Quantifying value robustness of OSV designs taking into consideration medium to long term stakeholders' expectations

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ABSTRACT

This work presents an evaluation of the robustness of Offshore Support Vessels (OSVs) based on offshore market forecast using epoch-era analysis. Designing the right vessel for the right mission over time requires more than immediate matching of owners' requirements and vessel capabilities. Temporal and future uncertainties adds a critical aspect of complexity to the design process, since what constitutes a good mission performance may change over time due to changes of markets, regulations, players and site related circumstances. A possible (but costly) solution is to invest in a high-capability vessel, able to perform across a wide range of missions during its lifetime. Alternatively, one may invest in a low capability vessel, able to perform to a specific mission, with an option to upgrade the vessel in case of significant operational context changes. In this paper, we present a set of feasible options, which can deal with such uncertainty and fluctuating mission requirements during concept design, and evaluate their robustness in terms of low initial investment versus high initial investment and still possibility to perform well under different epochs. Our proposition is that stakeholders' expectations can be parsed into design and epoch variables, and a robustness value can be evaluated in each design compared to a tradespace benchmark, according to the return of investment of each solution. The formulation starts from a simple two-option case for a PSV, with an additional study case on Ulstein's PX121 family and the flexibility option of the Blue Ship case.

KEY WORDS

Design robustness, Epoch-Era Analysis, Offshore Support Vessel Design; Decision-Making;

INTRODUCTION – THE RIGHT VESSEL FOR THE RIGHT MISSION

The offshore oil and gas industry, like other important sectors of society, is adjusting to a bigger *claim* in which the idea of optimum design and cost cannot be considered easily in isolation. Increased attention has been given to other elements such as environmental aspects, risk awareness, and a rapidly changing commercial and regulatory environment. (Gaspar, 2013) As example, DNV-GL has adopted the motto *Greener, Smarter, Safer* (GSS) in most of its projects (Richardsen, 2013), whilst Ulstein Group already considers a multi-perspective analysis during its conceptual phase, merging GSS with technical, operational and commercial aspects (Ulstein and Brett, 2012 and 2015; Ebrahimi *et al*. 2015).

In ship design this claim brings to the table the extension of current boundaries (Hagen and Grimstad, 2011), transforming the classical question *Is this vessel able to fulfill the stakeholders requirements?* into *Is this the right vessel to the right mission?*. This implies the need to go beyond fixed stakeholders' requirements in the design process (Andrews, 2011), identifying system level performance metrics that capture more abstract system-level values such as GSS.

The *right* vessel becomes, instead of the larger, faster or stronger, the one able to bring return of investment in face of the uncertainty of missions that a ship may encounter. Thus, in the offshore industry, where a vessel is not used only for transport (such as supply) but also for a wide range of services (such as anchor handling, pipe laying, towing), discovering the *right mission* then becomes an essential part of conceptual design. It is only when having the correct set of requirements that we

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are able to decide upon the correct vessel. Sometimes, it will appear that the different mission requirements to suit stakeholders changing expectations over time will be partly contradictory and ambiguous, as to how easy and relevant it will be to cater for them all in one specific vessel design solution. Historically, it has proven true that in most cases a multi-functionality prepared for vessel be technically sensible, but hard to trade and operate. Such a paradox has in many cases ended up proving after all a multi-useless vessel (Ulstein and Brett, 2015). The long ago so popular OBO-vessels and PROBO-vessels in the dry and wet bulk sectors of merchant shipping are examples of such righteous vessels become commercially tricky to operate and eventually obsolete. Multi-functionality in the offshore sectors has seen better appropriateness and lends itself better for multi-contractual trading. Nevertheless, with many offshore shipping firms stretching their organizations skills and expertise sspects such as vessel fleet capability and capacity, organizational trading and operational skills and expertise as well as technical management and manning of such vessels are critical factors to be deeply understood with respect to their contribution to project robustness. Figure 1 presents some examples of multi-functional OSV ships.

OSVs multi-functional vessel's examples (Ulstein and Brett, 2015)

In a broader view, the total size of the offshore support vessel (OSV) market is highly dependent on external exogenous factors such as GDP growth rates and oil prices, affecting both the size and structure of the market, as well as freight/day rates. Future environmental regulations, in particular the location of emission control areas, will be important for the selection fuels as well as other emission controls. And rapid technology development may render design solutions with non-optimal configurations non-competitive after only a few years.

The offshore and maritime economy and trading context is enormously complex (Stopford, 2009), so it is paramount to simplify the supply and demand model by singling out those factors that are most important. Details should not be ignored, but too many details can hinder a clear analysis. Different site operations take place under varying weather conditions and different site support needs are evolving. The final particulars, capacities and functional capabilities of OSVs are set based on very detailed site related boundary conditions. It is, therefore, quite clear that to study value robustness of vessels being so much dependent on the initial geographically bound mission requirements a very precise description is needed of the pre-supposed likely characteristics of the future developments, In contrast to merchant shipping vessel design and operation, they typically are designed from a much broader solution space perspective and in most cases they are designed to trade world wide without the need of further functional or capacity adaptations.

Experience shows that high oil prices and deepsea discoveries 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.

Thus, the design of a new vessel needs to strike a balance between optimizing the vessel for the (likely) first contract entered into, while investing in additional functionality and performance capabilities to meet future requirements and changes in its operating context, such as increased fuel prices, stricter environmental regulations, new and more cost-efficient technology, further north and deeper waters. To further add complexity, these additional capabilities might either be made part of the

vessel at the design time, or they may be provided as design options, to be called dependent on information made available in the future. Thus, there is a need for efficient methods to be used for the conceptual design of innovative ship solutions able to deliver sustained value to stakeholders over time, in a complex, uncertain and changing life cycle.

In this work, we apply the concept of *value robustness* including but not limited to aspects presented above, to define a better vessel among a design set. Market prognoses are used as examples of stakeholders' expectations, which are decomposed in epoch and eras via Epoch Era Analysis (EEA). The quantification of the robustness in medium (epoch) and long (era) terms is thus given by the performance evaluation of every design in every epoch/era.

VALUE ROBUSTNESS VIA EPOCH-ERA ANALISYS

The value of a complex system, as a ship in its business context - within set technical, operational and commercial boundary conditions, cannot provide all CAPEX, OPEX and VOYEX related economics (or value) purely monetarily. Minute details of the attributes and factors likely to prevail in the various different periods of time are hard work to define and typically each construct, factor or feature describing it, are linked to substantial uncertainty. Thus, it is important to accept and control the level of uncertainty and the necessity to tolerate risk in the analyses. This leads the focus of the research to the perception of value robustness in ship design.

Value robustness is the ability of a system to continue to deliver stakeholder value in face of shifts in context and needs (Ross and Rhodes, 2008). In ship design, this means a ship perceived successful by stakeholders throughout the lifetime of the vessel. Rather than maximizing value delivered by a ship in one situation, we need to maximize it over a range of situations and preferences of the owner (or other constituents). This might reduce the maximum possible reward but also minimize the maximum possible loss, with relevance increasing as uncertainty grows and investors become more risk aware (Gaspar 2013).

The EEA-method proposes a useful representation for the stakeholders' expectations, by decomposing, combining and encapsulating their contextual aspects on a group of scenarios. One scenario, containing a static set of factors on a fixed interval of time, and therefore, a medium term expectation, is defined as an epoch. Several epochs create a dynamic interval of time, a time-ordered set of contexts defined as an era (Ross and Rhodes, 2008). An era can represent the lifespan of a vessel, considering long-term expectations.

Significant changes in the expectations will trigger the start of a new epoch. Changes can include different context parameter values, which can be certain or uncertain. In the case of the design of non-transport vessels, these parameters are related to the following categories (Gaspar *et al*., 2012a):

- Place of Operation: The geographical location where the vessel operates determines many vessel capabilities, once it is connect to sea conditions, water depth, ice occurrence. The operation on a a new market may require different technology to be on board, such as ice class for an oil and gas field in the Arctic or ultra deep water equipment for operation in the Brazilian pre-salt offshore market.
- Technology Development: A new technology commercially available may require a different type of fuel (such as LNG machinery), or strengthened steel foundations on the hull and main deck (such as a larger new crane), altering the capabilities of a vessel.
- Policy / Regulations: Future regulations may create a new emission control area (ECA), such as limitation in SO_X or NO_X levels (SECA/NECA); or new rules related to dynamic positioning or fire- fighting, or even a mandatory air control method to prevent environmentally harmful emissions.
- Market: Shifts in the market can also trigger a new epoch, with alterations in the fuel and freight price, high or low demand condition, potential spot market options or high-risk level due to political instability.

In this context, the assessment of the right vessel mean to identify which changes this system will face during its lifetime, and quantify how the vessel will respond to these changes. Priorities should be given accordingly to the level of occurrence of a scenario as well as risk linked to the changes. Uncertainty mitigation in shipping is a very speculative task, merging market analyses, personal preferences, risk propensity and gut feeling. EEA attempts thus to control the uncertain by evaluating the behavior of the ship under a range of scenarios constructed based on what is expected to *come next,* transforming the speculation in a return on investment (ROI). Details on the formulation and other examples of EEA applied to maritime cases are found in Gaspar *et al*. (2012a)

QUANTIFYING VALUE ROBUSTNESS BASED ON STAKEHOLDERS' EXPECTATIONS

This section presents a methodology to quantify robustness based on stakeholders' expectations. Our proposal is that value robustness is achieved via the proper parsing of stakeholder expectations into epochs and eras. It consists of taking market prognoses from one key stakeholder (for instance, ship owner, designer, broker or company CEO) and parsing it into what can become values, in other words, changes on context. These options are then transformed into epoch variables. For instance *possibility of polar operations* is parsed into the necessity of ice class capabilities installed, while *future strength in environmental regulations* are parsed into the necessity of clean fuel or air control methods onboard.

An epoch space is then created, based on all the possibilities extracted from the expectations. The *right vessel* for every epoch is then designed, that is, the vessel with the exactly amount of capabilities required to proper deploy a mission in that scenario. Vessels with fewer capabilities will perform below average, obtaining smaller ROI. Over dimensioned vessels may perform well, but the higher capital and operational cost is also translated into a smaller ROI. The design set is the analyzed for every epoch, creating a tradespace (Ross *et al*. 2009).

Long-term scenarios are created by matching eras with the parsed predictions/expectations. Again, *possibility of polar operations* translates into non-polar operations in the present, with the future possibility of activity in the arctic; *Future strength in environmental regulations* can be understood as a middle term scenario with actual regulations, while some years in the future stronger regulations starts to be valid.

ROI analysis for every design during all the eras are then assessed, and statistical term are applied to obtain the most robust vessel, starting from a simple average if all eras are considered with same importance, to a probabilistic weighting of era and expectations when more information is available, such as freight-rates history and/or political occurrences.

For the sake of illustration, lets consider the following prognosis:

> *From the current dominance of medium depths and module sizes, we expect the OSCV market to develop towards 3000m and larger (200t) modules sizes. With subsea processing the module sizes can develop further to 250t. Strong oil prices and the withdrawal of current restrictions will strengthen the GOM ultra deep (4000m+) market, though with smaller modules. A major risk is the combination of continued increase in US oil production combined with an Euro crash, followed by low oil prices that would render many deep sea developments too costly to be continued, reverting to small scale satellites*

The parsing process can be understood as the analysis of a sentence in order to associate groups of meaning inside the message, in some sort of semantic quantification. In other words, we are decomposing it into units that can be associated to contextual factors. Therefore, *hints* on how to construct scenarios are underlined on the prognosis above.

In this case, we can understand the sentence under the overall perspective of low, medium and high market, exemplified by two context parameters: Modules Size, taking values 150, 200 or 250ton; and Depth, taking values 2000, 3000 or 4000m. Lower market will require a less capable vessel (150ton module and 2000m depth) while a high market will have use for a high capable vessel (250ton module size and 3000 depth).

Epoch variables capture thus these context parameters, connected to the category *Market Requirements*. The three options observed for Modules Size as well as three options for Depth are transformed in requirements. Epochs are thus created combining these options into the 9 possible scenarios, according to Table 1.

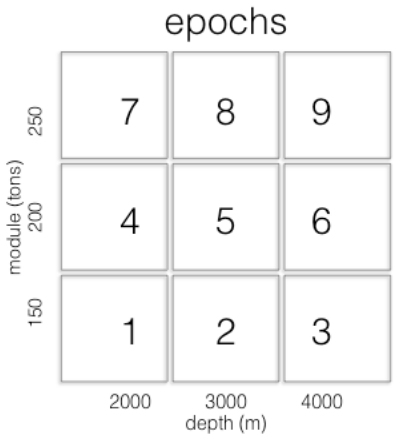
Table 1 – Epoch Variables

Category	Epoch Variable	Unit	Range	Steps
Market Req.	Module Size	m	150, 200, 250	3
Market Req.	Depth	m	2000, 3000, 4000	3
			Epoch space (total):	9 epochs

The epoch space contains all the possible epochs that can be created based on the parameters. Table 2 presents the epoch space based on Table 2, with all 9 epochs. Each epoch is different from the other, either by the Module Size or Depth parameter.

Table 2 – Epoch Set

Epoch Number	Module Req.	Depth Req.
Epoch 1	150ton	2000m
Epoch 2	150ton	3000m
Epoch 3	150ton	4000m
Epoch 4	200ton	2000m
Epoch 5	200ton	3000m
Epoch 6	200ton	4000m
Epoch 7	250ton	2000m
Epoch 8	250ton	3000m
Epoch 9	250ton	4000m



Considering this over-simplified case, rational choice theory (March, 1994) can be straightforward applied for the problem: the *right vessel* is the one that brings most of the benefit with least of investment. Benefit is understood as being able to execute the mission without capabilities penalties, while investment is connected to the installation of these capabilities on board. Therefore the highest ROI vessel for each epoch will match the epoch requirements by definition, and we can imagine so many unique vessels as there are unique epochs. Table 3 present thus our design set, consisted of 9 designs, which were created with two design variables and three options for each variable, matching our epoch set.

Table 3 – Design Set

Design Number	Module Inst.	Oper. Depth
Design 1	150ton	2000m
Design 2	150ton	3000m
Design 3	150ton	4000m
Design 4	200ton	2000m
Design 5	200ton	3000m
Design 6	200ton	4000m
Design 7	250ton	2000m
Design 8	250ton	3000m
Design 9	250ton	4000m

A tradespace evaluating the economical performance of each design in each epoch should be created. Tradespace evaluation is a process in which the design alternatives (design set) are evaluated in terms of (performance) attributes, utilities, and costs for each epoch (Ross *et al*., 2009). Our assumption here is that this performance is a value for the ROI of the vessel in an epoch. A vessel designed to perfectly match an epoch's requirement is assumed to have ROI equals to 100 units, once it matched 100% of the stakeholder's expectations. Penalties should be given for vessels not matching the epoch, either by lack of capabilities onboard and therefore not being able to proper execute the mission; or by over dimension of the capabilities, performing well the mission but being penalized by a higher capital and operational cost.

For the sake of illustration, hypothetical penalties' values are applied in this case, with no connection to real life number. A penalty of -10 units is applied when the vessel does not have enough capability installed, and a penalty of -5 units is applied when the vessel is over dimensioned.

The tradespace evaluation presenting the ROI for all designs within all epochs is observed in Table 4.

Table 4 – Tradespace Evaluation –Vessel/Epoch Return on Investment

	Epoch 1	Epoch 2	Epoch 3	Epoch 4	Epoch 5	Epoch 6	Epoch 7	Epoch 8	Epoch 9
Design 1	**100**	90	80	90	80	70	80	70	60
Design 2	95	**100**	90	85	90	80	75	80	70
Design 3	90	95	**100**	80	85	90	70	75	80
Design 4	95	85	75	**100**	90	80	90	80	70
Design 5	90	95	85	95	**100**	90	85	90	80
Design 6	85	90	95	90	95	**100**	80	85	90
Design 7	90	80	70	95	85	75	**100**	90	80
Design 8	85	90	80	90	95	85	95	**100**	90
Design 9	80	85	90	85	90	95	90	95	**100**

Eras are constructed by considering a sequence of epochs. Long-term performance evaluation is thus obtained by analyzing the performance in each of the epochs for that era and combining them, either by simple ROI sum; or by a more advanced weighting/probabilistic/stochastic technique.

In this example, let's consider each era composed by three epochs. Each era start with the same scenario (same requirements' value) that is, with the same epoch (Epoch 1). Market behavior will dictate future epochs. Growing markets will require larger modules or deeper depths after a period of time. A fast growing market may require both. Shrinking markets may require smaller requirements than the previous epoch.

Analyzing the market prognoses of our example, 4 eras are suggested in Figure 2.

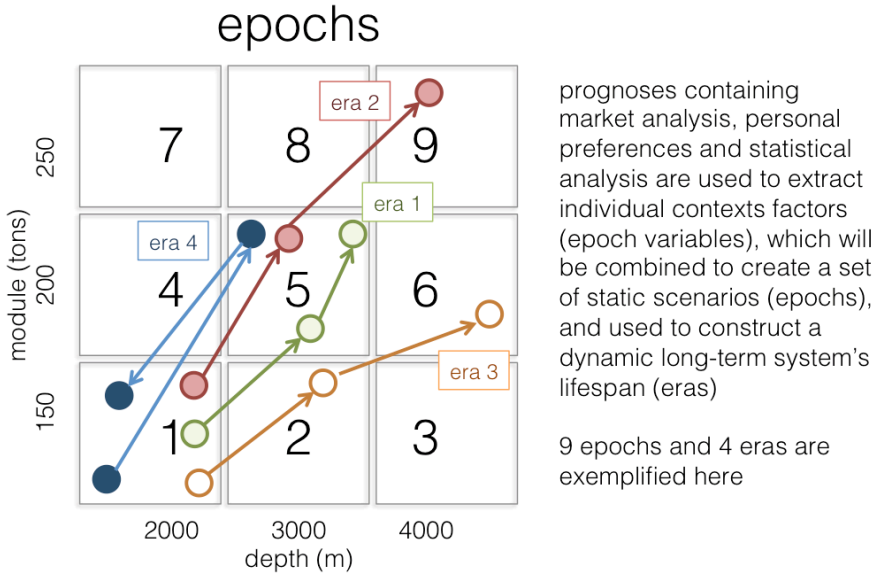


Figure 2 - Suggested eras based on market prognoses

A closer look in each of the eras is described:

- Era 1 – Growing to medium modules and medium depth: Epoch 1 + Epoch 5 + Epoch 5
- Era 2 – Faster Growing until maximum modules and medium depth: Epoch 1 + Epoch 5 + Epoch 8
- Era 3 – Growing to medium modules and maximum depth: Epoch 1 + Epoch 2 + Epoch 6
- Era 4 – Growing to medium modules and medium depth and back to initial epoch: Epoch 1 + Epoch 5 + Epoch 1

Table 5 presents the era analysis, with the ROI in an era considered as the sum of the ROI in each era's epoch. Assuming all eras with equal importance (weight) value robustness is considered thus as the highest ROI averaged from Era 1 to Era 4.

Table 5 – Quantifying robustness among eras

	Era 1	Era 2	Era 3	Era 4	Average	
Design 1	260	250	260	280	**262.5**	
Design 2	275	265	275	280	**273.8**	
Design 3	260	250	275	265	**262.5**	
Design 4	275	265	260	280	**270**	
Design 5	290	280	275	280	**281.3**	- max ROI among eras
Design 6	275	265	275	265	**270**	
Design 7	265	265	245	265	**260**	
Design 8	275	280	265	265	**271.3**	
Design 9	260	265	260	250	**258.8**	

The design with a higher sum is considered the one with more ROI among eras, and therefore the most robust design. Considering equal era probabilities, we would have Design 5 as the more robust. ROI values per se have no meaning, and should be only considered when comparing solutions among peers. Moreover, the value of the penalties has tremendous influence on the process, and therefore should be carefully investigated by analytical and empirical data. Similar exercise can be done if we consider different probabilities for each era or specific epochs.

BLUE SHIP INVEST CASE

Blue Ship Invest case (BSI) corresponds to the order of six Ulstein PX121 platform supply vessel (PSV) from Ulstein shipyard (Figure 3). The ship has the basic characteristics of 83.4 meters and a beam of 18 meters. In its standard version it has a cargo deck capacity of 850 square meters and a load capacity of 4200 tons (deadweight). The ship meets the requirements of DNV's Clean Design notation and has a maximum speed of circa 16 knots and accommodation for 24 persons (Ulstein Group, 2012).

Figure 3 – BSI family concept (left) and PX121 Blue Prosper during its sea trial (right),

Cargo Runs and Mobile Temporary Storage is the core of our PSV's supply missions. This hypothetical case is based on the idea that BSI wishes to explore the feasibility of expanding the PX121s functionality beyond purely supply tasks, to also be able to perform well in missions with the following extra requirements: Oil Recovery and Stand by; Light Well and Extra Accommodation; Towing and Salvage; Fire-Fighting; and Arctic (ice class required). Therefore, wishes and expectations from the stakeholder allows several scenarios, combining the supply mission with extra ones. The parsing of these expectations into Epoch variables is observed in Table 6.

Table 6 – Epoch Variables, based on Stakeholders' wishes

Category	Epoch Variable	Unit	Range	Steps
Mission	Oil Recovery and Stand by (OR & SB)	no/yes	no - yes	2
Mission	Light Well and Extra Accomodation (LW & EA)	no/yes	no - yes	2
Mission	Towing and Salvage (T & S)	no/yes	no - yes	2
Safety	Fire-Fighting (FF)	no/yes	no - yes	2
Environmental	Ice Class (IC)	no/yes	no - yes	2
			Epoch space (total):	32 epochs

Each epoch variable represents a different requirement within a contract, that is, a possible category change in a contextual factor, and is used as instrument to the mapping between context parameters and vessel performance.

The epoch space is constructed creating each of the 32 possible epochs, from epoch 1 (standard supply mission) until epoch 32 (supply mission plus all the five requirements). This process is illustrated in Figure 4.

Spatial and structural complexities play a big role in any ship design (Gaspar *et al.*, 2012b). Therefore, empirical knowledge is applied to size constrains, and differently from the case presented in the last section, we cannot create a design space of 32 vessels with similar characteristics as the PX121 and expect them to perform with excellence. As stated by Ulstein and Brett (2015), *with robustness aspects the vessel is meant to represent a strong and not likely to fail system or become weak over its life time, referring to the ability of the bespoke vessel, or system, to resist performance reductions over time given a change in operating context, without adapting its initial configuration, reducing the ability to perform too many different operations and becoming multi-useless*.

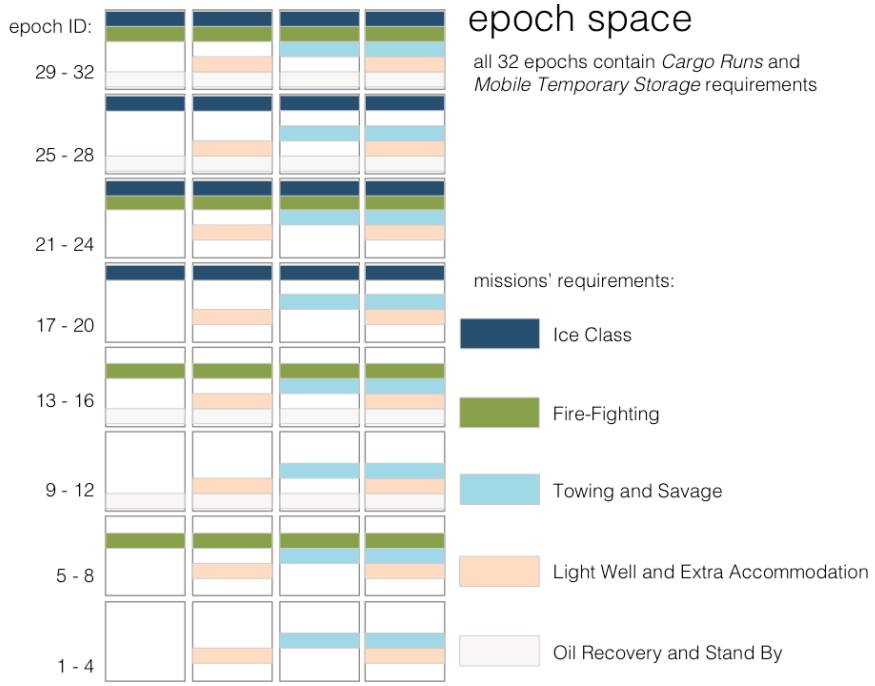


Figure 4 – BSI case Epoch Space, with 32 epochs

Therefore, the designer team came up with five market variations of the PX121 design (Mrk1-Mrk5), each of them with high-performance capability within their installed equipment. The variations are based on the standard PX121, modified to keep the same performance in cargo runs (DWT) and mobile temporary storage (cargo deck area) whilst incorporating a given set of functionalities, according to Table 7. All variations are able to receive ice-class at an extra CAPEX.

Table 7 – PX121 Functionality – Mission Match

Vessel missions and use	PX121 Mrk1	PX121 Mrk2	PX121 Mrk3	PX121 Mrk4	PX121 Mrk5
Cargo Runs	V	V	V	V	V
Mobile Temporary Storage	V	V	V	V	V
Oil Recovery and Stand by			V	V	
Light Well and Extra Accomodation					V
Towing and Salvage		V	V		
Fire-Fighting				V	
Ice Class	*	*	*	*	*

* - Optional at extra CAPEX

The next step consists of the decomposition of the structural aspects of a PSV PX121, via a discretization in terms of design variables, within a range maximum-minimum. A design is defined by one of the possible combinations of the variables, while the sum of all designs defines a design space. Table 8 presents the five types of PX121 (Mrk1 - Mrk5), plus ice class capabilities. The Design space with 10 designs is illustrated in Figure 5

Table 8 – BSI Design Variables

Category	Design Variable	Unit	Range	Steps
Variants	Type	Design Type	Market 1 - Market 5	5
Class	Optional Ice Class	Class	no - yes	2
			Design space (total):	10 designs

Each design variable represents a possible categorial change in the ship, and is used as instrument to the mapping between context parameters and vessel performance.

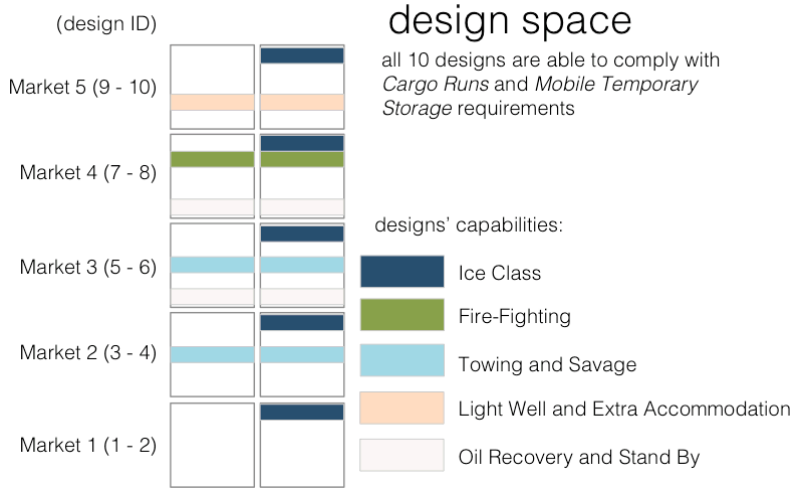


Figure 5 – BSI case design space, with 10 designs

Design Attributes are used as one of the criteria to evaluate the performance of a design under an epoch/era. A set of concepts and assumptions is then defined, for the mapping between the design variables and design behavior. This process includes the knowledge intrinsic to the design process. In this example, only for illustrative purposes, our KPIs will be connected solely to ROI, as discussed in previous section, with similar assumptions: a vessel matching 100% of the requirements will have a ROI of 100 units. A penalty of -10 units is given to designs below capacity, while -5 units penalty is given to an over dimensioned vessel. Due to restrictions connected to arctic scenarios, vessels without ice class will not perform during half of the year, and therefore are assumed to have a ROI equivalent of half of its sister's vessel ROI with ice class capability.

Tradespace Evaluation is the step of the process where the design space is evaluated within the performance attributes. It means evaluating the whole tradespace (the span of enumerated design variables) for each of the epochs (fixed set of epoch variables). This evaluation is made via modeling and simulation, and as output we obtain the ROI of each design for each epoch, observed in Table 9.

Table 9 – BSI case Tradespace Evaluation

	Design									
Epoch	1	2	3	4	5	6	7	8	9	10
1	**100**	95	95	90	90	85	90	85	95	90
2	90	85	85	80	80	75	80	75	**100**	95
3	90	85	**100**	95	95	90	80	75	85	80
4	80	75	90	85	85	80	70	65	90	85
5	90	85	90	85	80	75	95	90	85	80
6	80	75	80	75	70	65	85	80	90	85
7	80	75	90	85	85	80	85	80	75	70
8	70	65	80	75	75	70	75	70	80	75
9	90	85	90	85	95	90	95	90	85	80
10	80	75	80	75	85	80	85	80	90	85
11	80	75	90	85	**100**	95	85	80	75	70
12	70	65	80	75	90	85	75	70	65	60
13	80	75	80	75	85	80	**100**	95	75	70
14	70	65	70	65	75	70	90	85	80	75
15	70	65	80	75	90	85	90	85	65	60
16	60	55	70	65	80	75	80	75	70	65
17	50	**100**	47.5	95	45	90	45	90	47.5	95
18	45	90	42.5	85	40	80	40	80	50	**100**
19	45	90	50	**100**	47.5	95	40	80	42.5	85
20	40	80	45	90	42.5	85	35	70	45	90
21	45	90	45	90	40	80	47.5	95	42.5	85
22	40	80	40	80	35	70	42.5	85	45	90
23	40	80	45	90	42.5	85	42.5	85	37.5	75
24	35	70	40	80	37.5	75	37.5	75	40	80
25	45	90	45	90	47.5	95	47.5	95	42.5	85
26	40	80	40	80	42.5	85	42.5	85	45	90
27	40	80	45	90	50	100	42.5	85	37.5	75
28	35	70	40	80	45	90	37.5	75	32.5	65
29	40	80	40	80	42.5	85	50	**100**	37.5	75
30	35	70	35	70	37.5	75	45	90	40	80
31	35	70	40	80	45	90	45	90	32.5	65
32	30	60	35	70	40	80	40	80	35	70

Medium term expectations are captured by each of the epochs, via the epoch analysis. This process deals with the extensive amount of data obtained from the tradespace evaluation. The objective is to obtain insight from these data, via an analysis of the good design solutions among the epochs.

The possible era space is normally very large, and with a high computational cost for it to be calculated in its entirety. This space can be based on probabilistic distribution and/or stakeholder's preferences (a more risky or conservative approach, for instance). For the sake of illustration, let's create eras via storytelling approach. Stakeholders are stimulated to give their educated guesses about the future. This information, combined to stochastic data and other probabilistic techniques allow us to describe the future market via quantified changes from one epoch to another.

For this example, epochs will represent two years in time. The total era will simulate 10 years of the operational lifespan of the vessel, being made of five epochs. Given the large amount of uncertainty for longer periods of time, each epoch will have different weighting for the final era ROI. The period to 0-2 years has weight 1, 2-4 years 0.8, 4-6 years 0.6, 6-8 years 0.4 and the last era, given its higher lever of unpredictability, weight 0.2. The obtained eras are:

- Era 1 – Standard supply mission for all the 10 years, for the sake of comparison; Epoch 1 + Epoch 1 + Epoch 1 + Epoch 1 + Epoch 1
- Era 2 – A growing market, with the first two years with standard supply mission, adding a new mission requirement every two years; Epoch 1 + Epoch 5 + Epoch 7 + Epoch 8 + Epoch 16
- Era 3 – A high market now, with shrinking fluctuations every two years, until only the standard mission is required in the last period; Epoch 12 + Epoch 10 + Epoch 11 + Epoch 3 + Epoch 1
- Era 4 – Standard supply mission in the first two years with the appearing of arctic missions from the next period, with the requirements of these mission growing every period. Epoch 1 + Epoch 17 + Epoch 19 + Epoch 20 + Epoch 24
- Era 5 – Standard supply mission in the first four years with eventual arctic missions from the next two periods, and back to standard supply missions. Epoch 1 + Epoch 1 + Epoch 17 + Epoch 19 + Epoch 1

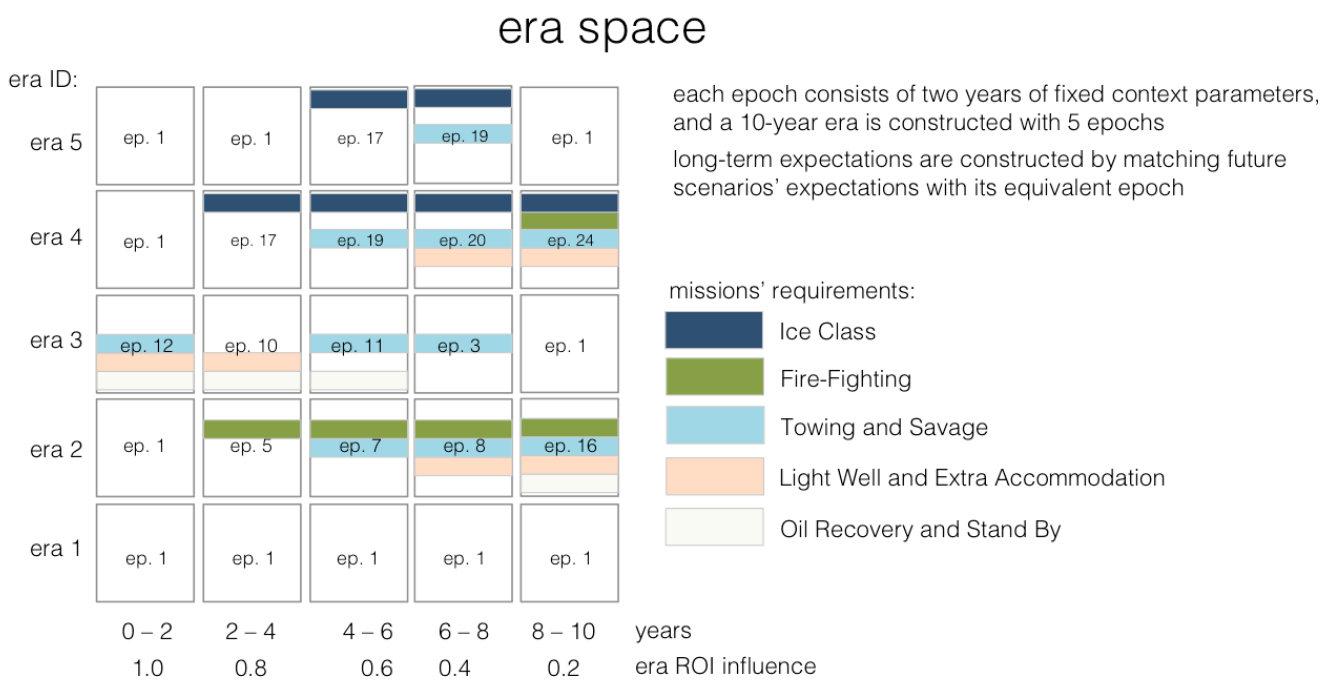


Figure 6 – BSI case era space, with 5 eras

Considering every era with the same importance, that is, the same chance of occurring, the ROI obtained is observed in Table 10. Design 4 is thus the one with higher ROI.

Table 10– BSI case value robustness quantification among 5 eras (equal chances of occurrence among eras)

	Era																										
	1					2					3					4					5						
epochs	1	1	1	1	1	1	5	7	8	16	12	10	11	3	1	1	17	19	20	24	1	1	17	19	1		ROI among eras
Design																											weighted average
1	100	100	100	100	100	100	90	80	70	60	70	80	80	90	100	100	50	45	40	35	100	100	50	45	100		1236
2	95	95	95	95	95	95	85	75	65	55	65	75	75	85	95	95	100	90	80	70	95	95	100	90	95		1314
3	95	95	95	95	95	95	90	90	80	70	80	80	90	100	95	95	47.5	50	45	40	95	95	47.5	50	95		1236.5
4	90	90	90	90	90	90	85	85	75	65	75	75	85	95	90	90	95	100	90	80	90	90	95	100	90		**1319**
5	90	90	90	90	90	90	80	85	75	80	90	85	100	95	90	90	45	47.5	42.5	37.5	90	90	45	47.5	90		1200
6	85	85	85	85	85	85	75	80	70	75	85	80	95	90	85	85	90	95	85	75	85	85	90	95	85		1275
7	90	90	90	90	90	90	95	85	75	80	75	85	85	80	90	90	45	40	35	37.5	90	90	45	40	90		1171.5
8	85	85	85	85	85	85	90	80	70	75	70	80	80	75	85	85	90	80	70	75	85	85	90	80	85		1236
9	95	95	95	95	95	95	85	75	80	70	65	90	75	85	95	95	47.5	42.5	45	40	95	95	47.5	42.5	95		1194
10	90	90	90	90	90	90	80	70	75	65	60	85	70	80	90	90	95	85	90	80	90	90	95	85	90		1269

Different weights for the eras influences the analysis. For instance, Table 11 presents the same case when it is believed that Era 2 and Era 3 have the double of chances of occurrence when compared to Era 1, while Era 4 and Era 5 have half of the occurrence probability. In this condition, Design 3 is observed to be the one with higher ROI.

Table 11– BSI case value robustness quantification among 5 eras (era 2 and 3 with double chances of occurrence, eras 4 and 5 with half of the chances)

	Era																									
	1					2					3					4					5					ROI
epochs	1	1	1	1	1	1	5	7	8	16	12	10	11	3	1	1	17	19	20	24	1	1	17	19	1	among eras
Design																										weighted average
1	100	100	100	100	100	100	90	80	70	60	70	80	80	90	100	100	50	45	40	35	100	100	50	45	100	1515
2	95	95	95	95	95	95	85	75	65	55	65	75	75	85	95	95	100	90	80	70	95	95	100	90	95	1501.5
3	95	95	95	95	95	95	90	90	80	70	80	80	90	100	95	95	47.5	50	45	40	95	95	47.5	50	95	**1546.75**
4	90	90	90	90	90	90	85	85	75	65	75	75	85	95	90	90	95	100	90	80	90	90	95	100	90	1535.5
5	90	90	90	90	90	90	80	85	75	80	90	85	100	95	90	90	45	47.5	42.5	37.5	90	90	45	47.5	90	1522.5
6	85	85	85	85	85	85	75	80	70	75	85	80	95	90	85	85	90	95	85	75	85	85	90	95	85	1507.5
7	90	90	90	90	90	90	95	85	75	80	75	85	85	80	90	90	45	40	35	37.5	90	90	45	40	90	1481.25
8	85	85	85	85	85	85	90	80	70	75	70	80	80	75	85	85	90	80	70	75	85	85	90	80	85	1461
9	95	95	95	95	95	95	85	75	80	70	65	90	75	85	95	95	47.5	42.5	45	40	95	95	47.5	42.5	95	1473
10	90	90	90	90	90	90	80	70	75	65	60	85	70	80	90	90	95	85	90	80	90	90	95	85	90	1458

CONCLUDING REMARK

A central aspect of temporal complexity in the design of (offshore) service vessels is the uncertainty related to future mission profile and contract opportunities. This needs to be taken into account in the development of the design specification, being a core strategic decision for ship owners as part of a fleet renewal or expansion program, with a high financial risk and a long time horizon of typically 30-40 years. This type of temporal complexity is one out of several complexity aspects to be handled as part of a ship design process (Gaspar *et. al,* 2012a).

In this paper we model possible future realizations of the vessel's operating context for a vessel using Epoch-Era analysis in order to capture the corresponding value robustness performance, to be used in the tradeoff with other system capabilities. Here, we use the epochs as the primary instrument for capturing major market developments. We further screen these contracts towards the capabilities of alternative vessel designs, thus forming vessel specific eras corresponding to the length of the planning horizon.

We present a case study related to the design of a platform supply vessel. The case study illustrates the complexity involved in striking the correct balance between optimizing the vessel for the first known contract of the vessel, while at the same time providing additional capabilities to be competitive in the context of future market requirements, as well as to cater for changes in stakeholder's needs and preferences.

The scenario-modeling framework in the cases study here is a simplified one. Alternative methods for capturing future uncertainties in the maritime marketplace are discussed in a parallel paper (Erikstad and Rehn, 2015), using historical data to derive the statistical parameters needed as input to representative stochastic models. These stochastic models can then be used to generate plausible future context scenarios, for instance using tree-building methods or Monte Carlo simulation.

Much need to be discussed about the proper way to handle value robustness in ship design. Though shipping markets have always been volatile, the traditional approach in marine design has been to assume a fixed set of requirements to which the final design must comply. To the extent that alternative scenarios for the future operating context have been considered relevant, the most common response has been to design towards the most likely scenario, and subsequently analysing the sensitivity of the final solution towards variations in key operating parameters (Erikstad, 2013).

This is not to say that flexibility is not being valued in the maritime sector. We have seen many examples of versatile vessels able to serve multiple cargoes, services and markets. OBO carriers, car carriers with hoistable decks, and offshore vessels with multi mission capabilities are typical examples (Figure 1). To some extent vessels and systems are designed with additional capabilities that goes beyond the immediate requirements. This implies hedging towards changes in the operating context that may render the vessel less competitive in the future, while at the same time providing a level of specialization that can be a liability in a second-hand market that puts a premium on standard solutions. Also, options are routinely provided as parts of specifications and build contracts, setting a predetermined price on changes that may be exercised in the future. However, the quantitative valuation of robustness and options is a challenge, both with respect to determining the optimal capability level, the price of options, and for conveying the operating value of these additional capabilities and options to prospective customers.

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