Combining Design and Strategy in Offshore Shipping

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ABSTRACT: This paper presents the design-strategy planning (DSP) procedure as a framework that integrates life cycle strategies of a ship into the early stages of the design process. We argue that understanding strategic, tactical, and operational aspects is essential when it comes to design of complex systems under uncertainty. Unfortunately, these are often neglected in ship design today. Using a Markov Decision Process Methodology, we demonstrate the insight gained from the concurrent exploration of system configurations and strategies, to better understand what to do when in the operational phase of the lifecycle. A case study is presented, where different tactical strategies of an offshore vessel are characterized. The results indicate that there are significant advantages in explicitly addressing ship owner strategy through DSP, when designing offshore support vessels that may be reconfigured in their lifetime.

1 INTRODUCTION

1.1 *Motivation*

Ship design is traditionally done with limited consideration of business strategy, even though acquisition of new ships is an important decision from that perspective. Ships are capital-intensive assets, meaning that design decisions will affect the overall financial viability and future business strategy of ship owners. Owners and designers will approach the same project with vastly different mindsets, meaning that there is a need to close the gap between overall strategic planning for the operational phase of the ship, and the decisions made by ship designers. In this paper, we attempt to close that gap.

1.2 *Literature review*

Early attempts at bridging the gap between shipping strategy and ship design include Benford (1967) who studied the connection between the initial sizing of cargo vessels, and maximizing the economic benefits given forecasts of cargo availability, while considering logistics. Erichsen (1989) and Wijnolst & Waals (1995) highlight the differences between the ship designer as an engineer concerned with the development of a ship description, and the ship designer as one someone who can translate business strategies into a ship description. Stopford (2009) also briefly consider ship design, suggesting that designers should understand the trades the vessel will serve, and the subsequent capacities, speeds and degree of flexibility. Lorange (2009) points out that shipping has moved significantly in the direction of specialization. Whereas before, shipping companies integrated across multiple activities such as owning, using, and operating ships, today's maritime business environment is more complex. He describes four strategic archetypes for actors in the maritime industry; owning steel, using steel, operating steel, and innovating around steel.

The connection between ship design and business strategy has also been elaborated on in previous International Marine Design Conference (IMDC) papers, including the work by Ulstein and Brett (Ulstein & Brett 2009; Ulstein & Brett 2012; Ulstein & Brett 2015). They specifically address the need for an interplay between technical, operational, and commercial considerations in ship design, signaling to shipowners that it is important to avoid too technical details at the early stages of the design process. They build on Brett et al. (2006), who introduce the Accelerated Business Development (ABD) process as a methodology for considering the link between shipping strategies, the shipping company value proposition, and the ship design process. The starting point for ABD involves four sub-processes in which the ship owner develops the business concept, with considerations of needs, expectations, risk and competitive positioning, building on the classical work of Porter (1979). Porter introduces five forces that drive industrial competition. The competitiveness of a firm is challenged by the strength of its suppliers, potential new entrants to the marketplace, the buyers of its products or services, substitutes, and current rivals. The outcome of the ABD process will be conceptual designs developed with basis in the ship owner strategy. Hence, the business proposition of the ship owner will strongly influence what functionality is sought, and consequently what concept the designers should iterate on.

With respect to the connection between the operational phase and ship design decisions, Erikstad et al. (2011) introduce the ship design and deployment problem (SDDP), as a mixed-integer programming model. Their model accounts concurrently for lifecycle deployment, and optimal design decisions. Further, Gaspar et al. (2012) provide added insights to the temporal aspects of the offshore ship design problem combining SDDP with Epoch-Era Analysis (EEA). For more information on EEA, see Ross & Rhodes (2008).

Uncertainty is an important consideration of the operational phase, which has received significant focus in the systems design literature. Ross et al. (2008) introduce the concept "value robust" to reflect the characteristics of a system that enables it to continue to deliver value throughout its lifecycle. What is valuable to a shipping company evolves as exogenous uncertainties resolve, and the strategies and tactics of the shipping company evolves as new aspects gain importance. Ships may be designed either to be able to statically deliver value as the context and owner strategies change, or ships can evolve through retrofits and reconfiguration to provide new functionality, as context and strategies change. The latter is often addressed by the term physical design changeability. Changeability is defined by Fricke & Schulz (2005) to be the superset of robustness, flexibility, adaptability and agility. The changeability concept has a strong link to the links between business strategy and ship design. Further, changeability has a strong link to real options, often characterized as the right but not the obligation to perform some action. This field of research has received attention also in the maritime industry. An overview of traditional real options research for managing risk in shipping is presented by Alizadeh & Nomikos (2009). Examples of options that have seen wide application in the shipping world include lay-up, the option to charter in additional capacity at peak demand, or the option to take on spot cargoes. Real options in the context of systems design has become a popular topic in recent years, as exemplified by de Neufville & Scholtes (2011).

For marine design applications, Niese & Singer (2014) introduce a methodology for assessing system changeability based on Markov decision processes (MDP). MDP is a structured method for modeling sequential decision-making under uncertainty, accounting for both the outcome of current decisions and future decisions opportunities (Puterman 2014). Previous research using MDP applied to ship design include analysis of ballast water treatment compliance (Niese & Singer 2013), energy efficiency (Niese et al. 2015) and emission control area regulation compliance (Kana & Harrison 2017).

1.3 *Contribution*

This paper argues for the importance of considering the strategic and tactical aspects of the operational phase of a ship lifecycle, already at the early stages of the ship design process. Further, this paper presents the design-strategy planning (DSP) framework that considers operational phase strategies and tactics of a ship at the initial stages of the design process. In addition, the DSP framework can support active management throughout the lifecycle. A case study is presented, where different strategies of an offshore vessel are characterized, and design characteristics valuable for each strategy are identified.

2 MANAGERIAL STRATEGY

2.1 *Strategy as a plan*

There is an abundance of definitions of *strategy*. Recognizing the multiplicity, Mintzberg (1987) presents five definitions (the five Ps) of strategy: as plan, ploy, pattern and position, for which this paper aligns with the first. As a plan, strategy is *some sort of conscious intended course of action, a guideline (or set of guidelines) to deal with a situation* (Mintzberg 1987). Thus, fundamental characteristics of strategy is that it is developed deliberately in advanced of being deployed. Other definitions following the idea of strategy as a plan are: *a careful plan or method: a clever stratagem (trick); the art of devising or employing plans or stratagems towards a goal (*Merriam-Webster). A specific plan of action to reach a particular objective (Mieghem & Allon 2015), and a *coordinated set of decisions* (Skinner 2009). In light of these definitions, we define *strategy as a plan to coordinate a set of decisions to reach a particular objective.* As stated by Andrews (1987): *Anything that is not planned is not a strategy, such that successful pattern of action that was not intended is not a be called strategy, rather brilliant improvisation or just plain luck.*

Strategy is often used to describe multiple managerial planning archetypes, while at the same time describing the highest planning level – the strategic level. The managerial strategy planning horizon are commonly divided into strategic, tactical, and operational levels, all terms referring to the use of the vessel in the operational phase of the lifecycle. For shipping applications, we define these terms as follows (Christiansen et al. 2007):

- **Strategic planning** refers to decisions with long-term implications, typically several years. For a ship owner, these decisions include acquisition, including ship design, sales and scrapping of vessels, as well as shipping network design.
- **Tactical planning** refers to decisions with medium-term implications, typically up to one year. For a ship owner, these decisions include chartering, deployment, lay-up, routing and scheduling.
- **Operational planning** refers to decisions with short-term implications, typically from days to months. Decisions at this level include speed optimization, and other detailed planning of marine operations.

Confusingly, the *operational phase* describes the entire time the ship is in operation. In a lifecycle perspective, the operational phase is everything that happens between production and disposal. The ship *design phase* is the process of finding a description of the ship to be built. Hence, ship design in itself is a strategic decision problem (Christiansen et al. 2007).

Figure 1 illustrates that there is a need for integrating the asset management philosophy used for the operational phase within the design process. To the left, the operational phase is decomposed from the strategic level, further to tactics and operations. To the right, the design process is described as an iterative mapping between function and form. The point of Figure 1 is that there needs to be an interplay between strategies for managing the ship in the operational phase of the lifecycle, and the ship design decisions in the conceptual design stage of the lifecycle.

For example, if the strategy of a ship owner is to operate a vessel in the platform supply North Sea spot (short-term) market, his ship design preferences will likely be different than if the newbuilding is intended for a long-term tender contract with a large oil company. A ship designed for the spot market would favorably be agile and be able to remobilize quickly, possibly with modular interfaces between the integral ship platform and topside equipment. In comparison, a ship designed for the tender contract may be less modular.

A parallel here can be drawn to “requirements elucidation”, proposed by Andrews (2011). Where requirements elucidation favors that requirements are developed along with solutions, we here favor a strategy elucidation, where ship designers seek to critically understand the ship owner strategy when developing solutions.

There is an important difference between transportation shipping, such as bulk, tank or container shipping, and non-transport shipping, such as offshore service providing ships heavy lift and construction vessels. Christiansen et al. (2007) discuss aspects of planning for *transportation shipping*, which are not necessarily transferable to *non-transport shipping (offshore).* Shipping strategy is also discussed by Lorange (2005), who also points out the important difference between commodity shipping and other types of shipping. He mentions several successful niche strategies in shipping, such as developing leverage niches, build niches and transform niches. What is of significant relevance for the strategies in these two segments is the competition. Lorange also emphasizes the *time scale* of competitive strategies, as where barrier to competition vanish in the long-run. However, human know-how and soft skills can be difficult to copy.

2.2 *Shipping strategies*

Christiansen et al. (2007) present examples of strategic planning problems. These including (not limited to) market design and trade selection, *ship design*, network and transportation system design, and fleet size and mix decisions. Thus, ship design is fundamentally characterized as a strategic problem. The same holds for retrofits of the ship that may be done throughout the operational phase of the lifecycle.

In the context of fleet renewal and ship design, strategic planning can be connected to the business models of a shipowner. Business models in shipping are often classified in the following way:

- **Asset play:** Operational costs are not that important, as the main source of profitability is from the well-timed purchase and sale of ships (Lorange 2005). Hence, the owners will try to minimize capital expenditure.
- **Full ownership:** Long-term ownership is supported by operational cost minimization. This is similar to the “operations based strategy” by Lorange (2005). These actors care about technical and operational aspects, and will have strong ship design preferences.
- **Tonnage provider:** Focus is on buying and developing assets, for then to lease them on bareboat.
- **Other:** Depending on the specifics of the shipping case, one can also have combinations of one or more of asset play, full ownership and tonnage provider.

2.3 *Shipping tactics*

Christiansen et al. (2007) present examples of tactical planning problems. These include (not limited) fleet deployment, ship routing and scheduling, and ship management. Tactical planning decisions for offshore ships comprise contract and area selection. Contracts are of different length, and tactical decisions also involves the selection of operation in the spot or term

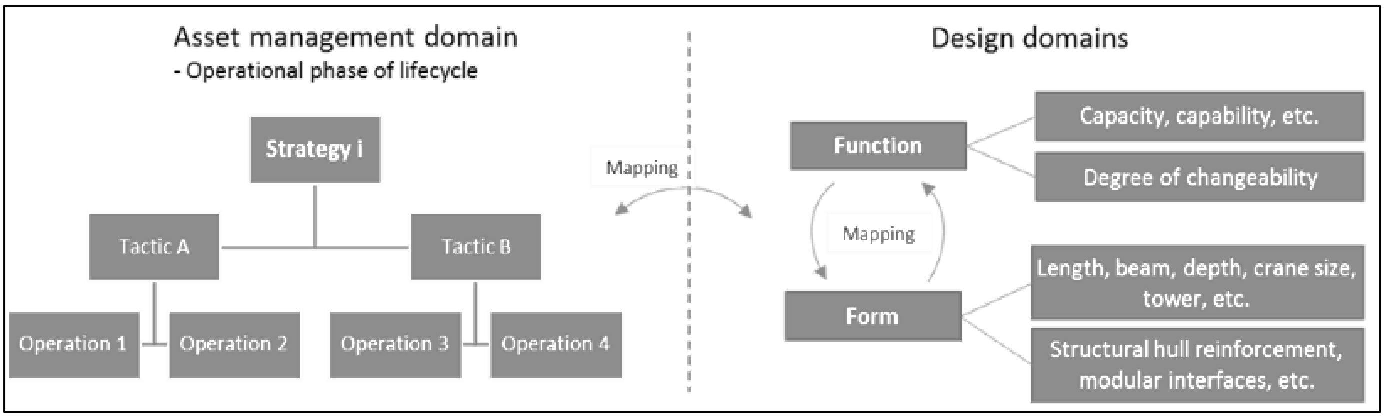


Figure 1: Connecting aspects of strategy, tactics, and operation to the traditional design problem.

market. Other aspects of ship management to consider at the tactical level is real options, such as lay-up and reactivation of ships, and expansion or equipment retrofits

2.4 *Shipping operations*

Christiansen et al. (2007) present examples of operational decision problems in shipping. These include, (not exhaustive) for example cruising speed selection, ship loading and environmental routing. Operational planning will not be covered in this paper.

2.5 *Strategy as a pattern*

As pointed out by Mintzberg (1987), in addition to defining strategy as a plan, one should consider the resulting stream of actions - the *pattern*. One definition of strategy as a pattern is *consistency in behavior, whether or not intended* (Mintzberg 1987).

Thus, while the plan creates an *intended strategy* (i.e. plan of action), only some of the intended strategy is *realized.* The d*eliberate* strategy represents the parts of the intended strategy that is retained, and *emergent* strategy represents strategy that becomes apparent along the way (Mintzberg & Waters, 1985). Therefore, while maritime decision makers attempt to develop strategic plans setting the direction for their operations, the plan is without value if the intended set of actions are not carried out.

2.6 *Design of strategic systems*

This paper proposes the term *strategic systems* to map the asset management domain and the design domain (Figure 1). The term strategic system refers to a specific design-strategy configuration, which will be used interchangeably. *Design* refers to the physical aspects of the vessel performing the operations resulting in stakeholder value, while *strategy* refers to the managers available options (both on an operational, technical and strategic level) to utilize the design. Using language of *real option*, this configuration encompasses a set of real *in* and *on options* (Wang & de Neufville 2005). While the real *in* options related to the physical design, the real *on* options relates to the management of the system.

This paper states that the objective of the conceptual design phase should be to create a strategic system. This extends the traditional view on design, from solely focusing on the physical configuration, to also considering how the physical configuration is an enabler for the strategic, tactical and operational decisions over the vessels lifetime. The strategic system should encompass a set of real options able to be aligned with the constant changes in context and needs, thereby creating a *sustained competitive advantage* and becoming *value robust*. In two extremes, the design configuration can either be perfectly aligned with the current context and needs, or not fit for all. The same goes for the strategies. Thus, the strategic systems are *unsuccessful* when neither the design or the strategy are fit to the current needs. On the other side, the strategic system is highly successful, and have a high competitive advantage, when both the design and strategy are aligned with the current context and needs.

In the process of adapting the strategic system to its environment, the key question to ask in the design domain is *how should the vessel be configured to have the functionality to meet the current market demands?* In the strategy/managerial domain, the key question to ask is *how should the vessel be utilized to gain competitive advantage?*

3 METHODOLOGY

3.1 *Design Strategy Planning (DPS)*

Design-strategy planning (DSP) is a systematic framework for supporting active management of exogenous uncertainty throughout the lifecycle of offshore vessels. As an iterative, four-step procedure, the framework consists of an (I) identification phase (II) development phase (III) implementation phase, and (IV) monitoring phase. The framework is presented in

Figure 2. Note that, while the figure indicates a distinct sequential flow between the four-steps, this is not necessarily how it would play out. Especially the initialization and development phase consist of irregular activities, that are intertwined. Therefore, the procedure will often end up jumping back and forth between these phases. The feedback arrow illustrates this.

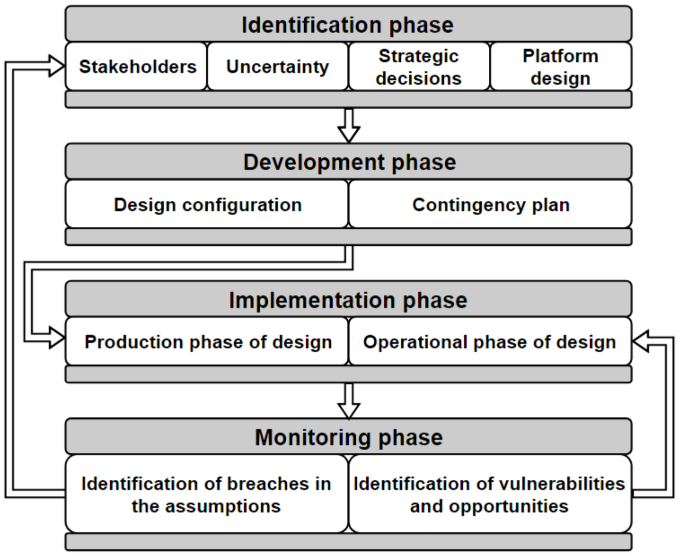


Figure 2: Illustration of the Design-Strategy Planning (DSP) framework.

3.1.1 *Phase I: Identification phase*

The identification phase is a collaborative process between major stakeholders, for addressing strategic decisions and platform designs that together forms a “strategic system” able to deliver high stakeholder value and handling future uncertainty. The key objective is to get a shared understanding of the commercial, operational, and technical aspects of the design problem, to lay the foundation to find a design solution that fits with the business and operational domain.

First, major stakeholders are identified, and their objectives and resources clarified. Major stakeholders to include are, amongst others, designers, engineers, owners, operators, and analysts. The owners contribute with the commercial intent of the vessel, in addition to technical and operational expectations. The designers and engineers provide insight into feasible technical solutions, and the operators provide expertise in the vessel’s performance and operational needs. It is crucial to ensure a joint understanding of the objectives, as this defines the criteria for the vessel's lifecycle success. Combining the different domain expertise from the very beginning is key for creating value robust solutions. Then, the internal assessment should focus directly on key stakeholders’ resources related to operating the vessel. The focus should not only be on the tangible resource base, but also on intangible, such as knowledge, capabilities, attitude, and relationship to its network. Furthermore, only understanding the current stakeholders, objectives and resources is insufficient; it is essential to analyze how these potentially can develop over the vessels lifetime.

Secondly, major drivers of exogenous uncertainty must be identified, and, to the extend it is possible, quantified. The assessment should both consider the direct market environment and the wider contextual environment. Both the likelihood and the consequence should be assessed, to focus the process on the most high-risk aspects of the future. To be aligned with all aspects affecting the lifecycle of the design, all aspects from both the commercial, operational, and technical sides of the vessel should be analyzed.

Third, a set of platform designs should be identified. A good way to develop flexible engineering systems is to start from an existing set of platform designs, as it relaxes the computation burden of starting from scratch (Cardin 2014). The base designs will further be enriched by adhering to design principles for changeability. Modularity and redundancies are examples of design principles enabling changeability (Fricke & Schulz 2005). (Rehn et al. 2018) introduces the choice of changeability level, to illustrate that the ease of change by executing a change option (both in changing cost and time) can be controlled. The underlying hypothesis is that incorporating changeability becomes more relevant with increasing uncertainty, and for systems with longer planning horizon.

As the last point in the initialization phase, strategic decisions for mitigating vulnerabilities and exploiting opportunities inherent in the uncertain aspects should be identified and analyzed. As earlier pointed out, it is important to consider both strategic, technical and operational level in the strategy domain to grasp the full extent of how the vessel can adapt in the face of changes in context and needs to stay competitive.

3.1.2 *Phase II: Development phase*

In the second phase in DSP, the development phase, we want to iteratively develop and select a design configuration, and a contingency plan. The objective is thus to identify under which circumstances various strategic design and operational options should be executed. The underlying hypothesis implied by creating the contingency plan is that the future too uncertain for not having a pre-defined plan stating how to response to changes in the changes in context and needs.

Design configuration

The selected design configuration consists of a platform design, in addition to a set of selected principles of changeability and levels of changeability. Arguably, incorporating changeability is a means for the base design to better dealing with uncertainty. However, one key challenge is to strike the balance between the implementation and carrying cost of incorporating a changeability (referred to as the design for changeability level, or DFC level) and cost of executing the options, against the cost of executing the options without having it pre-installed in the design.

Contingency plan

The contingency plan states which real options that should be executed on a technical and/or operational level as a response to trigger information. Triggers are occurrences that require a response from the contingency plan to mitigate risks or take advantage of opportunities. Triggers can also result in a reassessment of the DSP as the underlying assumptions of the development phase are changed. Contingency planning recognizes that generating sustained value is not only about making solid design decisions in the early phase, but also a continuous managerial decision problem over the lifecycle of the vessel.

A well-developed contingency plan should be robust, meaning that a broad range of different futures should be considered, related to the technical, operational, and commercial domains of the vessel, both in the near future and in the end of the vessel's lifetime. Secondly, the contingency plan should be flexible, meaning that a broad range of tactical measures should be considered to find the best measures to handle the uncertain future. Third, the plan should be specific, stating which measure to implement under which situation. Also, it is of high importance to consider the ability of the manager of executing the planed procedures, and the resources available in the situation.

3.1.3 *Phase III & IV: Implementation & Monitoring phase*

Following the development phase, some of the actions are immediately implemented in the production phase of the design. These actions are related to the building of the platform design selected. After the vessel is launched, in the monitoring phase other actions can be implemented in the operational phase of the lifecycle, but only as a direct response to trigger information.

In the monitoring phase, the environment of the vessel is monitored seeking for trigger information indicating vulnerabilities to mitigate and opportunities to exploit. If found, the contingency plane states which actions to implement.

The DSP process should be reassessed if the monitoring phase identifies major changes in the context and needs that breaches the underlying assumptions of the development phases. If so, the process would not start from the very scratch, this time the process starts off with a vessel design. Another reason for considering reassessing of the DSP process would if one deviates from the intended strategy outlined in the contingency plan. This could be a result of limited resources and/or capabilities of managing change. If that is the case, the contingency plan itself should be reassessed. However, another reason for not following the plan could be stakeholder's inherent resistance to change. If that is the case, one should seek to overcome this rigidity to change, rather than changing the plan.

3.2 *Markov Decision Processes (MDP)*

Markov decision processes (MDP) is a technique to quantitatively model and solve sequential decision problems. Since MDP can determine the "optimal" initial vessel design, and which real options to implement over the vessel's lifetime for maximizing long-term profit, it is able to support the development phase in the DSP framework.

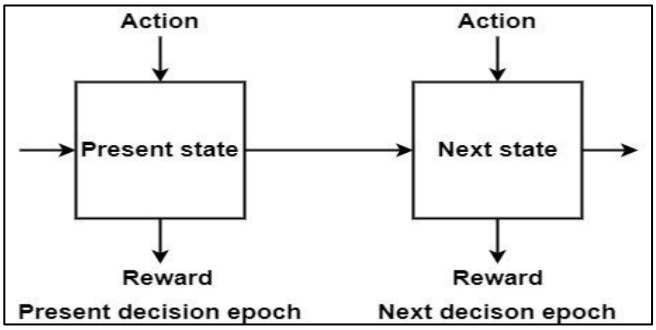


Figure 2: Symbolic representation of sequential decision-making problems (Puterman 2014).

Figure 3 illustrates a symbolic representation of a sequential decision problem. At a specific point in time, a system is in a state (or decision epoch), in which an action is to be made. The action is made from a set of available decisions, and is based on a decision rule, stating which action to make under which circumstances. It is assumed that the action is made with a complete information of the system state. The consequence of the decision is two-folded: first, the decision maker receives an immediate contribution, secondly, the system transits to a new state. Which state the system transits into is both dependent on the decision made, and of some exogenous information revealed first after the action is made. After the new state is entered, the procedure is repeated. The procedure can last for a finite or infinite time. The objective of a sequential decision problem is to find the optimal policy which maximizes the contribution over the lifetime of the system. A policy is a sequence of decision rules, stating which action to make, for each future time step, under different circumstances. The optimal policy is often presented in a decision matrix (DM), as presented in Table 1.

Table 1: Illustration of a decision matrix.

		System space			
		s = 1	**s = 2**	**…**	**s = |S|**
Time space	**t = 1**	Act. II	Act. XI	…	Act. I
	t = 2	Act. I	Act. I	…	Act. IV
	…	…	…	…	…
	t = |T|	Act. XI	Act. X	…	Act. I

More formally: At time t, the system is present in state $s \in S_t$, for which an action is made $x_t \in X_t$. Which action to make is stated in the policy, $\pi \in \Pi$. The policy is a function $\pi_t : S_t \rightarrow X_t$, that for each time step t, maps the current state to an action to make. After the action is made, the system receives an immediate contribution determined by the contribution function, $C_t(S_t, x_t)$, dependent on the current state and the action made. In the next time step, the system transits to a new state, S_{t+1}, determined by the transition function, S^M, as given in Equation 1.

$$S_{t+1} = S^M(S_t, X_t, W_{t+1}) \tag{1}$$

The transition function can be dependent on the current state, the decision made, and the exogenous information revealed first after the decision is made, W_{t+1}, making the transition uncertain. The probability of transitioning from state S_t to S_{t+1} is given by the one-step transition matrix, $\mathrm{P}(S_{t+1} \mid S_t, X_t)$, which depends on the current state and the current action made.

Extending Figure 3, Figure 4 illustrates a realization of a three-step system path. Depending on the nature of the problem, the sequence can continue for finite or infinite time, and the state, action and time space can be discrete or continuous. In addition, the contribution and the transition probability can be stochastic or deterministic. In this article, the focus is on stochastic, finite horizon processes, with discrete data, decisions, and time space.

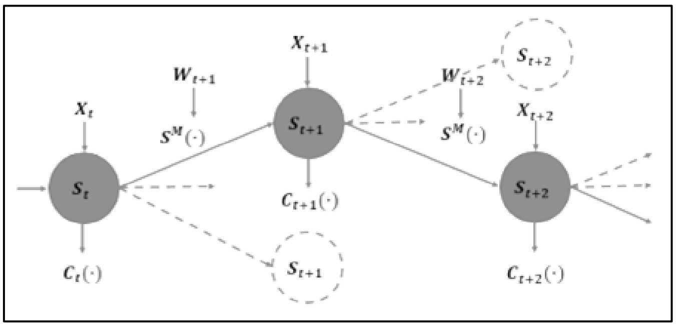


Figure 4: Markov Decision Process illustration (Strøm, 2017).

The performance metric represents the performance of a specific policy. A traditional performance metric is the expected discounted contribution over the lifetime of the system, stating that receiving a contribution in the future is less of worth than receiving it immediately. By the discounted contribution performance metrics, the policy is evaluated as given in Equation 2.

$$\psi_i^\pi \equiv \mathbb{E}\left\{\sum_{t=0}^{T} \gamma^t C_t^\pi(S_t, X_t^\pi(S_t)) \mid S_0 = i\right\} \tag{2}$$

Here, T is the length of the system's lifetime under consideration and γ^t is the discount rate. The expectation, E, is over the exogenous information affecting the contribution function. By using the discounted contribution metrics, the performance of a policy can be evaluated using the expression given in Equation 3.

$$\max_{\pi} \ \mathbb{E}\left\{\sum_{t=0}^{T} \gamma^t C_t^\pi(S_t, X_t^\pi(S_t))\right\} \tag{3}$$

Despite its complexity, there are methods available for solving the Equation 3. To do so, let V_t be the value function, expressing the expected value of making the optimal decision, $x_t^*(S_t)$, in a given state, at a given time step. One way of expressing the value function is the standard form of Bellman's equation, as given in Equation 4.

$$V_t(S_t) = \max_{x_t \in X_t} \left(C_t(S_t, x_t) + \gamma \sum_{s' \in S} \mathbb{P}(S_{t+1} = s' \mid S_t, x_t) V_{t+1}(s')\right) \tag{4}$$

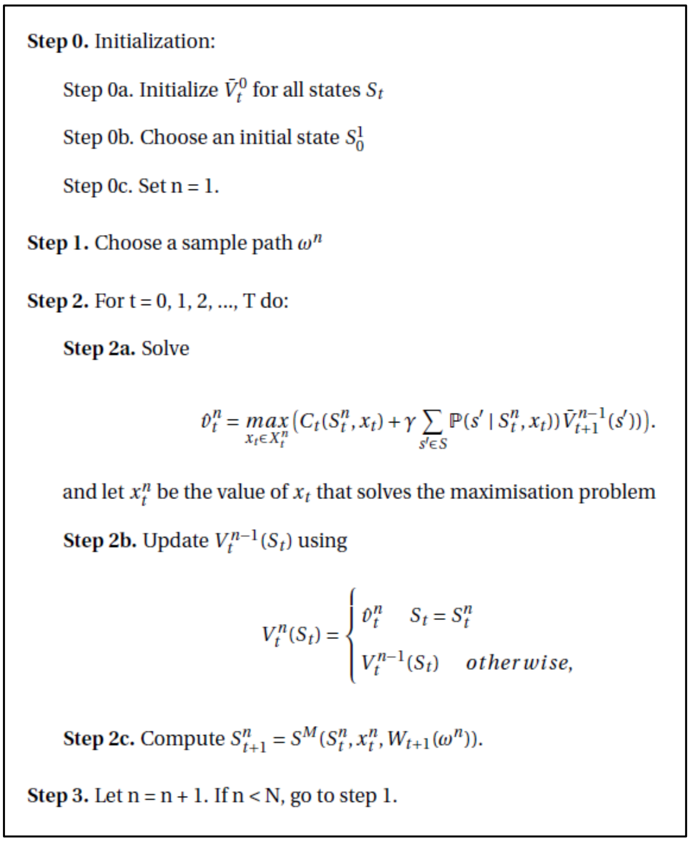
By knowing the value function in each successive step, for all possible transition states, the optimal action is found by the argument of the maxima of the expression in Equation 5.

$$x_t^*(S_t) = \underset{x_t \in X_t}{argmax} \left\{C_t(S_t, x_t) + \gamma V_{t+1}(S_{t+1})\right\} \tag{5}$$

Following the equations presented above, there is a need for a method that calculates the value function in each state-time combination, such that the optimal set of actions can be found. There are several methods for doing so, one of which is approximate dynamic programming (ADP).

In Figure 5, a generic ADP algorithm is presented. First, in step 0, the value function is initialized to zero, and a starting state, S_o^1, is selected. Note that instead of using the true value function, a statistical estimate (i.e. approximation) after n iterations is used, $\bar{V}_t^n$. Here, n is the interation counter stating the number of times the algorithm is run. Secondly, in step 1, ω^n is the sample path the process follows at iteration n, representing how the stochastic information unfolds.

Thus, $W_t(\omega^n)$ represents the realisation of the stochastic information at time t following specific sample path. Note that following a single set of sample realizations would not generate anything of value (as the same instances would occur each iterations), hence the procedure need a new sample path for each iteration. Third, in step 2, the algorithm loops over the time step of the system's lifecycle (t = 0,1,2,3…T). In each time step, a sample estimation, $\hat{v}_t^n$, of the value of being in state S_t^n is calculated using the approximation of the value function calculated in the previous iteration ($\bar{V}_{t+1}^{n-1}$). From this, action x_t^n is chosen to be the one that solves the maximization problem. The sample estimation is used to update the value function in the current iteration. Then, the system transits into a new state, before the process continues. The procedure is repeated for N number of iterations. After the final iteration, the approximated value function in each state-time combination is used to find the optimum decision with Equation 5. The set of optimal decisions comprises the optimal policy.



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Step 0. Initialization:
    Step 0a. Initialize $\bar{V}_t^0$ for all states $S_t$
    Step 0b. Choose an initial state $S_0^1$
    Step 0c. Set n = 1.
Step 1. Choose a sample path $\omega^n$
Step 2. For t = 0, 1, 2, ..., T do:
    Step 2a. Solve
        $\hat{v}_t^n = \max_{x_t \in X_t^n} \left( C_t(S_t^n, x_t) + \gamma \sum_{s' \in S} \mathbb{P}(s' \mid S_t^n, x_t)) \bar{V}_{t+1}^{n-1}(s') \right).$
    and let $x_t^n$ be the value of $x_t$ that solves the maximisation problem
    Step 2b. Update $V_t^{n-1}(S_t)$ using
        $V_t^n(S_t) = \begin{cases} \hat{v}_t^n & S_t = S_t^n \\ V_t^{n-1}(S_t) & otherwise, \end{cases}$
    Step 2c. Compute $S_{t+1}^n = S^M(S_t^n, x_t^n, W_{t+1}(\omega^n))$.
Step 3. Let n = n + 1. If n < N, go to step 1.
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Figure 5: Pseudocode for a generic approximate dynamic programming (ADP) problem using the one-step transition matrix (Powell (2011), p.120)

For instructional purposes, this paper outlined a generic form of ADP, while actually using the Q-learning algorithm (QLA) on the illustrative Case. QLA is one of the fundamental algorithms in ADP and reinforcement learning. We did do because the QLA is more comprehensive, and therefore encourage readers with interest in this field to Powell (2011) for a riche presentation of it.

3.3 *MDP in support of DSP*

The Markov decision process (MDP) methodology models the decision problem using the insights gained in the implementation phase of design-strategy planning (DSP). Following the notation presented in the former section: The time space represents the points in time over the vessel's lifetime in which decisions concerning the design-strategy configurations are made. The state space represents all states the strategic system can encounter. The decision space represents all actions stakeholders can execute to alter the system spaces. These actions are both related to the altering of the physical design configuration and the altering of the operational mode or strategy. The contribution function models the gains, or losses, from executing an action in a given state, depending on which state the system transits into. The transition function models how the strategic system evolves from one system state to another, which is dependent on the current state, the decision made and exogenous uncertain factors. The stochastic variable represents the exogenous uncertainty in the decision problem that makes the outcomes of every decision made (i.e. the contribution gained, and the state transitioned into) uncertain.

After having modeled the decision problem, the MDP methodology solves it. The output is a decision matrix (ref. Table 1) recommending decisions in every state, at every time step, to maximize the expected life cycle contribution of the strategic system. The decision matrix can further be used as input in a life cycle simulation to for instance analyze the expected life cycle contribution, and gain insight from other metrics. This Markov decision process methodology is inspired by the approach proposed by Niese & Singer (2014) for assessing changeability. The decision matrix and the output from the life cycle simulation can then be analyzed to provide valuable insight to the development phase of the Design-Strategy Planning (DSP) problem.

4 CASE STUDY – OFFSHORE SHIP

4.1 *Case description*

Using an illustrative offshore case, this section presents how Design-Strategy Planning (DSP), supported by the Markov decision process (MDP) methodology, can be used to support the ship design process. The presented work is based on Strøm (2017).

4.2 *Phase I: Initialization*

In this illustrative case, the stakeholder is a shipowner seeking to build an offshore vessel targeted to operate in the offshore construction segment. The objective is to build a vessel with the highest expected discounted life cycle value. Thus, the case centers around a strategic level decision of choosing vessel design.

Initially, the vessel is to undertake a five-year offshore decommission contract in the North Sea. After the initial contract ends, the vessel is assumed to continue to operate in the North Sea. The time span of the analysis is 15 years from present, and since the first five years are determined, we analyze the subsequent 10 years thereafter.

A high degree of uncertainty affects the performance of the vessel over its lifecycle, where particularly the overall economic market state and operational requirements are of high importance. In addition, there is uncertainty related to whether the shipowner wins future contracts, and the dayrates for each mission.

One platform design is considered, with the following main dimensions: a length of 120 meter, beam of 25 meter and a depth of 10 meter. It has accommodation capacity for 250 persons, and main crane capacity of 400 tones. For more comprehensive design analyses, multiple platforms can be considered.

Tactical decisions to consider are selection of missions, associated contract duration, in addition to the options to lay-up or sell the vessel. In addition, the shipowner can alter the configuration of the vessel by altering the accommodation size, replace the main crane, add light well intervention equipment, remotely operated vehicles, cable laying equipment and a moonpool.

4.3 *Phase II: Development*

4.3.1 *Modelling the system space*

Combining the information found in the initialization phase with the MDP methodology, the state space comprises: the design state, strategy state, mission state, market state and technical state.

$$\textit{State space} = (\textit{design, strategy, mission, market, technical}) \quad (6)$$

Design state

The design state represents the set of possible vessel configurations under consideration, comprising both fixed and variable parameters. The fixed parameters represent the dimensions (length, beam, depth) of the platform design, and the variable parameters represent the design parameters that can be altered. *Table 2* presents the set of design state variables.

Enumerating all the combinations of the design variables gives 216 unique design configurations, some of which are not feasible. Reducing the design space is crucial for lowering the complexity of the procedure. To reduce the design space, physical design feasibility, stability criterion and freeboard criterion were imposed.

Table 2: Design state variables.

Design state variables	Units	Values
Accommodation	Persons	[50, 250 400]
Main crane capacity	Tonne	[0, 400, 800]
Light well intervention	Tonne	[0, 300, 600]
Remotely operated vehicle	[-]	[No, Yes]
Cable laying equipment	[-]	[No, Yes]
Moonpool	[-]	[No, Yes]

The physical design feasibility constraint removes all designs with a deck area off less than zero square meters. The stability criterion removes all designs with an initial metacentric height (GM) less than 0.15 meter. The freeboard criterion removes all designs with a freeboard less than 1.5 meters. Imposing these constraints reduced the number of designs configurations to 12.

Strategy State

The strategy state represents the shipowner's available decisions, mainly concerning tactical options. From the implementation phase, there are four options availed. These options are whether to operate the vessel in the spot market, operating on one-year contracts or in the long-term market, operating on three-year contracts. The vessel owner can, after the initial contract ends, also sell the vessel or lay it up.

Mission state

As presented in Table 3, eight missions are considered. It is assumed that all are available in the North Sea market at all times. However, which mission the shipowner takes is dependent on three factors: First, there are technical requirements associated with each mission that the vessel must comply with. These are dependent on the general requirement state in the market. Secondly, the vessel competes for the contracts with other vessels operating in the North Sea. The probability for winning a contract is a factor of the supply-demand ratio of vessels which depends on the market state. Finally, it is assumed that the vessel owner always takes the mission, of those available to him, with the highest day rate. The day rate is a stochastic variable, depending on the mission taken, the contract duration and the state of the market.

Table 3: Mission states.

Mission	Abbr.
Subsea Installation and Construction	OSC
Inspection Maintenance and Repair	IMR
Light Well Intervention	LWI
Field Decommission Support	ODS
Offshore Accommodation	ACC
Offshore Cable Laying	OCL
Offshore Platform Supply	OPS
Offshore Aquaculture Support	OAS

Market state & technical requirement state

The state of the market and the technical requirements represent the two major sources of exogenous uncertainty to the shipowner. Both are modelled as stochastic processes, with a discrete representation. The market state is modelled to follow a seven-year cycle, and the technical requirements are modelled as a stepwise, linear function representing the assumption that the difficulty of meeting the requirements will increase in the future. Table 4 presents the relative levels of the exogenous uncertainty. The overall activity in the market is represented by the "market state", which is assumed strongly correlated with the oil price. A high market state thus represents high activity levels, and a resulting strong demand for offshore vessels services. A strong demand side results in higher dayrates, everything else equal.

Table 4: Exogenous information (market and technical) and discretized levels.

Exog. information	**Level**
Market State	[Low -, Low, Medium-low, Medium-high, High, High +]
Technical Req. State	[Low, Medium, High]

4.3.2 *Starting State*

Following Equation 6 modeling the state space, it is assumed that model initially starts off from the platform design (seq. 4.2), operating on short-term contract in a market with low technical requirements. The market state is uncertain, but with a higher probability of being in the lower end of the scale. Also, the initial mission is uncertain. The mission selected is the one with the highest dayrate of the missions the vessel can undertake under the current state of technical requirements.

4.3.3 *Modelling decisions*

The shipowner can alter the state of the strategic system by making one of the following decisions: the shipowner can change the design configuration and change which tactic to follow (i.e. taking short- or long-term contract, and which mission to take). A decision for each of these tree considerations, on whether to change or remain as before, must be made in each state. If the shipowner decides to retrofit the vessel, the switching time reduces the number of annual operational days in the subsequent period. If the decision only deals with which tactic to select, the vessel immediately starts the next operation. The decision is only made at the end of a contract. Hence, if there is a long-term contract, the strategic system remains unchanged constant over the length of that contract. For operations in the spot market, the frequency of decision-making is higher.

4.3.4 *Modelling the transition function*

The transition function is dependent on the current state, the decision made, and the exogenous information revealed to the decision maker after the decision is made. Thus, the transition function comprises one stochastic and one deterministic part. While the transition from one design state to another, between strategy and mission states, is fully dependent on the decision made and therefore deterministic, the transition between market states and technical requirement states are independent on decisions made and is therefore stochastic.

4.3.5 *Modelling the objective function*

The objective of the case is to evaluate vessels based on the net present value (NPV) of their lifecycle performance. Only monetary value is considered, assumed to only be dependent on building cost, operational revenues and switching costs.

4.3.6 *Results from the development phase*

The MDP model was solved by approximated dynamic programming, using a Q-learning algorithm.

Table 5 presents an excerpt of the derived life cycle policy, stating which strategic action to take under each state-time combination. Exemplified, if the vessel, in year 11, has design configuration 2, operating in a short-term contract in a medium-low market, with a high technical requirement (i.e. currently in model state 63), the shipowner should exercise action 26, whose details are presented in Table 7.

Table 5: Excerpt of life cycle policy for system state 61-64 (of 648).

	System state					**Year**				
	Variable									
#	**Des.**	**Strat.**	**Mkt.**	**T. req.**		**8**	**9**	**10**	**11**	**12**
61	2	S	ML	L	**Action #**	4	10	5	10	35
62	2	S	ML	M		11	10	11	11	5
63	2	S	ML	H		1	34	11	26	11
64	2	S	MH	L		28	5	5	11	5

Table 7 presents an excerpt of the action list, presenting tactical decisions made over the course of the vessel lifecycle. Continuing the example above, action 26 represents a change to design configuration 9, in addition to switching to a long-term contract continuing operating short-term contracts. Retrofitting to design configuration 9 increases the accommodation capacity to 400 persons.

Following the MDP methodology, the lifecycle policy is used in a lifecycle simulation for further analysis.

4.3.7 *Results from the lifecycle simulation*

The statistics of expected net present value of the analyzed vessel are presented in Table 6. Numbers are in million USD and are based on 1000 lifecycle sim-

Table 1: Excerpt of the action list

Act. #	Strat.	Des. #	Design configuration					
			ACC [Persons]	MC [Tonne]	LWI [Tonne]	ROV [-]	PC [-]	MP [-]
1	Short	1	250	400	0	No	No	No
4	Short	2	250	400	0	No	No	Yes
5	Long	2	250	400	0	No	No	Yes
10	Short	4	250	400	0	Yes	No	Yes
11	Long	4	250	400	0	Yes	No	Yes
26	Long	9	400	400	0	No	No	No
28	Short	10	400	400	0	No	No	Yes
34	Short	12	400	400	0	Yes	No	Yes
35	Long	12	400	400	0	Yes	No	Yes

ulations. The average number of design reconfigurations indicate that, in fact, the simulated ship usually undergoes some sort of retrofit during the lifecycle simulations, and switches design configuration.

Table 6: Expected net present value (NPV) of the life cycle simulations for the considered design, 1000 simulations, numbers in million USD.

Characteristic	Value
Mean value	24.5
Standard deviation	16.8
Max. value	93.3
Min. value	-23
Average number of design reconfigurations	2.13

Figure 6 presents the frequency in which (a) the market state, (b) strategy state, (c) mission state and (d) design state occurs. As seen in Figure 6 (a), the North Sea market is highly cyclical, indicating that the shipowner is to expect a low market state when the initial contract ends and a high market in the end of the period analyzed. Figure 6 (b) indicates that the shipowner will take short-term contracts in the first years, and then start taking long-term contracts. The vessel is never sold in this simulation. Figure 6 (c) indicates that the vessel normally continues to operate on the ODS contract after the initial five years. Then, the OPS, ACC and OAS contracts are taken most frequently. The description of these contracts is given in Table 3. Note that these are the "mission modes" which have the least technical requirements. Figure 6 (d) presents which design configuration that the vessel has, i.e. the equipment installed. After the initial contract, the vessel always keeps its initial design configuration (design 1). However, as time passes by, reconfiguration occur more frequently. After design 1, in declining order, ship design 11, 3 and 9 are most often changed into. The details of these vessel configurations are found in Table 5. Both design 11 and 3 have ROVs installed. Design 11 has an accommodation capacity of 400 persons, in contrast to the 250-person capacity of design 3. Retrofitting to design 9 only increases the accommodation capacity to 400 persons. This could indicate that it might be beneficial to have ROV capacity from the beginning, and that the shipowner also could consider increasing the initial accommodation capacity.

4.4 *Phase III: Implementation and monitoring*

4.4.1 *Implementation in the design stage*

Following the analysis above, the shipowner should build a vessel with an accommodation capacity of 250 persons, a main crane capacity of 400 tons, in addition to installing an ROV. Beside the ROV, the selected vessel configuration is similar to the base design.

4.4.2 *Monitoring phase/Implementation over the vessel lifetime*

To illustrate the monitoring phase, one lifecycle simulation for the chosen vessel alternative was performed by following the contingency plan. The life

Table 2: Example of one life cycle realization of the vessels lifecycle

	Year	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Uncertainty	**Market**	H	L	L(-)	L(-)	ML	H	H+	H+	H	ML
	Requirement	L	L	L	L	L	L	L	L	M	M
Decision	**Design #**	1	1	1	1	5	5	5	5	5	5
	Strategy	Short	Short	Short	Short	Long				Long	
	Mission	OAS	OAS	ACC	OAS	OPS	OPS	OPS	ODS	ODS	
Contribution [mill. USD]		1.6	1.9	2.2	2.9	15.3				2.1	

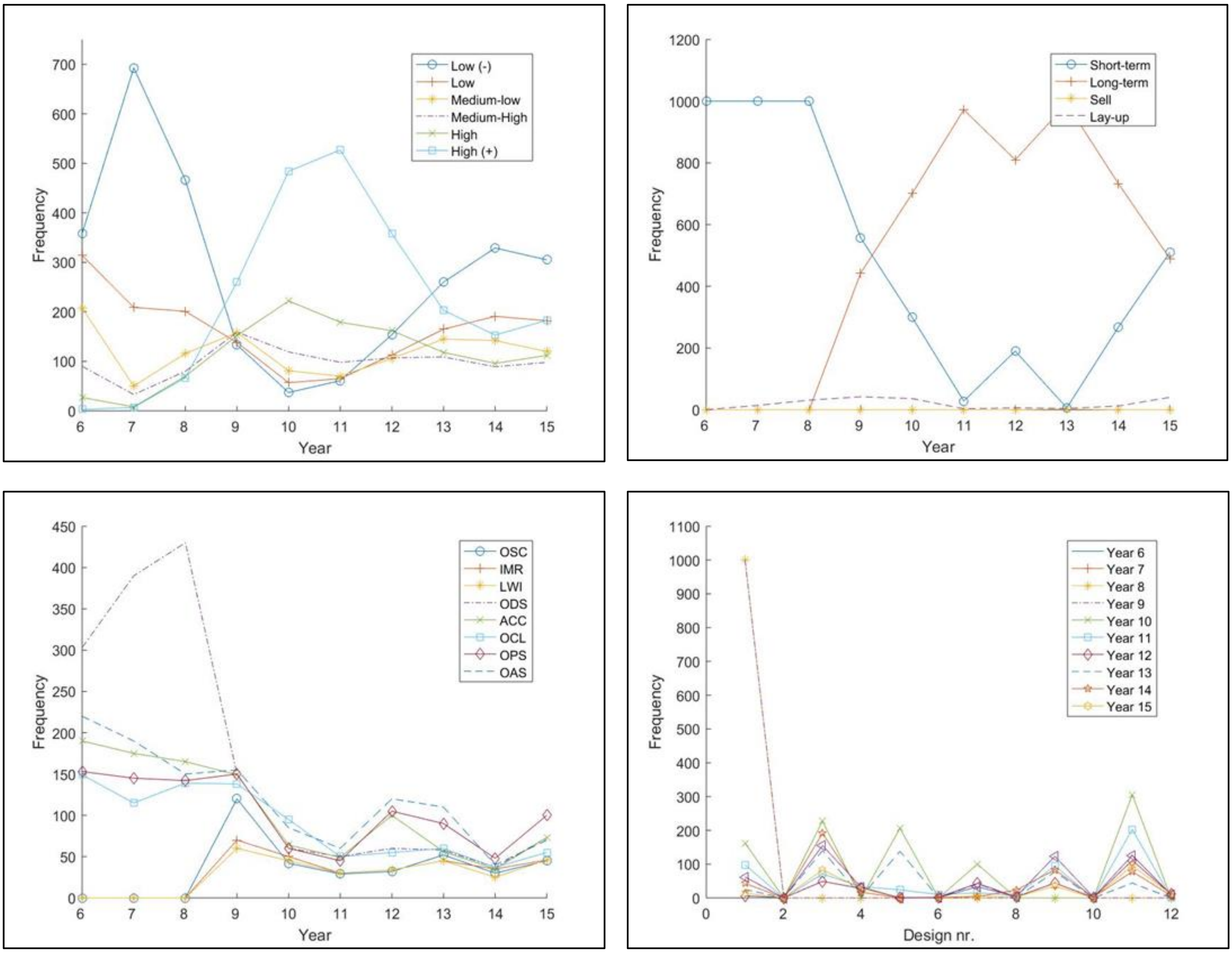

Figure 3: Top left (a) Market state, top right (b) Strategy (tactic) state., bottom left (c) mission state, bottom right (d) design state.

cycle simulation is presented in Table 8. The table presents how the vessel would circulate between the implementation phase and the monitoring phase in the DSP framework. From the development of the uncertain information, the vessel experiences cyclical market, and a long period with low technical requirements, before the requirements are increased to medium in the end of the period analyzed.

To cope with the market dynamics, the policy states that the shipowner initially (i.e. after the initial five-year contract ends) should keep the initial design configuration (design 1) and operate on short-term OAS and ACC contracts. Then, in year 10, the shipowner would switch the design configuration to design 5, representing an increase in the accommodation capacity from 250 persons to 400 persons. In addition, the vessel will operate on long-term contracts for the remainder of the lifecycle, first on a three-year OPS contract, before ending with a three-year ODS contract. In this life cycle realization, the shipowner earned 44.8 million USD, in present values. Over 1000 lifecycle simulations, the vessel earned on average 35 million USD, with a standard deviation of 16.3 million USD. This is better than the initial base design analyzed, indicating that the analyses improved decisions made.

5 DISCUSSION

This article attempts to close the gap between overall strategic planning for the operational phase of the ship, and the decisions made by ship designers.

Opposed to most literature treating the strategic decision of ship design, this paper highlights the importance of considering the available managerial tactical and operational strategies for the vessel's life cycle utilization. We argue that a deep understanding of how managerial strategies and design functionalities interacts are important when creating value robust systems. Unfortunately, it seems like this managerial domain often are neglected in the ship design process, and consequently crucial factors of the ship owners' preferences are not reflected in the design models.

Supported by similar research, this paper argues that embedding flexibility increases the vessel performance by reducing the time and cost associated with adapting to changing circumstances, despite increase in initial building cost and carrying cost. However, despite often increasing the expected lifecycle value, increasing the building and carrying cost increases the financial risk. Therefore, if not utilized, the embedded flexibility ends up becoming an extra liability.

We have introduced the design-strategy planning framework with Markov decision processes to bridge the gap between shipping strategy in the operational lifecycle phase and ship design.

From the illustrative case, it is evident the DSP framework supported by the MDP methodology can support the conceptual ship design process. The framework supports the development of a flexible concept design and can be used to derive a contingency plan, stating under which circumstances (i.e. trigger information) the various tactical design and operational options should be executed. Using the contingency plan as input to a lifecycle simulation enables the use of metrics (such as average number of design reconfigurations) to gain valuable knowledge to support the development of strategic system. This is an area for further research. Note that although the case is based on relevant information from subject matter experts, the case presented is intended for illustrative purposes.

With the desire to form strategies for the future, we find ourselves in a tension between creating strategies that shapes the future, and simultaneously needing to realize that the future is uncertainty such that one after all end up with needing to change the strategy. In the perspective of Mintzberg & Waters (1985), the DSP framework creates an *intended* strategy (i.e. plan of action), however, as the future unfolds, only some aspects of the intended strategy is *realized*. The Design-Strategy Planning framework copes with this tension. The framework recognizes that the future is highly uncertain, and develops a contingency plan stating how the manager should alter the design and/or operational strategies to adapt to changes in context and needs. This planned adoption balances the opposite demands of the deliberate and emergent strategy, by having a formal process developing the plan, while still recognizing the range of multiple scenarios that can unfold, thereby providing the option to alter in response to changing scenarios. This stands in contrast to most traditional approaches for supporting uncertainty management that is based on a deterministic view of the future and does not pre-define how the manager should respond to changing circumstances. Generally, the core purpose of this framework is getting key stakeholders to exchange knowledge and ideas, establish lines of communication and coordinate all the activities taking place.

Incorporating flexibility in vessel design requires a more forward leaning approach in the management, by actively looking for opportunities to exploit and threats to avoid by utilizing the strategic options embedded in the contingency plan. This should be a constant process, where all levels in the organization – from top management to the vessel operator – interact to analyses future development and decide how to response to it. This increases the importance of what we call monitoring phase.

Despite having a contingency plan in place, there are many factors that hampers its use, some of which are the shipowners/managers inherent ability and willingness to utilize it. The ability is related to recognizing the emerging vulnerabilities and opportunities in context and needs, understanding of the strategic options available in the contingency plan, and the ability to select the best one, in addition to having the required resources (tangible and intangible) to do so. Strøm (2017) refers to these factors as manager *aptitude*. Note that this is not only related to the manager in charge, but also the organization as a whole. It is therefore related to organizations psychological and cultural factors that can either hamper or encourage change. In relations to its importance, this paper has not emphasized this issue. As manager aptitude directly affect to which degree the intended strategy is realized, it is important to recognize the managerial dimension in the development of the contingency plan.

With great flexibility, the MDP methodology captures the dynamic interaction between the system domain and managerial domain. Supported by MDP, the DSP framework can develop a more comprehensive contingency plan. However, recognizing the range of strategic options and the managerial dimension, increases the complexity of the already highly complex traditional ship design problem. It is questionable that increasing the dimensionality of the design problem increases the accuracy of the design solution, or making it more uncertain as there are more available decision paths for the strategist, therefore causing the need for more assumptions about the problem. As with all quantitate techniques for modelling the future, MDP relies on a trade-off between the realism of the model and its complexity.

There are several methods for solving MDPs, many of which falls under the umbrella term Approximate dynamic programming. In general, the Q-learning algorithm (QLA) applied is appropriate to use in problems with small state and action space. One of the reasons for using QLA is that it overcomes the need for the one-step transition matrix. This is important because it is impossible to probabilistically describe the outcome in environments characterized by a high degree of exogenous uncertainty.

Further challenges with the MDP methodology is that it to some degree is a black box. Thus, as the policy is based on millions of lifecycle iterations, it is hard, if not impossible, to fully understand the output of the model, besides some trivial relations. To trust the output results, it is important to trust the generic model and the input parameters. Unfortunately, it is difficult to create “realistic” models and difficult to find reliable data to base analyses on. For instance:

What is the probability of winning a contract having different functionality installed? And, how much time does it take to increase the crane capacity by a certain amount? Not to forget, how do should you model future market and technological development? As pointed out by Stopford (2009) (pg. 608), the extremely small size of the market for non-cargo ships (special vessels) make it extremely difficult to analyze the market with any authority.

The ship design problem is characterized as a *wicked* (Andrews 2012) and *ill-structured* (Simon 1973; Pettersen et al. 2017). For several reasons, one could say that the attempt to develop a contingency is impropriate when dealing with problems of such characteristics, some of which are: The wickedness makes it difficult to understand the underlying drivers in the problem, therefore there is no definitive formulation of it. The ship design problem can be interpreting and defined in so many ways, and because one cannot get a complete understanding of it one might end up “paralyzed” in the analyses – unable to make pragmatic progress for real life decision making. Further, as stated in *Knagg’s Law:* the more grandiose plan, the larger the chance of failure. Thus, attempting to create a comprehensive plan to manage the life cycle of offshore vessels may be like asking for trouble. In addition, as pointed out by Mason & Mitroff (1981): Generating a broad variety of alternatives in the design and operational strategies for coping with uncertainty will increases problem complexity, however it is essential for finding better quality decisions. Due to these aspects, we question whether the MDP methodology is the best tool for supporting the DSP framework, since we find it hard to apply such qualitative tool on such strategic and highly complex problems.

Scenario planning approaches of lower complexity could stand out as a better approach. In scenario planning, scenarios, rather than forecasts are developed to describe the future. These forms the basis for discussion of how to react do different plausible scenarios. This can be regarded as an approach of dividing the problem into sub-problems, before tackling them one-by one. The solutions to each subproblem can then be combined into a cohesive whole, forming a contingency plan.

Despite the potential lack of authority in any strategic planning process focused on wicked problems, we still encourage design- and operational decision makers to perform analysis of this kind. We do this because the most value is not necessarily in the results itself, but in the insight gained by following a step-wise framework, and developing the models for supporting it. We especially highlight the important role of such frameworks as a mechanism of coordination, communication, and control in the conceptual design process. We believe improvement of these factors increase the likelihood of successful outcomes.

6 CONCLUSION

In conclusion, we state that embedding changeability in a design have the potential to increase its life cycle performance, by enhancing the ability to adapt to changing circumstances. However, embedding changeability increases the financial risk, such that if it is not realized it ends up becoming an extra liability.

We state that it is advantageous to explicitly addressing the options inherent in design and operational strategies to cope with the unforeseen changes in future operational context. Design-strategy Planning is of a framework supporting such a process.

Supported by the MDP Methodology, the DSP framework was found to be able to develop a comprehensive contingency plan. A key strength in the MDP methodology is that is can capture the dynamic interaction between the system domain and managerial domain. However, as with all models attempting to predict and future, we find it hard to rely on the analysis.

Still, we encourage decision makers to follow a step-wise procedure for analyzing the options inherent in the design and operational strategies for managing the future and support it with some sort of quantitative analyses (e.g. MDP or scenario planning). We do so because the real value is not necessarily in out output (which after all is unreliable), but in insight gained from performing the analyses.

Deeper insight into the strategic, operational, and technical aspects of the designs lifecycle is expected to enable decision makers to better handle uncertainty.

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