are to be undergone. A frequently used form of identification shown in Figure 9, the Pareto Frontier, highlights the best technical designs while at the same time reflecting stakeholder interests via the value function defined during the earlier phases. It is also here one of the main challenges of Epoch-Era Analysis lies; namely the correct representation of stakeholder interests. The visualization itself does not pose any insurmountable obstacles, but it is the definition of what constitutes value that often will serve as a source of insecurity. In order to visually convey the many aspects of vessel designs a discretization of information is often necessary when capturing stakeholder's interests, which subsequently could lead to marginal generalizations. These generalizations, however few they may be, by manipulating information they diminish the specificity of the original source. Taking this into account, as well as the fact that stakeholders may very well change their interests during a conceptual design process, would be a monumental task to solve completely. However, it is currently more than adequate as a decision support tool, as long as the epoch analysis captures the stakeholder's perception of value in a sufficient manner.

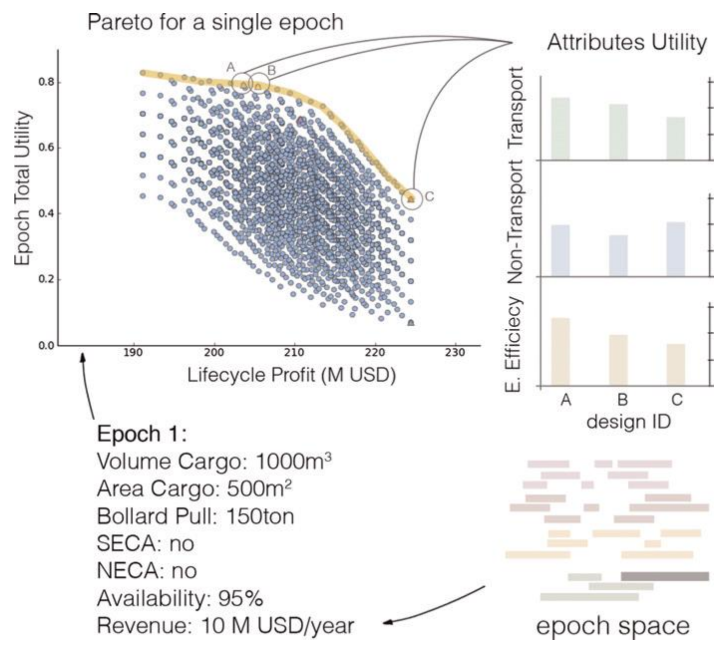


Figure 9 - Pareto Frontier (Gaspar et al., 2012b)

As defined in section 2.2.1 the value-driving context in this case is whether the stakeholder would be able to operate in specific geographic regions with or without ECA-compliance, and to which cost each solution is proposed. In other words, the more regions a specific design is capable of operating in while complying with ECA regulations in a cost-effective manner, the more value is created.

Because this introduction case has a relatively small tradespace, the result from a multiepoch analysis could simply be the average value a design provides over different epochs. Thus, adding a dimension of perspective gives us the possibility of evaluating a design across epochs given a criterion. In this case, the perspectives of not needing to be ECA-compliant and not needing to travel in Arctic conditions have been added as dimensions. As previously mentioned, Figure 8 illustrates the average value for each design. Shown below in Figure 10 is a more visual interpretation of each perspective, supplemented with the total CAPEX for each design. The graph clearly shows that designs #1-4 create a higher degree of value if the owner decides that ECA-compliance is not of significant importance. Furthermore, designs #2 and #4 are almost maximally valued because of their arctic capability, and if for instance the owner would like to have an option of accepting contracts in arctic areas, but does not need to venture into ECA regulated areas, these designs would be proposed. The only difference between the two is the X-bow on design #4. This feature adds 5% CAPEX, but if the vessel is to operate in harsh wave conditions over periods in its lifetime, the increased amount of initial spending would most likely create a positive return on investment quite quickly.

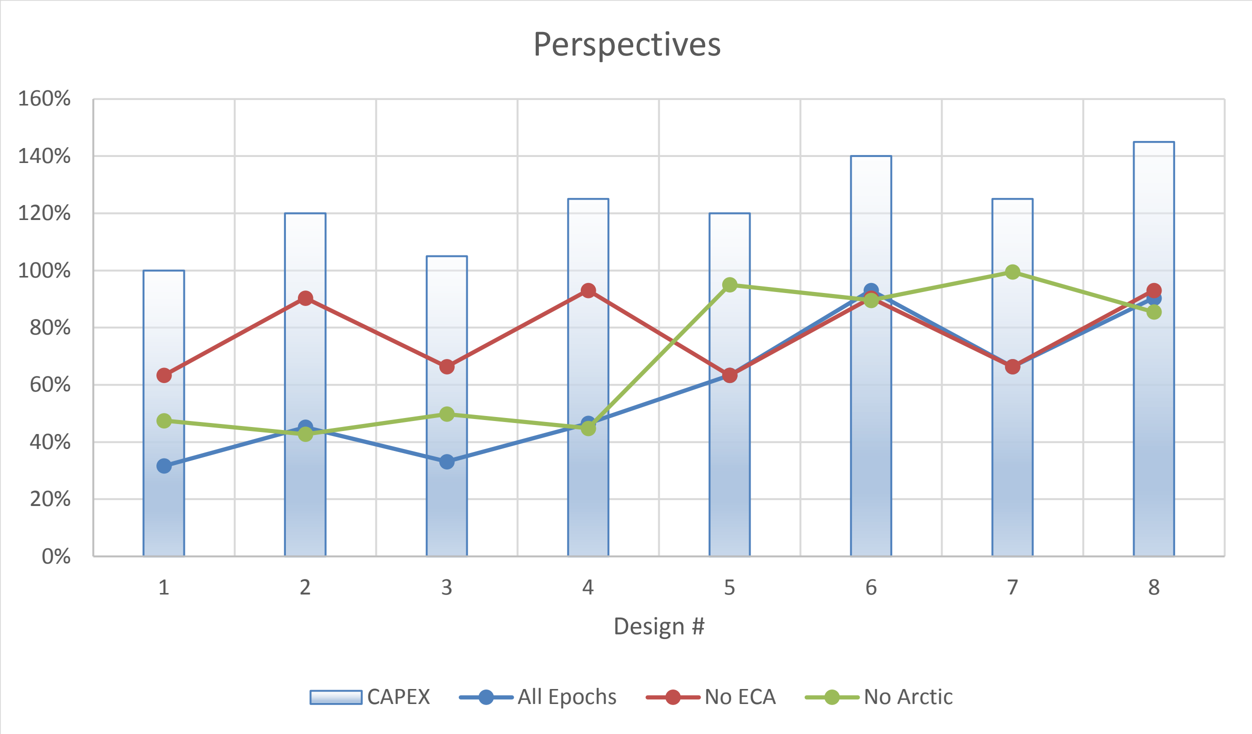


Figure 10 - Perspective Based Multiepoch Analysis

The resulting value of these calculations is based on an arithmetic mean for simplicity, but a typically used measure of value is the utility with which each attribute is appreciated. This is best utilized when epoch variables or design attributes have many possible values and can be categorized by perceptual value. Combining this and a form of economic dimension such as lifecycle cost/profit stands to effectively illuminate valuable designs.

2.2.6 Era Construction

In the previous subsection the main goal was to identify value robust designs across varying contexts. During this phase of the EEA analysis, much of the same principles exist through attempting to identify valuable designs, however this time with much less ambiguity. The purpose of this phase is to construct a lifetime comprised of many different time-ordered epochs with the accompanying constraints, and yet again find a measured output value.

This process is typically computationally demanding if one is to evaluate all possible epoch combinations. Therefore, a more subjective and simplistic construction method often used is the storytelling approach. This narrative approach allows one to manually construct a vessel's lifetime by simply selecting the epochs that are either most worthy of investigation, or the most plausible, to sew them together and create a timeline comprised of many different epochs. Various probabilistic methods can also be incorporated in this phase to weight certain expectations, but in this case the storytelling approach is applied.

To compare, two different eras have been constructed by aggregating three different contexts in time, or epochs.

Era	**i**			
Contract:	**I**	**II**	**III**	
	Brazil	North Sea	North Sea	
	ECA	ECA	ECA	
Epoch	B	D	D	Revenue
Designs				
1	0 %	0 %	0 %	**0 %**
2	0 %	0 %	0 %	**0 %**
3	0 %	0 %	0 %	**0 %**
4	0 %	0 %	0 %	**0 %**
5	100 %	90 %	90 %	**93 %**
6	90 %	81 %	81 %	**84 %**
7	100 %	99 %	99 %	**99 %**
8	90 %	89 %	89 %	**89 %**

Table 6 - ERA I

Era	**ii**			
Contract	**I**	**II**	**III**	
	Brazil	Arctic	Arctic	
	ECA	None	ECA	
Epoch	B	E	F	Revenue
Designs				
1	0 %	0 %	0 %	**0 %**
2	0 %	0 %	0 %	**33 %**
3	0 %	0 %	0 %	**0 %**
4	0 %	0 %	0 %	**33 %**
5	0 %	0 %	0 %	**33 %**
6	90 %	100 %	100 %	**97 %**
7	0 %	0 %	0 %	**33 %**
8	90 %	100 %	100 %	**97 %**

Table 7 - ERA II

The assumptions for ERA I are that environmental regulations will have a widespread governance, with which the owner would like to comply, and that the operational areas are strictly restricted to Brazil and the North Sea. As for ERA II, the first contract is assumed to be in Brazil at a time when ECA-compliance is mandatory, and the following contracts are to take place in the arctic in which the last one will be ECA-regulated. A representation of 0% means that the design does not meet the minimum requirements of an era. Visualizing this graphically leads to Figure 11.

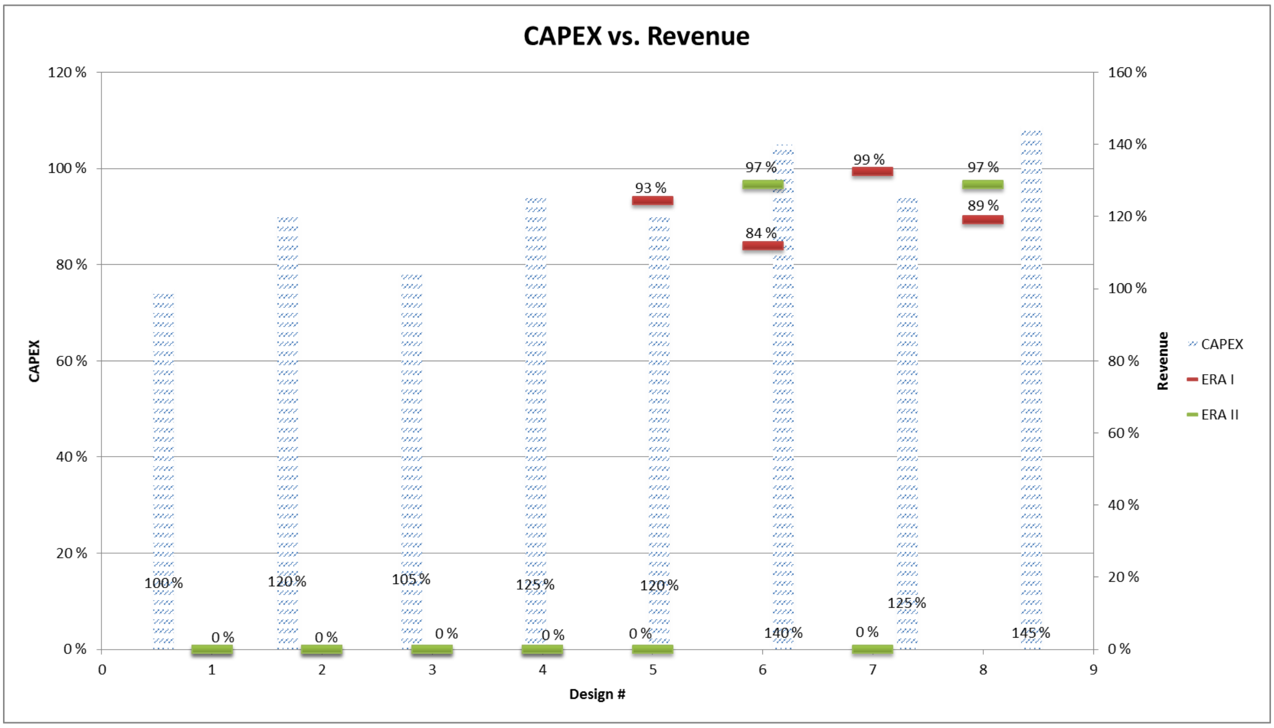


Figure 11 - ERA Construction

Here, the collective revenue per design is represented in conjunction with the respective CAPEX in order to evaluate the total value, given the context of each era. Simply told, one can see that if ERA I is opted for, design #7 would be the most proficient choice if a 125% CAPEX is acceptable. The only other realistic option would be design #5, which has a value decrease of 6% and only a CAPEX reduction of 5%. It also clearly eliminates designs that do not comply with requirements and therefore are not applicable.

2.2.7 Lifecycle Path Analysis

The last phase of the resource comparison method focuses on highlighting the factors that contribute to value robustness. Moreover, an evaluation of tradeoffs, compromises, and alterations gives both the designer and stakeholders a broader foundation with which to base their final decision upon. The typical approach, already instigated in phase four – the tradespace evaluation – begins with an evaluation of the multi-objective space consisting of utility and some form of economic dynamic (typically lifecycle cost or revenue). This is done in order to identify the non-dominant solutions that provide high utility at low cost. Then, after being modeled through various contexts and timelines in phases five and six, the resulting information provides a sense of clarity as to how various futures will impact a specific design. However, the question that still remains is what will happen if a design is altered underway, and what will then the cost be? Henceforth, this final phase is all about comparison of solutions and time-based strategies to uncover which options the designer has for providing added functionality early on, and have the potential to become value contributors later in the lifecycle.

In our case, an interesting situation to investigate could be what the difference in initial costs and estimated revenue would be between having an ice-classed vessel and operating in a non-ECA regulated Brazil for a period of two contracts and subsequently receiving a high-yield contract in the Arctic (ERA II), as opposed to one without ice-class being incapable of accepting and therefore having to accept a North Sea contract with ECA regulations (ERA I) provisionally. Figure 12 illustrates this situation.

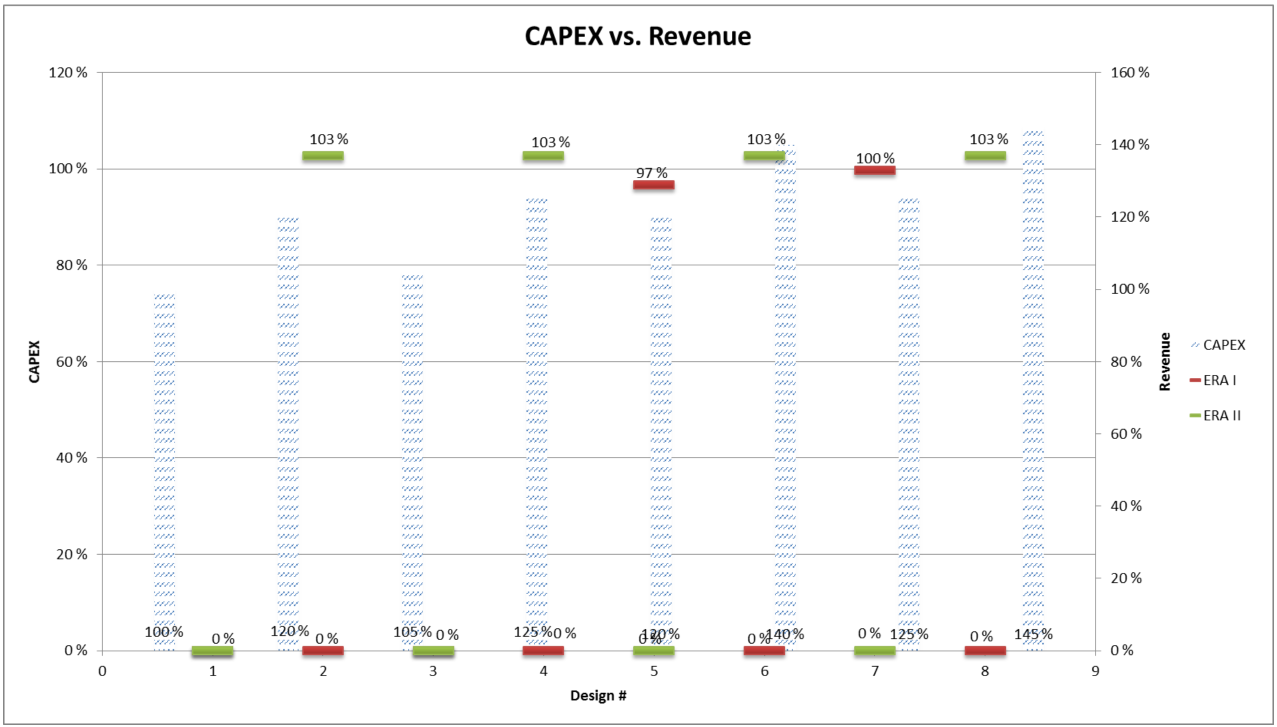


Figure 12 - Lifecycle Analysis

Here it is assumed that as a result of the arctic contract and increased risk, ERA II will increase its lifetime revenue by 10% compared to a North Sea contract. The Arctic is assumed to be non-ECA regulated. First off, one can observe that the arctic capable vessels all provide the same yield, which is higher than any of the competing designs in ERA I. This means that the obvious choice is dependent only on initial cost, given that the contract proposals are already known at the time of design, which turns out to be design #2 with the lowest initial expenditure of 120%.

Another scenario of interest could be whether one would see a positive ROI by adding the functionality of an ice-class only after the first two contracts are completed. The assumptions in this case are that the vessel is to have its first contract in Brazil, second in the North Sea, and last in the Arctic. None of the areas are ECA-regulated and the cost of upgrading the vessel is assumed to be 5% higher than the original estimated CAPEX because of extra downtime and labor during the vessels operational lifetime. Figure 13 depicts this situation.

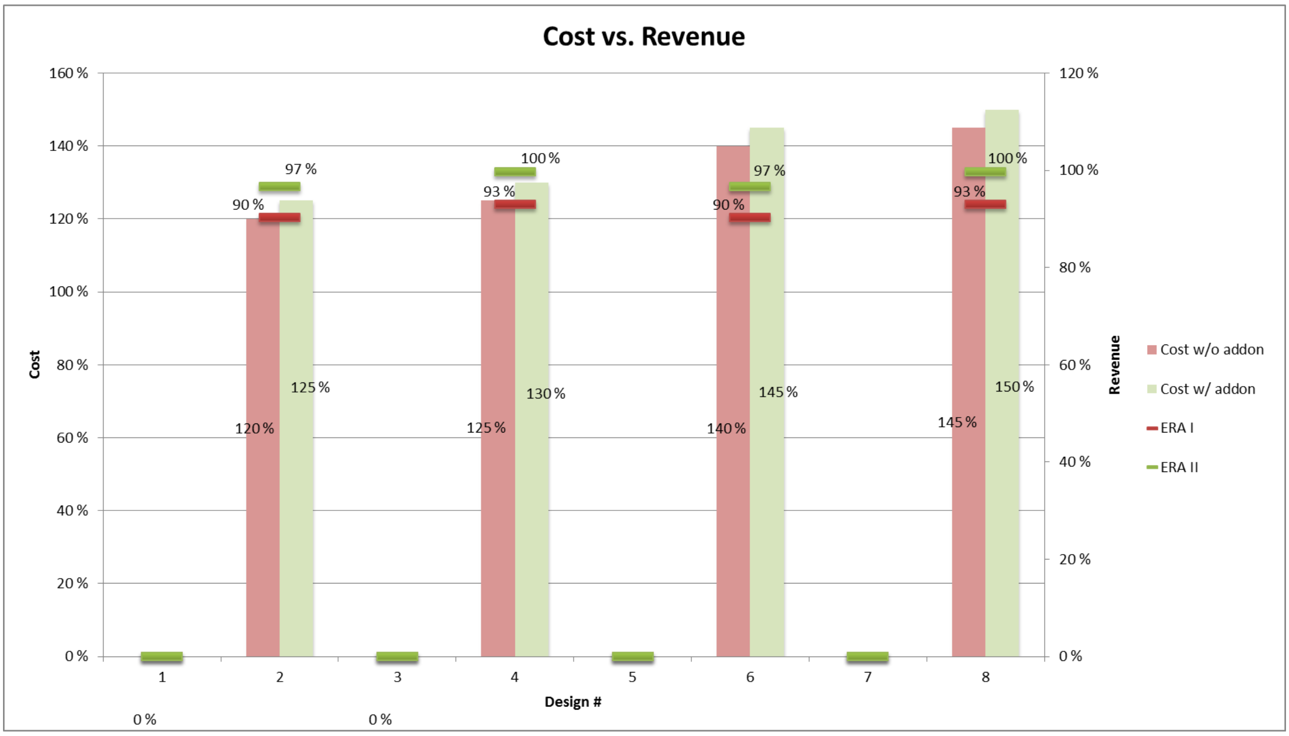


Figure 13 - Capability Upgrade Estimate

The obvious choice here fulfilling all requirements and providing the smallest differential between the two era's revenues and the lowest costs, both with and without add-on functionality, is design #2. The increased revenue results in ERA II come from the reduced amount of consumed fuel caused by less hull-weight without an ice-class.

The numbers presented here are only for illustrating purposes, and would obviously be dependent on the actual price-range since the representation is based solely on percentages, resulting in a relative comparison. Having an ice-class as add-on functionality is not completely plausible as such an upgrade would require vast amounts of changes to the vessels structural build, heating arrangements for fuel tanks and ballast tanks, just to name a few. Additionally, there are an immense amount of other considerations to be made that could potentially have an impact on the feasibility of such add-on functionality projects, such as the topside layout, hydrodynamics, acceptable downtime, expected return on investment, and so on.

3 Navigating Uncertainty

This chapter aims to present some of the main contributions that have been made in the field of Epoch-Era Analysis and additionally provide an overview of other relevant methods that could potentially add significant value by providing flexible design solutions with an increased ability towards subsiding the effect of uncertainty in conceptual ship design.

3.1 History & Application of Epoch-Era Analysis

It was Adam Ross and Donna Rhodes at the Massachusetts Institute of Technology who can be said to have pioneered Epoch-Era Analysis. They have co-authored many publications and have evolved their methods through a systems engineering perspective of mitigating complexity. Traditionally the approach would be to optimize the system with regard to a set of system objectives, as defined in a given context. In a world of constantly changing contexts, however, such an approach is not value robust and would not be capable of delivering sustained value to stakeholders over time (Ross, 2006).

In order to understand system changeability across a system lifespan, quantification is a necessary step and a rational approach to comparing many different systems is through a tradespace (Ross and Hastings, 2005) (see also section 2.2.4). This method by itself had been used in traditional system engineering, but typically more oriented towards a static context. Realizing that a dynamic tradespace exploration could help realize value robust solutions was the beginning of a temporal parameterization of tradespaces, known as Epoch-Era Analysis (Ross and Rhodes, 2008).

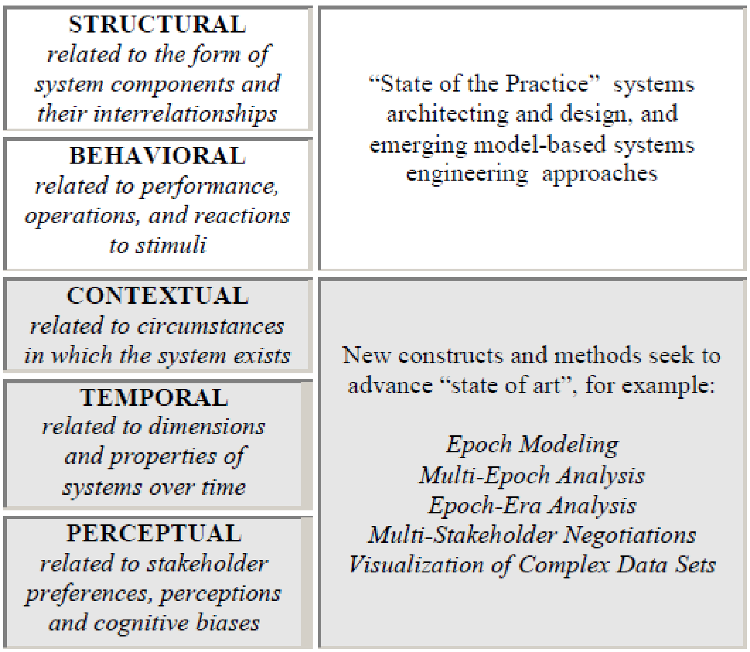


Figure 14 - Five Aspects of Complexity (Rhodes and Ross, 2010)

Later, a framework was developed in order to capture more aspects of complexity than previously thought possible, as shown in Figure 14 (Rhodes and Ross, 2010). Not only did these added aspects contribute towards elaborating existing method and structuring current taxonomy, but it also highlighted the possibilities of temporal analysis, which previously has been notoriously difficult to decompose adequately into analytically eligible segments.

Epoch-Era Analysis has since been adapted towards utilization in conceptual ship design by Stein Ove Erikstad and Henrique Gaspar through several publications illustrating proof-of-concept with regards to Epoch-Era Analysis' applicability in a naval context (Gaspar et al., 2012a, Gaspar et al., 2012b, Gaspar et al., 2012c). The papers orbit various topics of the method's usability in the maritime industry, and touch upon a general AHTS design application and the plausibility of incorporating an optimization algorithm supporting the concurrent identification of the optimal ship design and the corresponding optimal deployment of the vessel, the Ship Design and Deployment Problem (SDDP). Both practical cases clearly illuminate the potential benefits through identifying the most value-oriented and profitable solutions by examining realistic circumstances with a set of rudimentary parameters.

Moreover, and towards a more relevant purpose for this thesis, Gaspar et al. (2012b) applied the complexity mitigation method presented in Figure 14 and combined it, as mentioned earlier, with an Epoch-Era Analysis of an AHTS. Presenting through the Responsive Systems Comparison methodology, the analysis took into consideration a range of common attributes such as availability, fuel consumption, cargo area, CAPEX, L/B and B/D ratios, and so on. Ultimately the paper concludes that *"… the designer is able to address the additional information that nowadays is necessary to identify a good design, that is, a value-robust one"*. It also sheds more light towards the role of uncertainty in conceptual ship design and the process of developing robust solutions in parallel with stakeholder discussions at a very stage.

As the general purpose of an Epoch-Era Analysis is to simplify the interpretation of a complex temporal problem in a dynamic context, this type of analysis can potentially be utilized to simplify any design problem involving a set of potential products given a reasonable amount of future contextual uncertainty. It does however come to its own when used in conjunction with very complex problems entailing vast amounts of information needing to be condensed, visualized, and interpreted.

Ross et al. (2009) perform an EEA on a satellite radar system, quantitatively analyzing the impact of changing contexts and preferences based on "best" system designs for the program. Several thousand design-alternatives were evaluated according to their ability to meet imaging, tracking, and programmatic expectations. The conclusion reads *"while insights on tradeoffs are discovered within a particular epoch, further dynamic insights become apparent when comparing tradespaces across multiple epochs"*.

Further research of Epoch-Era Analysis includes an examination of its role with regards to sources of uncertainty and how it opposes a traditional Monte Carlo Simulation (Rader et al., 2010) and a case-based scenario evaluation for selecting affordable system concepts within naval ship design (Schaffner et al., 2014).

3.2 Relating Uncertainty During Conceptual Design to EEA

It is widely accepted that during the conceptual design phase of ships, the majority of performance characteristics and up to 80% of the total lifecycle cost for a vessel already has been determined at this stage despite the fact that normally only between 5-8% of the total cost has been expended (Gaspar, 2013). Making a mistake at this time can quickly lead to costly compensation measures in the future, which promptly employs decision makers to use caution when evaluating which features and capabilities to incorporate into designs. Minimizing risk is often regarded a priority in this context, and as a result a tendency to favor the optimization of features for the first available contract may very well often be the case. Such rationale masks the effects alternative future contracts and scenarios will have on the current developed design, and because of that it is extremely important to uncover and decompose as much of the uncertainty as possible.

A long lasting mentality regarding the design of complex offshore vessels has been illustrated in Figure 15 by Gaspar (2013). This concept identifies the desire to build the best possible ship by optimizing behavior characterizations (function) through structural elements (form). However, since the methodology of optimization infers certainty, the factors of an uncertain future remain, leaving the possibility of inflicting serious damage to perceptual value should an unforeseen circumstance arise at a later stage of the vessel's lifecycle.

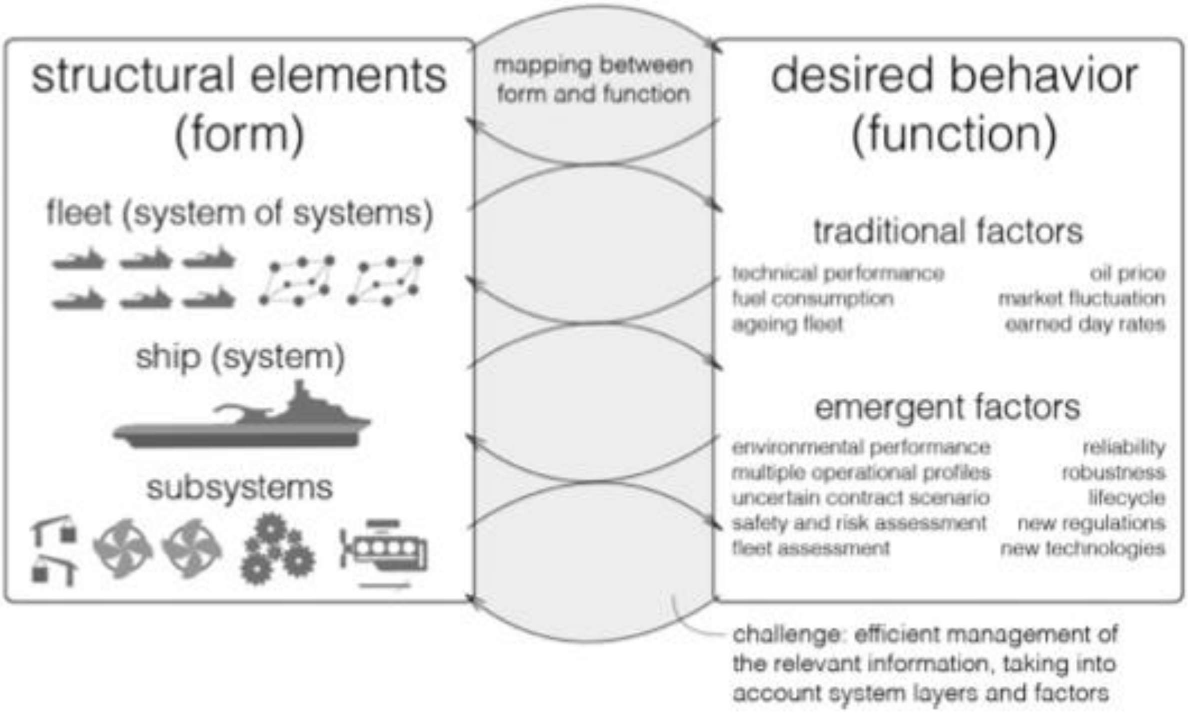


Figure 15 - Mapping Form and Function during Conceptual Design (Gaspar, 2013)

As Epoch-Era Analysis deals mainly with the temporal aspect by decomposing potential contextual changes, this feature adds a dimension currently lacking in the mapping between form and function, namely a holistic overview of the potential effect of decisions made at the present. As engineers constantly face an increased level of pressure to create innovative solutions as quickly and cheaply as possible, this feature could provide them with a needed capability of exploring more opportunities and enabling a deeper knowledgebase.

3.3 Methods of Accounting for Uncertainty

Here a condensed overview of methods most prominently used in the literature are presented to supply the reader with a context within which to place this type of analysis, and additionally how EEA is positioned accordingly.

Conceptual design, regardless of application or industry, is constantly tormented by sources of uncertainty surfacing from design requirements, boundary conditions, stakeholder interests and much more. Uncertainties arise mainly from two categories: endogenous and exogenous, respectively meaning uncertainty relating to modeling and performance, and uncertainty according to unknown future changes in context. Endogenous sources are inherent in most software packages and mathematical models trying to replicate real-life systems by estimation, and the exogenous factors can be explained through an unstable economic and political environment, potential shifts in technology, competition or market positions, and general changes in operating context. Panetta et al. (2001) suggest that 60-80% of all system errors can be tallied up to a failure of adequately identifying user requirements.

Historically, an abundance of developed methods for handling uncertainty can be divided into three general segments: qualitative, semi-quantitative, and quantitative methods. Qualitative methods include ranking and sorting of events into risk-prone classifications, morphological analysis, and scenario planning, seeking to forecast the likelihood of future events. Semi-quantitative methods often generate margin and parameter estimates based on historical data, and also quantify risk based on technological maturity and experience. Finally, quantitative uncertainty categorization methods seek to generate statistical functions correlating to a distribution of outcomes, also called probability density functions. Herein lies common types of analysis such as fault tree analysis (FTA), failure mode and effects analysis (FMEA). Taking this course of action usually yields powerful insights, but is nevertheless unlikely to account for all possible events. Epoch-Era Analysis is a quantitative method with a unique ability to simplify the temporal system value and decompose a system's lifecycle into sequential epochs. Ultimately, in a statistical sense, this method attempts to quantify the value of each possible scenario given future uncertainty.

3.4 Complimentary Approaches

The methods described herein are not directly aimed towards the mitigation of uncertainty, but contribute towards the same purpose nevertheless and are therefore worth mentioning for the scope of this thesis.

3.4.1 Modularization

The term modularization is used in several fields of study, each containing slight nuances in connotation. The basic commonalities can however be said to include a division of a larger system into smaller parts with the ability of self-sufficiency to a certain degree, and the amalgamation of the subsections into multiple end products (Erikstad, 2009).

The practice of this concept with regards to shipbuilding often is referred to during the production and installation phases, and encompasses a certain degree of mapping between form and function. The relationship between form and function in a modularization setting pertains to how on board capabilities can be exchanged, without infringing too much upon spatial alterations or interaction between neighboring functions. During these parts of the building process a modular approach could support a higher degree of production efficiency through topics such as parallel production and material management, and in addition ease the exchange of components both during production and after the commencement of operations. This is however besides the scope of this thesis where an application closer to conceptual design will be investigated.

In the past many highly customized vessels, or “one-offs”, have been constructed for specific purposes, undoubtedly resulting in higher investment costs than a more generalized vessel comparable in capability and size. As unique vessels may propose significantly higher degrees of stakeholder value for customized operational purposes, this strategy is certainly a viable option in some cases, but in the bigger picture a cheaper vessel with interchangeable capabilities and functionalities will be attractive for a broader audience. Some general benefits from modularity are customization and variety, reduced lead time when responding to tender invitations, increased efficiency, and reduced risk. On the other side, obvious drawbacks include a less optimal physical layout resulting in increased weight and size, and a less optimal performance. As such, the introduction of modularity during the design phase will always involve a tradeoff between the value of interchangeability and diminished operational optimization.

For the purpose of conceptual design of OSCVs, the modularization technique has been applied significantly less than for standardized tonnage. This may be a result of highly specific constraints set by the owner, drastically increasing the relational complexity between systems and components. Additionally, Erikstad (2009) indicates that complex shipbuilding has a tendency to prefer individual projects over long-term thinking and process improvements, and a shortened timeframe compared to other industries similar in complexity such as automotive and aviation, resulting in fewer projects to share the costs of developing a configurable product platform. If such a platform eventually is opted for, however, multiple benefits can be identified, exemplified by, for instance, the possibility of reducing the required time and effort of developing new designs by layering custom solutions on top of standard components and parametric models, or simply the ability of providing significantly increased levels of operational flexibility.

3.4.2 Real Options Theory

> *"The future is uncertain... and in an uncertain environment, having the flexibility to decide what to do after some of that uncertainty is resolved definitely has value. Options-pricing theory provides the means of assessing that value." (Merton, 1998)*

The introduction of real options was first introduced to the financial realm of business in the late 1970s serving as an option – but not the obligation – to undertake certain business initiatives. The application of this concept has since been expanded to include decision making under uncertainty, by converting developed techniques for financial options to more "real-life" decisions. Its purpose is to provide a dynamic strategic plan that incorporates and values flexibility by reflecting the way decisions are already made, waiting for uncertainty to be resolved.

A key variation one must overcome in order to apply this concept in ship design is the extension to the public sector. A vessel's capabilities, potential missions, and budgetary uncertainty do not deal with a real market, but rather uncertainties exogenous to the project. As such, systems within the maritime industry inescapably must deal with risk and risk aversion at some point, involving some sort of decision analysis. Those produced assessments can serve as a basis for real options analysis, allowing flexibility to be incorporated into the design and enabling potential changeability so that efficiency can be upheld under changing conditions. Real options permits the designers to govern what types and amount of flexibility is justified in a system design (Neufville, 2000, Neufville, 2003).

The mentality of this approach is to build flexibility into the design through the inclusion of adaptability, i.e. being capable of change without requiring it. Taking into account the rapid rate at which technology is developed, it is impossible to predict future conditions with any significant degree of certainty, and as a result, owners and operators need to be able to alter the course of a project in light of technical or market changes (Shishko and Ebbeler, 1999). This is contrasted by the traditional approach of decisions being made at the beginning of a project and remain unchanged for the duration.

In order to fully understand the methodology of *real options*, it is necessary to define what an *option* is by itself. This term must be differentiated by its meaning in everyday language and instead be thought of as the right to perform some action in the future, but not the obligation. This feature comes to its right when emphasis is put on information gathering so that options can be exploited at the correct time, also providing benefit to the options holder. By holding an option, only positive outcomes are realized while losses are truncated. The price of executing such an option remains separate from the acquisition cost, but since it does not vary with time it can directly be compared to the current profit margin at any point.

Taking the aforementioned definition of options, *real options* can now be defined according to the same principles as financial options, just ported towards the concept of systems design. An option in this case denotes any facet of a system that can offer flexibility and be incorporated into the design either conceptually, or physically. By using this strategy as a conceptual tool, the strategic value of intangibles such as changeability, flexibility and operability can be explained and managerial flexibility increased.

4 MARKET ANALYSIS

This chapter provides a comprehensive overview of the current market situation regarding offshore activities and subsea-related activities around the world. An attempt has been made to identify main development trends both heuristically and methodologically in order to illuminate various aspects that may have an impact on the final analysis (chapter 6), which consequently is based on these findings. The information presented here will also serve as a supplement to the reader's awareness of the industry surrounding offshore subsea construction vessels, making the background of assumptions made at a later stage more transparent. Additionally, an introduction to typical features and the prevalence of certain capabilities is provided.

4.1 MISSION TYPES & CAPABILITIES

Before delving into an abundance of market information, it is important to be able to relate functions and capabilities to mission types, and successively where specific mission types usually are performed geographically (chapter 4.2). Missions, or the nature of operation, most often demand certain types of functionality, inherently provided by which capabilities a vessel has.

A vessel can have a single purpose or the ability to handle several different operations without the need for much reconfiguring between missions. The latter is referred to as multifunctionality, and to which degree a vessel can be deemed multifunctional could affect the mission types a vessel is able to undergo successively. In other words, the more operating modes and capabilities a vessel has, the more missions it will be suitable for – in theory.

In practice, however, there is a fine line between making a vessel multifunctional and what is referred to as "multi-useless" by having too many capabilities which impact the effectiveness of others. Adding the capabilities to perform multiple mission types will rarely go unscathed in terms of trade-offs between usability, available space, cost and/or performance – all of which are subject to the operator/owner's requirements and constraints.

To say that the perfect design for a multifunctional ship has been created could be a plausible statement for a single operator, contractor or charterer and a single purpose, but taken into a more holistic consideration, and perhaps a more accurate picture of reality where several operators, contractors, charterers, and purposes are evaluated, the claim of a perfect design could arguably be scrutinized as an oxymoron. For that reason, capabilities used as design variables for the analysis in chapter 6, will largely be based on the capabilities of a "Multiservice" vessel as defined in Construction Vessel Base (CVB) (Table 8) (IHS, 2013).

The relationships between mission types, functionalities and capabilities can prove to be quite complicated and difficult to portray in a logical manner, which is also applicable in practice. Gaspar and Erikstad (2009) have developed a framework which proposes a divided approach in order to relate certain capabilities to the specific mission type in question. Quite simply the context is explained by placing a mission type at the top, and proceeding to drill down through operational profiles, operational states and end up with the associated functions and capabilities (as illustrated below).

This approach allows us to be able to directly relate various assortments of mixed vessel capabilities to a specific mission type and, in turn, which combinations and proportions adhere to which categories.

Shown in Table 8 is a frequency comparison of which measures (capabilities), CVB uses to describe vessel specifications in addition to being sorted by main vessel type (primary mode).

	PrimaryMode							
	Bury/Trench	Derrick	Derrick Pipelay	Diving Support	Multiservice	Pipelay	ROV Support	Support
DP_Relative	100%	100%	100%	99%	100%	97%	99%	100%
StaticLiftCapacity_Relative	100%	100%	100%	97%	91%	93%	92%	93%
Accommodation_Relative	100%	93%	97%	96%	100%	91%	96%	87%
SatDive_Relative	100%	87%	92%	98%	73%	85%	95%	87%
HullDepth_Relative	100%	91%	91%	80%	82%	90%	70%	73%
Draft_Operating_Relative	80%	82%	87%	76%	86%	80%	78%	80%
DivingBells_Relative	100%	73%	70%	74%	68%	67%	58%	53%
Speed_Relative	80%	51%	37%	80%	95%	42%	84%	80%
DeckArea_Relative	60%	40%	63%	84%	91%	49%	86%	73%
SupportedHelicopters_Relati..	80%	25%	60%	67%	64%	57%	53%	53%
DWT_Relative	60%	22%	26%	61%	86%	43%	74%	73%
MaxStaticLiftRadius_Relative	40%	27%	50%	42%	50%	29%	48%	47%
MoonpoolArea_Relative	60%	20%	21%	47%	45%	26%	49%	40%
DiveCapacity_Relative	40%	13%	14%	82%	41%	12%	31%	40%
DiveDepth_Relative	40%	13%	13%	74%	41%	12%	28%	33%
MaxWorkingWaterDepth_Rel..	40%	25%	51%	20%	23%	52%	10%	13%
MaxPipeDiameter_Relative	0%	0%	91%	4%	45%	89%	0%	0%
TotalPower_Relative	40%	5%	9%	29%	41%	16%	39%	40%
PipeTensionerCapacity_Rela..	0%	0%	87%	0%	41%	88%	2%	0%
PipeReels_Relative	20%	4%	15%	18%	50%	38%	24%	33%
PipeReelWeight_Relative	20%	4%	17%	14%	55%	37%	23%	27%
MaxRevolvingLiftCapacity_R..	40%	35%	59%	9%	14%	14%	10%	0%
BoomLength_Relative	20%	38%	43%	11%	9%	34%	2%	13%
MaxPipeInstallationDepth_R..	0%	0%	62%	0%	9%	67%	1%	0%
Draft_Transit_Relative	0%	36%	28%	11%	18%	14%	11%	13%
FuelConsumption_Transit_R..	20%	0%	2%	35%	27%	8%	24%	13%
FuelConsumption_Operating..	20%	0%	2%	35%	18%	7%	17%	13%
Displacement_Relative	0%	18%	32%	22%	9%	21%	7%	0%
ROVSupportCategory_Relati..	0%	0%	0%	0%	0%	0%	99%	7%
MaxRevolvingLiftRadius_Rel..	0%	18%	39%	2%	18%	15%	5%	0%
PipeTensionerSpeed_Relative	0%	0%	15%	0%	9%	11%	0%	0%

Table 8 - Capability Abundance in % by Vessel Type

This table clearly shows which vessel capabilities are most abundant amongst various operating modes in regards to which operating mode the vessel is designed for. It is important to note that this list does not necessarily directly reflect which capabilities best describe different vessels because there is a chance that these specific measures are highly utilized as a result of public availability. In other words, low rated capabilities such as "pipe tensioner speed" may exhibit meager statistical probability just because the information simply isn't publicly available.

Finally, to illustrate which typical mission types are most common in different regions Table 9 was developed based on the number of occurrences from CVB. It rates the probability from 1 to 3 (1-lowest) of where a specific mission type is likely to occur.

-	Heavy Construction	Light Construction	Pipelay	Cablelay	Multipurpose
Australia	2	3	3	2	3
Far East	3	1	2	3	2
Gulf of Mexico	3	3	2	2	1
Middle East	3	1	3	3	1
Northwest Europe	1	3	2	2	3
South America	1	3	3	2	3
Southeast Asia	3	1	3	3	1
West Africa	2	2	3	3	3

Table 9 – Typical Mission Types by Geography

4.2 GEOGRAPHICAL ANALYSIS

Geographically speaking, the areas of interest from a subsea construction point of view are located in deep waters, far from shore, and are known to sustain difficult and challenging climate conditions. Below is a geographical heat map, also developed from CVB, depicting geographical regions associated with vessels operating in deep water. The darker the colors, the deeper the average depth of vessels operating near these countries is.

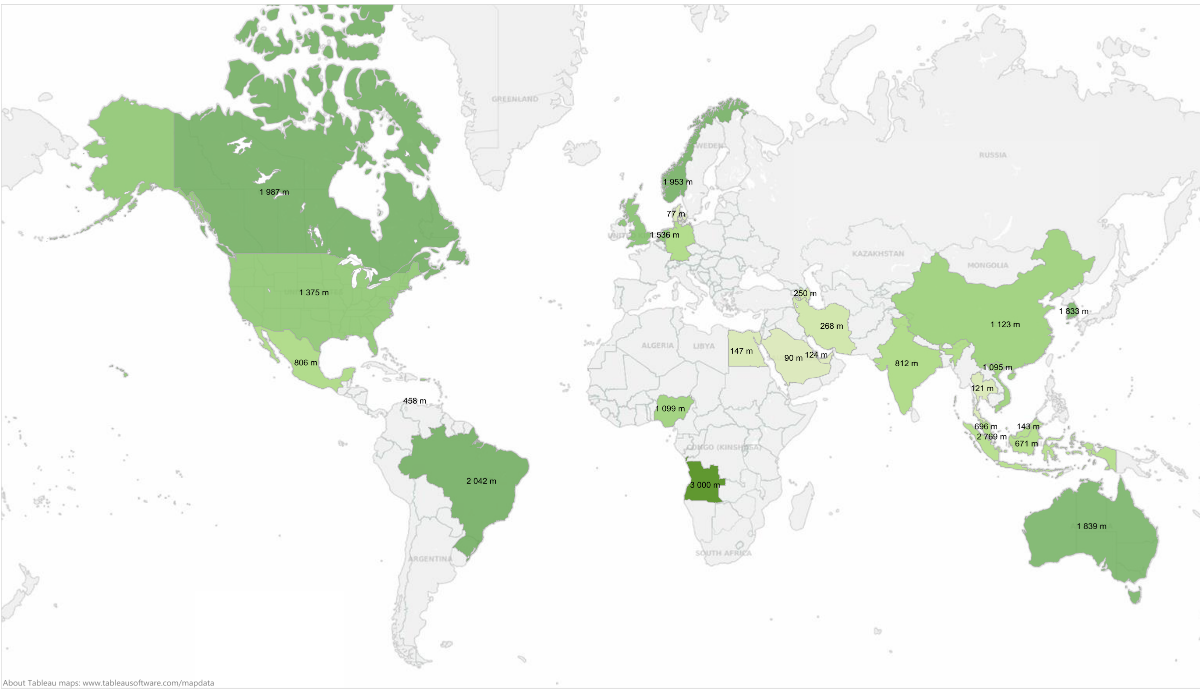


Figure 16 - Geographical Average Operating Depth

Illustrated a little differently one can see a clear tendency of operational depths towards different regions.

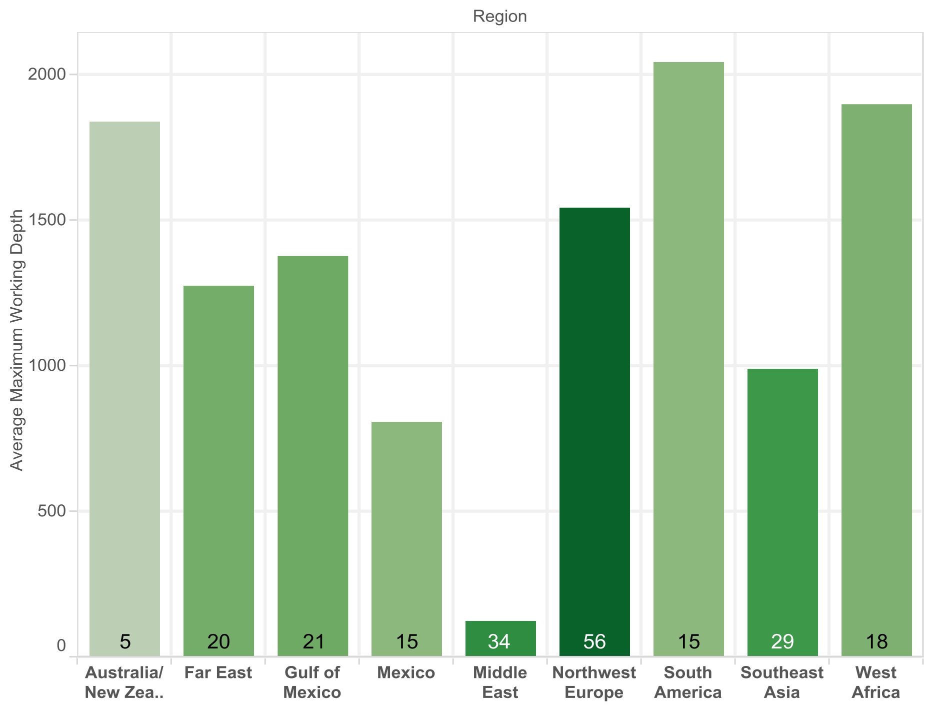


Figure 17 - Regional Average Operating Depth

The CVB data is based on the maximum operating depth of a single vessel and the bar color represents the calculation strength based on the number of vessels present in the associated data set (shown on the bottom of each pylon). Because the North Sea actually is a fairly shallow operating area, the Northwest Europe column gives a slightly false impression based on the 56 vessels operating there. This is because vessels operating in or around the Norwegian Continental Shelf usually are dimensioned for extremely harsh conditions and are as a result mostly comprised of newer vessels also capable of operating in deep waters. Figure 18 clearly shows that the fleet's age distribution of vessels operating in the Northwest Europe region is dominated by builds delivered after 2007 which would further support the probability of their ability to operate in deeper waters.

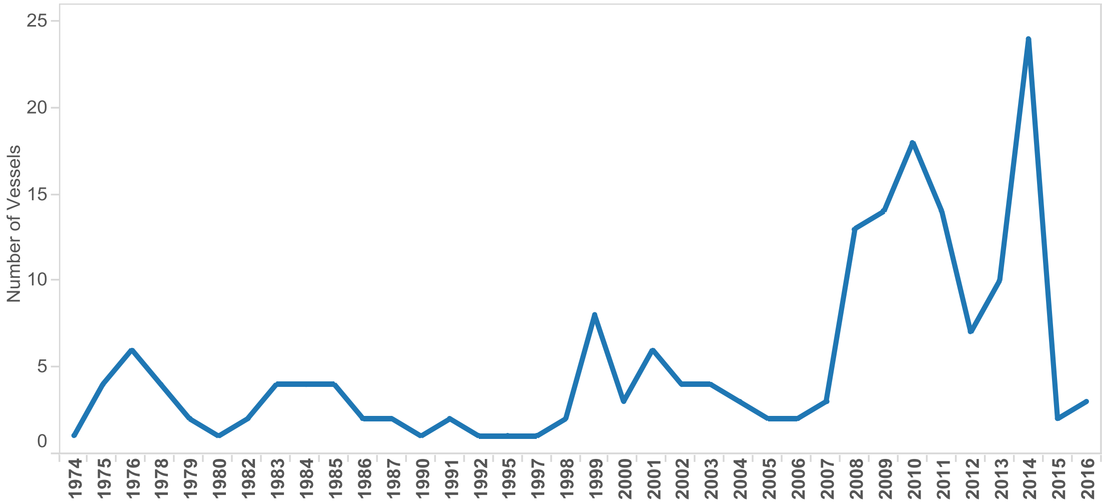


Figure 18 - Northwest Europe Age Distribution

Disregarding Northwest Europe which is mostly constituted of the North Sea at an average depth of 95m (MUMM, 2014), there are four distinct regions directly associated with waters deeper than 1300 m: South America (2042 m), West Africa (1895 m), Australia (1839 m), and the Gulf of Mexico (1375 m). The number of vessels associated with these regions also shows that Australia (5 registered vessels) is fairly new to this type of market and does not fully represent the whole scope of Australia's associated working depths. Disregarding Australia as a result, the three remaining regions associated with ultra deep waters constitute what is referred to as "the golden triangle", namely the connection between South America (Brazil), West Africa (Angola, Nigeria) and the Gulf of Mexico. As seen from Table 10, the average operational oilfield depth is dominated by Brazil and the Gulf of Mexico with an average locational depth of 1377m and 872m, respectively. "Africa – Other" and the Mediterranean are disregarded based on lack of plentiful data with only a maximum of three registered operating rigs.

Region	avg	median	# of locations	% of total	Variance %	St. Dev %	% of max
Africa - Other	2 382	2 382	2	33,3%	67,14%	81,94%	100,00%
S. America - Brazil	1 377	1 368	56	60,9%	93,83%	96,86%	57,78%
Mediterranean	1 139	1 600	3	15,0%	127,88%	113,09%	47,80%
N. America - US GOM	872	803	86	88,7%	106,30%	103,10%	36,62%
Africa - West	574	118	9	14,3%	117,03%	108,18%	24,10%
Australia	526	469	6	50,0%	29,07%	53,92%	22,06%
Europe - North Sea	183	115	75	45,5%	5,47%	23,39%	7,69%
S. America - Other & Carib.	182	91	3	37,5%	6,42%	25,34%	7,62%
Asia - Far East	109	31	3	8,3%	3,04%	17,42%	4,58%
Asia - SouthEast	86	56	12	13,8%	1,74%	13,17%	3,61%
N. America - Mexico	52	47	10	22,7%	0,17%	4,07%	2,18%
MidEast - Persian Gulf	17	12	5	5,5%	0,02%	1,44%	0,71%

Table 10 - Oilfield Depths by Location (RigZone, 2013)

To extract the provided information into a framework capable of segregating market characteristics by geography, coupled with the ability to discern various design impacts these might have on a vessel, more filters than depth will be needed. Nonetheless, operating depth is a very capable indicator for predicting what the design drivers are going to be. By introducing an operational depth requirement of 1500 m or below, one can immediately deduce an increased need for higher crane and winch capacities, moonpool and ROV infrastructure for seabed work or observation, and a larger deck area as a result of an operational mode designed either for the transport and installation of large subsea modules, or perhaps a need for piping/cable spools which can take large amounts of space.

Besides the initial indication that operational depth can provide, meteorological traits normally vary by location. As a result, traits such as temperature, significant wave height, wave period, wind and current speeds and sea ice probability can all be relevant design criteria and most definitely have the ability to impact a final design quite drastically.

4.3 Region Specific Analyses

A common goal among vessel owners is to be able to identify which regions their vessels are capable of performing operations in, and to do so requires insights as to which mission types and inherent functionalities are necessary per location. Not to mention the ability of forecasting *which* functionalities will be required *where*, so that owners can order vessels ahead of the market. As both goals can be modeled with an Epoch-Era Analysis, and are equally likely to come up as questions during conceptual design, a concise overview of market developments by region is therefore warranted and presented in this chapter.

As mentioned briefly in the introduction, an increased interest in the subsea market has lately been stimulated by an encouraging oil price at about $100/barrel and an increased level of E&P spending the last few years by oil companies looking to extract oil from places that – not many years ago – would have been considered technically infeasible or too expensive.

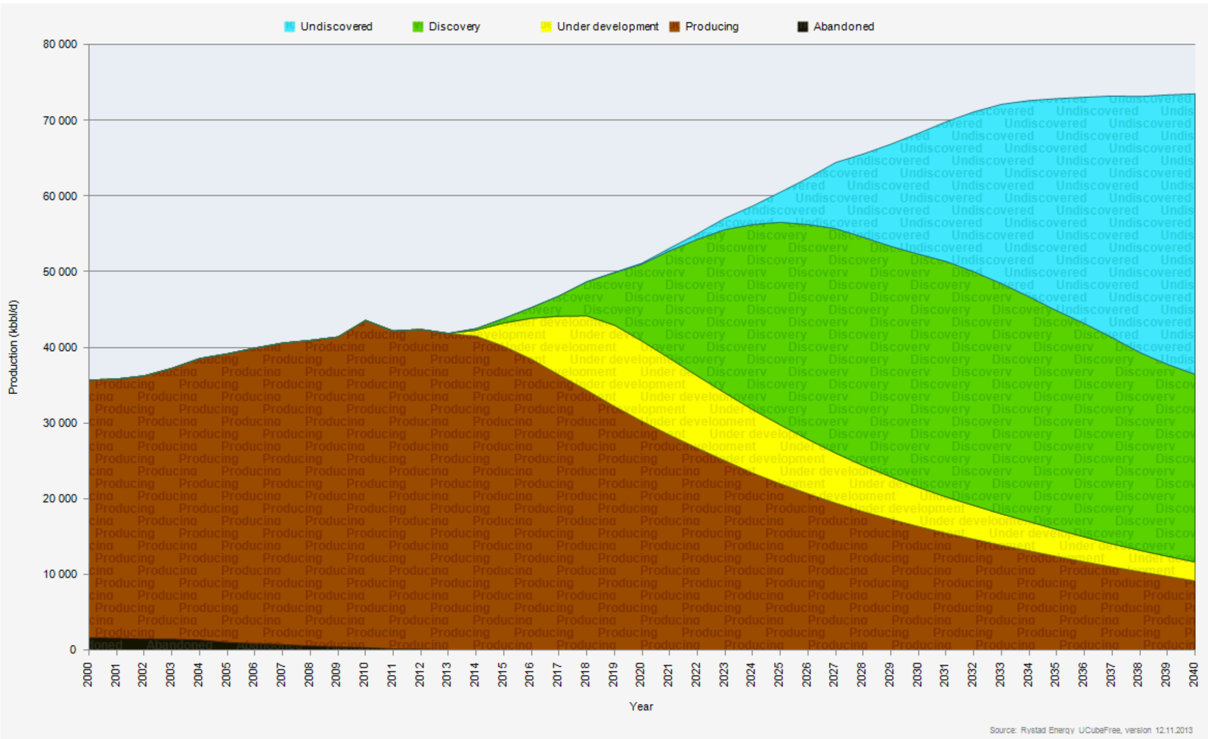


Figure 19 – World's Oil Production Forecast (UCube, 2013)

From Rystad's predictions in Figure 19 one can see that the expectations for future oil production are still quite high despite increased cost levels and widespread environmental movements lobbying for "cleaner" energy. This means that as a result of depleted resources categorized as "easy oil", oil companies are now turning towards harsher environments, longer from shore, colder climates, and especially deeper waters.

4.3.1 Australia

Australia was in 2012 among the top 25 oil and gas producers in the world with a production of 1.43 mboepd and is expected to increase towards 2025 to approximately 5.4 mboepd. Of more than 50 sedimentary basins available to Australia, currently only 13 are actually producing oil and gas while the remaining ones have not been explored to any significant extent.

The offshore sector is located mainly around the North West Shelf and the Timor Sea, of which the latter is especially known for its deep waters and susceptibility to tropical storms or cyclones.

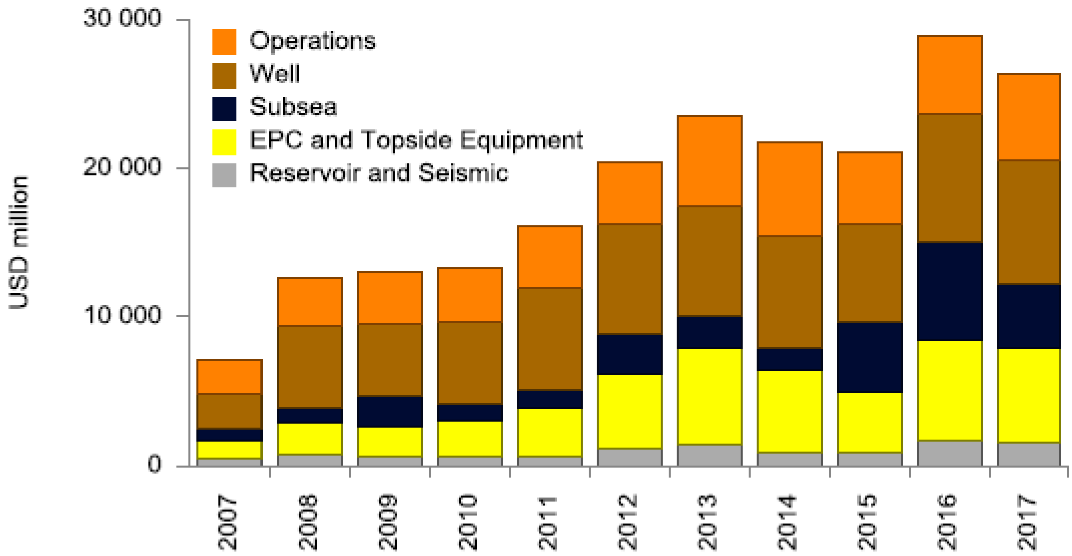


Figure 20 - Australia: Offshore Spending Distribution (INTSOK, 2014)

Figure 20 shows a rather large subsea market share from 2015 and onwards. This increase is mainly sparked by large SURF (Subsea Umbilicals, Risers, and Flowlines) and subsea equipment expenditure on the Icthys, Prelude and Greater Laverda Area projects, which are largely gas discoveries under construction.

4.3.1.1 Characteristics & Trends

Even though the north coast of Australia is susceptible to tropical storms, the wave heights are relatively low compared to the conditions east of Tasmania and along the southern coast. As a result of most oil-related operations being situated on the Northwest Shelf, the main design driver for OSCVs is depth. In this segment, crane capacities, winch capabilities, operational depths and other mission-specific equipment such as carousel capacities, cable/pipe-laying functionalities and derrick/vertical lay system capacities dominate as value driving capabilities. Pipelay vessels are highly relevant in this region because of the vast amount of gas developments and LNG production.

4.3.2 Far East

The term Far East here refers to the Northeastern parts of Asia, such as China, Japan, Korea and East Russia.

China is according to the International Energy Agency the world's largest energy consumer, and second largest oil consumer behind the United States. This high demand has led China to become an extremely influential part in the global energy markets. Their offshore market is driven by spending in the South China Sea, and is mainly related to operations or Engineering, Procurement, and Construction (EPC) contracts. The subsea segment has traditionally been dominated by fixed platform developments or wellhead tiebacks, but towards the next couple of years SURF activity is expected to rise as a result of several planned projects, where the Liwan 3-1 by Husky Energy could be seen as the main driver.

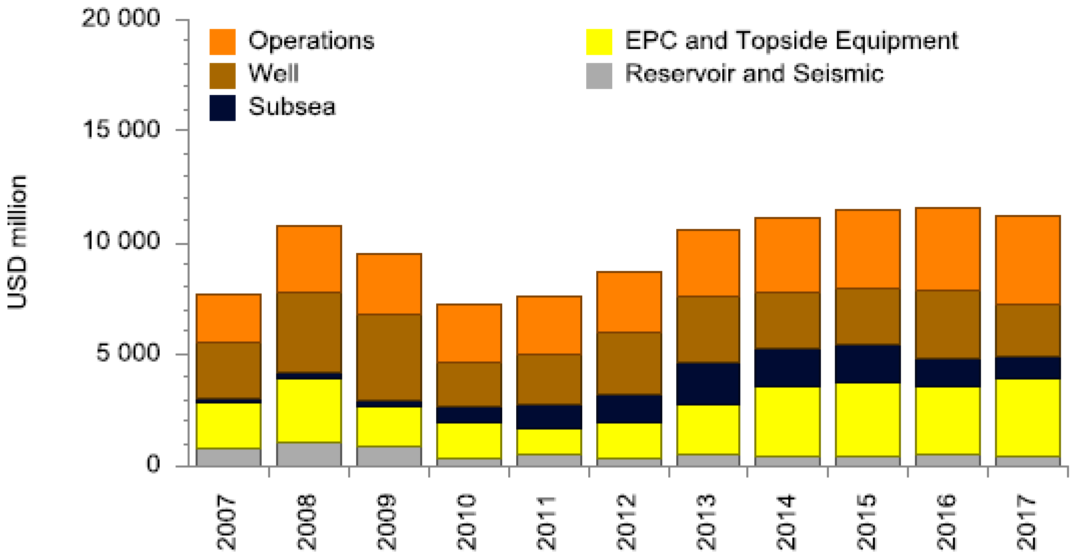


Figure 21 - China: Offshore Spending Distribution (INTSOK, 2014)

Regarding Russia's market situation, their production is defined mainly by onshore facilities as less than 3% of the total production in 2011 came from offshore. Worth mentioning regarding the subsea segment is, however, an increased push towards the arctic. The current situation portrays an interest in large fixed installations built to handle the harshest conditions in areas such as the Kara Sea, Barents Sea, Caspian Sea, the Sea of Okhotsk, Chuckchi Sea and the Pechora Sea. However, trends continuing further north and farther away from shore would be highly reliant on subsea technology in order to efficiently produce because of (amongst other reasons) an extremely fragile environment and a drastic increase in operational expenditure when operating in ice.

4.3.2.1 Characteristics & Trends

The South China Sea has not yet developed any significant deepwater productions or subsea developments. Fixed platforms, large barges, and smaller vessels for support generally populate the region and as the main developments in Chinese oil and gas are primarily onshore related, a significant trend regarding OSCVs cannot yet be observed in this market. Taking Russia into account, however, will show a clear aspiration to profit from increased temperatures in the arctic. After finally reaching an agreement with Norway regarding division of the Barents Sea in 2011, Russia has not only opened field licenses there and in the Kara Sea, but they have also largely been allocated and some have even already started production. The first frontier in this segment is the shallow watered fixed installation resources, but not long after allocated fields further north will follow as concepts are validated and qualified to handle the harsh environment and technical/logistical/operational challenges. Abilities to operate in and handle ice, as well as operational duration, accommodation and winterization will be crucial during this push.

4.3.3 Gulf of Mexico

The U.S. Gulf of Mexico (GoM) has been in a production decline from about 2.4 mboepd in 200 to about 670 kboepd in 2012. The expectation, however, is a growth from 2015, driven by deepwater production, which holds a positive outlook. Figure 22 reveals huge amounts of subsea spending in this region the next three to four years, and as an already established deepwater producer will serve as a driver for ultra deepwater developments both regarding technology and HSE (not the least as a result of the Macando accident).

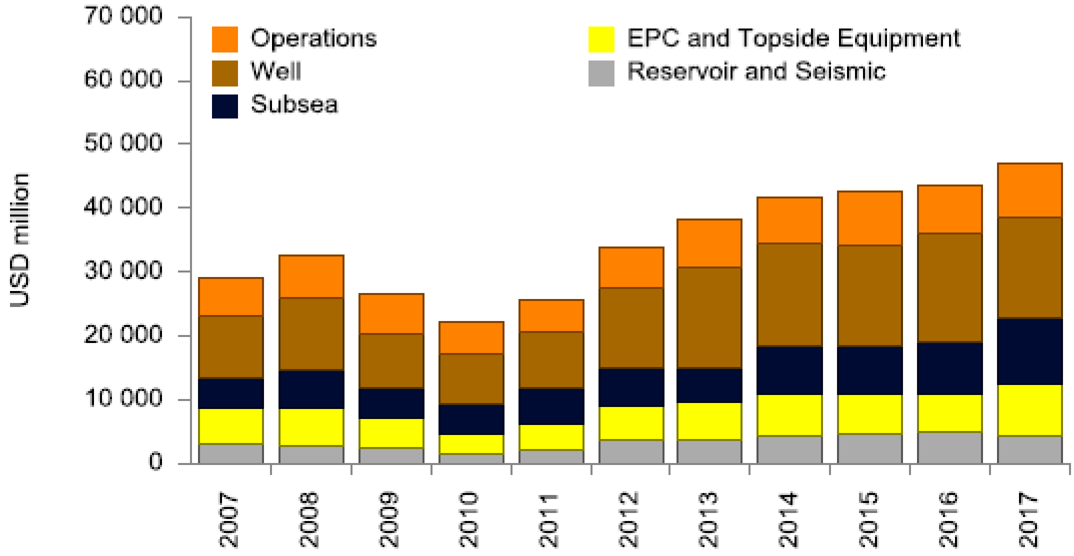


Figure 22 - Gulf of Mexico: Spending distribution (INTSOK, 2014)

By 2017, Rystad Energy has forecasted an increased spending on ultra deepwater projects to reach 65% of the total subsea market of around $10.4 billion. One of the key projects contributing to this figure has been Shell's Stones; an ultra deepwater project on block 508, 320 km offshore and at a depth of 2896m – which would establish the world's deepest production facility.

4.3.3.1 Characteristics & Trends

Key characteristics of the GoM are deep operational waters, good conditions regarding waves, currents, temperature and wind, and access to a large coastline for logistics support. After the Macando accident a key development will be to regain the public trust by introducing strict HSE requirements and regulations. This may impact the agility with which new developments – especially deepwater and other developments requiring new technology – will be able to turn a profit. As a result, one can expect actors in the region to approach technological innovations with a meticulous mentality. In turn, this could cause a slight decline in deepwater development pace and an increased focus on enhanced recovery (IOR), but as of now any such indication is miniscule.

4.3.4 Mediterranean

The Mediterranean can be viewed as somewhat of an outsider compared to the leading players in the North Sea, Gulf of Mexico, Africa and South America. Despite housing some of the largest gas discoveries over the last decade (Dyring, 2012) this area has remained somewhat hidden except for a few large subsea developments off the coast of Egypt.

A focal point of 2013 has been Israel's forced E&P activity as a result of Egypt no longer providing gas export over the Sinai desert, from which 40% of Israel's total domestic consumption has been gathered. Noble Energy, AGR, Adira Energy and Shemen Oil & Gas are all actively operating on projects in the country which require anchor handling and supply assistance.

The Mediterranean currently has three rigs operating at an average depth deeper than 1000m (where data is available) and even though there are available resources at depths which could potentially boost subsea spending in the area, other regions have taken precedence. The Tamar field, involving a large H-851 barge from Heerema and heavy installation work from EMAS AMC, is however planned to be operational in 2014 and will likely draw some attention to the region and perhaps spawn some new projects. Typical demands include heavy lifting, accommodation and cable/pipe-laying vessels.

4.3.5 Middle East

The Middle East is characterized by some of the largest proven petroleum reserves in the world with about 50%, as can be seen in Figure 23.

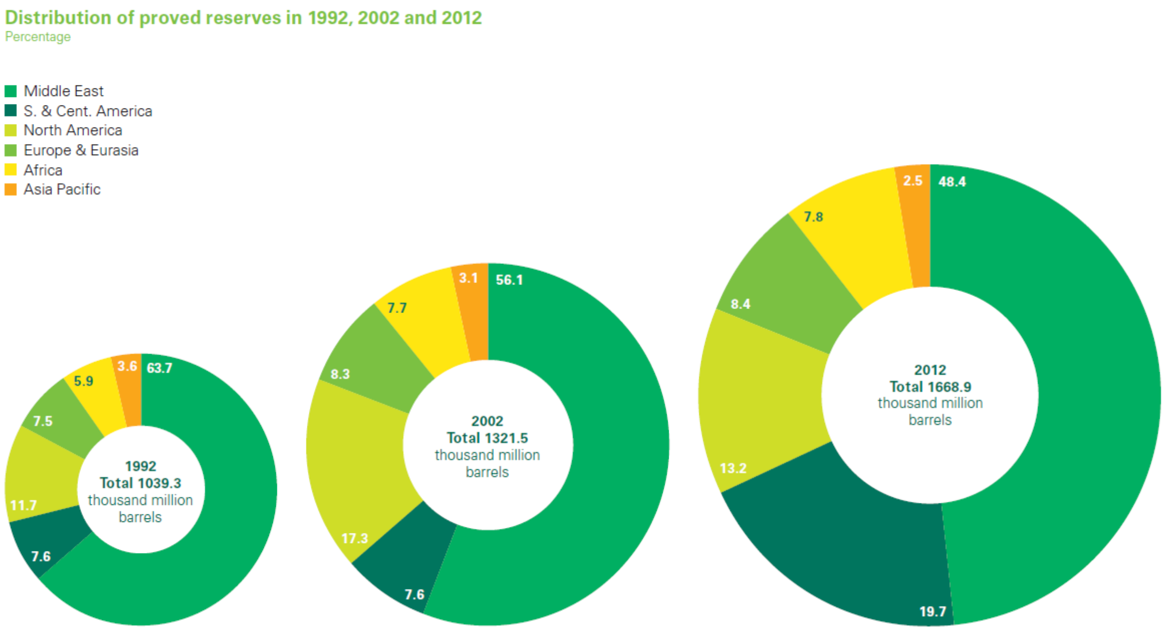


Figure 23 - Proven Oil Reserves (BP, 2013)

The region's production can be described as highly volatile, driven by an unstable political situation and many different wars having plagued the region over the years. Nonetheless, Iraq, Saudi Arabia and Qatar have steadily increased their offshore production from 3.5 mboepd in the beginning of the 2000s to around 7.3 mboepd in 2012. Figure 24 also shows that the level of subsea spending in the area is extremely low compared to other phases of operation.

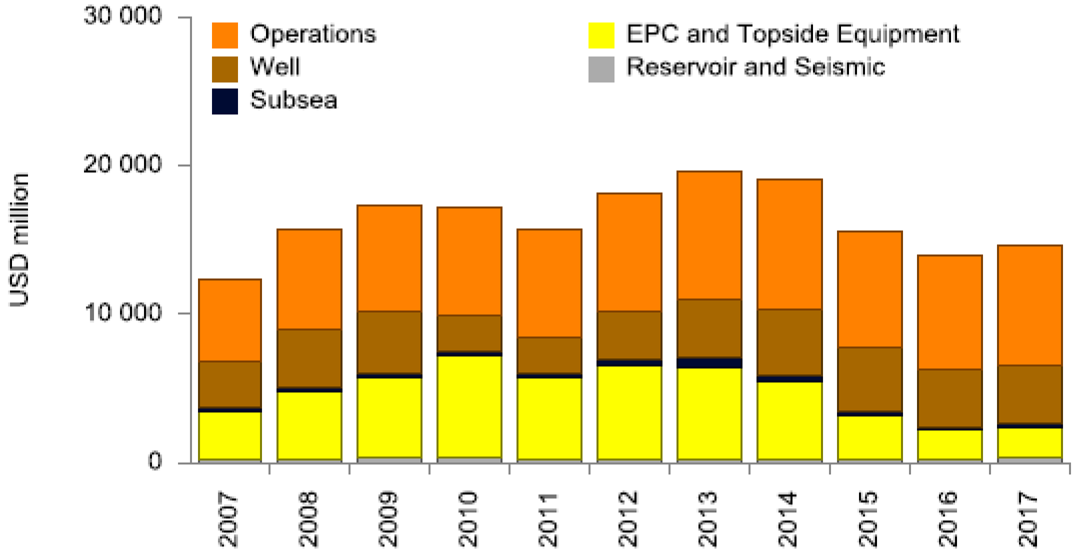


Figure 24 - Middle East: Offshore Spending Distribution (INTSOK, 2014)

4.3.5.1 Characteristics & Trends

The operations are mainly related to pipelines and due to a generally shallow operational depth most installations are fixed steel platforms with a significantly smaller need for subsea construction services than deepwater installations do. Heavy lifting and cable/pipe-laying activity will largely dominate this subsea construction segment.

4.3.6 Northwest Europe

Mainly the United Kingdom, Norway and other operators in the North Sea cover this region. The UK is the largest producer of oil in the region, and the second largest producer of natural gas, trailed by the Netherlands. In 2012, at about 140 mboepd, the UK contributed to about 1.2% of the total global oil and gas production and was as such ranked among the top 21 oil and gas producers, globally. In total, about 90% of resources in the region are originated in the North Sea alone, the remainders being the Irish Sea (5%) and West of Shetland (5%). The UK is a significant subsea market player as shown in Figure 25, expected to reach a peak in

2015 at almost $8 billion, but because of shallow waters it will not be able to directly compete with the GoM or Brazil regarding deep subsea developments.

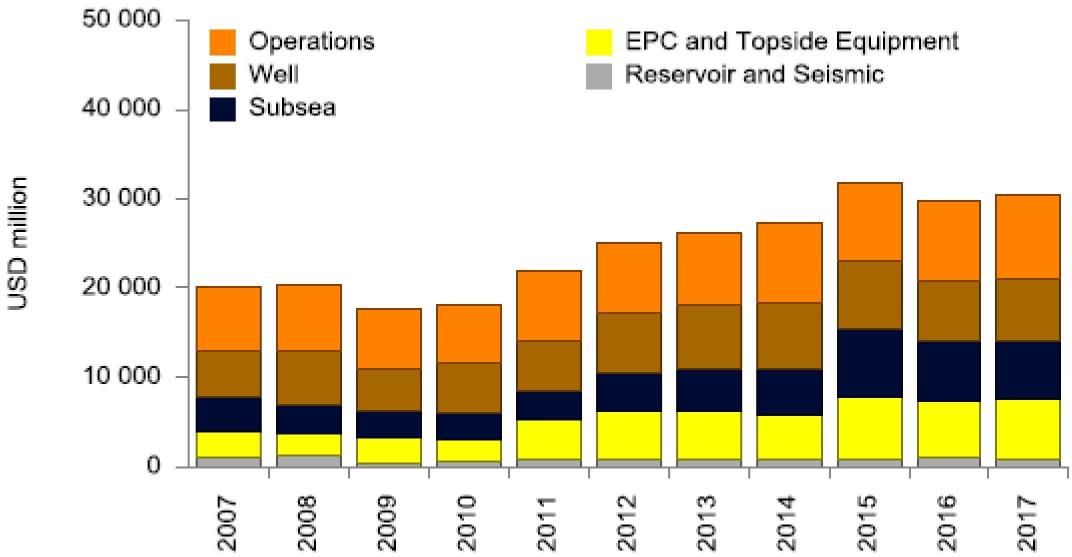


Figure 25 - UK: Offshore Spending Distribution (INTSOK, 2014)

The Norwegian segment of Northwestern Europe is comprised of large parts of the North Sea, the Norwegian Continental Shelf (NCS), and further north, the Barents Sea – all of which have provided the country with vast oil and gas resources, peaking at 3.4 mboepd in 2001.

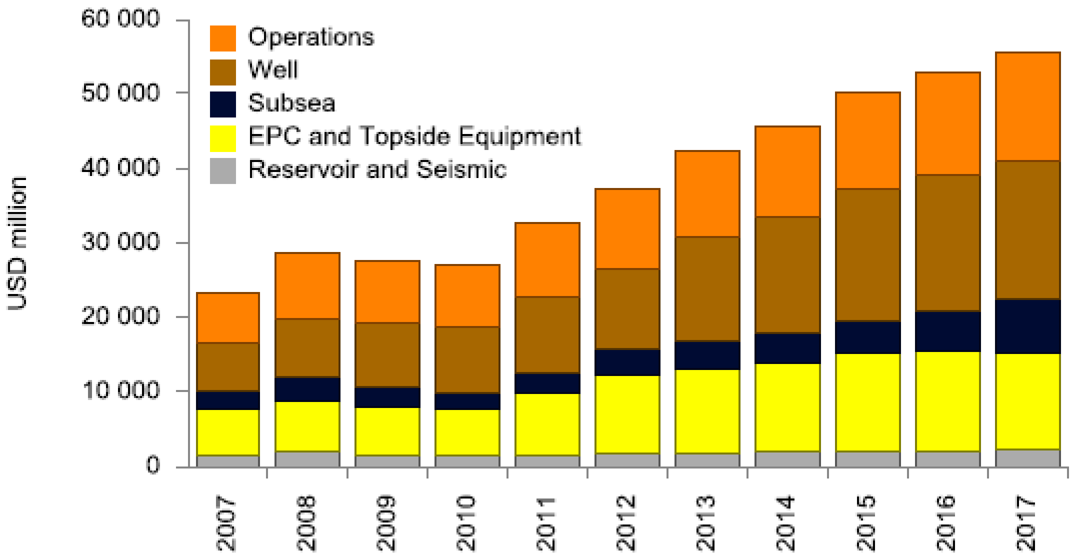


Figure 26 - Norway: Offshore Spending Distribution (INTSOK, 2014)

Figure 26 shows a slight steady increase in subsea spending towards 2017, and this reflects the partially government owned company, Statoil's plans to move production towards the seabed (described in more detail below). However, the most comprehensive subsea projects will not be feasibly operational until 2020 at the earliest and when those developments come into play they could have the potential to create a worldwide market shift, given that the required technology provides the means to turn a solid profit.

4.3.6.1 Characteristics & Trends

Statoil, Norway's largest oil company has led the way in the industry towards what they refer to as "the Subsea Factory" through their fast track program, aiming to have a fully operational subsea oil factory by the year 2020. Already a massive subsea gas compression module is to be operational at the Åsgard field by 2015. This increased focus towards moving production beneath the sea surface has demanded immense technological developments from involved companies. FMC Technologies and Aker Solutions, for instance, have become global industry leaders within subsea technology, and furthermore, these developments have driven shipbuilders/designers to push the boundaries of what their vessels are capable of, especially in terms of moonpool size, crane capacities, modularity, station/sea-keeping, and utilized levels of multifunctionality.

4.3.7 South America

Brazil and its national oil company, Petrobras, are the worldwide leaders regarding the pre-salt segment of oil and gas reserves.

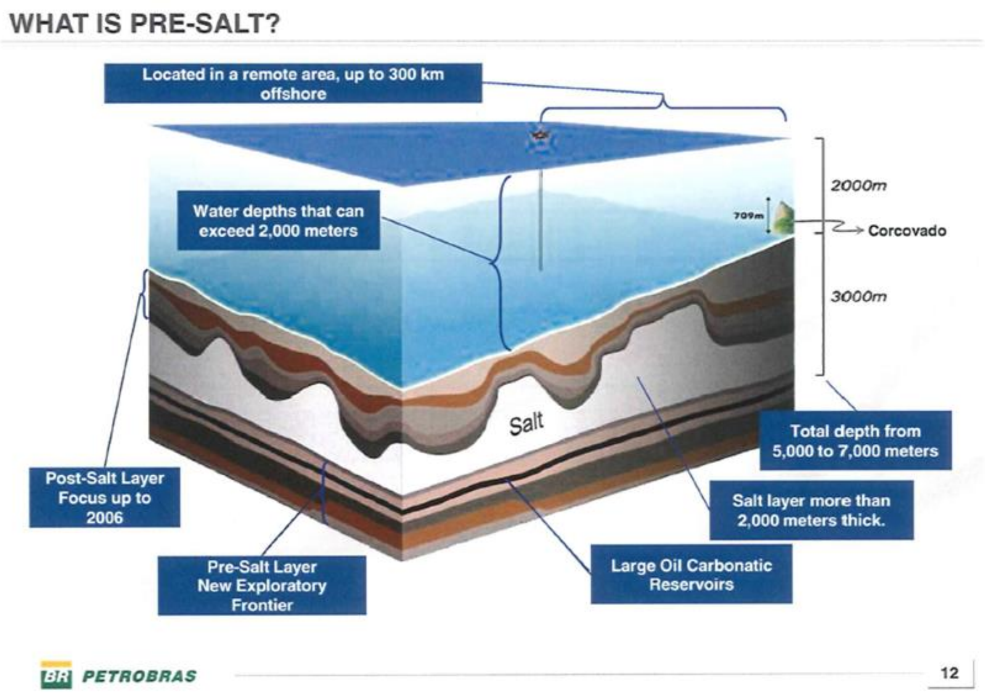


Figure 27 - Pre-Salt Explanation (Petrobras, 2012)

As Figure 27 illustrates, “pre-salt” indicates that there is a thick layer of salt between the seabed and potential reserves. Drilling through the salt layer is very expensive and almost always implies deep waters. It also poses a challenge in terms of susceptibility to corrosion, fatigue and high pressures. However, the Brazilian National Petroleum Agency just opened the 1500 km^2 Libra pre-salt prospect, expected to hold between 8 and 12 billion barrels of recoverable reserves.

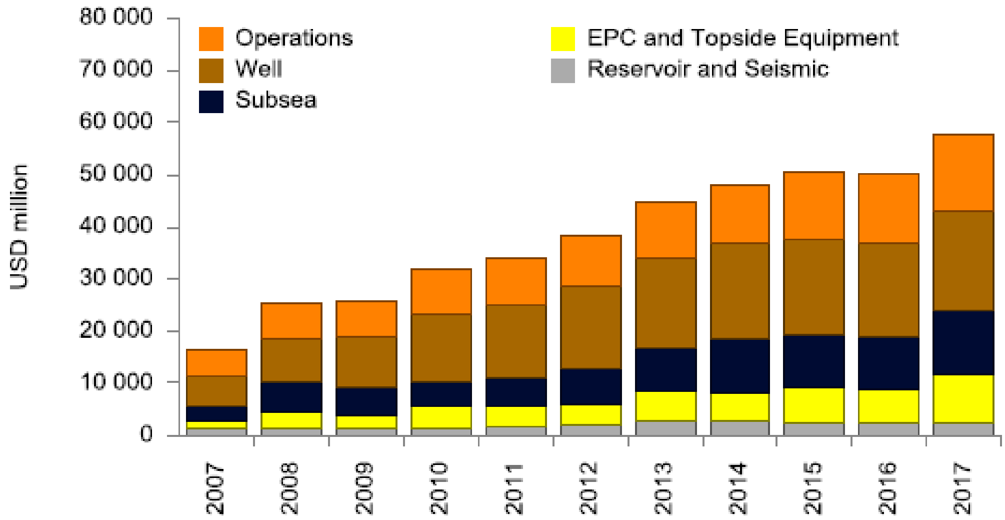


Figure 28 - Brazil: Offshore Spending Distribution (INTSOK, 2014)

The increasing amount of subsea infrastructure Petrobras installs in order to connect to FPSO developments is thought to be a main subsea driver towards 2017. Also, as subsea wells and pipelines age, and the installed base increases, there will be a continuous increase in demand for subsea services, especially maintenance work by ROV.

4.3.7.1 Characteristics & Trends

The OSCV market in this region is being pushed further and further offshore as Petrobras continues their pursuit of pre-salt reservoirs. The finds are also happening in deeper and deeper waters increasing demand for technology able to cope with such depths. During the summer of 2013 Petrobras ordered three new pipelay vessels from Subsea 7 and four additional ones from Technip and DOF. These massive orders have been a result of profitable finds far offshore creating an increased need for tie-back capabilities and more powerful cranes to handle the depths. Most of the vessels from Technip and DOF will have a 650-ton laying tension capacity, while deliveries from Subsea 7 will boast a 550-ton top tension capacity with an additional 600-ton active heave compensated crane and twin 4000-

ton baskets for storage of flexible pipe, umbilicals and cables. They are all designed to operate in depths of up to 3000 meters, which shows how much Petrobras emphasizes the importance of deepwater capability. The current heavy subsea construction market will likely be more or less satisfied by the recent large orders placed by Petrobras during the initial building phase. However, there will also likely be a need for lighter construction vessels with the ability to deploy WROVs to depths beyond 2000 meters and transport/install lighter equipment up to 250 tons.

4.3.8 Southeast Asia

Included under the term Southeast Asia are mostly countries situated south of China and East of India. However, the subsea focus lies mainly with Malaysia and Indonesia.

Malaysia is Southeast Asia's second largest crude oil producer after Indonesia and is the third largest producer of LNG, preceded only by Indonesia and Qatar in 2010. In total, exploration activities have resulted in discoveries of 140 oil fields and 182 gas fields producing 1.74 mboepd in 2012. Malaysia's total resources are estimated to be around 24.4 bnboe, with dry gas accounting for around 62%. Production is completely dominated by offshore fields, accounting for over 99% in 2012. This offshore domination, in addition to an increase in domestic consumption further weighed by declining crude oil production rates, has ignited several deepwater projects of up to 1500 m depths, in order to reach a higher rate of crude oil production.

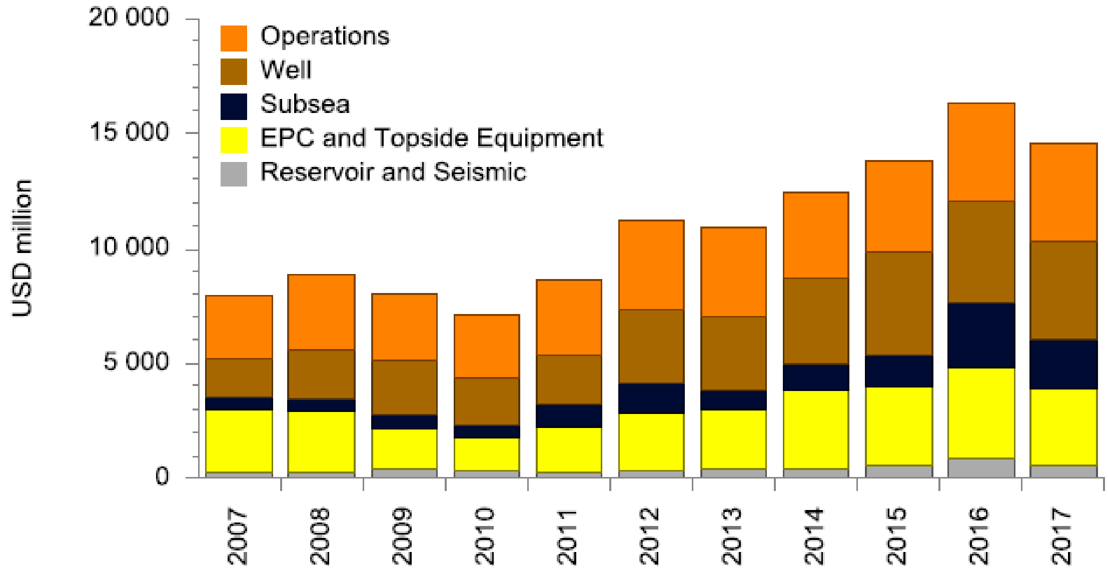


Figure 29 - Malaysia: Offshore Spending Distribution (INTSOK, 2014)

Indonesia has a very similar situation to Malaysia with a total production of 1.99 mboepd in 2012 and a continuously declining production of liquids (crude oil, condensate and NGL) from 57% of the total in 1999 to 48% in 2012. As a result, Indonesia had to leave OPEC in 2008 because it had struggled to meet its output quota. The offshore segment, as opposed to Malaysia, only accounts for little over half of total production but nonetheless has some significant deepwater developments ongoing. The Chevron operated Gendalo-Gehem project will be the country's first large scale deepwater development, boasting a three-field complex between depths of 1000 to 2000 meters. Resources in currently producing fields are estimated at 6.9 bnboe and for discovered fields about 16.6 bnboe. In other words, activity in this region will not tire any time soon.

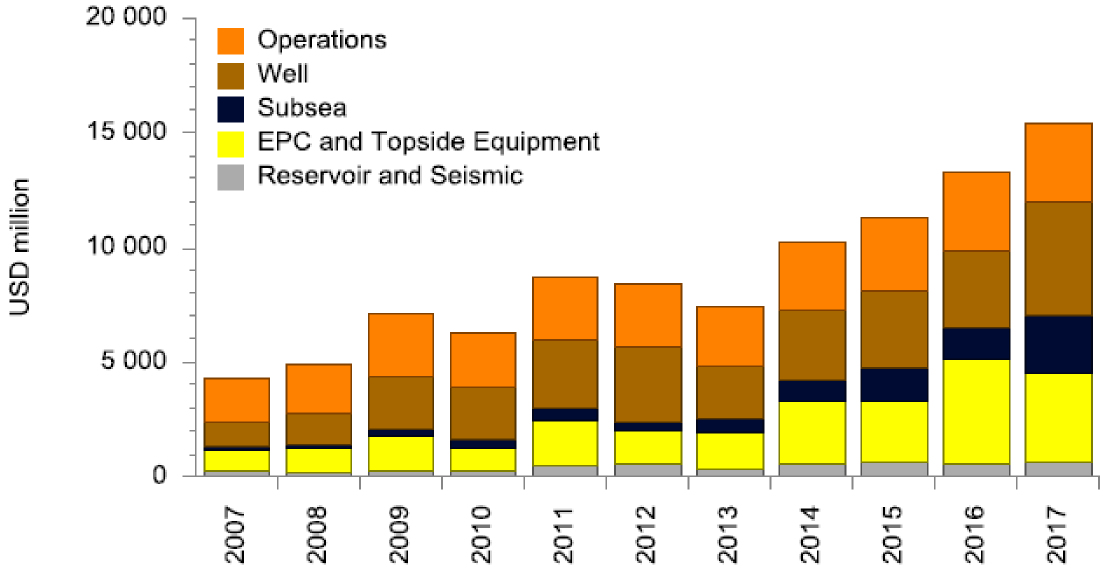


Figure 30 - Indonesia: Offshore Spending Distribution (INTSOK, 2014)

The subsea market in Indonesia has traditionally been dominated by SURF contracts accounting for over 60% of the spending in 2012, but moving forward the market is forecasted to steadily increase, especially with regards to the installation of subsea equipment following deepwater field developments.

4.3.8.1 Characteristics & Trends

Since deepwater projects in this region still are being developed, currently at an early stage, and the skimpy levels of attention paid towards subsea processing technology, the trending operating profiles will be dominated by heavy construction and lay-vessels until the projects reach their next stages. These operations are additionally not too far from shore and thusly will not require larger and more expensive multipurpose vessels because cheaper single purpose vessels can be mobilized in a short amount of time and require a lower rate of charter.

4.3.9 West Africa

In this context, West Africa will include Angola, Nigeria and Ghana.

Since the end of Angola's civil war in 2002, the production of oil and gas has been on steady inclination over the last decade and reaching the top 20 oil producers globally with a total production rate of 1.8 mboepd in 2012. The focus here is predominantly oil and producing assets amount to 5.2 bnboe as well as 3.3 bnboe under development. The government has issued a regulation requiring all international companies operating in the country to meet a 70% local content rule regarding staffing. Combined with the vast lack of capital and technical competence, this regulation has led to congested harbors, frequent backlogs and has forced the issuer to relax enforcement.

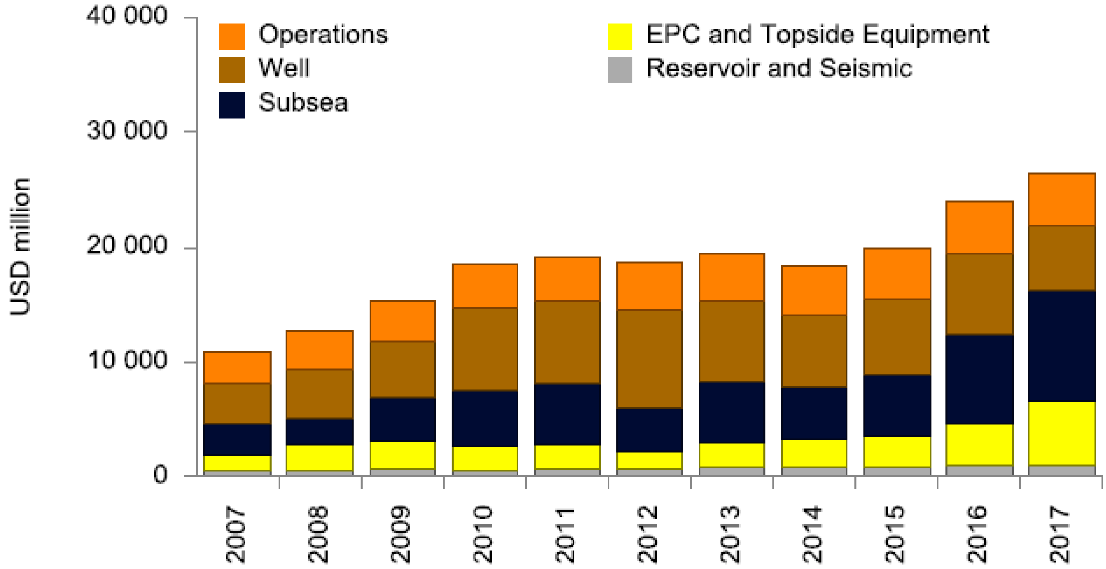


Figure 31 - Angola: Offshore Spending Distribution (INTSOK, 2014)

The offshore segment has largely been driven by technologically complex deepwater developments headed by international oil companies. As Figure 31 suggests, the subsea segment is also set to increase drastically over the next few years led by even more complex ultra deepwater fields such as Kizomba or Kaombo.

Nigeria produced a total of 3.2 mboepd in 2012 and is as such Africa's largest producer and top 15 globally. Currently producing assets and fields under development generate 20 bnboe with an additional 21 bnboe estimated in recent discoveries. Even though oil and gas exports account for 80% of the country's revenue, deepwater offshore operations are highly prone to piracy related attacks (53 in 2011), potentially crippling their own economy. This, combined with local content clauses and major corruption issues, serves as a substantial hinder for international companies seeking opportunities. Ghana, however, is ranked much higher regarding corruption, but there are still some issues regarding a maritime dispute with the Ivory Coast and a goal of 90% local content and participation within a decade.

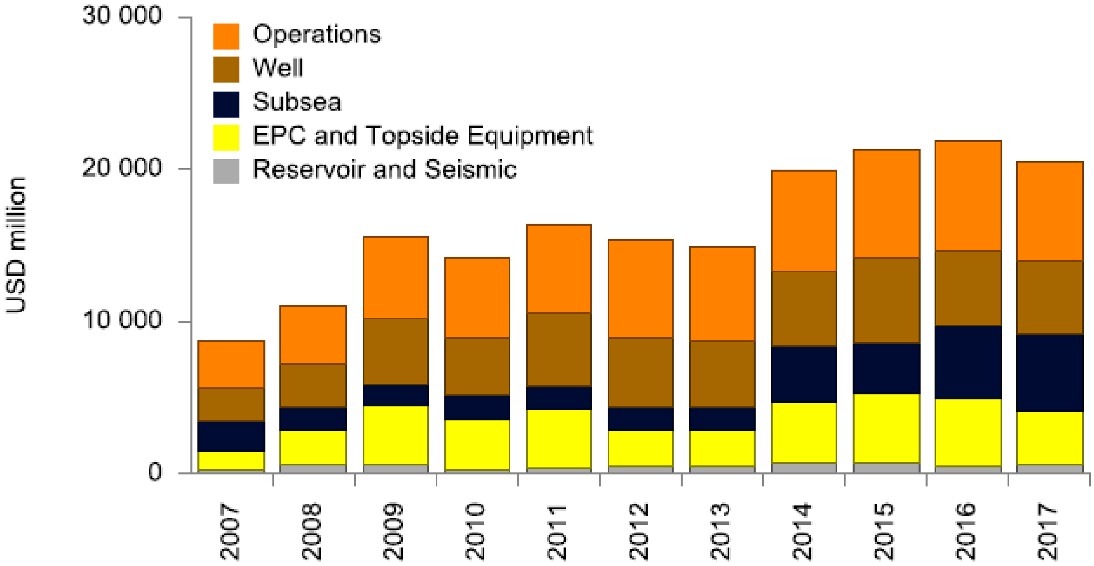


Figure 32 - Nigeria/Ghana: Offshore Spending Distribution (INTSOK, 2014)

In total, West Africa is a very interesting market for many international oil companies because of highly profitable and plentiful resources, but the uncertainty still remains whether issues such as prevalent piracy could deter major players, or demanding local content clauses could congest necessary support functions.

4.3.9.1 Characteristics & Trends

It is clear that there have been a large number of interested international oil companies probing various opportunities in West Africa. The question that remains to be answered regarding the local content clauses is will they create a bottleneck for offshore support as international actors are waiting in line for their turn? This could cause a sudden halt in proposed projects for the region, but as of now the government does not seem to enforce these specific regulations to any significant degree. So as long as the interest is sustained the deep waters off the coast will drive the design criteria for operations in this area. The distances could also play into account by demanding single vessels capable of several operations for increased efficiency and lower transit-related fuel costs.

4.4 Concluding Remarks

To sum up some of the findings of this short market analysis, there are clearly different trends ongoing in different regions. However, there is a general consensus that in lack of more accessible resources, a trend can be identified where operators are slowly migrating towards what previously has been labeled as secondary options. The options in question, which may have seemed only marginally profitable a few years ago, are now becoming more and more attractive as technology is developed further, creating more efficient operations as currently operational wells are beginning to deplete. When these alternatives inevitably do reach their limit, the alternatives and their characteristic obstacles will serve as the only remaining viable options for companies in the industry trying to turn a profit. The oil and gas industry has slowly come to realize this shift, and are now scrambling all available resources towards the development of new technology.

One of the clearly identifiable effects this technology push has had, especially in the North Sea, is the discovery of being able to autonomously turn a profit from the seabed. By eliminating large segments of manual labor, operators have created an opportunity for themselves to stay profitable provided the required equipment can be developed. This includes larger subsea modules, new compressor and separator technology, and much more. The implications this has for the construction vessel on the surface can however be condensed to a need for increased capacity. Larger moonpools, deck areas, winches, and crane capacities will all be necessary if the next generation of OSCVs are to be able to install the forecasted magnitude of the desired equipment.

Furthermore, increased vessel capacities have led to abilities of operating farther from shore and in harsher climates where more carbon resources can be extracted. As a result of expanding operations into uncharted territories, authorities are struggling to keep up the pace when issuing new regulations. Especially regarding operations closing in on the Arctic Circle, there has been much dispute whether to allow carbon extraction in such a fragile environment when proper evaluations are inconclusive and due process bypassed. Norway and Russia are the forerunners in this segment, and continue to push boundaries resulting in new legislation. It is therefore reasonable to assume that regulations and legislation in this area are far from robust, and will unquestionably face addendums with time.

Besides the aforementioned trends, there are clear factors that affect the direction of both carbon extraction and technology development, perhaps the most pertinent of which can be identified as the oil price. Appraised by many sources of influence, among other the availability of resources, the oil price has the direct power of turning a profitable project into a sinkhole for operators. Subsequently, this decides which direction technology developments are free to take. In other words, if for some reason the price of oil should fall considerably, advanced and costly operations, such as those in particular being developed in the North Sea, will be scrapped and new priorities assumed.

4.5 Relation to Analysis Variables

The aforementioned concluding remarks mean little to nothing unless they can be converted into useful information as input for the main purpose of this thesis, the Epoch-Era Analysis. This sub-topic will attempt to connect the two and comment on the degree to which they can be regarded as uncertain.

Undoubtedly, all factors stated here are uncertain to a degree. To which degree however, is the question involved parties would prefer answered. The blunt answer is that there is no way of knowing for certain. The future will always remain uncertain, and attempting to forecast certain paths will unquestionably end in numerous failures. As presented in chapter 3 there are a plethora of methods available attempting to diminish the effect such uncertainties have, but to quantify them as input for use *in* an analysis sufficiently, is difficult to say the least. For the scope of this thesis, the resulting input variables are therefore created solely by assumptions founded on the presented market analysis.

A consequence of the push towards the seabed, as previously identified, is a general increase in OSCV size to compensate for deeper waters and larger modules. As this is a very large part of Statoil's strategy and to a degree has already been implemented, this scenario can be assumed true with a relatively small level of risk. Remembering that any change in context or operational circumstance results in a new epoch being created, it would be wise to incorporate many variations of such a scenario in order to cover as many scenarios as possible that also are assumed probable.

Further difficulties ensue, however, when determining which *consequences* each scenario will have and how to model this in the analysis (this is discussed further in chapter 6.8). Regarding the design considerations it is quite clear that in order to be capable of increased functionality, increased capability is required. For this reason the chosen design variables have been quantified based on the *high-end* segment of the market, covering aspects such as dynamic positioning, ROVs, powering, speed, accommodation and ice class. The resulting ranges are all plausible within this segment and do to no degree display ranges that are non-realistic.

Additionally, besides such factors as imposed emission regulations from which the consequences imposed on a vessel are quite clear, other developments in the market or breakthroughs in technology are significantly more difficult to interpret. The resulting epoch variables are therefore based on probable situations such as increased distances offshore, deeper operational depths, harsher weather, which in spite of future scenarios will provide valuable information regardless.

5 METHODOLOGY OF DATA-GENERATION & ANALYSIS

This chapter presents the structure and reasoning behind the programmatic model creating the data for an Epoch-Era Analysis, as well as the methodology of analyzing the created data. The data is generated using a programming language called JavaScript, mainly chosen by recommendation, but also because of its simplicity and ability to run in virtually any web browser, enabling the user to dynamically change input values producing different results with each pass. The overall aim while developing the script has been to mirror the RSC-methodology introduced in chapter 2.2 up until the analytical phase begins, i.e. phase four (see chapter 5.3).

The process as a whole includes the creation of all possible combinations of designs and epochs, as well as applying utility ranges and value calculations serving as indicators useful during analysis. A flowchart of the JavaScript processes and methods can be found in Appendix I. This will be more thoroughly explained in the following subsections.

5.1 INTRODUCTION

The methodology is based on the RSC-method as described in chapter 2.2 and is designed to produce a large tradespace taking into account as many variables as possible, enabling a more comprehensive analysis.

As illustrated in Figure 33, the JavaScript code is designed to take a range of input variables and convert them into useful values, which at a later stage will be further analyzed by use of a more interactive and powerful analytical piece of software. Each step will be further explained in the next section.

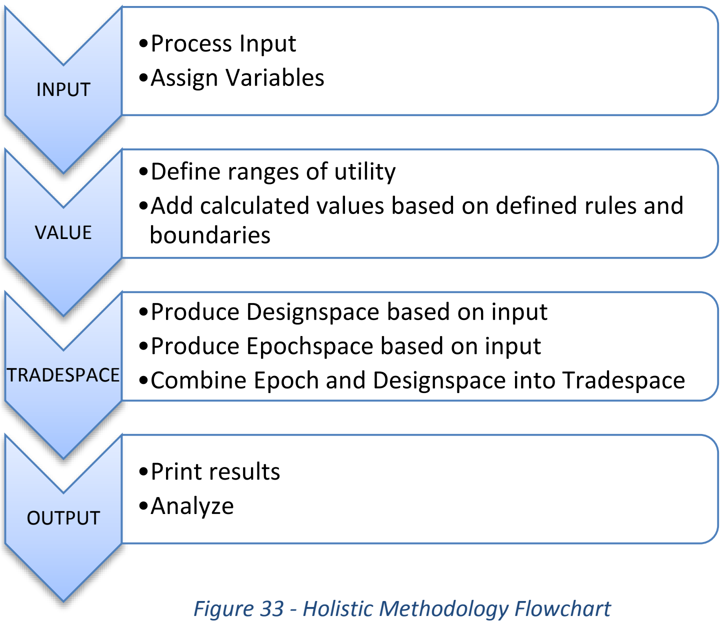


Figure 33 - Holistic Methodology Flowchart

5.2 JavaScript

As previously illustrated, the code can be roughly divided into four modules. These four modules will serve as the foundation for further explanation where structure, methods, limitations and assumptions will be presented and discussed.

5.2.1 Input

```
Designs (MinValue) (MaxValue) (StepSize)
Powering 10000 16000 3000
Ice_Class 0 1 1
Speed 10 16 3
Accommodation 90 140 25
Crane 150 450 150
DP 2 3 1
Length 100 150 25
Beam 20 30 5
Helideck 0 1 1
ROV_Hangar 0 1 1
ROV_Number 1 3 1
Moonpool_Size 5 15 5
Moonpool_Number 1 2 1
Deck_Area 1000 2500 750
ERN 3 4 1
SPS 0 1 1
NOFO 0 1 1
OILREC 0 1 1
RESCUE 0 1 1
SOLAS 0 1 1
```

Figure 34 - Input Text Box

Input to each variable in the script is received from a basic HTML text area box. An example is shown in Figure 34. Each variable must be presented on a new line with a desired minimum and maximum value and a corresponding step size to calculate the number of possible combinations.

Each of these is then parsed into variables iteratively through a for-loop, so that both the variables and their values can be referenced in later calculations.

Variables are divided into three categories: (1) design variables, (2) epoch variables, and (3) attribute variables. Design variables are used to calculate the designspace and are often referenced in utility calculations (more on this in the next section).

After the variables have been parsed and assigned, two methods are used to calculate the step size of design and context variables, and the utility range, calc_steps and calc_util respectively. This defines all the possible values each design and epoch variable can have and also how the utility range is weighted (see section 5.2.2).

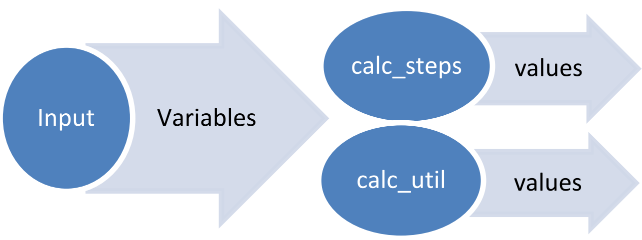


Figure 35 - Input Methods

To exemplify, we can define an input variable for the design, length, and assign a lower bound of 90m, a higher of 130m, and a step-size of 10. The vector of possible results for the length variable is then defined as [90,100,110,120,130].

5.2.2 Value

Utility is the term used in this context to describe how preferred something is, in other words how much value it poses. As previously mentioned, the utility ranges are defined in the input text box. These ranges are static in the sense that they have to be predefined, before all of the calculations are performed. That means that these ranges signify how valued certain aspects of the input are. The second way of gauging how valuable a solution can be is defining methods that perform calculations based on input variables.

The first method of value generation can be illustrated by continuing the example from section 5.2.1. By hypothetically defining a scenario, we can assume that a potential ship owner prefers a ship above 120m because of the added capabilities this provides. In this case the utility range could be set to [110,130], meaning that the target value (which is calculated according to the arithmetic mean) of 120m is weighted at 50% utility. Using this range for the analysis allows us to weigh certain aspects according to owner preferences without eliminating any plausible results.

The second method involves calculations that are to be performed with inputs from designs, and/or epochs. These are called the attribute calculations and could consist of any mathematical calculation that one wishes to include in the final result. These calculations should incorporate various design and epoch variables so that a new measure of value can be created. For example, an indication of fuel consumption can be simplified to a function of machinery and vessel size. Since the consumption is dependent on these variables (which presumably are already served as design input), it wouldn't make any sense for any of these values to be pre-defined, because the result would be the generation of random of values with no coherence or dependability to design values. The alternative is to perform these calculations interactively in the script so that one specific design with defined specifications will produce fuel consumption that is in correlation with this design, and this design only.

Because the system architecture of offshore vessels can vary enormously, and the impact from one change in capability can cause endless ripple effects to the rest of a system's design, a scientifically correct mapping of form and function is beyond the scope of this thesis. Therefore, in order to create variables that indicate the value of a design or an epoch, some assumptions have been made.

First, in order to compensate for the magnitude variances among input variables, each of them had to be normalized. This is performed by normalizing each variable to a target value of 1000. Furthermore, it is reasonable to assume that some of the variables have a greater impact in some situations than others. As an example, a specifically required deck area will surely govern large quantities of the build cost because it directly impacts main dimensions such as length, beam and propulsion. If this investment first is made and the vessel has a fixed amount of deck area, the dimensions of this feature may perhaps constrain the payload capacity, but the degree to which this impacts operational cost is minimal in comparison to the building cost contribution. The complete calculations are shown in Appendix II and the formulas used in the script are shown below.

$$CAPEX = \sum_i \vartheta_i * \delta_i \, , \begin{cases} \vartheta = normalized\ correction\ factor \\ \delta = individual\ design\ variable \end{cases}$$

$$OPEX = \sum_i \xi_i * \varepsilon_i + \psi_D \, , \begin{cases} \xi = normalized\ correction\ factor \\ \varepsilon = individual\ epoch\ variable \\ \psi_D = design\ contribution \end{cases}$$

$$Fuel = P * v^2 + IC, \begin{cases} P = Engine\ Effect\ [kW] \\ v = Speed\ [kn] \\ IC = Ice\ Class \end{cases}$$

$$Revenue = \sum_i \xi_i * \varepsilon_i, \begin{cases} \xi = normalized\ correction\ factor \\ \varepsilon = individual\ epoch\ variable \end{cases}$$

A short overview of the correlating method-names are listed in Table 11 and are more comprehensively described below. For the exact numbers used, the reader is referred to the source code in Appendix III.

Method	Description
Calc_Opex	Calculates the estimated operational costs (OPEX) based on design variables such as speed, and epoch variables such as duration.
Calc_Capex	This method calculates an estimated build cost (CAPEX) based on just design variables, with the exemption of the scenario operating depth. It is assumed that designing for increased depths will increase complexity and heighten the cost.
Calc_Fuel	Here an estimation of fuel consumption is made based on machinery power, speed and ice class.
Calc_Revenue	The revenue function takes into account all epoch variables and produces a number proportional to an estimated degree of contract complexity, i.e. demanding missions earn more money.
Calc_Attrib	This function is in place simply to aggregate the other calculations so that each calculation can be references in an orderly manner later on in the script.

Table 11 - JavaScript Functions

The normalization of variables can be explained by the fact that if not performed, the variables containing the largest values would dominate the calculation results. This could be altered at the stage of input, but then the variable range would be humanly uninterpretable. In other words, to use a realistic value for the desired input of the propulsion machinery (which could be said to be in the range of 15.000 kW), a correction factor must be used so that other variables modelled by much smaller values can contribute to the formula equally. Subsequently, the weighting of the variables are purely done by intuition for the sake of illustration, and have no academic basis.

5.2.3 Tradespace Generation

The next step in the process is to use the calculated values received from the input phase and create the tradespace as a combination of the designspace, epochspace, attribute calculations and applied utility ranges. The tradespace is, simply put, just a term to gather all of the calculated values into one place. This is accomplished in JavaScript in two steps. First, the design-variable vector, $D_d = \{\delta_d^1, \delta_d^2, \delta_d^3, \delta_d^4, \delta_d^5\}$ and epoch-variable vector, $E_e = \{\varepsilon_e^1, \varepsilon_e^2, \varepsilon_e^3, \varepsilon_e^4, \varepsilon_e^5\}$, are served as input to the methods create_designspace and create_epochspace, respectively. These two methods work in the exact same manner, iterating through each possible value δ_m^i / ε_n^j until all possible combinations have been generated. These are then saved in a new array where each vector is a unique design or epoch E_i / D_j.

Finally, generating the tradespace involves assembling each of the pieces created in the last few steps. This encompasses iterating over all generated designs, all generated epochs, and simultaneously applying the attribute and utility calculations so that each tradespace value is unique. In practice, this process demands two for-loops generating the total number of combinations where each individual result is assigned an analysis id in order to differentiate.

5.2.4 Output

At this point, all that remains in the JavaScript code is to print all the results so they can be utilized in alternative software for further analysis. Several methods have been attempted because there is no native function in JavaScript that exports in-memory data to a format easily accessible to software such as Microsoft Excel, or Tableau. Unfortunately, this imposed considerable constraints on the input capability and processing time of the script because all calculations are performed locally in the browser, as opposed to server-side which usually is capable of higher processing speeds. The browser also has a tendency to interpret script calculations as an unresponsive webpage and cause a crash if the duration is too long. The easiest and most proficient solution found was found to be printing comma-separated values to an html webpage. The values can then be copied into excel for reformatting and cleansing, so that Tableau is able to properly interpret the data.

5.3 Analysis

Interacting with the data produced by JavaScript is unquestionably the most prominent value-generating aspect of an Epoch-Era Analysis. Being able to generate a range of possible future scenarios yields very little unless an analytical capability is present to eliminate unwanted aspects. This is where Tableau is introduced.

Tableau is a proprietary piece of software providing free one-year licenses to students. Its purpose is geared towards what is referred to as *Business Analytics* in the business world, meaning basically the ability to review and forecast central performance indicators by investigative exploration for the gain of valuable insights. It is able to source data from virtually any flat-structured source, i.e. a database, but for this purpose a simple Excel spreadsheet is used.

After the data import has completed various forms of data presentation can be comprised and interacted with in order to gain insights. In the case of this Epoch-Era Analysis, typically desired visualizations include total utility compared with capital expenditure (see Figure 36) and epoch comparisons in order to gain an understanding of the temporal aspect.

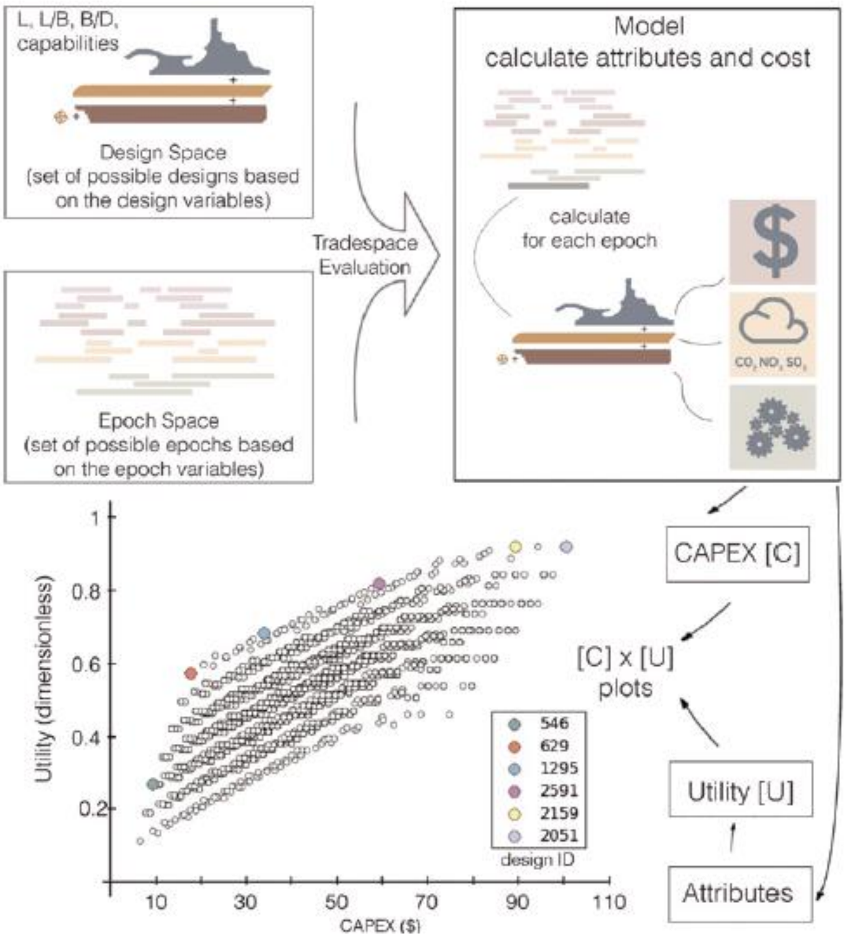


Figure 36 - Desired EEA Visualization

It is the configuration of epochs that create an era, which also can be viewed as a lifecycle, and directly represents any given scenario only governed by whichever assumptions one chooses to incorporate. A common desire is to model *what-if* scenarios attempting to predict the future, but as the future is uncertain and always will be, the more prudent approach would perhaps be to discover which contracts will maximize profit given certain market conditions and a set range of design variables. However, EEA does have the ability of incorporating probability distributions into scenarios so that the outcome of certain situations may be more probable than others, but that is beside the scope of this thesis. In addition, as mentioned in chapter 3.1, optimization models can be applied in order to determine which potential contracts in the market will optimize a given design's profitability.

6 EPOCH-ERA ANALYSIS

In this chapter an Epoch-Era Analysis (EEA) will be performed based on the JavaScript code developed and described in the previous chapter and the Responsive Systems Comparison (RSC) methodology as introduced in chapter 2.2.

As the purpose of this thesis is to illustrate the applicability of EEA when designing the next generation of subsea construction vessels, the underlying data is purely fictitious and based on assumptions made from the gathered information in the market analysis (see chapter 4). Additionally, because the highly complex nature of real scenario applications optimally would take into account several hundred factors, assumptions, probabilistic distributions and mathematical formulas, the scope here is limited to simply highlighting the potential benefit and revealing the steps in which such as analysis is performed.

As mentioned in chapter 5, because JavaScript uses local computational power based in a web browser the performance quickly dwindles when the number of variables are increased. In order to simply be able to perform an analysis to the extent desired, the process has been condensed as much as possible. Naturally, generating as many scenarios as possible will increase the probability with which a successful interpretation is completed. Therefore, maximizing the number of *design variables* and *epoch variables* without compromising the script's ability to run, is a priority. Additionally, the application of assumptions for certain costs such as build cost (CAPEX) and operating cost (OPEX) enable the identification of high value designs that are cost efficient. Incorporating this further means comparing the resulting high-value designs with a range of future scenarios, represented by *contracts*. Consequently, only designs that match requirements are taken into account and each possible scenario constitutes a single contract with a corresponding revenue, reflecting the complexity of the contract.

6.1 ASSUMPTIONS & INTRODUCTION TO THE GENERAL SCENARIO

As mentioned previously, the main reason for narrowing the number of calculation variables comes as a result of the shortcomings in JavaScript's output ability. Optimally, one would be able to input as many variables as desired in one run, so that a single dataset containing all relevant information can be analyzed in coherence. However, because an incremental increase in each variable's individual value, in effect will double the tradespace size, such a method is not always plausible. Accordingly, the use of Pareto's Principle (Koch, 2011) comes in handy by assuming that 20% of the desired variables are, in fact, vital to the analysis, and 80% become trivial. In the analysis, this is applied by condensing the desired features and capabilities unveiled in the market analysis to the fewest possible deemed incontrovertibly necessary. For reference, the main points and indications are summarized in chapter 4.4 and 4.5.

6.2 CONTEXT DEFINITION

The targeted scenario for this analysis takes place in the northern parts of the Barents Sea, featuring construction and installation contracts for well development preparations. This region was specifically chosen because of its demanding meteorological conditions, sustaining near freezing temperatures for the majority of the year in addition to its susceptibility to various other conditions such as currents, strong gusts of wind during dynamic positioning operations, and poor levels of visibility due to ice, wind, snow and wave-spray. Operations in this area are also far from shore and require increased attention to safety and rescue regulations.

The assumptions for this mission are generally indicative of high-end capability requirements, resulting in what would become a highly customized, specified, complex, and expensive solution. Detailed assumptions and variable levels for the analysis are given in Table 12.

	Description	Levels
Weather	Cold, poor visibility, possibility of considerable impact from current and wind. Assume all created designs must meet the harsh demands.	Weather: Severe [4] Calm-Average-Harsh-Severe
Distance	A large distance from shore will impact fuel consumption, quality of accommodation facilities, search and rescue / safety capabilities, and not the least maximum transit speed.	Distance: 200-400km [2] Accommodation: 100-200 [2] Speed: 16-19kn [2]
Class	This far north ice conditions are a challenge. Therefore the majority of considered designs should have a degrees of ice classification.	Ice Class: None-1C-1B [3]
Depth	Operational depth is not usually a prominent problem in this area as most current fields operate between 100-300m deep. In this case it is however assumed that future requirements include deeper waters, also in these areas.	Depth: 300-600m [2]
Crane	As the mission requires installation of heavy modules, crane capacity is a direct result of the projected work magnitude. This is also directly dependent on the operational depth. All are assumed to be active heave compensated.	Crane (main): 250-500 tons [2]
Deck Area	Deck Area is perhaps the main size contributor, but also governs large parts of the payload capacity. Two options are assumed: one average, and one large.	Deck Area: 1000-2500 m2 [2]
DP	Dynamic positioning is dependent on how stringent the requirements are for the designated missions, as well as how severe the wave, wind, and current conditions are on site. A minimum requirement for the mission in question is DP2.	DP: DP2-DP3 [2]
ROV	ROV operations are a central part of tie-in and completion work done during the installation phase. For high-end markets such as this mission is designed for the working standard for ROVs is at least two.	ROV: 2-3 [2]
Machinery	In order to decrease the OPEX, high transit speed and low consumption is preferred because of the long distance to and from shore. This results in increased demand for propulsion	Machinery: 15-20.000kW [3]

	machinery. A large accommodation will also have an impact on auxiliary machinery.	
Duration	The duration a vessel is contracted to stay on site might vary depending on the scope and nature of the mission. It is here assumed that the duration will be either 5 or 15 weeks.	Duration: 5-15 [2]
Location	Even if the specific scenario states a specific location, it is of interest in the analysis to compare given designs to other locations and other scenarios. Three additional locations are therefore included in order of assumed complexity: 1. Indonesia (easy operations) 2. West Africa 3. North Sea 4. Barents Sea	Location: 1-4 [4]
Oil Price	As the oil price undoubtedly will affect the profitability of missions, it is here included by a low price and a high price.	Oil Price: 80-120 USD [2]

Table 12 - Scenario Assumptions

6.3 DESIGN & EPOCH CHARACTERIZATION

Separating and grouping the variables from the table above gives us the resulting design and epoch variables used to perform the Epoch-Era Analysis below.

Design Variables	Units	Min	Max	Stepsize
Power	[kW]	15000	20000	5000
Ice Class	-	0	2	1
Speed	[kn]	16	19	3
Accommodation	[POB]	100	200	100
Crane	[ton]	250	500	250
DP	-	2	3	1
ROVs	-	2	3	1
Deck Area	[m^2]	1000	2500	1500
# of variables:				**384**

Table 13 - Design Variables

The design variables are meant to reflect the stakeholders' main considerations and interests regarding the vessel when modeling possibilities surrounding a given scenario. The epochs on the other hand represent changes in context, i.e. possible scenarios. Some important variables have been listed here, but ideally many more would be incorporated to increase and assess additional contexts and the effects among them.

Epoch Variables	Units	Min	Max	Stepsize
Oil Price	[USD]	80	120	40
Distance	[km]	200	400	200
Duration	[weeks]	5	15	10
Depth	[m]	300	600	300
Weather	-	0	2	1
Location	-	1	4	1
# of variables:				**192**

Table 14 - Epoch Variables

It is the combination of these variables that will constitute the final size of the tradespace, here accumulating to a total of 73.728. However, all possible combinations of input options does not provide insight, which is why a conversion of the stakeholders' needs and objectives must be captured during this phase. It is here the term utility comes to light by representing the desirable range of each attribute. By applying a scale where each design variable can be measured together with further attribute calculations, one immediately is able to perceive how good each part of a solution is. This will heavily contribute to how produced designs can be valued at a later stage. The assumed ranges are shown in the table below where each maximum value is normalized at a utility of 100%.

Attributes	0 %	100 %
Power	10.000	20.000
Ice Class	0	2
Speed	13	19
Accommodation	0	200
Crane	0	500
DP	1	3
ROV	1	3
Deck Area	0	2500
CO2 Emissions	300	100
Fuel Consumption	80	25

Table 15 - Attribute Valuations

It is important to underline that the ranges of the final two variables, CO_2 Emissions and Fuel Consumption, do not represent real values. The utility ranges have been normalized from the resulting calculations so that the lowest emission and consumption rates give a utility value of 100%.

6.4 TRADESPACE EVALUATION

The evaluation of all produced designs and epochs means comparing which designs meet the requirements of given epochs and assessing attributes such as how much it would cost to build and operate a specific design, and what sort of value then is retained for a given scenario. As this phase usually inherits significant amounts of data and the succeeding phases are mostly concerned with contextual elements as well as temporal constructions, the tradespace evaluation serves its purpose largely by properly decomposing the structural aspect so the designspace can be more thoroughly understood. This means that the pragmatic measures of cost and utility (stakeholder value) will be the focal points during this phase of the analysis.

In order to present a comprehensive designspace evaluation it is vital that all aspects of stakeholder value and cost contributors are incorporated. But perhaps most importantly, it must also be visualized in a manner not only providing the sought after information, but also enabling interaction and exploration inherently providing the user with the ability to actually understand the underlying data as opposed to simple static observation.

A dynamic environment is accomplished in Tableau with what is referred to as associative data. This means that after the visualization is complete, each selection can filter associated data only showing relevant values to what the user is interested in. Each part of the developed designspace will now be presented, but for the complete designspace dashboard the reader is referred to Appendix IV.

The most natural starting point of a designspace evaluation is to review the cost it takes to build a specific design versus how valuable it is. Since each input variable has a correlating utility range, these can be combined into an average, providing us with a single measure with which to base valuation upon. Figure 37 illustrates these measures as well as a simple method of identifying the best possible designs, namely whether they are Pareto optimal or not. In this case, the optimal objective is to minimize cost and maximize utility. The optimal designs are highlighted in blue.

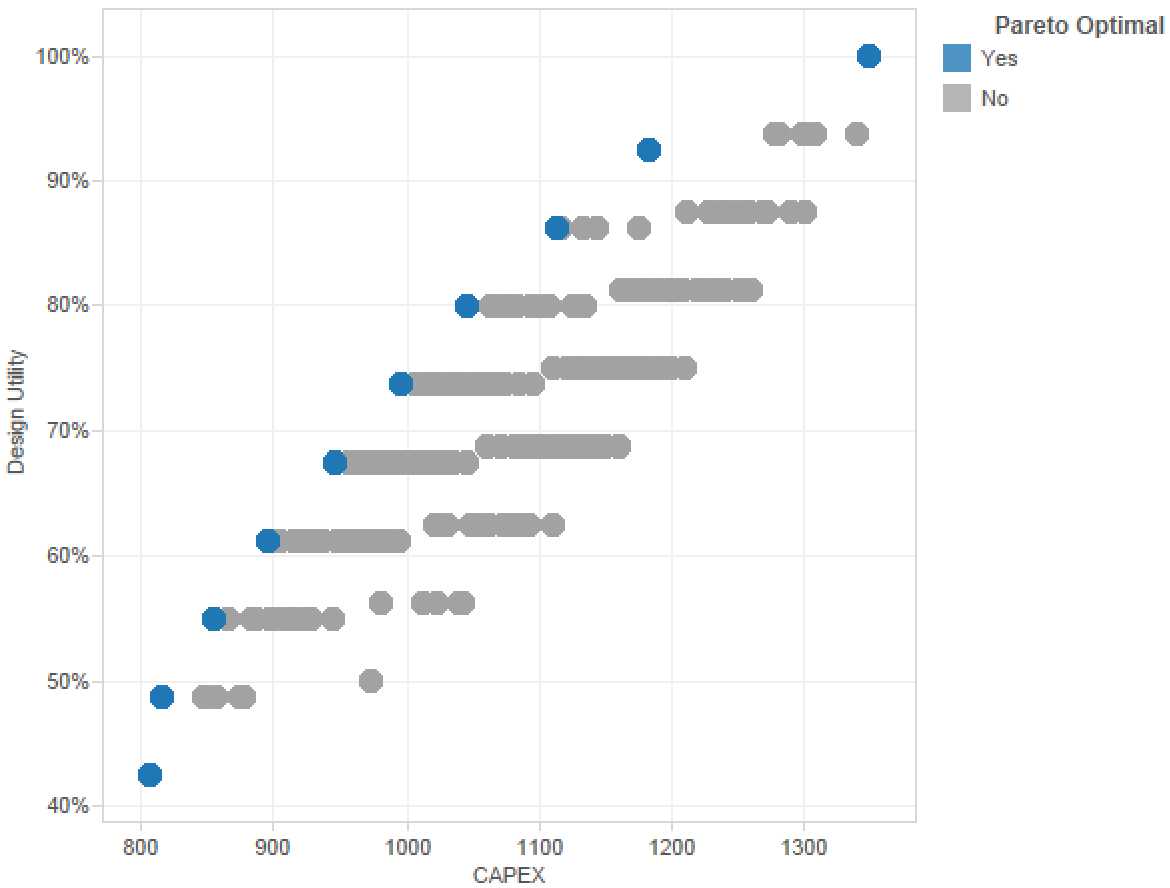


Figure 37 - Design Utility vs. CAPEX

By performing this analysis we have immediately reduced the area of focus from 384 designs, to 10. Of course, there may be other factors worth investigating that may impact perceived value such as operational costs and emission values. Nevertheless, this option provides large degrees of understanding with very little insight needed.

Having now identified a handful designs of interest, these can be investigated further in order to expand our understanding of how other variables might affect the "goodness" of each design. A natural next step would be to assess an estimated operating cost according to build cost and utility. This is shown in Figure 38.

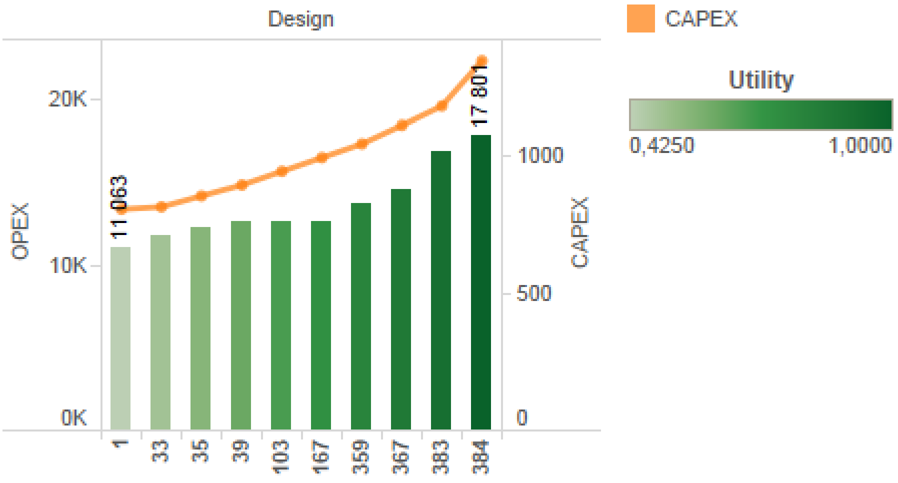


Figure 38 - Estimated OPEX vs. CAPEX & Utility

Keep in mind that the axis values are purely fictional, but this method of illustration still gives the user a clear and perhaps more understandable picture of what consequences certain choices might have. Exemplifying, it is clear that the most expensive design to build will provide the highest degree of value to stakeholders because it is contains all the desirable features, but given certain scenarios the cost-benefit ratio might be high enough to justify the high investment cost just the same. This will be discussed in the following segments. Simultaneously, the next logical progression will be to compare which features one forfeits by minimizing cost. An overview is therefore provided in Figure 39.

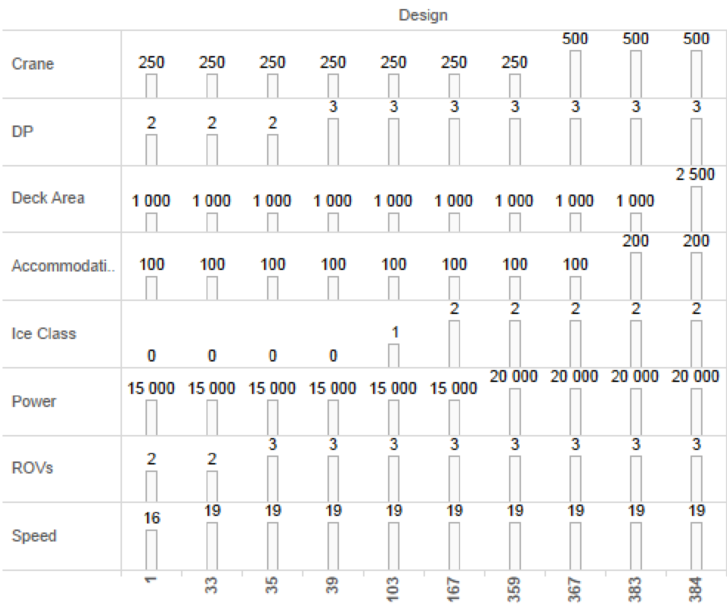


Figure 39 - Design Specifications

Lastly when evaluating potential designs, the visualization of additional attribute values is also pertinent. In this case the only calculated attributes that are not evaluated directly from input values are fuel consumption and CO_2 emissions. Evaluating these according to a range set by stakeholders, defining which values are desirable and not, Figure 40 is created.

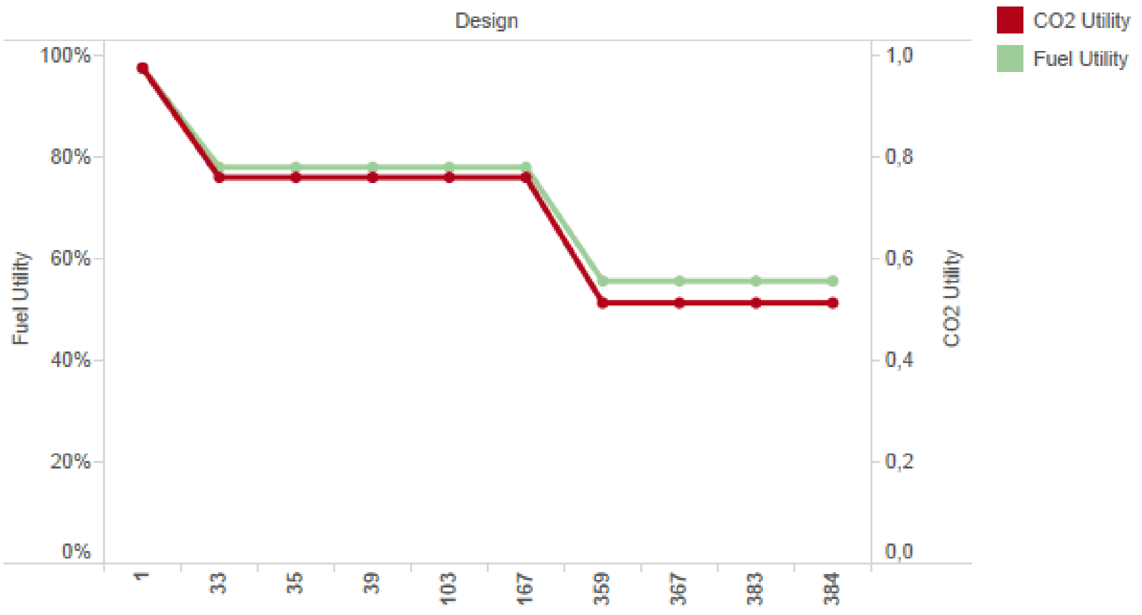


Figure 40 - Calculated Attribute Utilities

As such, if a potential owner already knows that his vessel will have to operate in emission regulated areas, a predefined benchmark can be set for this purpose in particular and designs evaluated accordingly.

6.5 Multiepoch Analysis

Continuing from where the previous phase left off, an indication of which designs are deemed valuable will serve as the basis for which scenarios they are able to operate in, and which of them will provide the highest profit margins, accordingly. During this phase it is extremely important that the analysis convey the proper interpretation of what constitutes value for the stakeholders. Identifying the best designs and evaluating them according to cost is not a significantly complicated process. The process of incorporating certain designs into contextual shifts however, can be incredibly complicated and must be interpreted with care in order to avoid confusion or otherwise hinder purely fact-based decision making.

By estimating a mission's (epoch/contract) revenue based on the degree of complexity a plausible profit margin can be calculated by subtracting the operational costs. Such an estimation is shown below. The complete dashboard can be found in Appendix V.

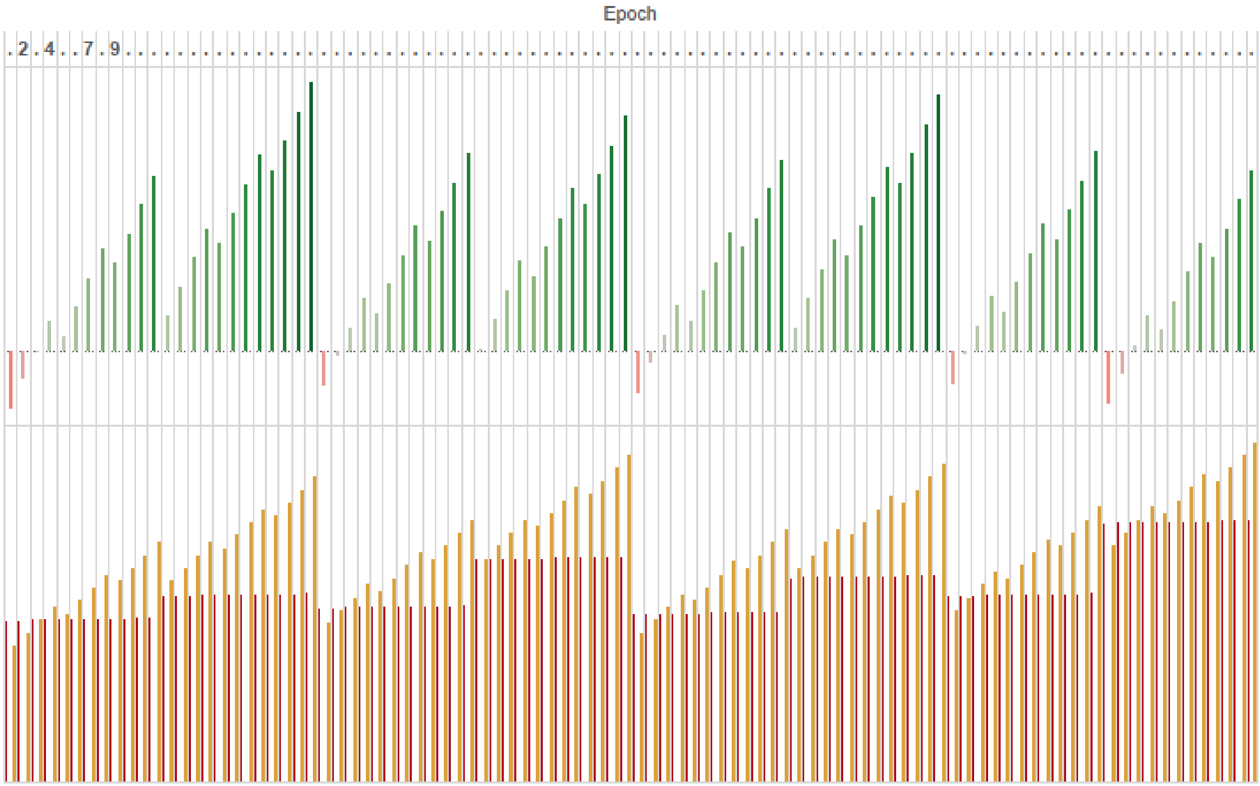


Figure 41 - Bottom: Revenue vs. OPEX. Top: Profit Margin

This visualization may seem a little indistinguishable and unrealistic, but it immediately provides information based on the provided data whether a given scenario is profitable or not. Represented slightly differently, the most attractive missions become quite clear.

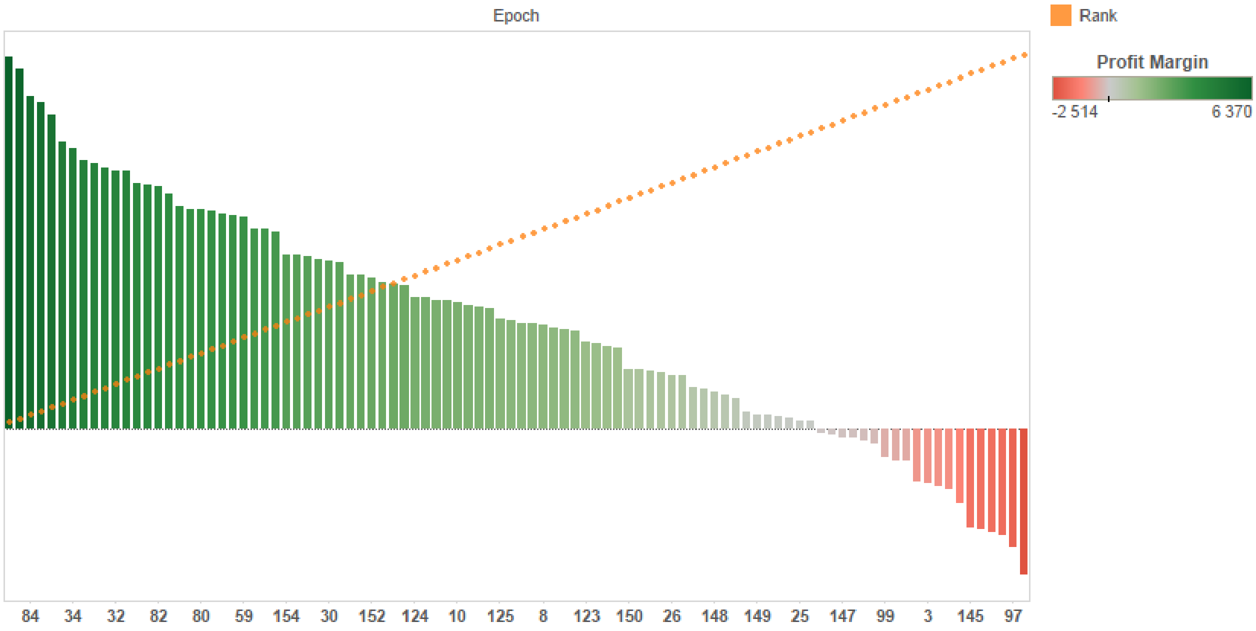


Figure 42 - Profit Margin Distribution per Mission

By further interacting with this information and highlighting the most profitable mission types, their characteristics can immediately be compared and evaluated according to which designs are needed to complete such a task.

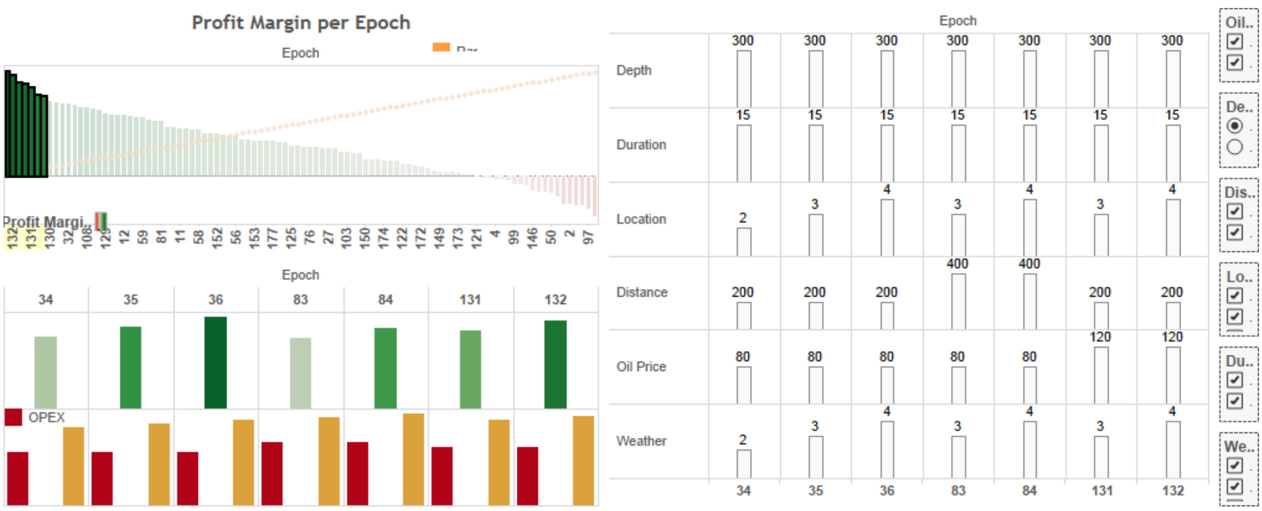


Figure 43 - Filtered Multiepoch Evaluation

6.6 Era Construction

Following the logic of multiepoch analysis, the owner would presumably seek to maximize the return on his investment, given a certain amount of constraints and conditions reflecting which missions are to be targeted at what time. An era represents the assembly of different missions over time and can be modelled simply by intuition, or by more advanced techniques incorporating probabilistic distributions, risk assessments, weighted scenarios and so on. Regardless, the process of assembling epochs must obey the rules of consistency applying to such factors as the chronological progression of contracts, technology developments and market advancements.

Below is shown a developed example of how various eras can be visualized by taking into account contract durations and expected revenue.

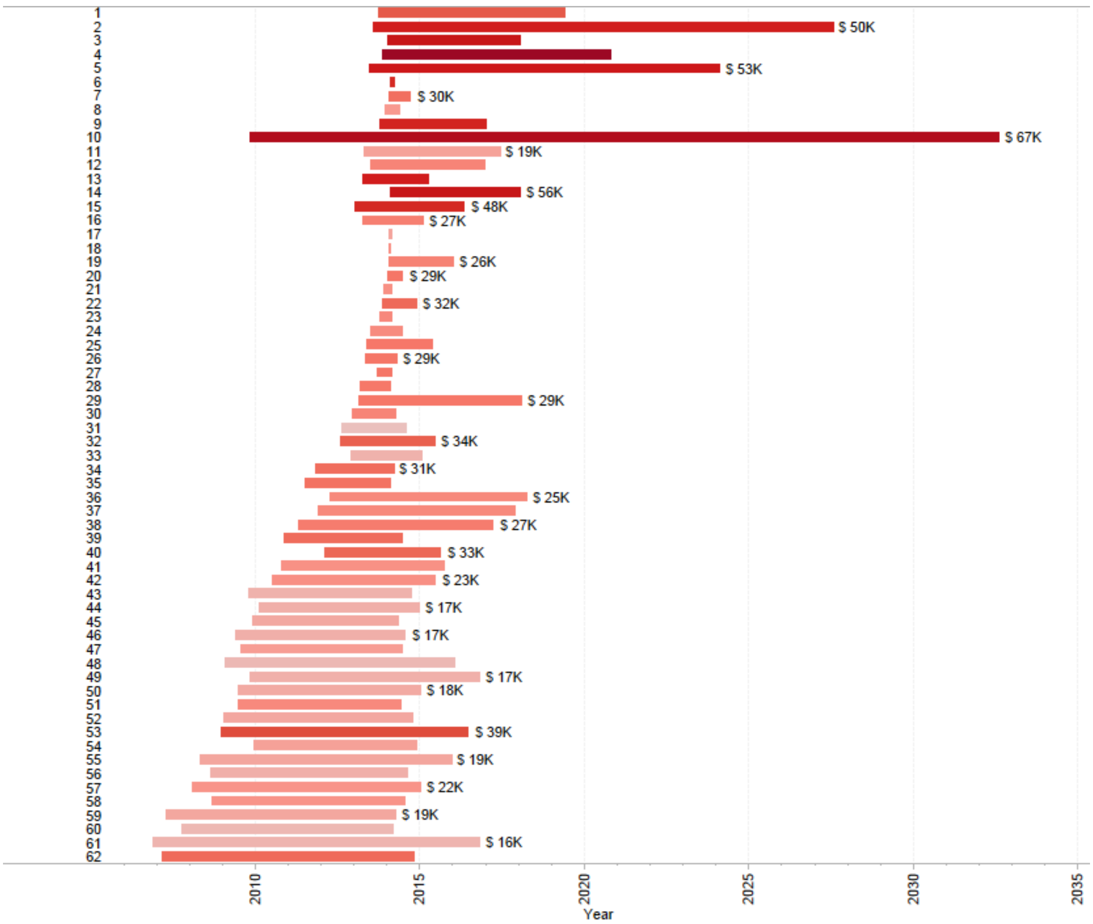


Figure 44 - Expected Revenue per Era

The strongest color clearly identifies the most valuable eras and when they take place. Ideally one would be able to incorporate certain probabilistic distributions into each epoch based on given assumptions, so that a simple drag-and-drop functionality could be applied and eras built interactively simply by preference or probability. Another option would be to apply an optimization algorithm such as the SDDP model described in chapter 3.1, which then could identify the most valuable contracts and associated path of execution, and furthermore apply the relevant requirements identifying valid designs. This is however beyond the scope of this thesis, and for the purpose served here a simple illustration of how various epochs can be assembled consistent with applied requirements will suffice.

In order to create a delimited set of possible scenarios, constraints must first be applied. In this case the chosen possibilities have been reduced to those listed in Table 16.

Epoch Variable	Value
Oil Price	$ 120
Depth	300 m
Distance	400 km
Location	North Sea Barents Sea
Duration	15 weeks
Weather	Average Harsh Severe

Table 16 - Epoch Constraints

These constraints lead to six possible epochs, each of which has an associated profit margin. Eliminating negative profit margins and grouping by contribution percentage results in Figure 45.

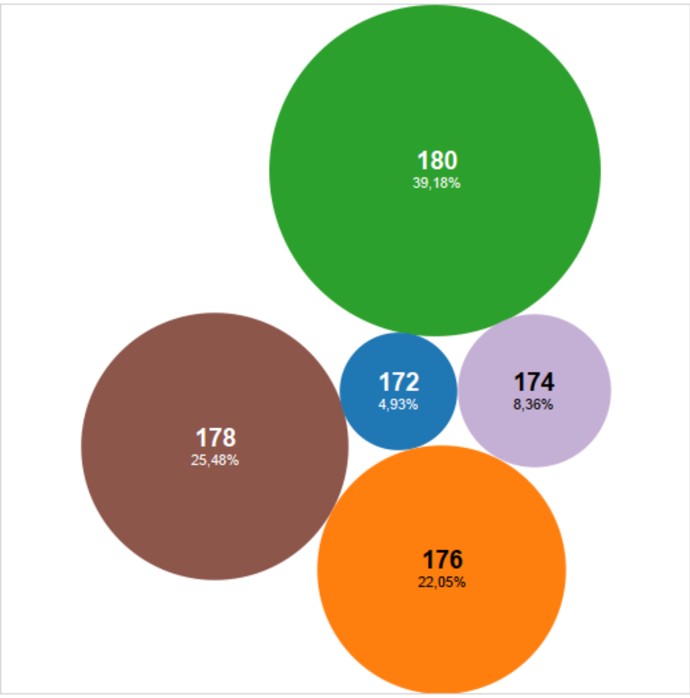


Figure 45 - Era Overview by Epoch Profit Margin

Assuming each of these contracts are for a period of five years and are sequentially available to create a 15-year era consisting of the aforementioned scenario limitations, maximizing profit would the choice of epochs 176, 178, and 180.

Furthermore, the imposed restrictions require designs with the corresponding level of capabilities which, if applied to the designspace, result in the following rank illustrating which designs not only meet the mission requirements, but to which degree they maximize utility and minimize build cost.

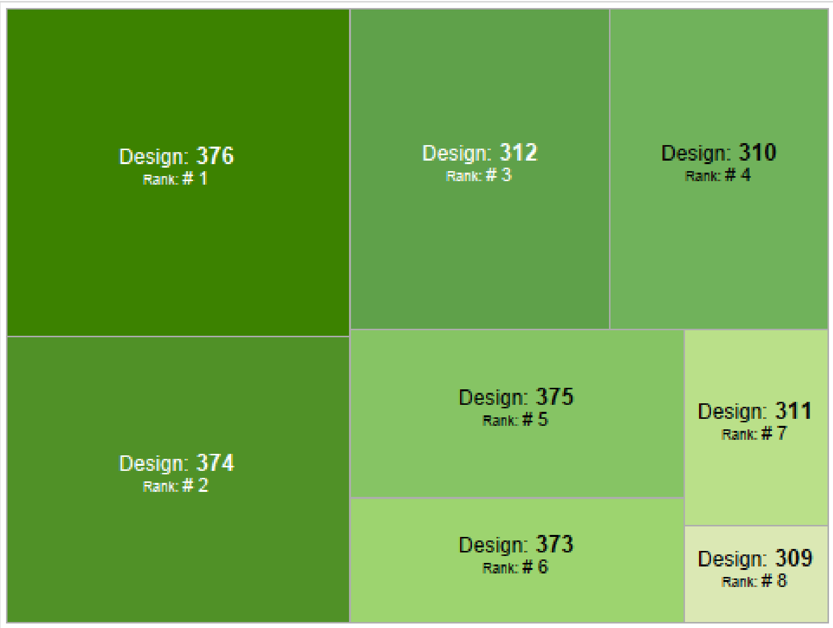


Figure 46 - Applicable Designs Ranked by Cost-Benefit Ratio

Based purely on cost-benefit ratio, design #376 is clearly the best choice among those meeting the required functionalities.

6.7 Lifecycle Path Analysis

The final stage of the RSC method is designed to highlight the consequences of choices and assumptions made underway. Comparison of designs under varying circumstances, possible trade-offs, and identification and development of value robust strategies are all central concepts pertinent to this phase of analysis. If the functionality of adding capabilities to designs is incorporated as an analysis input, this would be a most natural stage at which to investigate the effects of such add-on capability according to various scenario developments. However, extrapolating which of the given designs perform best under assumed eras could also be supplemented by identifying which factors contribute towards increased stakeholder value. More specifically, one could for instance try to assess which design aspects can be built cheaply, operated for a certain period of time and then perform a planned upgrade with an updated version, in order to uphold, or even increase, the perception value without exceeding the bounds of reasonable expenditure. Such considerations can quickly lead to the development of various robust lifecycle strategies, which consequently will directly result in methods of uncertainty mitigation.

An option mentality, such as the one just described, has not been incorporated into this specific analysis. As such, the main considerations to take into account would consist of design evaluations by choice of contract. Because the amount of epochs and designs quickly diverge, this process can be quite confusing if the proper aesthetics are not applied. To illustrate, the developed dashboard below shows OPEX, profit margin, fuel efficiency, and design utility by each epoch and design with an attempt made at colorizing the most attractive solutions. Minimizing operational cost yields green columns and maximizing utilities yields darker columns.

Figure 47 - ERA 1 Lifecycle Analysis

As can be seen from the top of the figure, slicers have been applied to each variable so that the number of possible designs has been considerably delimited. It is also assumed that this era (ERA 1) consists of three possible epochs identical to those shown in the previous chapter to be the most profitable: 176, 178 and 180. From here design constraints can be applied and the best designs identified.

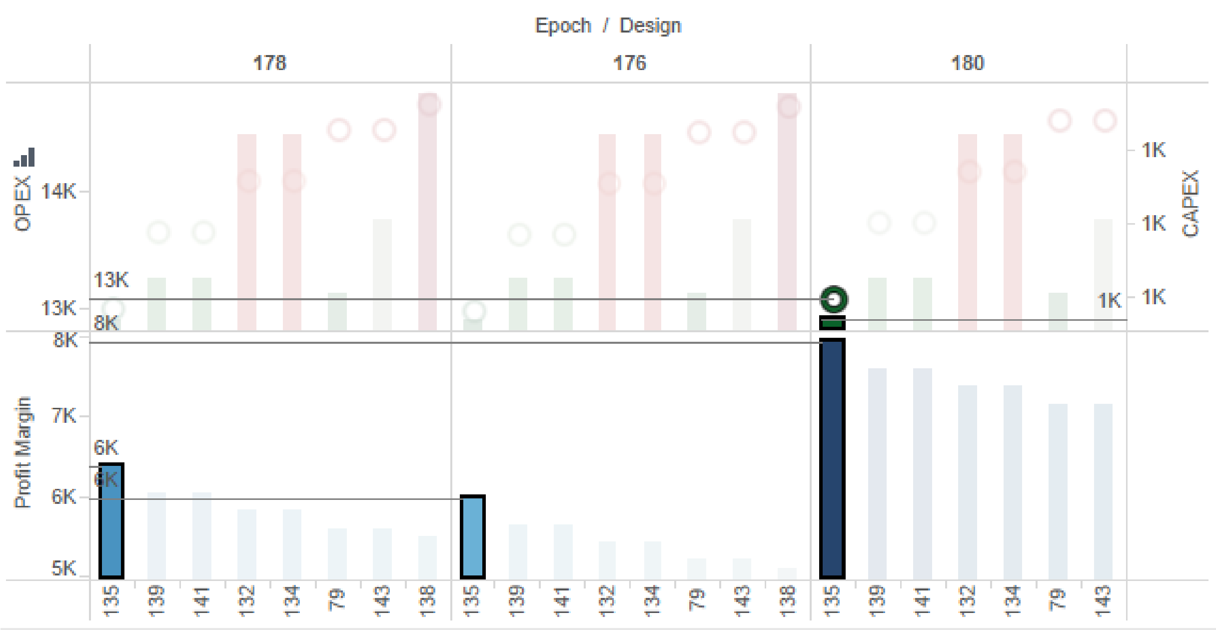


Figure 48 - Identifying Value Robust Designs

One can clearly see that both operational and investment costs are significantly below average for design #135, but comparing with fuel efficiency and design utility (Figure 49) shows that there are other designs more capable of withstanding an increase in complexity regarding mission requirements in the future.

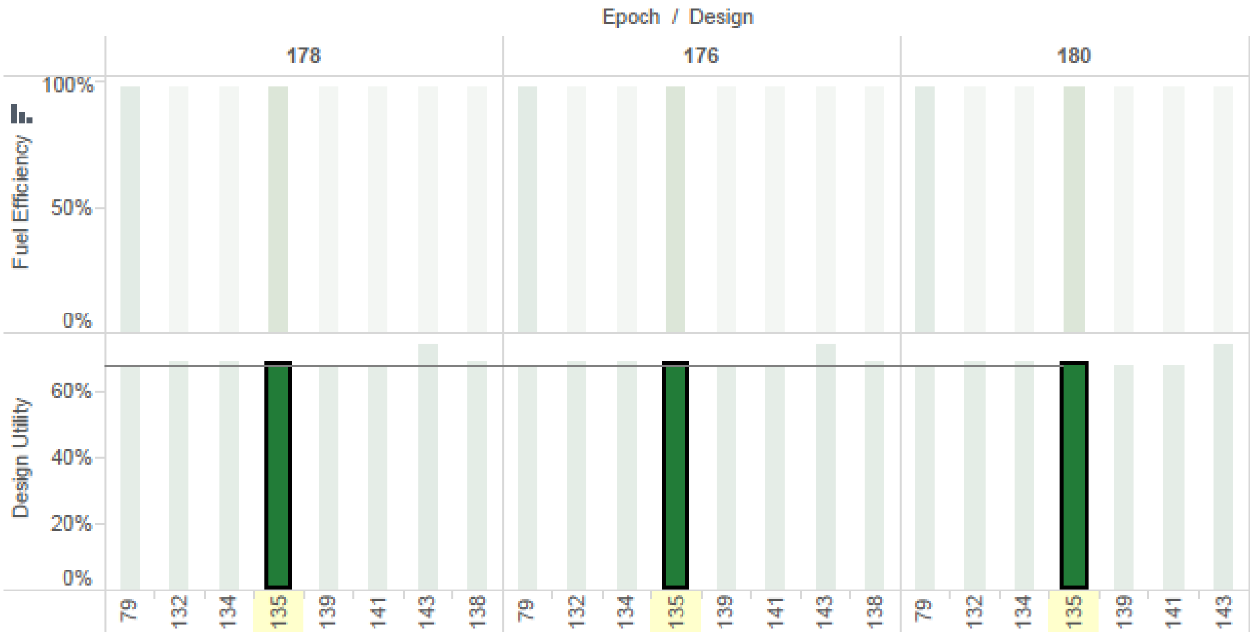


Figure 49 - Fuel Efficiency and Design Utility

The same thought process can also be applied in a much larger scale in order to visualize both valued designs and the range of their inherent values. This might provide an owner with a broader perspective when leveraging options in a difficult scenario, such as regarding poor contract options versus putting the vessel up for sale. Doing this enables a rapid estimation of potential losses when compared to its corresponding market value. Figure 50 illustrates such a scenario where a specific era has been composed by assumption of future developments, and through the highlighting of designs that have been previously identified as valuable in other scenarios, here provide a good idea of incurred costs should this era come true.

Figure 50 - ERA 2 Potential Scenario Evaluation

Not only does this provide the owner with valuable information through visualizing the effects of his decisions, but additionally it serves as a supplement to the decision making process by conjoining any desired range of epochs and immediately identifying correlating costs and benefits.

As an alternative approach, identifying value robust designs can be done by simply eliminating all scenarios below a given profit margin and highlight which designs are present. This does however presume that the resulting epochs are probable to occur as part of future scenarios.

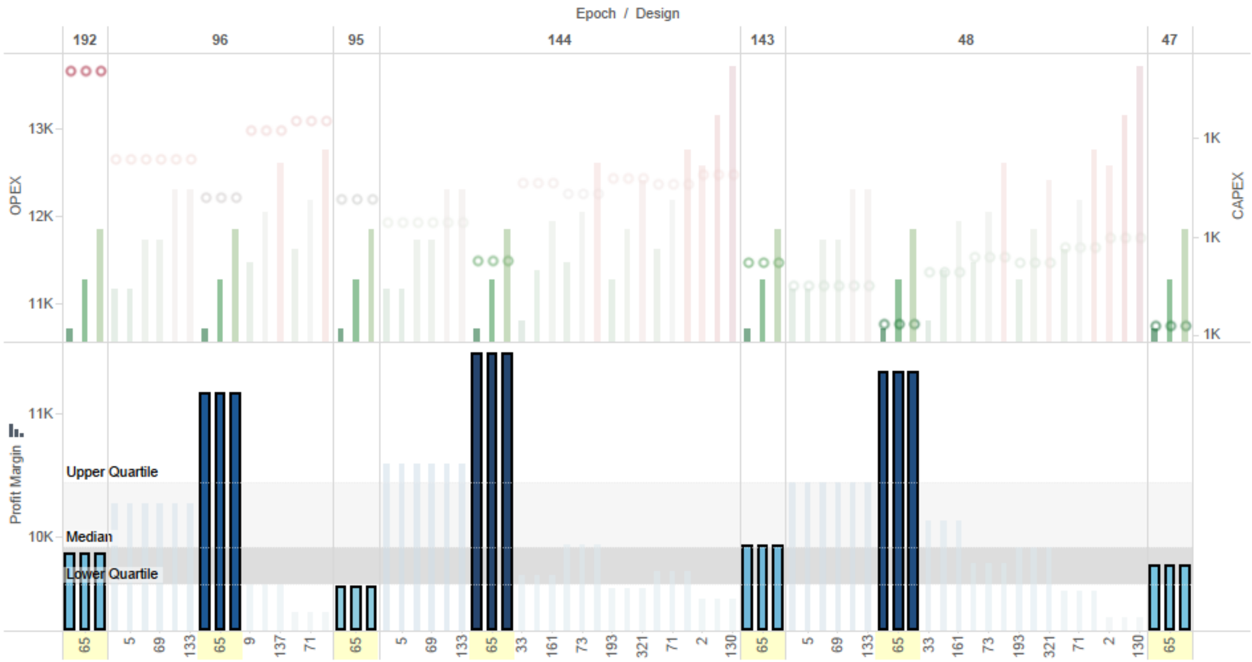


Figure 51 - Value Robust Design Identification

The only designs present in all resulting epochs, when only considering profit margins in the top 10%, have been identified in Figure 51. Not only do these three designs span a larger set of possible mission types, but they also inhibit some of the largest profit margins of all. Thusly, the optimal strategy when choosing a design for operation within the realm of the seven epochs listed above, would simply consist of choosing the cheapest that occurs in all of them, i.e. design #1.

6.8 Discussion

Assessing this analysis from a holistic perspective, many different approaches have been taken in order to illustrate some of the benefits Epoch-Era Analysis is capable of providing. Many different aspects and value propositions have been evaluated, each producing useful insights capable of providing stakeholders with key information during phases of acquisition, design, or even operation. As the conceptual phase often is driven by the assessment of economic gain amongst uncertain futures, this type of analysis has proven to be flexible enough to deal with the vast majority of the temporal aspects during ship design scenario problems.

One of the strongest features of EEA is its versatility and ability to incorporate other methodologies such as probability theory and optimization, without compromising any of its native features. It is however important to be aware of the fact that the vast amount of options when developing stakeholder value interpretations might appear somewhat limitless, but the ensuing intricacy of incorporating such complex methods will undoubtedly challenge the analyst's capabilities. Maintaining a logical structure during computations is as a formidable challenge when the scope is increased, and additionally creating visual interpretations with the required level of insight and interaction can serve as a trial of perseverance.

Taking into consideration that the data on which this analysis has been based is strictly fictitious, an increased number of variables would clearly be required in a real scenario evaluation. There are presumably many considerations, assumptions, calculations and assessments prevalent in industrial decision-making, and as much as possible of this information would need to be quantified accordingly. Nevertheless, the presented illustrations and key argumentation points would have remained the same and rendered valid also for a larger and more complex dataset, albeit with different margins and factual numbers. For the sake of this thesis, a more realistic representation of the impact certain changes in design have on adjacent components would have been a desirable feature to incorporate. Provided the scope however, such functionality has proven to be out of reach. Additionally, an industrial survey of what actual vessel owners and stakeholders view as valuable features could have induced a higher degree of plausibility.

Another point worthy of comment is that the programmatic solution of applying epoch requirements upon the set of possible designs, was unable to be found. This means that despite filters being applied to the epochspace in order to narrow down certain possible missions, all possible designs still were applicable. As a result of not being able to incorporate this into the code, the assumptions had to be manually transferred by use of filters in Tableau, which explicitly excludes all matching criteria from the results. For instance modeling various scenarios requiring the use of ice class to operate, non-ice capable designs had to be excluded in order to display the correct results. Nevertheless, despite the lack of this desirable feature in the programmatic solution, none of the results have suffered in quality or been impacted in any other way.

In conclusion, two fragments of Epoch-Era Analysis have been identified to be extremely fragile during development and undoubtedly have the potential of drastically influencing the analysis results. First off, as described in the first two processes of the RSC method, the identification and development of which factors contribute towards stakeholder value, as well as how to calculate it, determines the complete foundation of which insights are given. For instance, the utility range of how many persons on board a vessel is capable of is based on an assumption that is constantly subject to change. Leaving this range static during the process of an analysis could potentially eliminate perfectly applicable designs during assumed lifecycles. Including the capability of dynamic input in the programmatic methodology for this thesis has therefore shown to be a valuable option even if the inherent consequences of application haven't been discussed. Secondly, when modeling alternate future scenarios each of them will always have an infinite number of possible consequences based on assumptions. Taking the introduction of stricter emission legislation as an example, such a regulation will impact not only the allowed emission levels for specific designs, but also contributing factors such as machinery size and technology, choice of fuel, and logistics and routing options, each of which also will have in-built consequences. Not to mention the fact that many of these consequences are completely intangible and subsequently much more difficult to quantify into an analysis. Mapping these kinds of relations could very well prove to be a perpetual process. Therefore, being able to delimit and identify the main contributors may seem like a simple enough task during initial stages, but it is this task that lays the ground on which all following results are built and must thusly not be underestimated.

7 CONCLUDING REMARKS

This chapter will review the main points of this thesis and present a short summary of results and other findings.

This thesis shows the creation and application of an Epoch-Era Analysis based on realistic market-oriented parameters. Not only has the methodology in which such an analysis can be performed been illustrated, but also the identification of both pros and cons of the methodology in question have been presented. Using the Responsive Systems Comparison method, each segment has been processed step by step and the subsequent results accordingly discussed.

Because of the scarcity of readily available EEA software the calculations serving as the basis of the analysis had to be developed solely for the purpose of this thesis. JavaScript was the chosen language of programming in order to provide a dynamic way of altering input variables, but during the end of development it was discovered that the resulting processing power was insufficient for the initially desired purpose. Nevertheless, using Pareto's 80-20 rule, the most pertinent variables were identified and incorporated, creating a significant tradespace ripe for evaluation.

By creating such an exorbitant amount of design and scenario combinations the process of extracting valuable information can quickly become blurry. Therefore, the structured approach of the RSC methodology provided invaluable insights and organization to an otherwise incomprehensive dataset. The use of Tableau also significantly supplemented the ease of analysis by enabling interaction of associative information. Sectioning parts of the data and comparing it to predefined sets of interest has proven to be key during this type of analysis.

Regarding the results, many different approaches were taken in order to illustrate the adaptability and resilience of Epoch-Era Analysis. By utilizing a wide range of visualizations valuable information such as the most desirable cost-benefit ratios of proposed designs, which scenarios provide the highest profit margins, and a simple identification of the optimal design choices based on future scenario assumptions, can quickly be analyzed and presented in order to enhance the efficiency at which conceptual design process can be performed.

Although this thesis just serves as an illustration of the possibilities such an analysis provides, it is quite clear that the initial objective of investigating the plausibility of EEA, and whether it can deliver sustained value to stakeholders over time in a complex, uncertain and changing operating context, has been confirmed. By dividing and organizing temporal scenarios in an orderly manner, this type of analysis can provide insights paramount to designers, as well as stakeholders, during the conceptual stage.

7.1 FURTHER PROSPECTS

Epoch-Era Analysis is still a very fresh concept and has yet to be implemented in a larger scale for use in the offshore industry. There is a clear need to identify further applications within specified industrial segment, such as offshore vessel design, and to uncover where the bottleneck is situated in terms of complexity and realistic parameters.

Further work should attempt to incorporate real life scenarios and the implications such parameters incur on both the process as well as the results. Additionally, a more robust programmatic model should be developed to handle larger sets of constraints, increased variable ranges, automatic appliance of epoch requirements on designs, and alternate types of visualization that capture the maximum amount of valuable information as simply as possible.

If such a model is created, the next hurdle, and perhaps the most prominent, would regard how to decompose intangible stakeholder interests, scenario alteration implications and finally how to exactly quantify attributes such as *value*, *utility*, and *return on investment*. Many common attributes can be fairly straight forward to estimate, but the real challenge lies in aptly mapping the interactions between design variables and scenario assumptions. It is these attributes that directly provide insight, and consequently also govern the quality of which potential decision-making is based upon.

8 REFERENCES

BOEHM, B., ROSS, A., LANE, J. & SULLIVAN, K. 2013. Tradespace and Affordability-Phase 1. DTIC Document.

BP 2013. BP Energy Outlook. http://www.bp.com/content/dam/bp/pdf/Energy-economics/Energy-Outlook/BP_Energy_Outlook_Booklet_2013.pdf: British Petroleum.

CARLSON, J. M. & DOYLE, J. 2000. Highly optimized tolerance: Robustness and design in complex systems. *Physical Review Letters,* 84**,** 2529.

DOKKUM, K. & KOENEN-LOOS, C. 2013. *Ship Knowledge: Ship Design, Construction and Operation*, DOKMAR.

DYRING, P. 2012. June 2012 - Subsea and Specialized Vessels. *The Subsea Report.* www.fearnleyoffshoresupply.com: Fearnley.

ENERGY, R. Subsea Competence Analysis and Projection. Underwater Technology Conference, 2013 Bergen, Norway.

ERIKSTAD, S. 2009. Modularisation in shipbuilding and modular production. *Innovation in Global Maritime Production*.

ERIKSTAD, S. O. 1996. *A Decision Support Model for Prelimenary Ship Design*.

GAARD, M., ALAM, S. & STRÖM, J. 2013. Subsea Construction Support & Supply. Carnegie Research.

GALTON, A. 2009. Spatial and temporal knowledge representation. *Earth Science Informatics,* 2**,** 169-187.

GASPAR, H., ROSS, A., RHODES, D. & ERIKSTAD, S. Handling complexity aspects in conceptual ship design. International Maritime Design Conference, Glasgow, UK, 2012a.

GASPAR, H. M. 2013. *Handling aspects of complexity in conceptual ship design,* Trondheim, Norges teknisk-naturvitenskapelige universitet.

GASPAR, H. M. & ERIKSTAD, S. O. 2009. Extending the Energy Efficiency Design Index to Handle Non-Transport Vessels. *COMPIT.* Budapest.

GASPAR, H. M., RHODES, D. H., ROSS, A. M. & ERIKSTAD, S. O. 2012b. Addressing Complexity Aspects in Conceptual Ship Design: A Systems Engineering Approach. *Journal of Ship Production and Design,* 28**,** 145-159.

GASPAR, H. M., ROSS, A. M. & ERIKSTAD, S. O. 2012c. Handling temporal complexity in the design of non-transparent ships using epoch-era analysis. *Intl J. Maritime Eng.,* Trans RINA**,** 109-120.

GREGOR, J. A. 2003. Real options for naval ship design and acquisition: a method for valuing flexibility under uncertainty. DTIC Document.

HUSBY, A. & SØGÅRD, B. 2011. Subsea Standard & Rules - 'What is Subsea?'.

IHS 2013. Construction Vessel Base.

INTSOK 2014. Annual Market Report 2014-2017. INTSOK - Norwegian Oil and Gas Partners.

KOCH, R. 2011. *The 80/20 principle: the secret to achieving more with less*, Random House LLC.

KREUTZ, M. The International and Norwegian Financial Situation. Olje og Gasskonferansen, 2012 Sandnessjøen. DNB.

LAWLER, A. 2013. *OPEC Secretary General 'comfortable' with 2014 oil outlook* [Online]. Reuters. Available: http://www.reuters.com/article/2013/10/01/us-opec-idUSBRE9900TV20131001 [Accessed 25. March 2014].

MATHISEN, E. R. 2012. Subsea Sector Report Q4. DNB Markets.

MERTON, R. C. 1998. Applications of option-pricing theory: twenty-five years later. *The American Economic Review,* 88**,** 323-349.

MUMM. 2014. *Management Unit of the North Sea Mathematical Models* [Online]. Royal Belgian Institute of Natural Sciences. Available: http://www.mumm.ac.be/EN/NorthSea/facts.php [Accessed 2014 20. March].

NEUFVILLE, R. 2003. Real options: dealing with uncertainty in systems planning and design. *Integrated Assessment,* 4**,** 26-34.

NEUFVILLE, R. D. 2000. Dynamic strategic planning for technology policy. *International Journal of Technology Management,* 19**,** 225-245.

PANETTA, P. V., HASTINGS, D. & BRUMFIELD, M. 2001. Managing Programmatic Risk for Complex Space System Developments. *RECON*.

PETROBRAS. 2012. *What is Pre-Salt?* [Online]. http://www.petrobras.com.br/. [Accessed 20. February 2014].

RADER, A. A., ROSS, A. M. & RHODES, D. H. A methodological comparison of Monte Carlo Simulation and Epoch-Era Analysis for tradespace exploration in an uncertain environment. Systems Conference, 2010 4th Annual IEEE, 2010. IEEE, 409-414.

RHODES, D. & ROSS, A. Five aspects of engineering complex systems emerging constructs and methods. Systems Conference, 2010 4th Annual IEEE, 2010. IEEE, 190-195.

RIGZONE 2013. Rig Data: Worldwide Offshore Rig Fleet Information. RigZone.

ROBERTS, C. J., RICHARDS, M. G., ROSS, A. M., RHODES, D. H. & HASTINGS, D. E. Scenario planning in dynamic multi-attribute tradespace exploration. Systems Conference, 2009 3rd Annual IEEE, 2009. IEEE, 366-371.

ROSS, A. M. 2006. *Managing unarticulated value: changeability in multi-attribute tradespace exploration.* Citeseer.

ROSS, A. M. & HASTINGS, D. E. 2005. The tradespace exploration paradigm.

ROSS, A. M., MCMANUS, H. L., RHODES, D. H., HASTINGS, D. E. & LONG, A. 2009. Responsive systems comparison method: Dynamic insights into designing a satellite radar system. *AIAA Space 2009***,** 1-25.

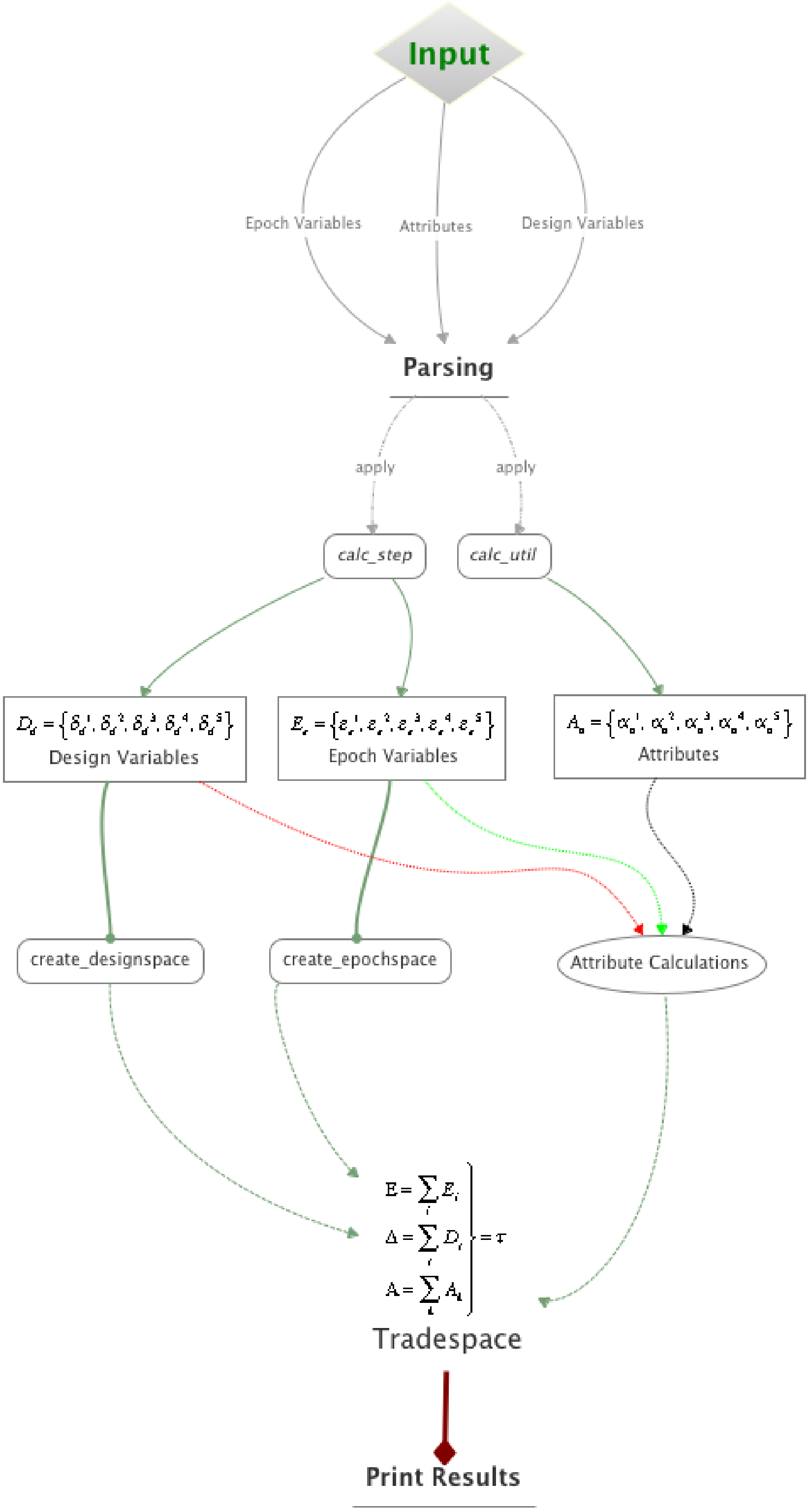
ROSS, A. M. & RHODES, D. H. Using natural value-centric time scales for conceptualizing system timelines through epoch-era analysis. INCOSE International Symposium, 2008. Citeseer.

SCHAFFNER, M. A., ROSS, A. M. & RHODES, D. H. 2014. A Method for Selecting Affordable System Concepts: A Case Application to Naval Ship Design. *Procedia Computer Science,* 28**,** 304-313.

SHISHKO, R. & EBBELER, D. 1999. A Real-Options Approach for NASA Strategic Technology Selection.

UCUBE 2013. Cube Browser. Rystad Energy.

APPENDIX I



Input
Epoch Variables
Attributes
Design Variables
Parsing
apply
apply
calc_step
calc_util
Design Variables
Epoch Variables
Attributes
create_designspace
create_epochspace
Attribute Calculations
Tradespace
Print Results

APPENDIX II

Variable Contributions

Target weight is 1000

Design	capex	opex	range		unit	average	C	magnitude	value	weight	O
Powering	15 %	3 %	15000	20000	kw	17500	**0,01**	*0,06*	17500	1050	**0,002**
Ice Class	5 %	0 %	0	2	-	1	**50,00**	*1 000,00*	1	1000	-
Speed	5 %	0 %	16	19	kn	17,5	**2,85**	*57,00*	17,5	997,5	-
Accommodation	10 %	15 %	100	200	POB	150	**0,70**	*7,00*	150	1050	**1,05**
Crane	10 %	5 %	250	500	tons	375	**0,27**	*2,70*	375	1012,5	**0,14**
DP	10 %	5 %	2	3	-	2,5	**40,00**	*400,00*	2,5	1000	**20,00**
ROV	10 %	5 %	2	3	-	2,5	**40,00**	*400,00*	2,5	1000	**20,00**
Deck Area	20 %	5 %	1000	2500	m2	1750	**0,11**	*0,57*	1750	997,5	**0,03**
Epoch	capex	opex	range		unit	average	C	magnitude	value	weight	O
Oil Price	0 %	5 %	80	120	USD	100		*10,00*	100	1000	**0,50**
Distance from Shore	0 %	5 %	200	400	km	300		*3,35*	300	1005	**0,17**
Duration on Site	0 %	5 %	5	15	weeks	10		*100,00*	10	1000	**5,00**
Weather Conditions	0 %	5 %	0	2	-	1		*1 000,00*	1	1000	**50,00**
Depth	15 %	10 %	300	600	m	450	**0,34**	2,25	450	1012,5	**0,23**
Location	0 %	5 %	1	4	-	2,5		400	2,5	1000	**20,00**
	100 %	**73 %**									
Resulting Fuel Cost		27 %									
Fuel Calculations											
Powering	0 %	50 %	15000	20000	kw	17500	-	*0,06*	17500	1050	**0,03**
Ice Class	0 %	10 %	0	2	-	1	-	*1 000,00*	1	1000	**100,00**
Speed	0 %	40 %	16	19	kn	17,5	-	*57,00*	17,5	997,5	**22,80**

Powering, Ice Class and Speed are taken into account during fuel calculations. The additional powering variable is to account for auxiliary power on board.

These three variables are incorporated into the calculated fuel cost.

Weather and Location are worked into the final opex calculation.

APPENDIX III

MAIN.HTML:

```
<html>

<style>
body { font: 12px Arial;}

text {
  font: 10px sans-serif;
}
</style>

<body>

<p>Input parameters for calculation. Separate by space.</p>

<!--This  textarea has an id "text_input" and we wll call it via javascript-->
<textarea id="text_input" rows="40" cols="60">
Designs (MinValue) (MaxValue) (StepSize)
Powering 15000 20000 5000
Ice_Class 0 2 1
Speed 16 19 3
Accommodation 100 200 100
Crane 250 500 250
DP 2 3 1
ROV_Number 2 3 1
Deck_Area 1000 2500 1500

Epochs (MinValue) (MaxValue) (StepSize)
Oil_Price 80 120 40
Offshore_Distance 200 400 200
Duration 5 15 10
Depth 300 600 300
Weather 0 2 1
Location 1 4 1

Attributes 0% 100% (Utility)
_Powering_U 10000 20000
_Ice_Class 0 2
_Speed 13 19
_Accommodation 0 200
_Crane 0 500
_DP 1 3
_ROV 1 3
_Deck_Area 0 2500
_CO2 300 100
_Fuel_Consumption 80 25

</textarea><br>

<!--Button to start computations: go()-->
<input type="button" name="submit" value="Assign Variables" onClick="go()">
<br>
<input type="button" name="submit" value="Perform Calculations" onClick="go2()">
<br>
<input id="pressme" type="button" value="Print Results" onClick="printValues()">
</body>
```

```
<!-- JS start -->

<script src="d3.min.js" charset="utf-8"></script>
<script type="text/javascript" src="calculations.js"></script>
<script>

// ##############################################################################
//                         ************ METHODS INITIATED ON PAGE LOAD ***********
// ##############################################################################

// Calculate step length of each variable
function calc_steps(start,end,step){
		designs =[];
		num_steps = (end - start)/step;

		for(i = 0;i <= num_steps; i++){
			value_calc = parseFloat(start) + i*parseFloat(step);
			designs.push({value: value_calc});
			};
		return(designs);
		};

// Calculate Utility
function calc_util(minv, maxv, value){
		return( (value-minv) / (maxv-minv) );
}

// Calculate Utility for inverse values
function calc_util_i(minv, maxv, value){
		return( Math.abs(value-minv) / Math.abs(maxv-minv) );
}

// Returns the attribute calculations to results_instance
function calc_attrib(des,epo){
		capex = calc_capex(des,epo);
		fuel_cons = calc_fuel(des)[0];
		opex = calc_opex(des,epo,fuel_cons);
		co2 = calc_fuel(des)[1];
		revenue = calc_revenue(epo);
		result_instance = [capex,fuel_cons,opex,co2,revenue]; // Attribute result array

		return(result_instance);
};

// ############# ATTRIBUTE CALCULATIONS ###############

// OPEX
function calc_opex(des,epo,fuel_cons){
		// Impact from normalized design variables on OPEX. Ending multiplication to scale operation and fuel costs
before weighting in opex calculation.
		operation_cost = ( 0.002*des.Powering + 1.05*des.Accommodation + 0.14*des.Crane + 20*des.DP +
20*des.ROV_Number + 0.03*des.Deck_Area + 0.23*epo.Depth) * 30; // MAX: 19590 MIN: 10470
		// Include normalized epoch variables in calculated fuel cost and resulting OPEX.
		fuel_cost = ( fuel_cons * 0.5*epo.Fuel_Price * 5*epo.Duration * 2*0.17*epo.Offshore_Distance ) / 1000; // MAX:
30220 MIN: 1785
		opex = ( 0.27*fuel_cost + 50*epo.Weather + 20*epo.Lokasjon + 0.73*operation_cost ); // Apply weighting
distribution to resulting OPEX
		return(opex);
};

// CAPEX
function calc_capex(des,epo){
```

```
capex = (des.Powering*0.01 + des.Ice_Class*50 + des.Speed*2.85 + des.Accommodation*0.7 + des.Crane*0.27 +
des.DP*40 + des.ROV_Number*40 + des.Deck_Area*0.11 + epo.Depth*0.34);
		return(capex);
};

// Fuel Consumption
function calc_fuel(des){
		fuel = ( ( 0.03*des.Powering * 22.8*Math.pow(des.Speed,2) ) + (100*des.Ice_Class) ) / 100000; // MAX: 49,38
MIN: 26,26
		co2 = fuel * 4;
		return([fuel, co2]);
};

// Revenue
function calc_revenue(epo){
		revenue = ( 0.5*epo.Fuel_Price + 0.17*epo.Offshore_Distance + 0.22*epo.Depth + 50*epo.Weather +
20*epo.Lokasjon + 10*epo.Duration ) ; // MAX: 1442.9 MIN: 456.6. +500 to prevent negative revenue.
		return(revenue);
};

// ########### CREATE DESIGN / EPOCH SPACE ############

// Function to create Design Space
function create_designspace(dvv){
		designs = [];
		d_id = 1;
		for (count_1 = 0; count_1 < dvv[0].length; count_1++){
			for (count_2 = 0; count_2 < dvv[1].length; count_2++){
				for (count_3 = 0; count_3 < dvv[2].length; count_3++){
					for (count_4 = 0; count_4 < dvv[3].length; count_4++){
						for (count_5 = 0; count_5 < dvv[4].length; count_5++){
							for (count_6 = 0; count_6 < dvv[5].length; count_6++){
								for (count_7 = 0; count_7 < dvv[6].length; count_7++){
									for (count_8 = 0; count_8 < dvv[7].length;
count_8++){
										id = d_id
										powering = dvv[0][count_1].value;
										ice = dvv[1][count_2].value;
										speed = dvv[2][count_3].value;
										accommodation =
dvv[3][count_4].value;
										crane = dvv[4][count_5].value;
										dp = dvv[5][count_6].value;
										rov_number =
dvv[6][count_7].value;
										deck_area =
dvv[7][count_8].value;
										design_instance = {id:d_id,
			Powering: powering,
			Ice_Class: ice,
			Speed: speed,
			Accommodation: accommodation,
			Crane: crane,
			DP: dp,
			ROV_Number: rov_number,
```

```
                    Deck_Area: deck_area

                    }; // Create designspace object
                                                                        designs.push(design_instance); //
Push object to designspace array

                                                                        d_id++;
                                                              };
                                                    };
                                          };
                                };
                      };
                };
          };
     };
     return(designs);
};

// Function to create Epoch Space
function create_epochspace(evv){
     epochs = [];
     e_id = 1;
     for (count_1 = 0; count_1 < evv[0].length; count_1++){
          for (count_2 = 0; count_2 < evv[1].length; count_2++){
               for (count_3 = 0; count_3 < evv[2].length; count_3++){
                    for (count_4 = 0; count_4 < evv[3].length; count_4++){
                         for (count_5 = 0; count_5 < evv[4].length; count_5++){
                              for (count_6 = 0; count_6 < evv[5].length; count_6++){
                                   id = e_id
                                   fuel = evv[0][count_1].value;
                                   offshore_distance = evv[1][count_2].value;
                                   duration = evv[2][count_3].value;
                                   depth = evv[3][count_4].value;
                                   weather = evv[4][count_5].value;
                                   lokasjon = evv[5][count_6].value;

                                   epoch_instance = {id:e_id,

     Fuel_Price: fuel,

     Offshore_Distance: offshore_distance,

     Duration: duration,

     Depth: depth,

     Weather: weather,

     Lokasjon: lokasjon
                                                                                   };
                                   epochs.push(epoch_instance);
                                   e_id++;
                              };
                         };
                    };
               };
          };
     };
     return(epochs);
};

</script>
</html>
```

CALCULATIONS.JS

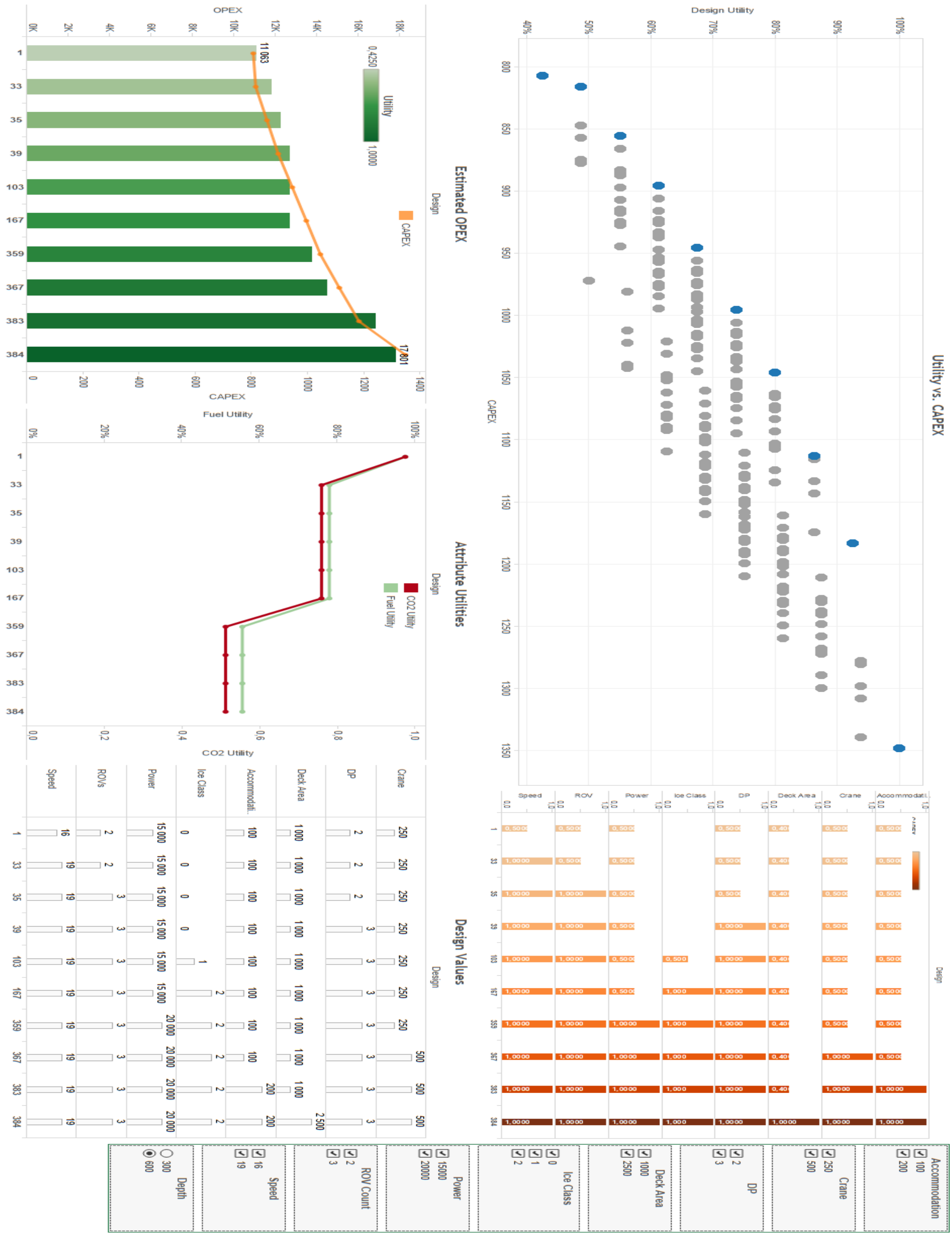
```
function go() {

// Receive inout from textarea box
		all_text = document.getElementById("text_input").value;

// Parse input. Split by space and linebreaks converted to space
		all_text = all_text.replace( /\n/g, " " ).split( " " );

// ##########################################################################

// Iterate and identify through textarea values
		for (var i = 0; i < all_text.length; i++) {

// Design Variables Input
				if (all_text[i]=="Powering"){powering_ = calc_steps(all_text[i+1],all_text[i+2],all_text[i+3])};
				if (all_text[i]=="Ice_Class"){ice_class_ = calc_steps(all_text[i+1],all_text[i+2],all_text[i+3])};
				if (all_text[i]=="Speed"){speed_ = calc_steps(all_text[i+1],all_text[i+2],all_text[i+3])};
				if (all_text[i]=="Accommodation"){accommodation_ =
calc_steps(all_text[i+1],all_text[i+2],all_text[i+3])};
				if (all_text[i]=="Crane"){crane_ = calc_steps(all_text[i+1],all_text[i+2],all_text[i+3])};
				if (all_text[i]=="DP"){dp_ = calc_steps(all_text[i+1],all_text[i+2],all_text[i+3])};
				if (all_text[i]=="ROV_Number"){rov_number_ = calc_steps(all_text[i+1],all_text[i+2],all_text[i+3])};
				if (all_text[i]=="Deck_Area"){deck_area_ = calc_steps(all_text[i+1],all_text[i+2],all_text[i+3])};

// Context Variables Input
				if (all_text[i]=="Oil_Price"){fuel__ = calc_steps(all_text[i+1],all_text[i+2],all_text[i+3])};
				if (all_text[i]=="Offshore_Distance"){offshore_distance__ =
calc_steps(all_text[i+1],all_text[i+2],all_text[i+3])};
				if (all_text[i]=="Duration"){duration__ = calc_steps(all_text[i+1],all_text[i+2],all_text[i+3])};
				if (all_text[i]=="Depth"){depth__ = calc_steps(all_text[i+1],all_text[i+2],all_text[i+3])};
				if (all_text[i]=="Weather"){weather__ = calc_steps(all_text[i+1],all_text[i+2],all_text[i+3])};
				if (all_text[i]=="Location"){location__ = calc_steps(all_text[i+1],all_text[i+2],all_text[i+3])};

// Design Attributes - Calculating Utility (applied under attribute calculations)
				if (all_text[i]=="_CO2"){_co2_0 = all_text[i+1]; _co2_100 = all_text[i+2];};
				if (all_text[i]=="_Powering_U"){_powering_0 = all_text[i+1]; _powering_100 = all_text[i+2]};
				if (all_text[i]=="_Fuel_Consumption"){ _FC_0 = all_text[i+1]; _FC_100 = all_text[i+2]};
				if (all_text[i]=="_Availability"){ _availability_0 = all_text[i+1]; _availability_100 = all_text[i+2]};
				if (all_text[i]=="_Crane"){ _crane_0 = all_text[i+1]; _crane_100 = all_text[i+2]};
				if (all_text[i]=="_Accommodation"){ _accommodation_0 = all_text[i+1]; _accommodation_100 =
all_text[i+2]};
				if (all_text[i]=="_DP"){ _dp_0 = all_text[i+1]; _dp_100 = all_text[i+2]};
				if (all_text[i]=="_Deck_Area"){ _deck_area_0 = all_text[i+1]; _deck_area_100 = all_text[i+2]};
				if (all_text[i]=="_Ice_Class"){ _ice_class_0 = all_text[i+1]; _ice_class_100 = all_text[i+2]};
				if (all_text[i]=="_Speed"){ _speed_0 = all_text[i+1]; _speed_100 = all_text[i+2]};
				if (all_text[i]=="_ROV"){ _rov_0 = all_text[i+1]; _rov_100 = all_text[i+2]};

		};

// ##########################################################################

// Assign variables to a vector
		design_variables = [powering_, ice_class_, speed_, accommodation_, crane_, dp_, rov_number_, deck_area_];
		epoch_variables = [fuel__, offshore_distance__, duration__, depth__, weather__, location__];

// Create design and epoch space
		designs = create_designspace(design_variables);
		epochs = create_epochspace(epoch_variables);

		var text = ("Variables assigned.");
```

```
		var html_body = d3.select("body")
			html_body.append("h2")
				.html(text);
};

function go2() {

// Start time of method
		now1 = new Date().getTime() / 1000;

// Assimilate into a single result vector
		results = [];
		r_id = 1;
		for (count_epo = 0; count_epo < epochs.length; count_epo++){
			for (count_des = 0; count_des < designs.length; count_des++){
				r_one_ed = calc_attrib( designs[count_des], epochs[count_epo] );
				result_object = {Analysis: r_id, Design: designs[count_des].id,
								Epoch: epochs[count_epo].id,
								// Calculated Attributes
								CAPEX: r_one_ed[0],
								Fuel_Consumption: r_one_ed[1],
								Fuel_Utility: calc_util_i(_FC_0, _FC_100, r_one_ed[1]),
								CO2_Emissions: r_one_ed[3],
								CO2_Utility: calc_util_i(_co2_0, _co2_100,
r_one_ed[3]),
								OPEX: r_one_ed[2],
								Revenue: r_one_ed[4],
								// Utilities based on input range
								Power_Utility: calc_util(_powering_0, _powering_100,
designs[count_des].Powering),
								Accommodation_Utility:
calc_util(_accommodation_0,_accommodation_100, designs[count_des].Accommodation),
								Crane_Utility: calc_util(_crane_0, _crane_100,
designs[count_des].Crane),
								DP_Utility: calc_util(_dp_0, _dp_100,
designs[count_des].DP),
								Ice_Class_Utility: calc_util(_ice_class_0,
_ice_class_100, designs[count_des].Ice_Class),
								Speed_Utility: calc_util(_speed_0, _speed_100,
designs[count_des].Speed),
								ROV_Count_Utility: calc_util(_rov_0, _rov_100,
designs[count_des].ROV_Number),
								Deck_Area_Utility: calc_util(_deck_area_0,
_deck_area_100, designs[count_des].Deck_Area),
								// DESIGN VARIABLES
								Power: designs[count_des].Powering,
								Accommodation: designs[count_des].Accommodation,
								Crane: designs[count_des].Crane,
								DP: designs[count_des].DP,
								Ice_Class: designs[count_des].Ice_Class,
								Speed: designs[count_des].Speed,
								ROV_Number: designs[count_des].ROV_Number,
								Deck_Area: designs[count_des].Deck_Area,
								// EPOCH VARIABLES
								Depth: epochs[count_epo].Depth,
								Offshore_Distance:
epochs[count_epo].Offshore_Distance,
								Duration: epochs[count_epo].Duration,
								Oil_Price: epochs[count_epo].Fuel_Price,
								Weather: epochs[count_epo].Lokasjon,
								Lokasjon: epochs[count_epo].Lokasjon
								};
```

```
					results.push(result_object);
					r_id++;
				};
		};

// Prints tradespace size
		var results_str = "Epochs: " + epochs.length + "<br>";
		results_str +=  ("Designs: " + designs.length + "<br>");
		results_str +=  ("Tradespace size: " + results.length + " analyses made. <br> <br> <br>");

// ###########################################################################

// What to show on the web page. Controlled by D3

		var now2 = new Date().getTime() / 1000;
		var time = ("Total calculation time: " + (now2 - now1).toFixed(3) + " seconds.");

		var html_body = d3.select("body")
			html_body.append("p")
				.html(time);
			html_body.append("div")
				.html(results_str);

};
// end of go()

function printValues() {

// Define CSV variable
		var results_csv = ["Analysis", "Design", "Epoch", "CAPEX", "Revenue", "Fuel Consumption", "Fuel Utility", "CO2 Emissions", "CO2 Utility", "Power", "Power Utility",  "Accommodation", "Accommodation Utility", "Crane", "Crane Utility", "DP", "DP Utility", "Ice Class", "Ice Class Utility", "Speed", "Speed Utility", "ROV Count", "ROV Utility", "Deck Area", "Deck Area Utility", "Depth", "Offshore Distance", "Duration", "Oil Price", "Weather", "Location", "OPEX" + "<br>"];

// Loop to log all iterations
		for (j = 0; j < results.length; j++) {
		results_csv += (results[j].Analysis + "," +
						results[j].Design +  "," +
						results[j].Epoch + "," +
						results[j].CAPEX + "," +
						results[j].Revenue + "," +
						results[j].Fuel_Consumption + "," +
						results[j].Fuel_Utility + "," +
						results[j].CO2_Emissions + "," +
						results[j].CO2_Utility + "," +
						results[j].Power + "," +
						results[j].Power_Utility + "," +
						results[j].Accommodation + "," +
						results[j].Accommodation_Utility + "," +
						results[j].Crane + "," +
						results[j].Crane_Utility + "," +
						results[j].DP + "," +
						results[j].DP_Utility + "," +
						results[j].Ice_Class + "," +
						results[j].Ice_Class_Utility + "," +
						results[j].Speed + "," +
						results[j].Speed_Utility + "," +
						results[j].ROV_Number + "," +
						results[j].ROV_Count_Utility + "," +
						results[j].Deck_Area + "," +
						results[j].Deck_Area_Utility + "," +
						results[j].Depth + "," +
						results[j].Offshore_Distance + "," +
```

```
                                        results[j].Duration + "," +
                                        results[j].Oil_Price + "," +
                                        results[j].Weather + "," +
                                        results[j].Lokasjon + "," +
                                        results[j].OPEX + "<br>");
        };
        var html_body = d3.select("body")
                html_body.append("div")
                        .html(results_csv);
};
```

APPENDIX IV



Utility vs. CAPEX
Estimated OPEX
Attribute Utilities
Design Values

APPENDIX V


Profit Margin per Epoch
Profit Margin
-2 514
6 370
Rank
Epoch
OPEX
Revenue
Weather
Oil Price
Distance
Location
Duration
Depth
Calm
Average
Harsh
Severe
5
15
Indonesia
North Sea
West Africa
Barents Sea
200
400
300
600
80
120