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# Introducing Cost Models to Conceptual Tradespace Exploration

Presented by: Alex Baylot, P.E., CSEP
US Army Engineer Research & Development Center
Information Technology Laboratory-Institute of Systems Engineering Research
Vicksburg, MS, USA
alex.baylot@usace.army.mil

# Objective and Outline

**Provide US DoD Engineered Resilient Systems (ERS) lifecycle cost (LCC) surrogate model method for linking cost models to performance models in generating large-scale tradespaces**

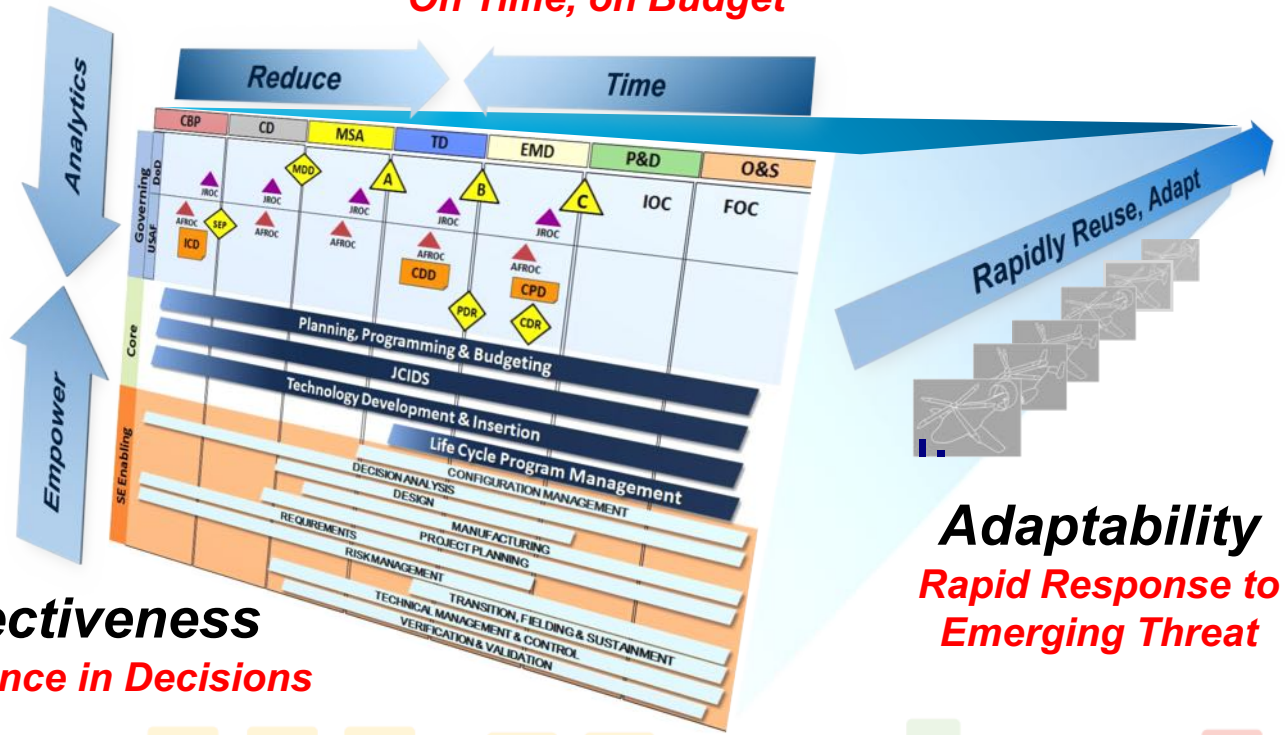
- Background
- Cost Estimating Techniques
- Cost Analysis Use Case
- Surrogate Model Creation Method
- Low-Cost Attritable Aircraft Use Case
- Surrogate Model Fit
- Results
- Future Exploration
- Summary
- Questions

# Background

***A goal of the ERS Program is to create a capability for linking cost and performance models for early concept exploration of design alternatives***

***Affordability***

***On Time, on Budget***




***Effectiveness***

***Confidence in Decisions***

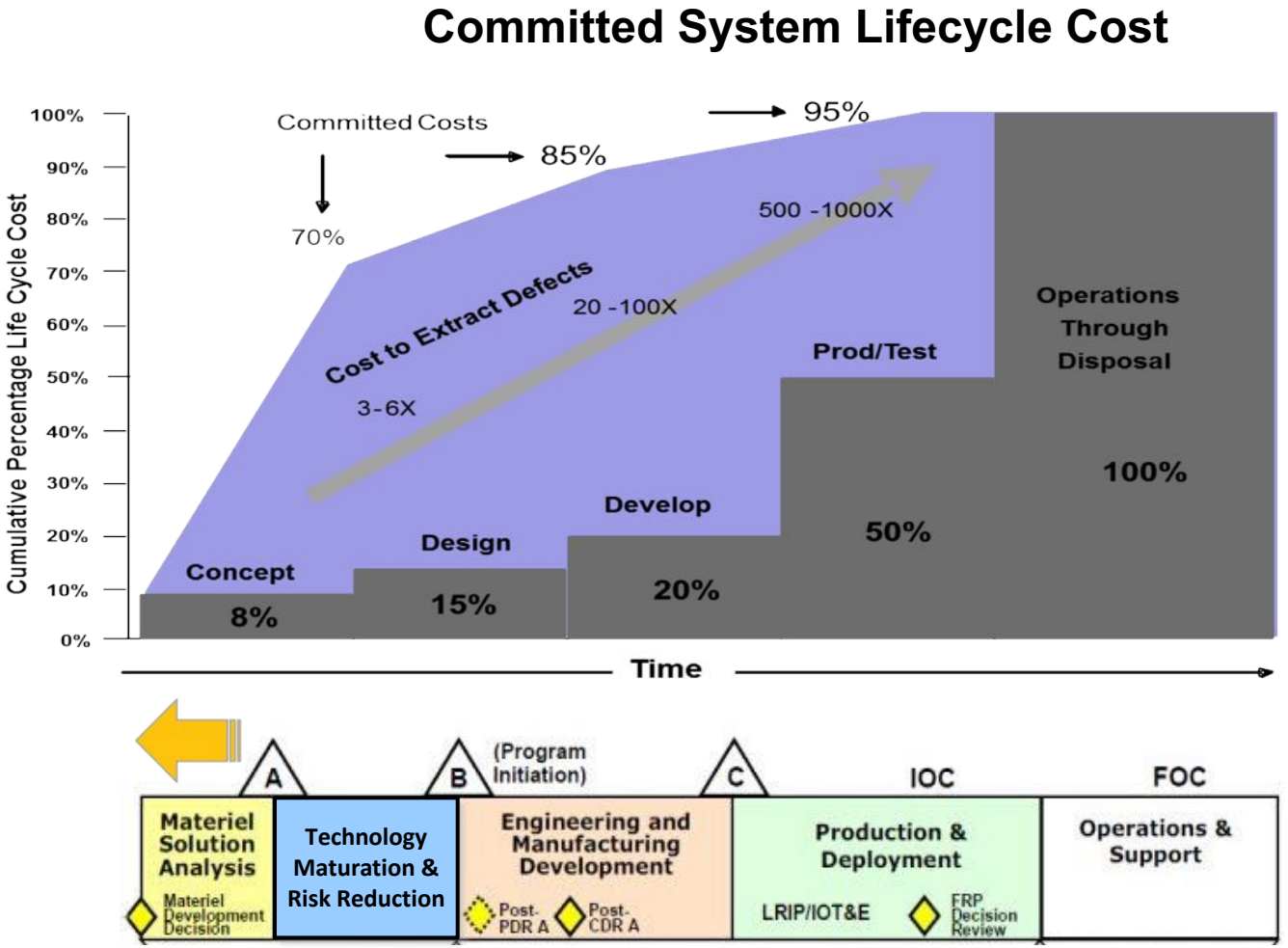
***Adaptability***

***Rapid Response to Emerging Threat***

# Background

## Affordability Analysis (Pre-Milestone A/B)

- Determine Affordability Goals/Caps
- Estimate Program Lifecycle Cost
- Establish Cost Targets
- Analyze Cost/Performance Trades




Reference DoDI 5000.02 Defense Acquisition Life Cycle Compliance Baseline

# Cost Estimating Techniques

**Analogy**

- Quick, inexpensive, easy-to-change
- Subjective, not precise, poor comparison between new and old systems
- Typically used pre-Milestone A through Milestone A

**Parametric**

- Cost estimating relationships, inexpensive, easy to do “what-if” drills
- Moderately subjective, precision only as good as databases
- Typically used pre-Milestone A through Milestone B

**Engineering**

- Very accurate in later stages of EMD, limited subjectivity, uses WBS
- Very expensive, very time consuming, “what-ifs” are difficult
- Typically used Milestone B through post-Milestone C

**Actual Costs**

- Limited subjectivity, very accurate
- Limited actual cost data, very expensive, very time consuming, “what-ifs” are difficult
- Typically used Milestone C through post-Milestone C

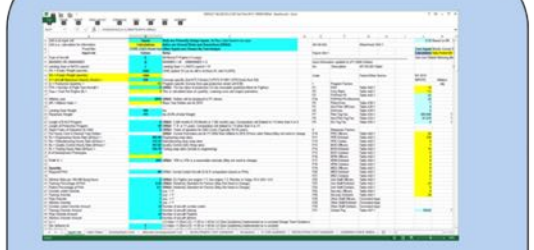
DAU ACQ 101

# Cost Analysis Use Cases

| | |
|---|---|
| **Create/Adapt Cost Model** | 1 – **Manual CER**: User manually enters Cost Estimating Relationships (CER) to build a cost model |
| | 2 – **Existing Menu**: User choses an existing cost constraint component and adjusts (calibrates) for specific cost generation |
| | 3 – **Historic Cost Data**: cost model from user provided historic cost data |
| **Link Existing Cost Model** | 4 – **Existing Analogy**: Allows user to provide an existing cost data set derived from any source to generate meta model for cost domain tradespace generation |
| | 5 – **Excel Cost Model**: Allows user to provide an existing excel based cost model to link to tradespace generation (greater than 50% of models) |
| | 6 – **COTS Cost Model**: User provides a COTS integrated tools model |

# Surrogate Model Creation Method

Connecting cost models to other tradespace models



Python Wrapper/Parser

Use existing spreadsheet cost model

I/O Combinations

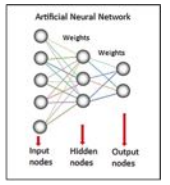
+100K

Use Monte-Carlo techniques

Surrogate Model

Generate surrogate-regression model

Artificial Neural Network (ANN) Model




Dynamics

Propulsion

Stability &

Cost

linked models

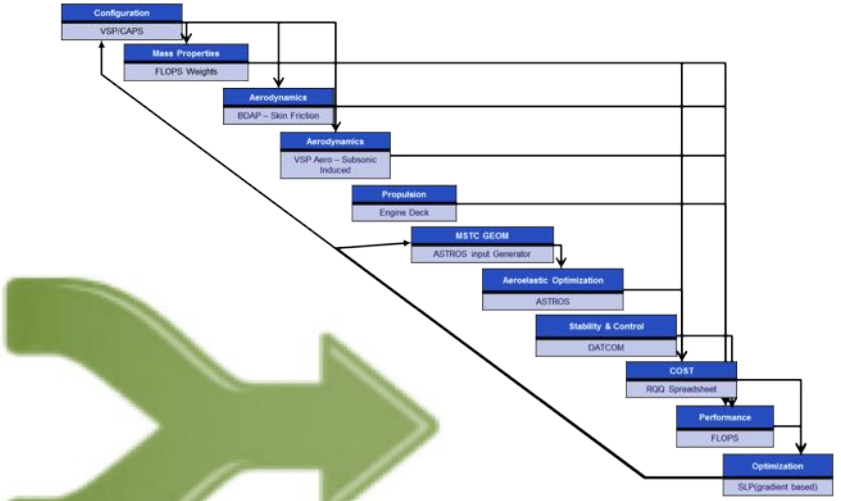
# Low-Cost Attritable Aircraft Use Case

## Current Method*

*49 Parameters*

Computer-language cost model derived from spreadsheet to MATLAB or Python

- 4 months development
- Slow response to changes



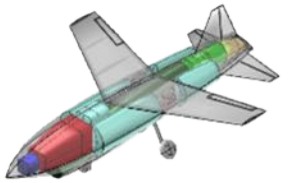

## Surrogate Method


- 24 hours development
- Quick response to changes

*Not typical

100X reduction in time period for cost model integration

Model Execution

- ❑ **Aero-elasticity**
- ❑ **Structural sizing**
- ❑ **Stability & Control**
- ❑ **Multi-Fidelity**
- ❑ **Parametric optimization**
- ❑ **Cost**

# ANN Model Fit

## Correlation Coefficients

| Total Development Cost | Total Procurement Cost | Total Ten-Year LCC |
|---|---|---|
| 0.861 | 0.891 | 0.889 |

## Total Ten-Year LCC

| Input Parameter | Correlation |
|---|---|
| Number of Units | 0.475 |
| Sensor/Avionics Payload Weight | 0.307 |
| Operating Weight Empty | 0.151 |
| Maximum Velocity | 0.142 |
| Contractor Test Reduction factor | -0.127 |

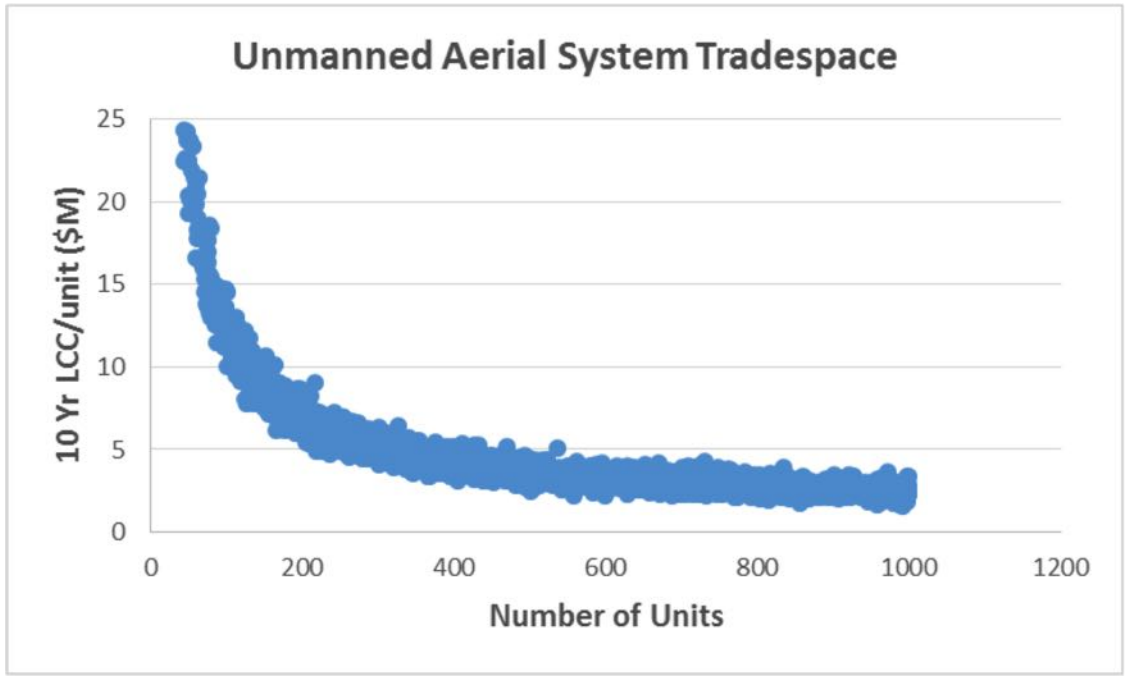
## Development Cost

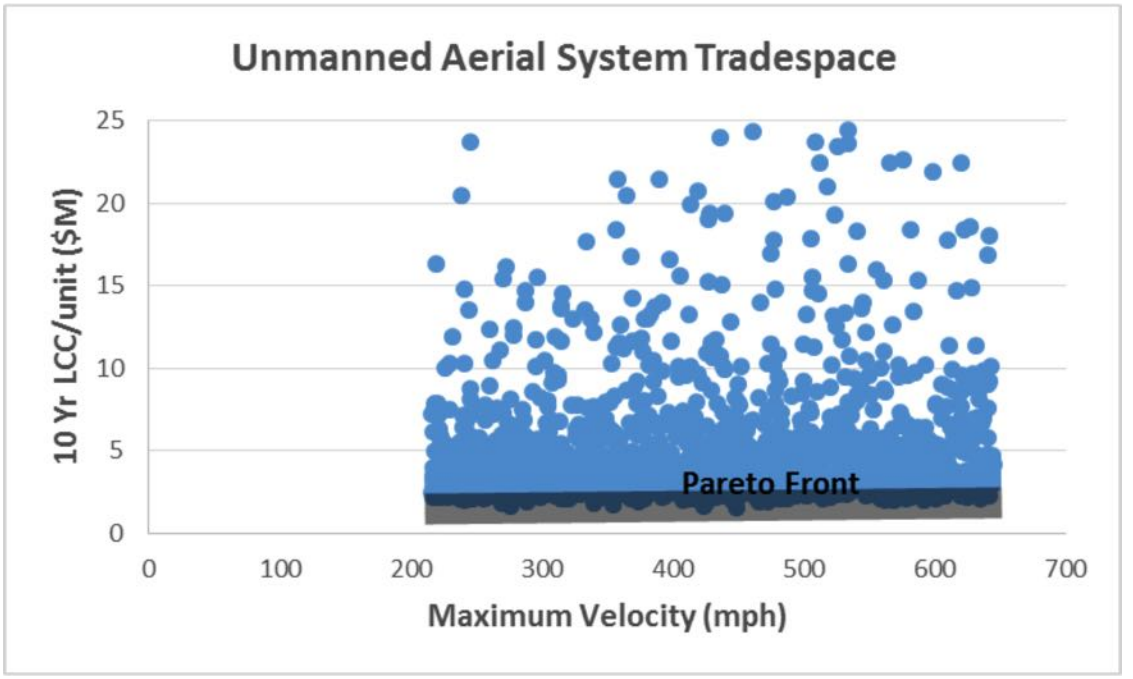
| Input Parameter | Correlation |
|---|---|
| Contractor Test Reduction factor | -0.795 |
| Rate-Engineering | 0.235 |
| Maximum Velocity | 0.153 |
| Operating Weight Empty | 0.147 |
| Software Airframe SLOC | 0.092 |

## Total Procurement Cost

| Input Parameter | Correlation |
|---|---|
| Number of Units | 0.490 |
| Sensor/Avionics Payload Weight | 0.314 |
| Operating Weight Empty | 0.128 |
| Maximum Velocity | 0.118 |
| Manufacturing Hour Reduction fact | -0.091 |

# Results




Ten-Year Total LCC/unit ($M) vs. Number of Units

Ten-Year Total LCC/unit ($M) vs. Maximum Velocity (mph)

*Note: Data is not US Air Force LCAAT, but a notional UAS*

# Future Exploration

- Explore and compare additional methods for manipulating spreadsheet cost models
- Develop a menu-based program to allow a non-programmer cost analyst to select the I/O cells with an Excel™ spreadsheet and perform a Monte Carlo simulation and/or design-of-experiments for sample set generation
- Implement an optimization algorithm to prune away un-sensitive and un-correlated input parameters during the construction of the surrogate model
- Explore Principal Component Analysis techniques as an alternative or in addition to correlation coefficients for identifying the most critical input parameters
- Research techniques for automatically producing a computer-language code of the surrogate model to automate the generation of the model for linking to other computer models for efficient and large-scale tradespace generation (e.g. Pycel)

# Summary

- The ERS Program is developing methods to better integrate cost models into large tradespaces for concept exploration
- Surrogate modeling methods show promise to greatly accelerate the integration process into large-scale tradespace exploration for pre-MS A & at MS A
- Building a surrogate model using techniques such as ANN, as opposed to direct computer language coding, can reduce the integration time of cost models.
- Generating large data sets from spreadsheet I/O is useful in discovering the significance and sensitivity of each input parameter and correlation to the output variables.

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## Authors

Mr. E. Alex Baylot, US Army ERDC, Alex.Baylot@usace.army.mil
Mr. James “Jed” Richards, US Army ERDC, James.Richards@usace.army.mil
Ms. Drew Kelley, US Army ERDC, Drew.Kelley@usace.army.mil
Ms. Deanna Hardin, US Army ERDC, Deanna.Hardin@usace.army.mil