UNIVERSITY OF Southampton

Engineering and the Environment

Aeronautics, Astronautics and Computational Engineering

Development of a Decision Support Framework for Aerospace Applications

UTC for Computational Engineering

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Introduction

The objective function in design optimisation represents the "goodness" of a system that we wish to improve i.e. a figure of merit. A typical figure of merit in aerospace design tends to be to minimise gross-takeoff-mass (GTOM), which usually acts as a good approximation to acquisition cost because a smaller aircraft carrying less fuel should cost less to build and operate. However, GTOM as a figure of merit is only valid at a fixed technology level and fixed operational requirements. Changes in, for example engine technology, avionics, materials, mission range, time on station, etc., can lead to a better system solution that can be more profitable or offer better performance capabilities.

The decision support framework developed from this research aims to identify *'high-impact'* architectural functions that strongly influence the overall system value and cost. The methodology works by defining the architectural decision making process as a network by representing architectural functional elements as nodes and the connecting edges represent the physical/preferential constraints imposed by the decision maker on the architectural space. The feasible architectures are then assessed to evaluate their impact on stakeholder value and cost. Value metrics act as a common measure of defining the 'goodness' of a systems performance. The intended result of the framework is to allow system architects to rationally trade between different architectural solutions and provide a means of numerically capturing the rationale behind the decision-making process. The framework makes use of Multi-Attribute-Utility Theory (MAUT) to capture stakeholder preferences, which allows the system architect to trade between stakeholder value and the cost of implementing and operating the system.

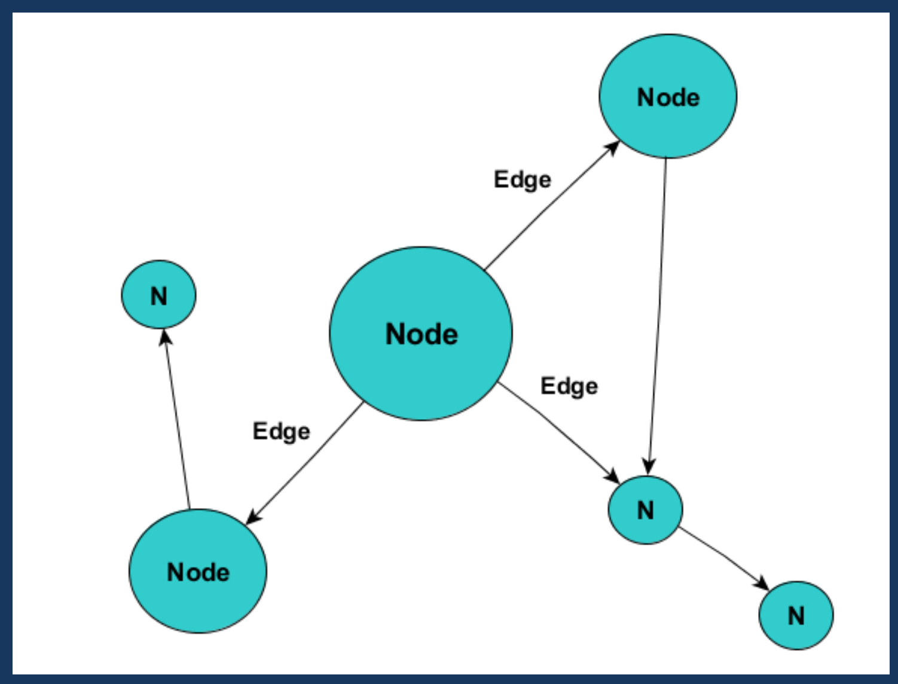
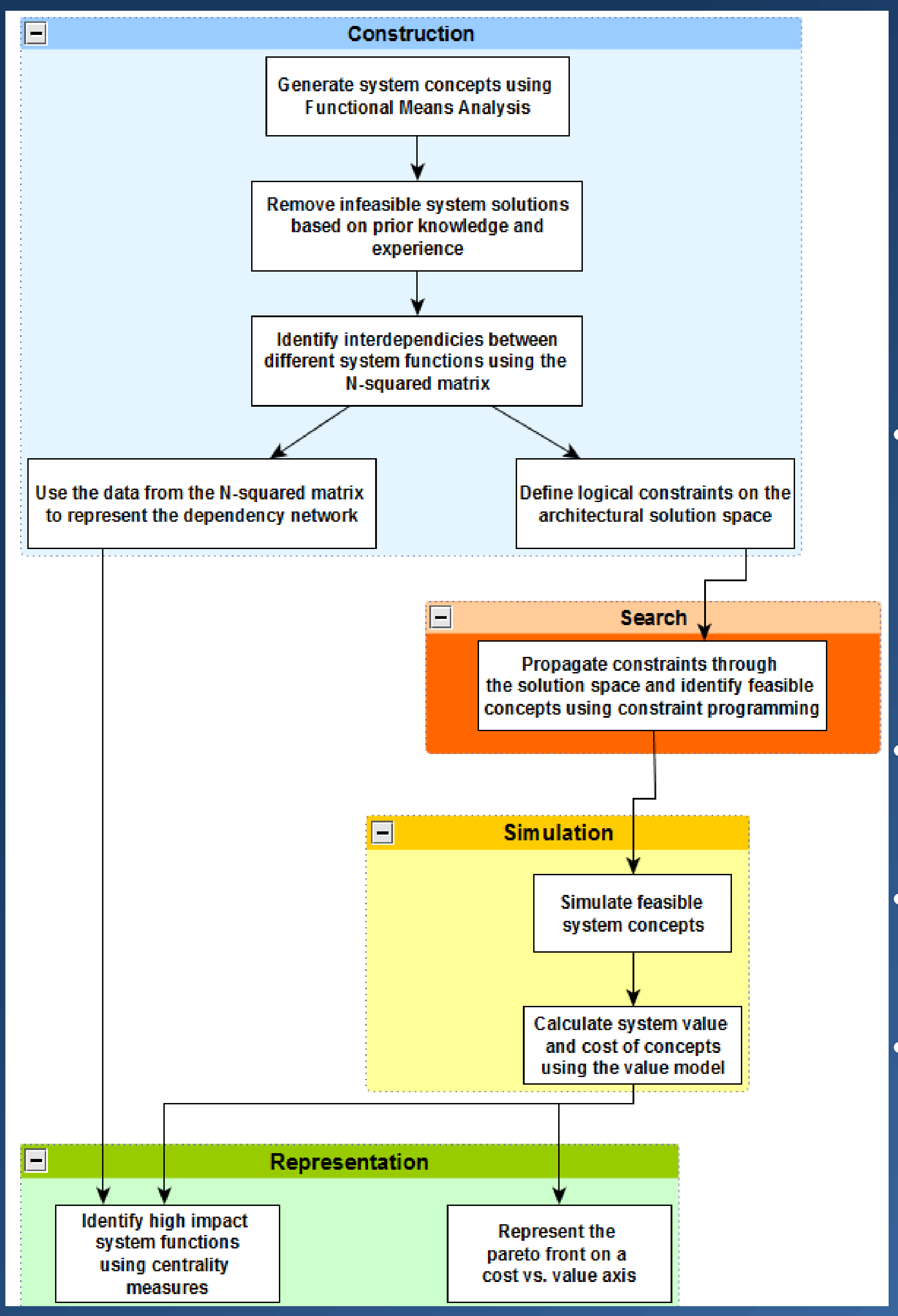


Figure 1: Representation of an architectural network

Decision Support Framework


Construction

Generate system concepts using Functional Means Analysis

Remove infeasible system solutions based on prior knowledge and experience

Identify interdependicies between different system functions using the N-squared matrix

Use the data from the N-squared matrix to represent the dependency network

Define logical constraints on the architectural solution space

Search

Propagate constraints through the solution space and identify feasible concepts using constraint programming

Simulation

Simulate feasible system concepts

Calculate system value and cost of concepts using the value model

Representation

Identify high impact system functions using centrality measures

Represent the pareto front on a cost vs. value axis

Figure 2: Decision Support System Framework

Case Study: Design of a Small Low-Cost Unmanned Aerial Vehicle (UAV)

The framework is validated by applying it to the design of a small UAV in use for costal monitoring and search and rescue operations. The main role of the UAV is to patrol costal areas for long periods looking out for vessels in distress, pollution, illegal activities, etc.

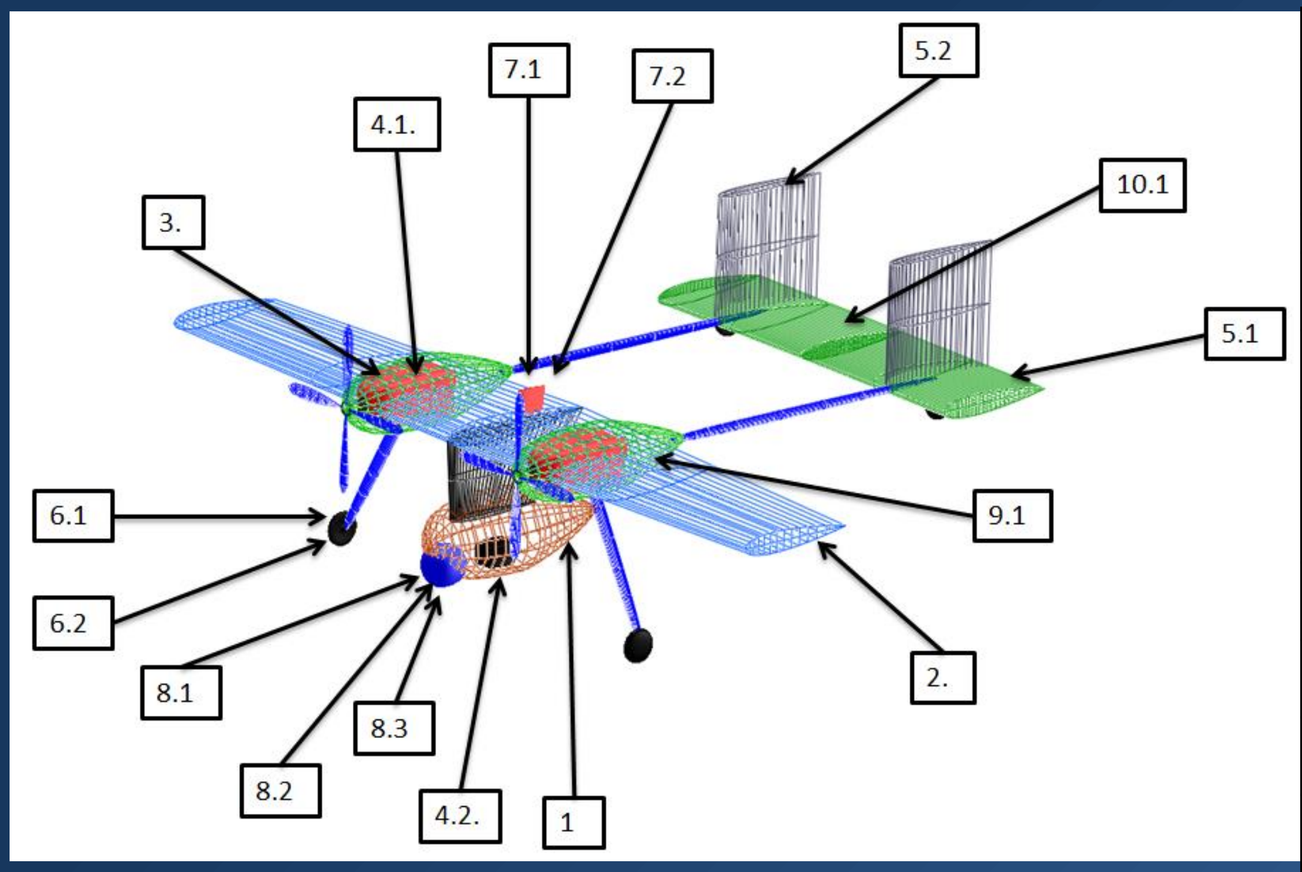


Figure 3: Functional decomposition at a platform level

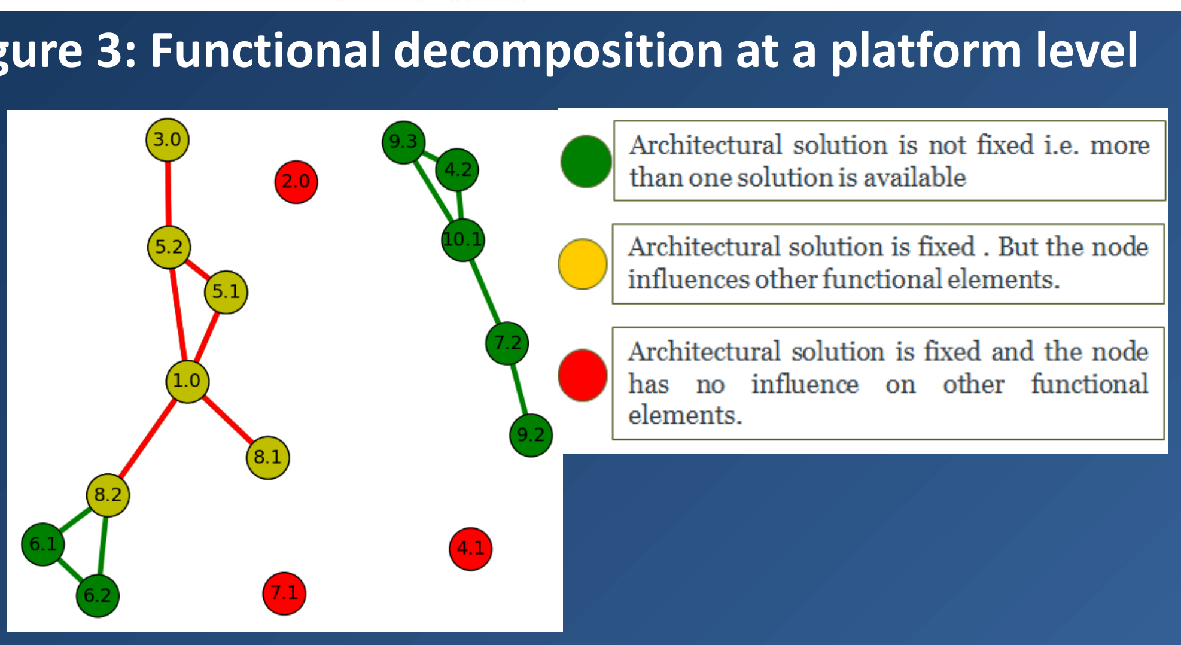


Figure 4: Architectural constraint/compatibility network

The imposed constraints generated 22 feasible system solutions. Future work is focused on simulating all the architectural solutions and identifying *high-impact'* architectural functions based on their impact on system value and cost.

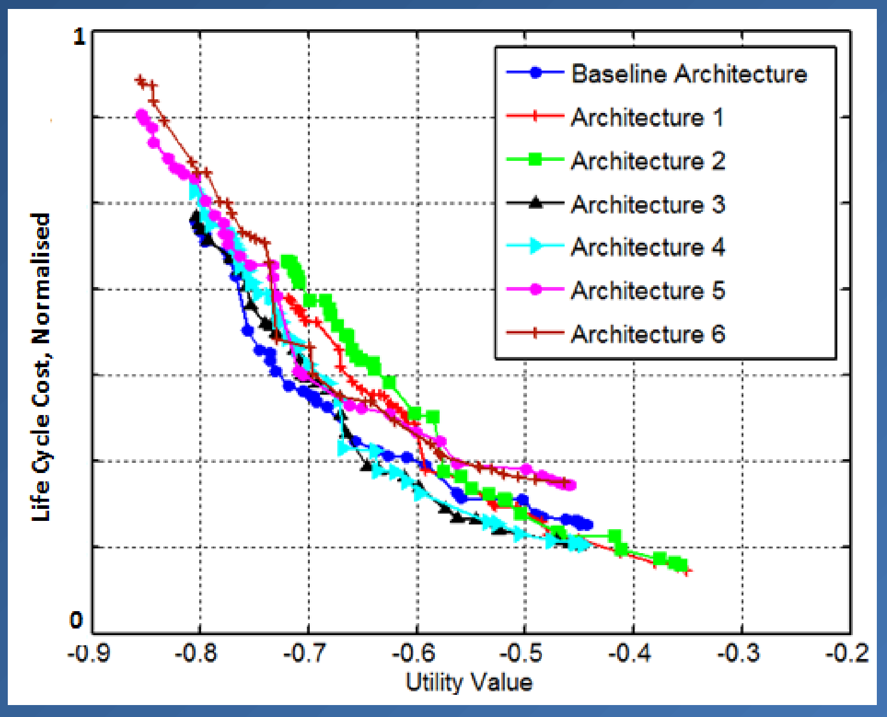


Figure 5: Pareto front of a set of architectural solutions

Function	MEANS		
1. Packaging and storage of payload and other system components	Detachable pod		
2. Generate Lift	High wing		
3. Deliver propulsive power	Twin 4 stroke engine		
4. Deliver electrical power			
4.1 Deliver electrical power to avionics & communication systems	Engine Generator		
4.2. Deliver electrical power to payload	Engine Generator	Separate battery source	
5. Provide control and stability			
5.1. Provide longitudinal stability	Conventional		
5.2. Provide lateral stability	Twin vertical surfaces		
6. Launch and recovery system			
6.1 Launch System	Tricycle	Tensioned Line Launch	
6.2. Recovery system	Conventional recovery	Cable-assisted recovery	
7. Communication of data between the airborne system and the ground station			
7.1. Antenna Integration	Lower fuselage / wing surface		
7.2. Transmit Data	Omni- Dipole, vertically polarisation, frequency 300 MHz - 12GHz, Gain 2dBi	Omni- circular polarisation, frequency 400MHz-14GHz, Gain 3dBi	Bladed Antenna, Omni - dipole, vertical polarisation, frequency 300 MHz-12GHz, Gain 2dBi
8. Detect and Identify objects of interest			
8.1. Mounting of sensors	EO/IR ball Pan-tilt		
8.2. Sensor location	Payload integrated into fuselage or pod		
8.3 Capture Sean Imagery	1080 x 1080, FOV(Field of View)= 5 deg, FOR(Field of Regard) = 15 deg	640x480, FOV(Field of View) = 9 deg, FOR(Field of Regard) = 15 deg	1280 x 720, FOV(Field of View) = 2 deg, FOR(Field of Regard) =15 deg
9. Protection of system from external environment.			
9.2 Environmental control systems (ECS)	No ECS	Ram air cooling	
10. Protection of system from failures			
10.1. Avionics Architecture	Simplex	Duplex with two sets of control surfaces	

Table 1: Functional-Means Analysis

- **Construction:**
  - Functional-Means Analysis: Captures and represents different architectural solutions in a tabular form.
  - N-squared matrix: Captures the compatibility relationships between different functional elements (i.e. the edges in the architectural network).
  - Logical Constraints: Quantifies the compatibility constraints in a mathematical form such that infeasible solutions are removed during the search phase.
- **Search:**
  - Uses algorithms from constraint programming, such as backtracking and constraint propagation to remove infeasible system solutions.
- **Simulation:**
  - The feasible system architectures generated from the search phase are simulated using physics based/analytical models to capture system value, using MAUT, and life-cycle-cost.
- **Representation:**
  - The results from the simulation phase are represented in two parts. First as a Pareto-front of value vs. life-cycle cost (i.e. Pareto optimal solutions). Second, quantifying high-impact architectural functions in terms of their impact on value and cost. This is captured by using a variation of the main-effects analysis (from the Design of Experiments (DoE) literature) and using Page-ranking centrality measure (from network analysis literature).

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