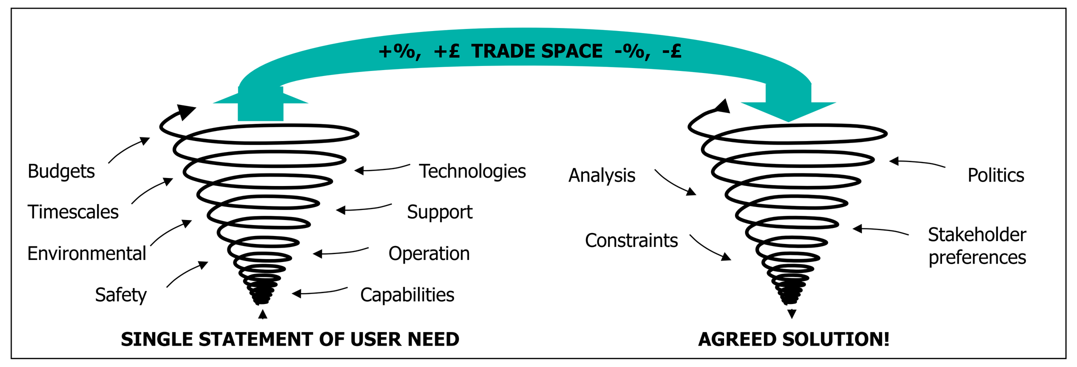
Modelling Systems and Making Decisions using BAEFASIP

Dr. M. D. Courts
Tel 03300 461550
malcolm.courts@baesystems.com

How & What?



Modelling

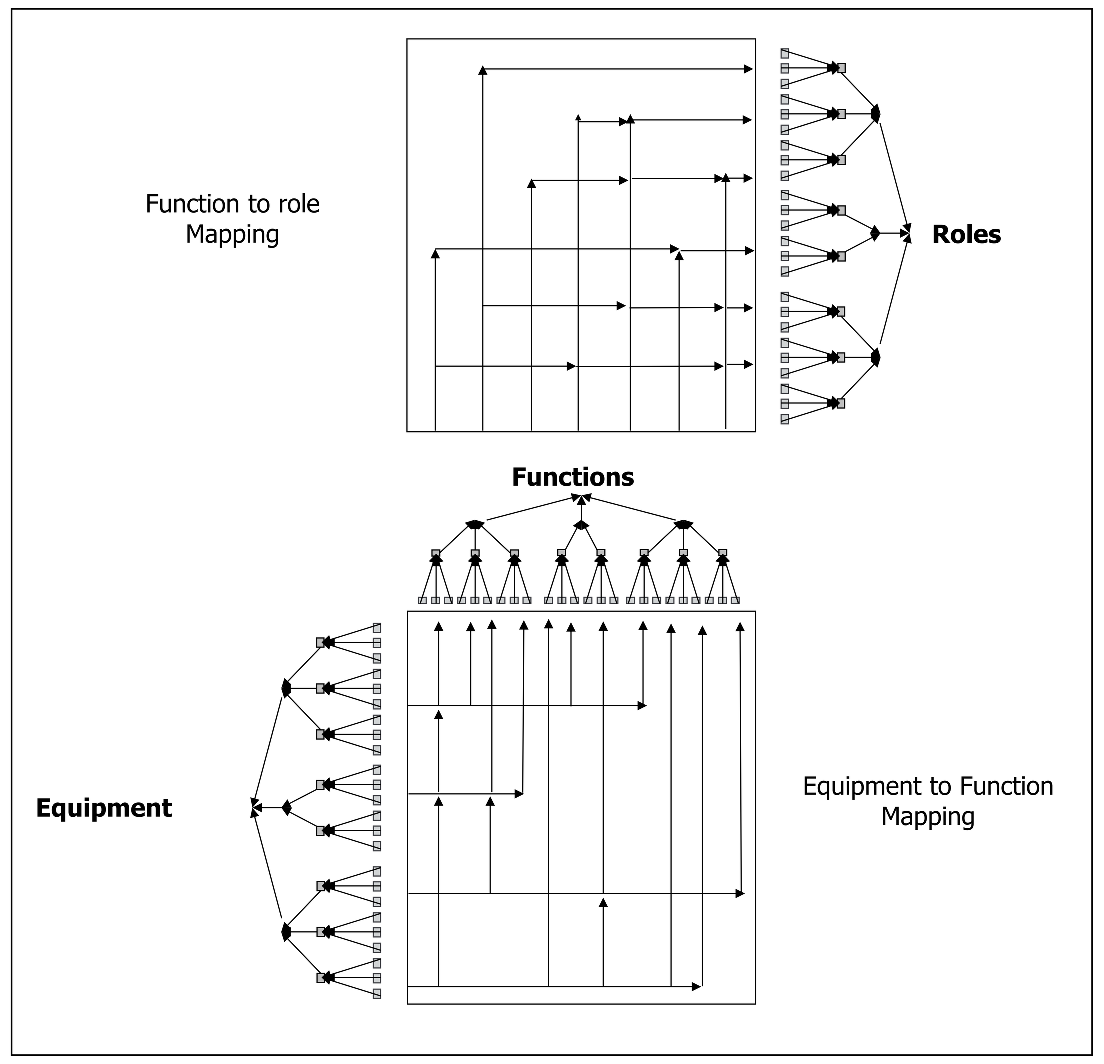
Functional Analysis of System Implementation Parameters

- To **Understand** the dependencies and interactions within a system
- To provide a rapid early stage **Assessment** of the performance, value and costs of a complex system
- To investigate a system's value in differing **Scenarios**
- To compare **Alternative** system solutions
- To investigate the effect of alternative sub system **Options**
- To find the most **Cost Effective** sub systems from a range of alternative options
- To investigate the effects of **Data Uncertainty**

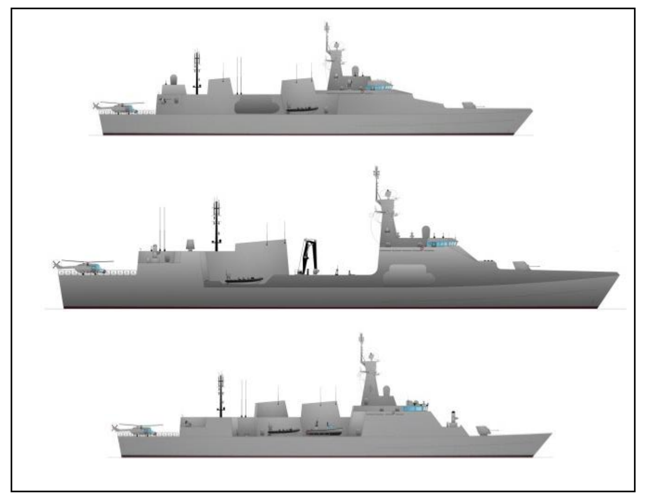
System Modelling Facilities

- Model constructed from **Multiple Data layers** (Up to 10) each built up on a **Tree Structure**
- Calculates **Multiple Properties** of a system through data tree layers and links
  - Upwards evaluation of properties - propagate up through layers
  - Downwards evaluation of properties - Equipment properties are evaluated throughout the lowest layer tree data items provided that they are linked through intermediate layers up to the top layer
- Allows a **Variety of Relationships** between properties of different data tree elements and layers, reflecting engineering dependency, redundancy etc.
- Generates **New Properties** from existing
- Allows **Selection of Subsets** of any data tree items for evaluation and sensitivity analyses
- Allows **Choices** of data items to be set up within data tree structures

Example Three Layer Model showing Data Tree Layers and Interconnecting Links



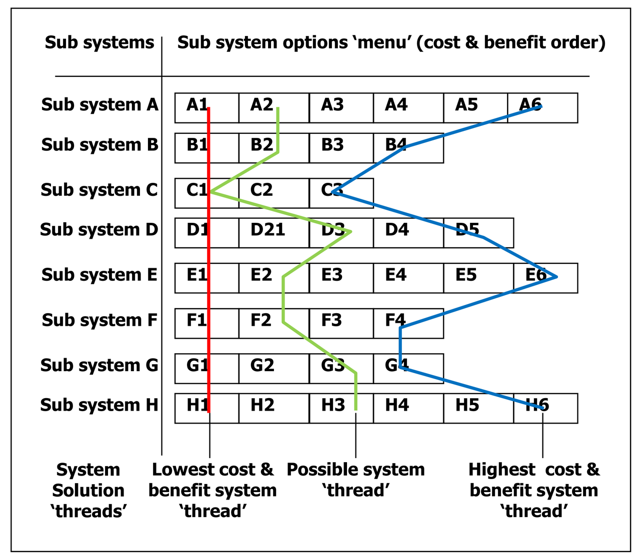
How Good?



Assessment

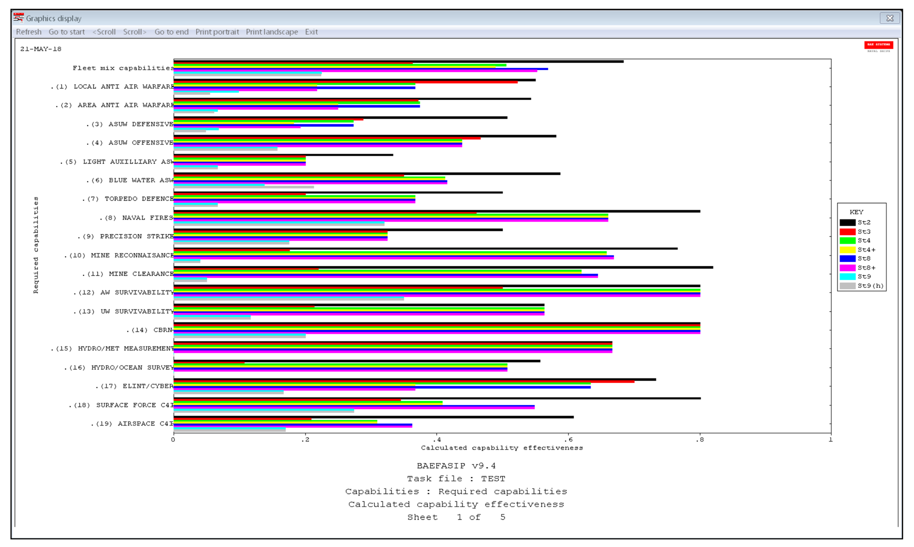
Analysis of Models

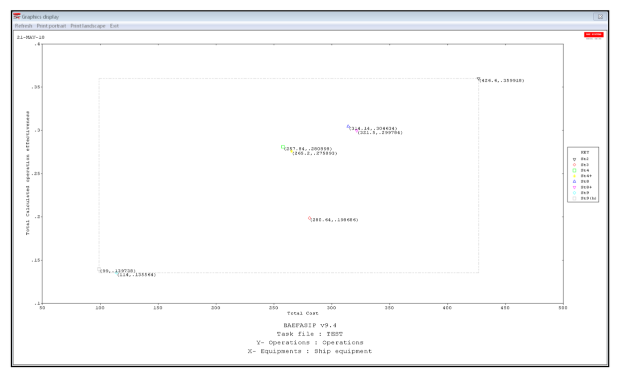
- **Selection** of elements - All **Data Layer** (e.g. Equipment, Function and Role) items can be turned on or off thus affecting the evaluated **Properties**
- If multiple Equipment Items are provided to perform similar functions in a model then a selection can be used to represent one system configuration by selecting one particular equipment from each of the choice sets available
- Multiple selections can be set up simultaneously thus allowing alternative system configurations to be compared against the same requirements
- Alternatively role selections or **Weightings** can be changed for different selections but with the equipment selection kept constant allowing system performance and cost effectiveness to be considered under different requirements
- A variety of graphical plots can be produced of element properties
- Sensitivity analysis showing effects on evaluated properties of varying particular or all item values



System options

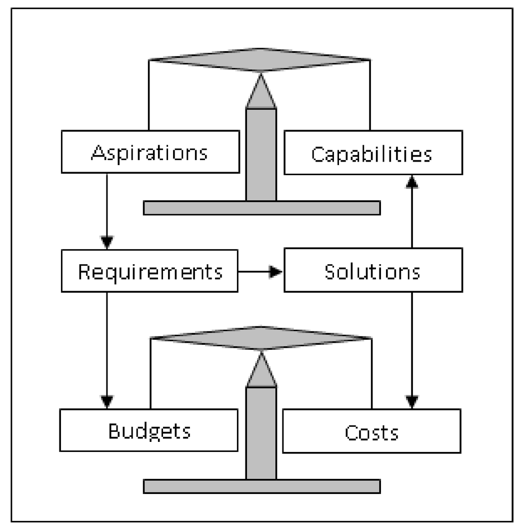
- A1 to A6 are possible options for choice area A arranged in order of increasing cost, B1 to B4 are possible options for choice area B and so on
- A complete system is made up of one option from each choice area, shown by the coloured lines running from top to bottom
- There are therefore 6x4x3x5x6x4x4x6 = 207,360 possible system solutions
- User system selections can be displayed and compared using a variety of different displays





Graphical Plots
Example plots showing capabilities and overall costs and benefits for different ship types assessed against capabilities linked in turn to a set of required operations.

What is Best?



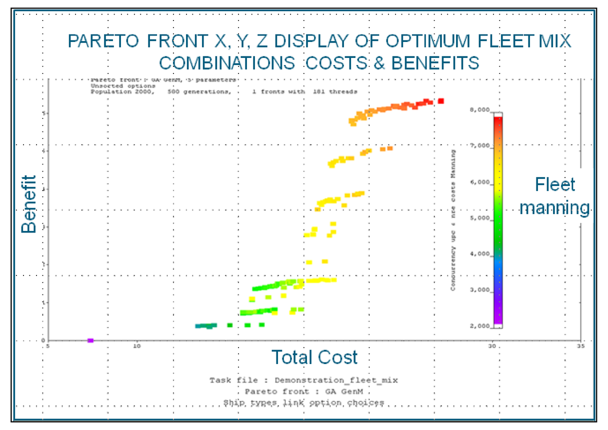
Optimisation

Multi Criteria Optimisation

- Allows **Pareto Front Multi Variable Optimisation** to optimise selection of choice options and selected model property and link values in complex trade spaces
- Allows **Constraints** to be imposed on solutions
- Allows **Rules** to be applied to choice combinations and property/link values, reflecting real world practicalities and engineering constraints
- Can find optimum solutions that are robust to **Variations** in property values

Fleet Mix Model

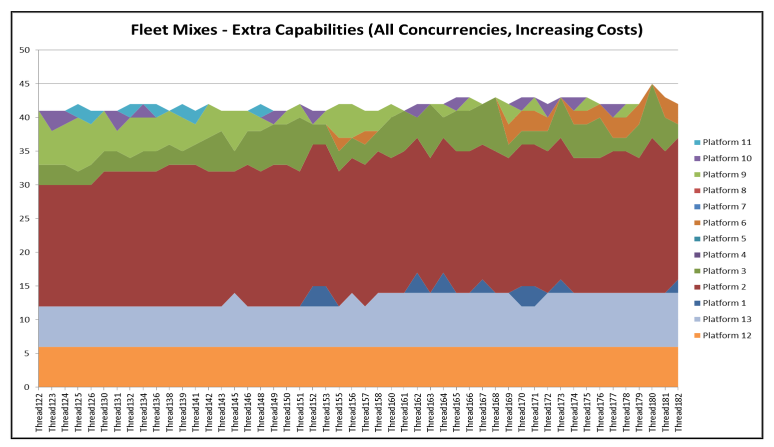
- Intended for assessment of alternative fleet mixes of different ship types
- Fleets assessed against multiple operational requirements and concurrencies
- Multi layer model to provide discrimination and understanding of how capabilities delivered by alternative fleet mixes
  - **Concurrencies**
  - **Operations**
  - **Ship types**
- Fleet mixes assessed and optimised against range of capabilities required for operations
- Operation and overall force structure coherency assured by use of rules and property calculations
- Model features
  - **Ship** inherent capabilities & capacity for deploying off board facilities e.g. USVs etc.
  - Numbers of **Ships** with capabilities required by **Operations**
  - Numbers of **Ships** with capabilities above critical level required by **Operations**
  - Numbers of **Ship** deployed off board facilities required by **Operations**
  - Critical total capability benefit scores for particular **Operations**
  - Rules tying one type of **Ship** to others required within an **Operation** (i.e. support ship per no. of other ships etc.)
  - **Operations** required by each **Concurrency**
  - Critical **Operation** benefit scores for particular **Concurrencies**
  - Relative importance of **Concurrencies**
  - Force generation factors for different **Ship** types
  - Manning and associated generation factors for each **Ship** type
  - Costs, both Unit Production Cost (UPC) and Non-Recurring Expenditure (NRE)
  - Limits of numbers of a **Ship** type across fleet (e.g. T45 and T26)
  - Additional items required to support fleet depending on numbers of **Ships** required & their costs/manning



Optimum Pareto Front (5D front)

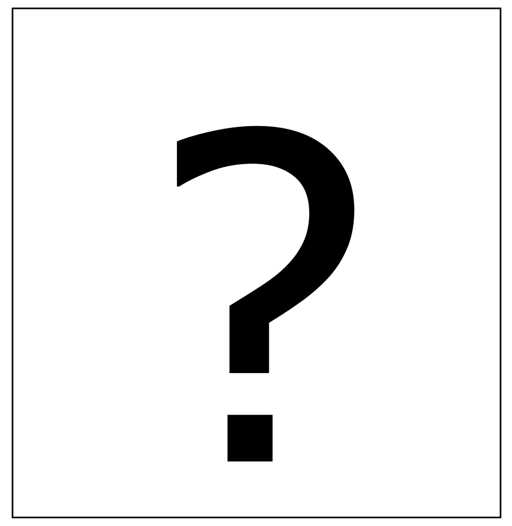
- Overall benefit scores calculated from capabilities for all Operations
- Total no. of Ships required for worse case concurrency identified
- Ships or Facilities required to support fleet identified
- Total costs calculated
- 5 dimension optimisation

Total costs (NRE & UPC)	Minimise
Total benefits	Maximise
No. of concurrencies	Maximise
Total manning (TLC driver)	Minimise
Number of classes (TLC driver)	Minimise



Optimum Fleet Mixes
Ship types in optimum fleet mixes able to meet all concurrencies shown in increasing order of total fleet cost (results output to spreadsheet and plotted)

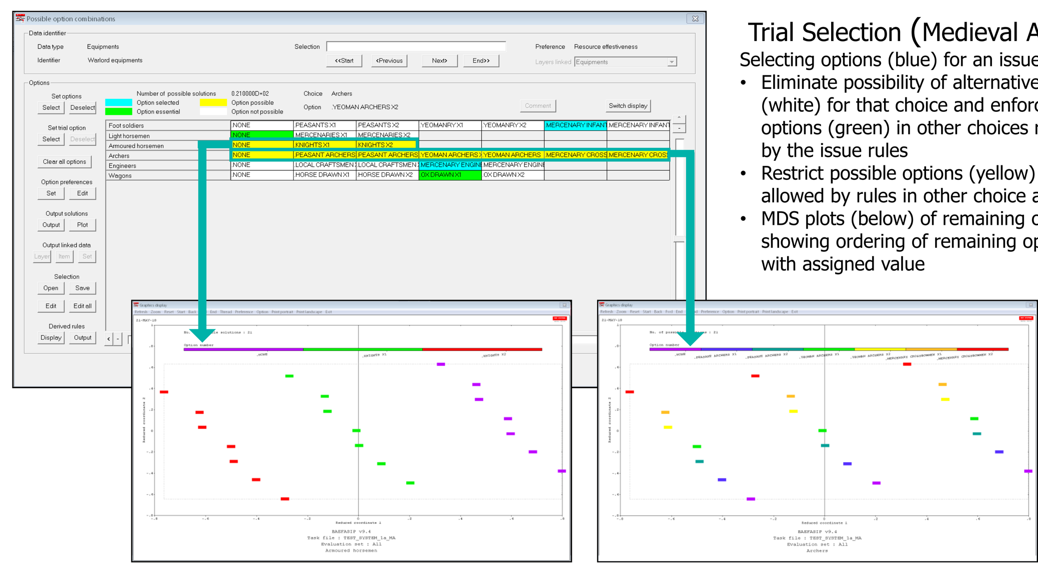
What If?



Uncertainty

Scenario Analysis

- **Morphological Analysis** (MA) is a non quantitative technique used to facilitate the resolution of difficult to define problems
  - Problem is described as a set of **Issues** with possibilities in each (Analogous to choice and option tree structure)
  - Identification of **Cross Criticalities** which eliminate particular scenario combinations (Analogous to rules definition)
  - Solution **Exploration** in which some options are selected and their implications on the other choice options can be explored
- MA analysis facilities are implemented using the standard model structure
  - Problem description is set up in a single Data Layer model using a variety of choice options types
  - Rules are set up as for optimisation (The full rule set is compatible with most MA models)
  - Solution construction is performed from an MA option screen
  - Solutions can be saved in Data Layer Selections
- Analysis can be extended by adding preference values to the issues and sorting possible solutions (once population is manageable after selections have reduced the total possible number) either through listing or graphically using Multi Dimensional Scaling (MDS)

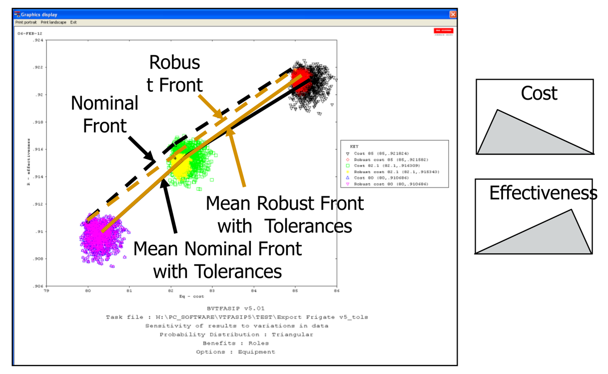


Trial Selection (Medieval Army!)
Selecting options (blue) for an issue will

- Eliminate possibility of alternative options (white) for that choice and enforce any options (green) in other choices required by the issue rules
- Restrict possible options (yellow) to those allowed by rules in other choice areas
- MDS plots (below) of remaining options showing ordering of remaining options with assigned value

Robust Optimisation with Data Variation and Uncertainty

- Pareto fronts that are robust to tolerance levels on specified data items can be found. There are two basic methods available
- The first averages multiple runs of the model at each calculation point with the data values varied according to a specified distribution
  - The results at each calculation point are the average of these multiple runs
  - This therefore greatly increases the run time and so is only suitable for small models
- The second allows the data to vary according to the specified tolerance distribution at each generation of a GA evolutionary process
  - It therefore avoids the need for multiple runs at each calculation point. However it does rely on the search requiring a reasonable number of generations to allow a history of variation to be built up, particularly when the front is converged
  - As such it can work well on larger models
- Analysis can be extended to include properties representing Value and consequent ordering of possible solutions



Robust Optimisation Results

- An optimisation of the equipment fit on a surface combatant was performed by minimising the total cost of the equipment and maximising the overall benefit across multiple roles
- Triangular probability distributions were applied to cost and benefit for some of the equipment options that were still in development in order to represent the risks involved and the optimisation repeated
- Points were taken at three nominal cost points from both fronts and Monte Carlo evaluations of the overall cost and benefit values conducted
- The results show that the robust front selections have reduced dependency on the development items giving a smaller potential cost and benefit range

BAE SYSTEMS
INSPIRED WORK