# Addressing the Coast Guard Fleet Mix Problem From a Value-Centric Perspective

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## Objective

The overall objective for this thesis is to visualize and describe how multiple stakeholder value preferences can be captured, interpreted and analysed during the selection of coast guard fleets at an early design stage. The focus is on revealing potential value-profitable fleet solutions through varying operating context.

## Introduction

The coast guard fleet mix problem is particularly complex since it involves a diverse set of stakeholders, from which all have a perception of what a coast guard fleet should do, and which system capabilities that are needed in order for the fleet to fulfil its statutory missions. This questions how many vessel a coast guard might need, as well as what types capabilities each vessel should be designed with.

Over the past years within naval engineering, high focus has been put towards achieving high system capabilities through rigid system requirements while minimizing cost. Due to the presence of exogeneous uncertainties, forecasting the exact mission demand for a coast guard is difficult, as well as which capabilities that are needed where and when. As a result, design focus has been towards designing system solutions that can tackle many future expectations. This has however often resulted in large and complex system solutions at very high cost levels.

The literature points in the direction that this is due to a "requirement-centric mindset", and that this comes a result of the difficulty of measuring the return on naval acquisitions. This because these types systems often provide non-monetary values through their accomplished tasks. As an answer to this, the literature suggests that a "value-centric mindset" might help decision-makers to better assess these types of problems.

## Theory

Value-centric design methodologies allows for the evaluation of system design evolution and cost benefits by combining scientific principles and cost models with a *valuation model*. For this thesis, Multi-Attribute Utility theory has been used to quantify the idea of value.

Multi-Attribute Utility theory is an extension of utility theory. Since stakeholders involved with the coast guard fleet mix problem might have multiple objectives, Multi-Attribute Utility theory aims towards maximizing such objectives, aiming to maximize system value with respect to these objectives. This can be accomplished by describing each objective through a set of attributes. When stakeholder preferences for an attribute is obtained, it can be quantified through a range of acceptable values. This range can then be translated into a utility metric ranging from 0 to 1, where the least acceptable range is equal to 0, and the most preferred is equal to 1. Mapping the range of values for an attribute then creates a single-attribute utility metric.

By aggregating multiple single-attribute utility metrics, a single multi-attribute utility metric can be obtained. If each attribute contributes independently to aggregate value, multi-attribute utility scores can be calculated using a weighted sum of single-attribute utilities as illustrated below.

$$U(X) = \sum_{i=1}^{N} U_i(X_i)\,\lambda_i$$

Here *U(X)* is the multi-attribute utility score for an alternative *X*, $U_i$ is the single-attribute utility score of alternative *X* with respect to attribute *i*, and $\lambda_i$ is the weighted importance of attribute *i*. *N* is the set of attributes under consideration [1].

## Methodology

Different value-centric design methodologies represented within state of the art research have been investigated: The Multi-Attribute Tradespace Exploration approach, the Epoch-Era approach and the Responsive Systems Comparison method from the systems engineering community at MIT.

Multi-Attribute Tradespace Exploration begins with identifying stakeholder needs, from which a set of attributes and design variables are derived in order to evaluate and compare possible system solutions using utility and cost as value measures, often represented by a cost-utility plot. Through the use of Epoch-Era analysis, a tradespace can be represented as a static context, an epoch. Each epoch is characterized by a set of variables from that might help decision-makers to describe how exogeneous uncertainties might affect a particular system solution. Combining single epochs into an Era can help decision-makers to describe system progression over time.

The Responsive Systems Comparison Method combines Multi-Attribute Tradespace Exploration and Epoch-Era analysis to derive value-profitable system solutions. The framework consists of 9 steps and a flowchart of the steps of this framework is shown in figure 1.

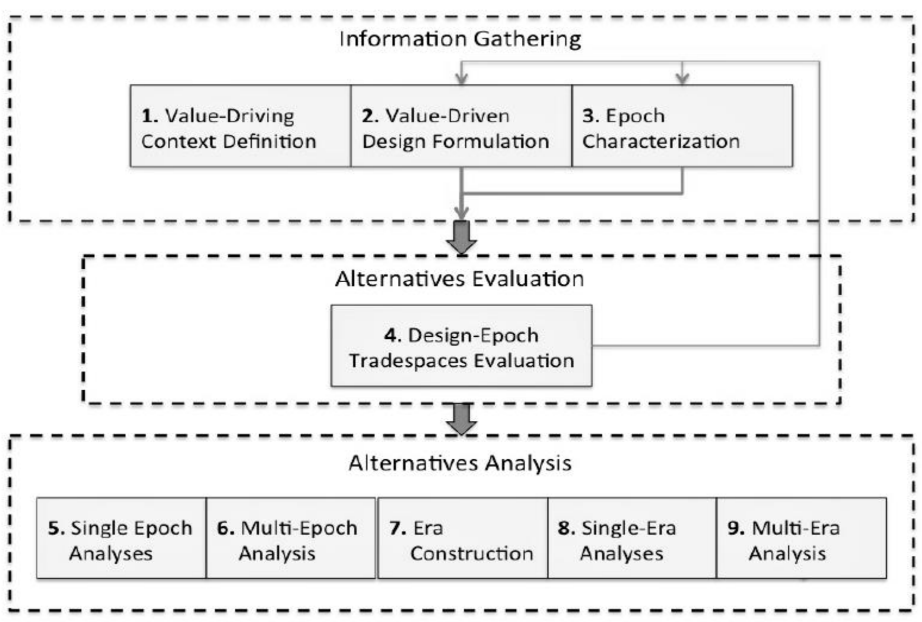


Figure 1: The 9 steps of the of the Responsive Systems Comparison method [2]

## Case Study

For this case study, a fictive coast guard department is to renew its entire fleet. The case study is limited to only consider sea-going patrol vessels. The stakeholders involved are assumed to be a government, a military enterprise (from which the coast guard department represents one branch), and the coast guard department. The coast guard is assumed to operate within a large geographical area, where their main priorities has been to control fishery activity and participate in search and rescue operations. In addition, it is expected that the coast guard should have capabilities that allows them to assist in case of marine casualties performing oil recovery- and tugging operations.

The value proposition of the stakeholder is to develop a coast guard fleet that creates value through acquisition affordability, operational affordability and mission capabilities. This proposition is fulfilled through a quantified set of performance attributes, design variables represented by 8 individual vessel, and epoch variables. The epoch variables describe how the future might develop with respect to fishery activity and commercial maritime activity. 32 epochs in total is derived. A design space is created enumerating the 8 vessels into feasible fleet alternatives. Next, a multi-attribute utility function is developed to evaluate each fleet alternative against each performance attribute. During the realization of each epoch, changing stakeholder perceptions is used to weight the importance of each attribute during a particular epoch. The activity levels needed from the coast guard in each epoch is represented by a required number of patrol days. It is assumed assigned a deterministic number of patrol days in which a vessel can perform per year. The first eight steps of the Responsive Systems Comparison method is used to evaluate the fleet alternatives.

## Results

Some results from using the Responsive Systems Comparison method is illustrated in figure 2. In the figure, each sub plot represents a tradespace for a given epoch, where each point solution represents a fleet alternative. The y-axis represents perceived utility for that particular epoch, and the x-axis represents cost. Good fleet alternatives are identified by looking at the set of Pareto optimal fleet solutions, represented in the plots by red colour. Choosing between the Pareto solutions involves making cost-utility tradeoffs. This means that a fleet on the Pareto front is the fleet that for a specific cost provides the highest utility in the eyes of the stakeholders.

As we can see from the sub-plots, the tradespace changes during the four epochs presented. Some alternatives moves down from the frontier, and some move up, describing how stakeholders might value different fleet alternatives over the long run.

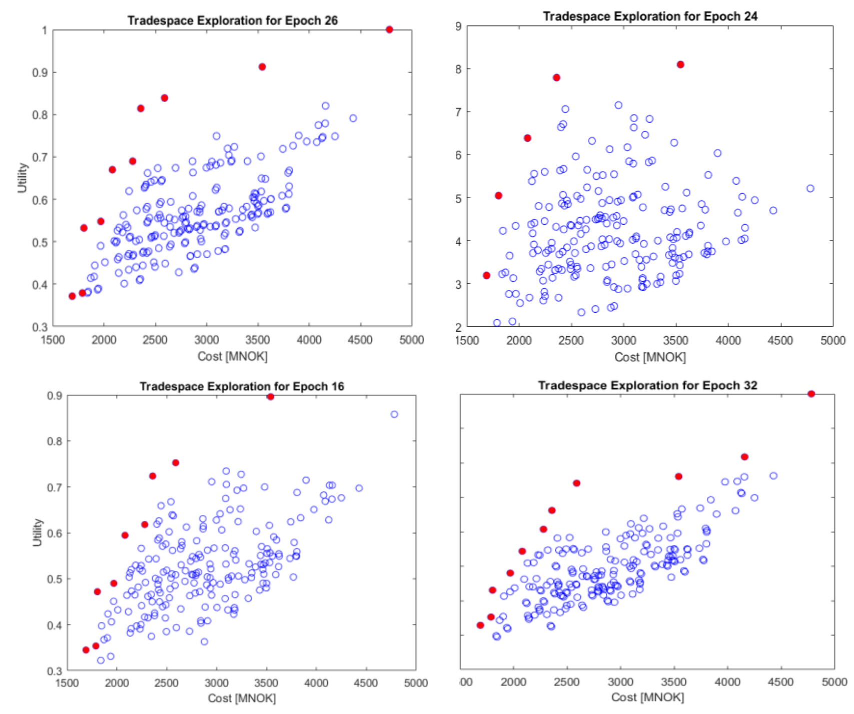


Figure 2: Tradespace plots for some epochs. Pareto solutions indicated in red.

In order to determine which fleet alternatives that are often on the Pareto front, a multi-epoch analysis is done evaluating all epochs. This shows which fleet alternatives that are passively value robust to context changes. Figure 3 shows the results from the multi-epoch analysis

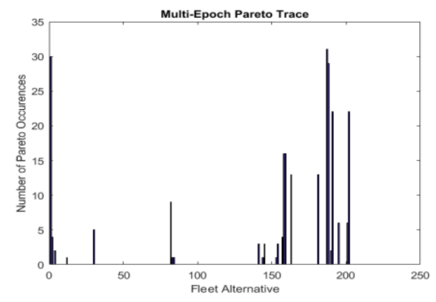


Figure 3: Pareto trace

## Conclusion

Using the Responsive Systems Comparison method to evaluate coast guard fleet mix problems can generate knowledge about which aspects that constitutes the "better fleet" when subjected to uncertainty. Tradespace representation combined with Epoch-Era analysis allows for communication, scoping a variety of alternatives before any designs actions has been made. This shows that a value-centric approach might sufficient to address the coast guard fleet mix problem. However, it is from the case study difficult to determine how good a particular fleet alternative actually is to perform a various set of mission tasks. This synthesises the need for other decision methodologies like simulation and optimization to be combined or incorporated with this method in order to enhance the tradespace exploration process.

## References

[1] : Keeney, R. L,. & Raiffa, H. (1993). *Decision with multiple objectives: Preferences and value tradeoffs.* Cambridge University Press.

[2] : Schaffner, M. A,. Ross, A.M, & Rhodes, D. H. (2014). *A method for selecting affordable system concepts: A case application to naval ship design.* Procedia Computer Science, 28, 304-313.

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