BMT Design & Technology

"Where will our knowledge take you?"

Rapid Generation and Optimisation of Ship Compartment Configuration based on Life Cycle Cost and Operational Effectiveness

Aidan Depetro, Rhyan Hoey

BMT Design & Technology, Melbourne, Australia

ICEAA Professional Development & Training Workshop
New Orleans, LA, 18-21 June 2013

Overview

- The majority of ship Life Cycle Cost (LCC) is incurred during the in-service period – strongly linked to the design of the ship and the decisions made during the early design phase, e.g.:
- Poor compartment configuration / inefficient hull selection

  → increased energy consumption and fuel costs
- Space limitations / inadequate removal routes / accessibility problems

  → expensive equipment overhaul and replacement

  → invasive removal methods

  → longer maintenance availabilities & increased maintenance costs

To minimise LCC, these factors should be objectified in the early design stages

Overview

We explore a methodology that utilises a combination of:

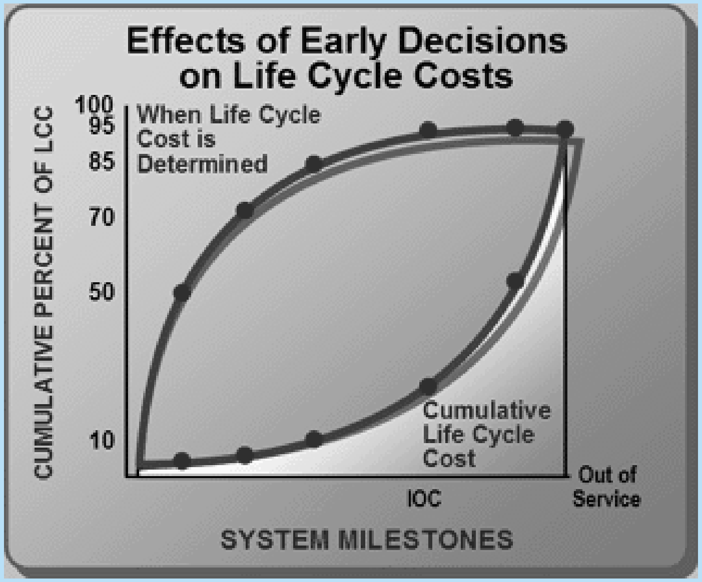
- Life Cycle Costing techniques,
- Multi Criteria Decision Analysis (MCDA), and
- Genetic algorithms
- Objectives
  - to rapidly generate and objectively compare valid ship compartment configurations in consideration of the effects on Life Cycle Cost (LCC)
  - To create a bespoke tool and apply it to a simplified ship design problem as a demonstration of the methodology. The aim of the exercise was to investigate the effect of increasing compartment space on LCC

Contributions to LCC

- Traditional design methods and decision analysis techniques focus on acquisition cost rather than LCC
- 'Life Cycle Cost Iceberg': many costs are less apparent and are generally given less consideration

Importance Of The Early Stages Of Design

- It has been well documented that the LCC of a ship is decided long before the costs are incurred
- Key decisions made during early design stages cannot be changed in the later development stages if requirements change or design flaws are revealed



LCC can be minimised by:

- Maintaining flexibility throughout development of the design; and/or
- ***Improving early stage design techniques and tools to facilitate better decision making***

This work provides an early stage design methodology that can allow key design decisions to be made in full cognisance of the LCC effects.

Ship size and LCC

- It has been observed that ships with greater density have higher ownership and production costs [1] – "…bigger is better, not necessarily more costly."
- Ship layout requires sufficient free space for fitment and maintenance of equipment (and efficient hull forms designed to accommodate such space requirements)

  → Slightly increasing ship size can generate savings from hydrodynamic efficiency gains and cheaper maintenance over a 25-30 year service life

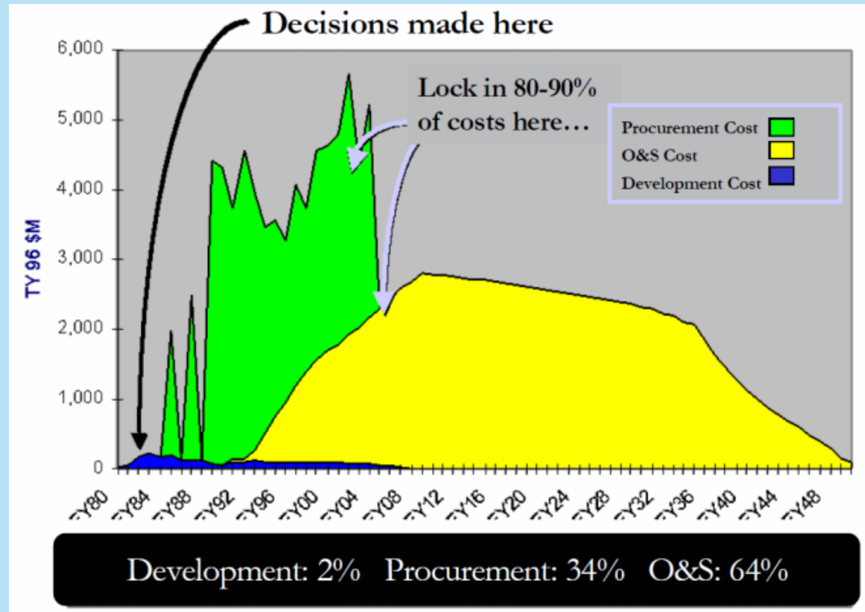
  → Savings can offset other increased costs associated with a larger ship and potentially reduce LCC

[1] Keane R.G., 2011, *"Reducing Total Ownership Cost : Designing Inside Out of the Hull"*, Ship Design USA Inc.

Acquisition cost versus LCC

- O&S costs typically make up 65-70% of the LCC
- Majority of LCC is effectively "locked-in" during early stage design

➔ Early stage design decisions hold greater consequence than just influencing acquisition cost



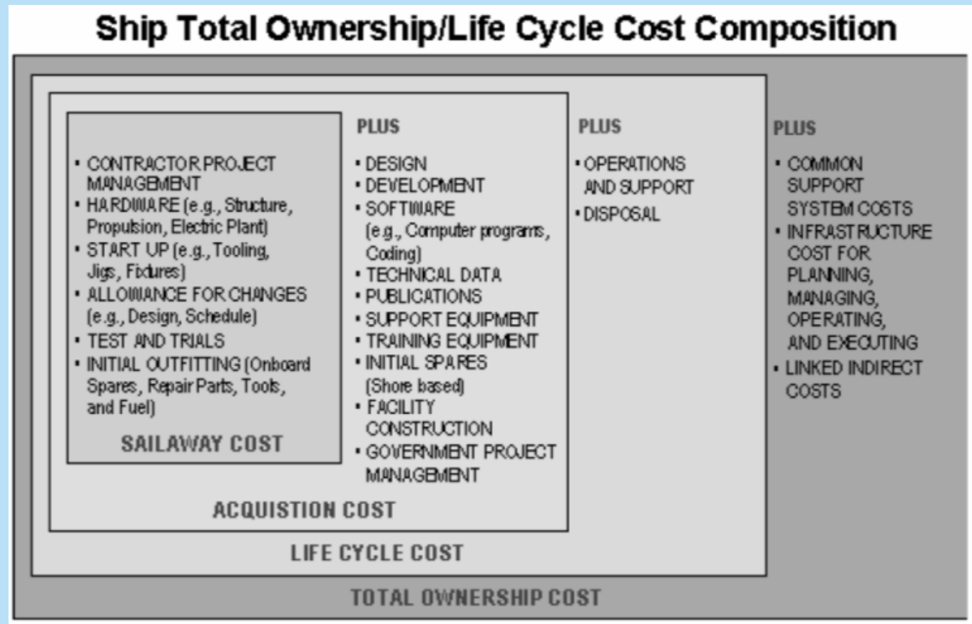
Acquisition cost versus LCC

Acquisition cost includes design, development, construction & commissioning costs

- Seen as tangible and quantifiable
- Impact of early design decisions more easily measured when just considering acquisition cost

→ Normally becomes the focus of the decision making process

Note: acquisition cost is typically only 30-35% of total LCC



Typical breakdown of costs for a military vessel (Navy Center for Cost Analysis)

Consideration of Cost in Automated Ship Design

- Existing tools for automated ship design generally include only one or the other of the following:
  - Integrated cost modelling
  - Explicit compartment layout

→ The effects of compartment layout on cost are not considered directly
  → can't optimise arrangement for minimal LCC

Inside-Out Design

Conventionally, ship design follows ‘outside-in’ approach:

- Compartments arranged to fit inside predetermined hull

  → Possible compartment arrangements restricted due to the hull form

  → Adjacency requirements, location preferences and maintenance/repair access considerations may not be simultaneously achievable

Alternative: arrange compartments first, ‘wrap’ hull form around them

- Prioritises systems arrangement to best achieve the required operational effectiveness, treating the hull mainly as a means of supporting the ship’s systems

Automated Arrangement - Motivation

Current design approach:

- Relies partly on intuition and experience → some important design decisions made on a subjective basis
- Labour intensive → limited range of possible designs can be considered

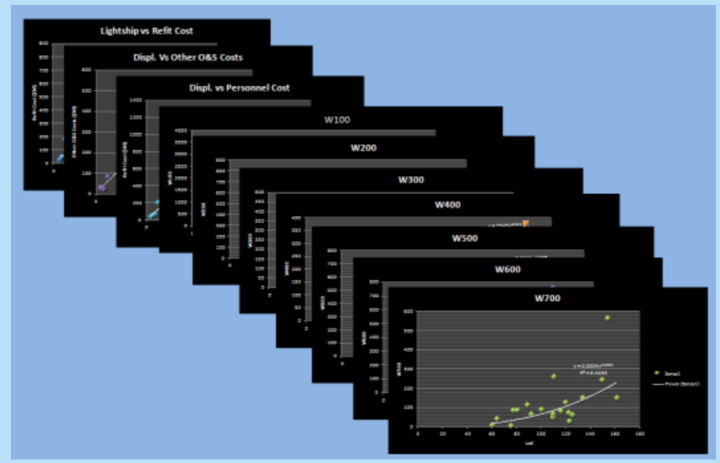
Automated generation of compartment configurations:

- Rapid generation of feasible arrangements, saving time/labour
- Many more possibilities can be considered – can discover a superior solution
- Objective comparison of configurations using quantitative measures of configuration merit – removes subjective elements from design process

Proposed Methodology

LCC Oriented MCDA Utilising a Genetic Algorithm

- Multi Criteria Decision Analysis allows comparison of different candidate designs
- Genetic Algorithm performs compartment arrangement
- Calculate Life Cycle Cost based on arrangement



Multi-Criteria Decision Analysis (MCDA)

- A systematic framework for decision making
- Provides a rational, objective means of comparing the choices available and their consequences, and deciding which should be preferred

A typical MCDA consists of the following steps:

- Identify choices and define assessment criteria
- Evaluate each option, giving a score for each criterion
- Weight these scores according to their importance to the decision
- Tally the weighted scores to give an overall score for each option

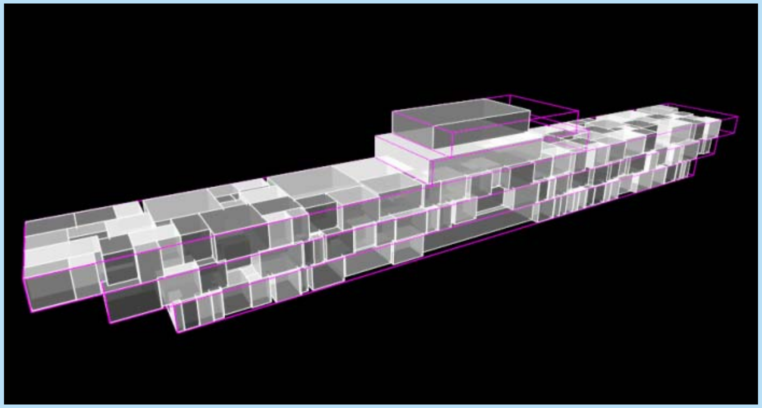
The options are then ranked according to this score, thereby placing them in order of preference

Compartment Arrangement

- Compartment arrangement is essentially an example of the layout problem (also known as the packing, packaging, configuration, container stuffing, pallet loading or spatial arrangement problem)
- Well studied problem - a multitude of approaches exist for producing solutions

Bin packing representation:

A number of objects with fixed dimensions must be placed within one or more bins as efficiently as possible (minimise number of bins used, or minimise size of bin(s))



Generation of Configurations

- Finding the global optimum within a reasonable time is not computationally tractable (very large number of potential solutions):
  - 20 compartments → 2.4x1018 permutations → 77 years @ 1 billion permutations/second
  - 30 compartments → over 600,000 times the age of the universe!
- Search space is usually multi-modal, meaning that simple gradient-based search methods usually ‘get stuck’ at local inferior maxima
- Most representations are discontinuous

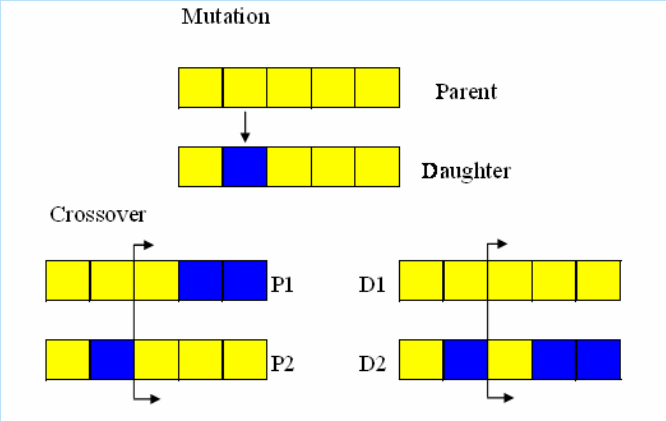
→ Many search/optimisation algorithms can’t be used

- Genetic algorithms are suitable and often used for solving layout problems

Genetic Algorithms

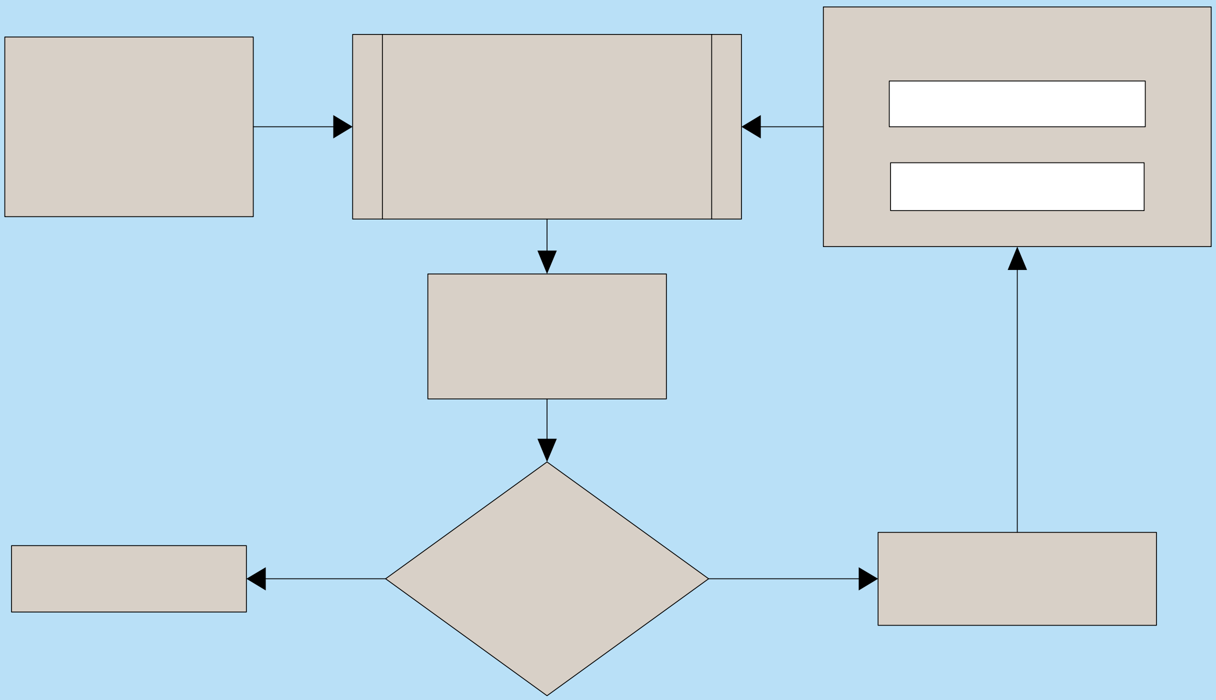
Genetic algorithms are a class of evolutionary search algorithms inspired by biological processes

- Represent solutions (uniquely) as strings of characters
- Start with a group ('population') of different solutions ('individuals')
- Generate new solutions by:
  - Combining segments of different strings ('crossover')
  - Randomly altering one or more characters of a string ('mutation')
- Evaluate each solution, and select the best to form the next 'generation'



Nick, E. K., 2008, "Fuzzy Optimal Allocation and Arrangement of Spaces in Naval Surface Ship Design", The University of Michigan, USA

Compartment Arrangement Genetic Algorithm



Arrangement as part of MCDA

- The compartment arrangement technique can be incorporated into an MCDA

  → allows comparison of different platform design options (different combinations of equipment/compartments)

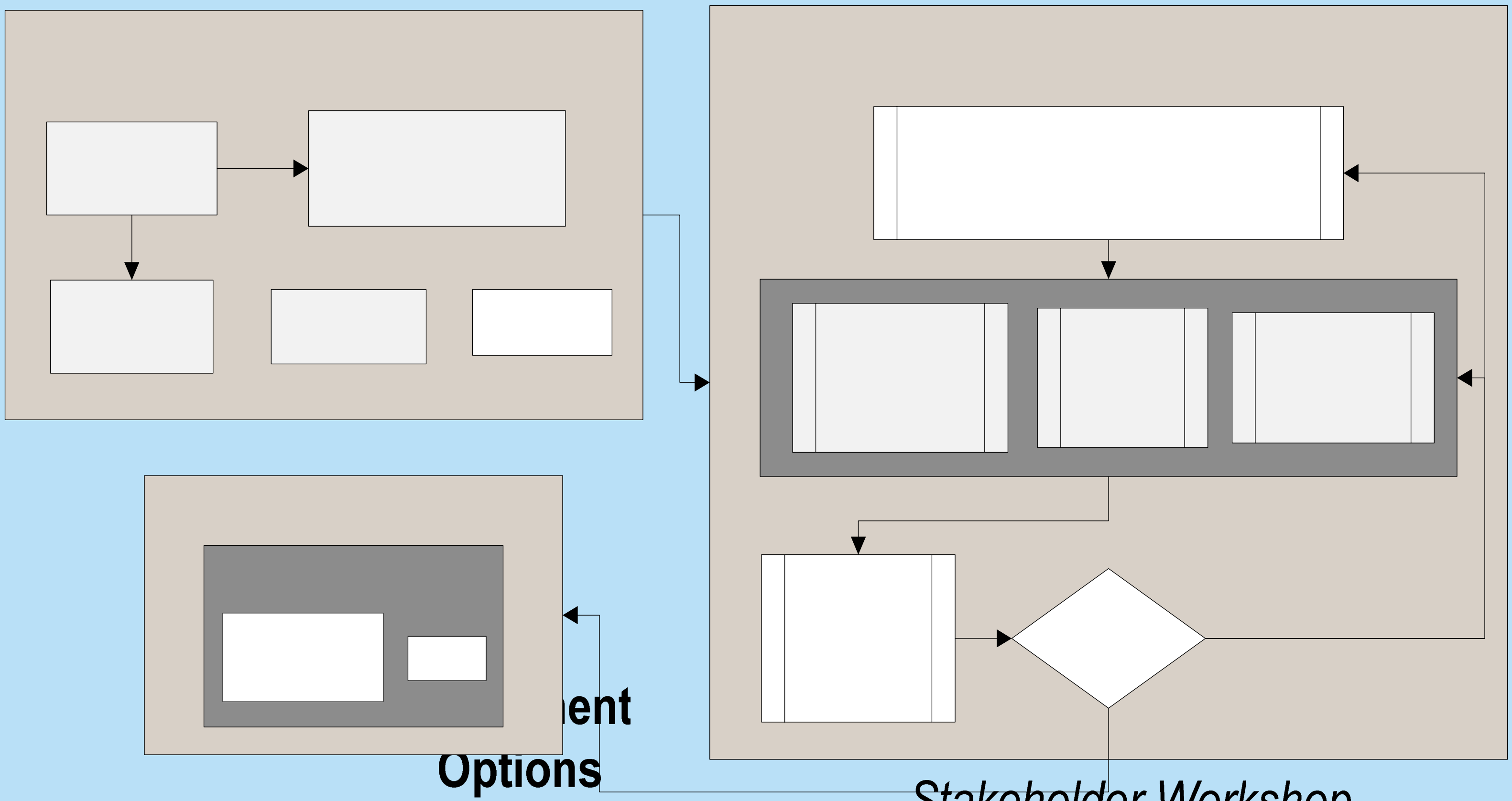
- For each option considered, the arrangement algorithm determines a feasible arrangement that meets the design objectives

  → rapid arrangement & evaluation of the various options

- Incorporate LCC model and measure of Operational Effectiveness

  → MCDA can quickly compare and rank different platform design options based on estimated cost and effectiveness

Proposed Technique



BMT Design & Technology

Proposed Technique

Weight objectives in genetic algorithm objective function according to priority

Objective function =

$$w_1 * (\text{objective 1 score}) + w_2 * (\text{objective 2 score}) + w_3 * (\text{objective 3 score}) + \ldots$$

Objectives include:

- Minimise LCC
- Maximise operational effectiveness

- Weights can be adjusted according to preference / priority

Simplified Ship Design Problem – Demonstration of Proposed Methodology

- Early stage design analysis and optimisation of a generic military ship design
  - Ship design and compartment listing based on typical capability requirements
  - Compartment size based on previous ship designs

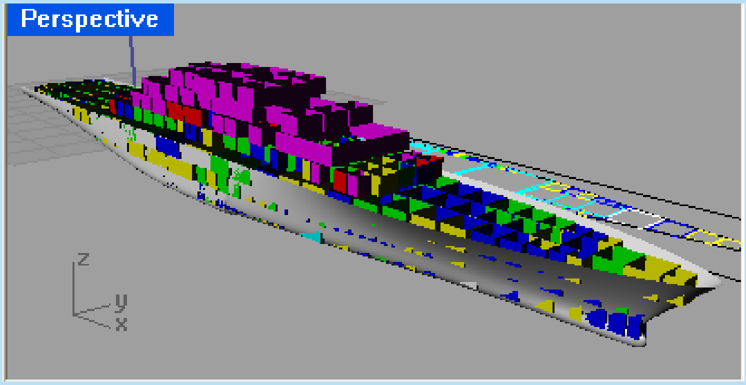
Method:

- Find a suitable compartment configuration using automated tool
- Cost the design using the proposed life cycle costing method
- Repeat with different compartment space allocation to explore the effect on LCC

→ The cost impact of additional space can be investigated and traded with the overall LCC

Method

- Compartment arrangement using the Rhinoceros CAD package with RhinoNEST add-on and a BMT-developed plug-in
- Designed to optimise space utilisation
- Compartment dimensions varied in size by 5% increments to form compartment listings at -10% to +20% of the original baseline sizes
- Arrangement produced for each listing; resultant design parameters for each used in LCC model to determine LCC



Genetic algorithm currently in development;
will allow for multiple objectives (e.g. preferred compartment locations, cost minimisation, etc.)

Results

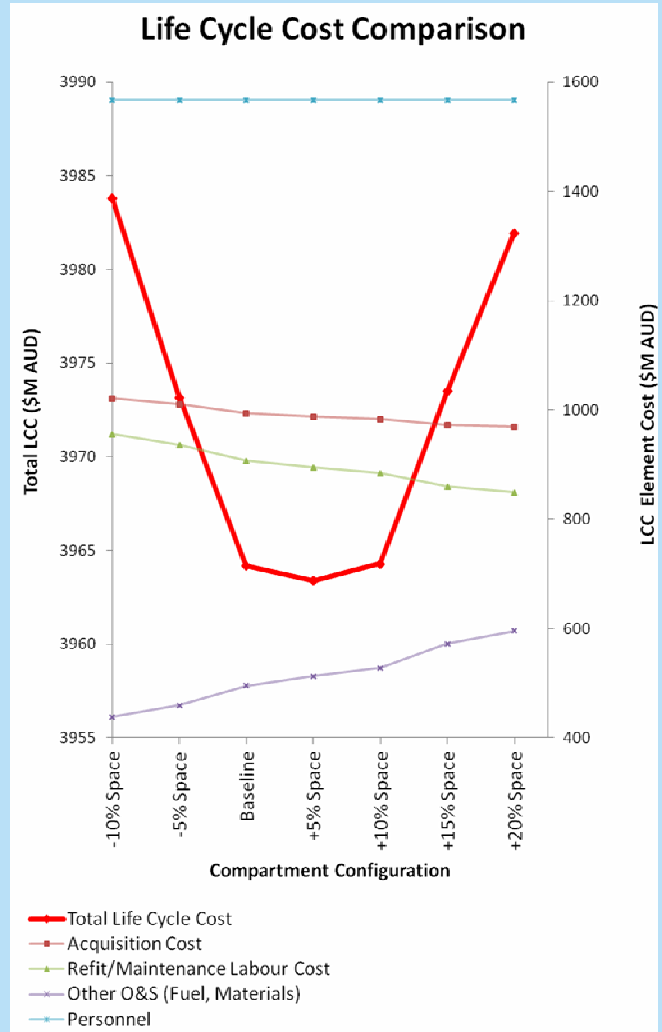
As space is added to compartments:

- construction and through-life maintenance costs decrease

  → overall decrease in acquisition and refit costs

- Increase in ship size leads to higher fuel and other upkeep costs
- The personnel cost remained constant

- Minimum LCC at +5% space
- Only slight increase in cost for the +10% solution when compared to the baseline.



Discussion

The analysis shows that:

- Up to 10% more space can be added to the ship with little consequence to LCC
- Making the ship smaller can significantly increase construction and maintenance costs
- LCC is quite sensitive to space allocation – must find balance

Discussion

Despite the simplified nature of this design problem, it raises some interesting points:

- This type of analysis in the early design stages could support the development of a slightly larger ship that traditional methods would have quickly discounted
- Resultant design could incorporate additional working space and removal routes
- The design would serve to reduce the risk of maintenance schedule delays and unforeseen complications

  → increase in vessel availability and decrease in budget blowouts

Conclusions

- Traditional design methods and decision analysis techniques focus mainly on acquisition costs – with little consideration for total LCC
- The LCC of ships is decided in the early stages of design
- Total LCC far outweighs acquisition costs

➔ Reducing LCC requires the right tools to affect the decision making process and influence ship design before LCC is set

- Example problem: up to 10% space can be added with little consequence to LCC
- MCDA, genetic algorithms and Life Cycle Costing analysis are more useful combined

  → can provide holistic and valuable input to early stage design decisions with significant effect
- *Key idea:* Incorporate feasibility, LCC and operational effectiveness into objective function of genetic algorithm → optimise early stage designs with respect to users' key objectives (e.g. cost, capability, overall value for money)

Further Work

- There is great scope for further development in this area
- The level of sophistication with which the compartment arrangement algorithm is able to produce concept designs can be vastly improved with further development
- Further data collection, analysis and validation could serve to improve the way in which cost dynamics are captured in early stage design trade-off studies
- Further research in this area can help to increase our understanding of LCC effects in the earlier stages of complex system acquisitions

Thank you

BMT Design & Technology