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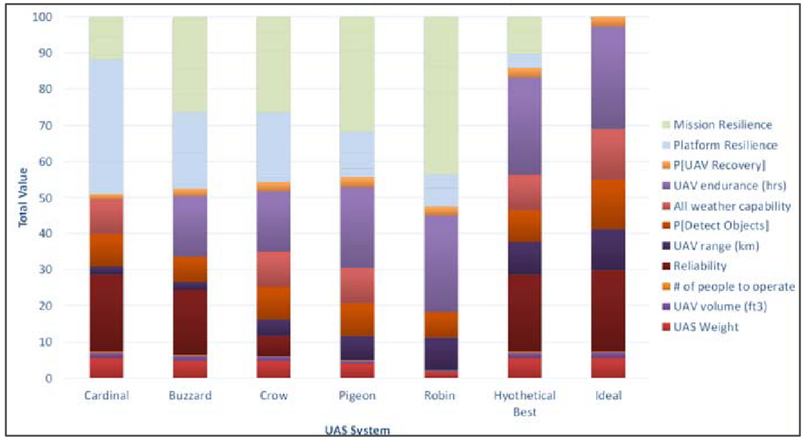
ENGINEERS AUSTRALIA SESA

Dr. Greg Parnell, Colin Small, Dr. Ed Pohl, Bobby Cottam, Eric Specking, Zephan Wade

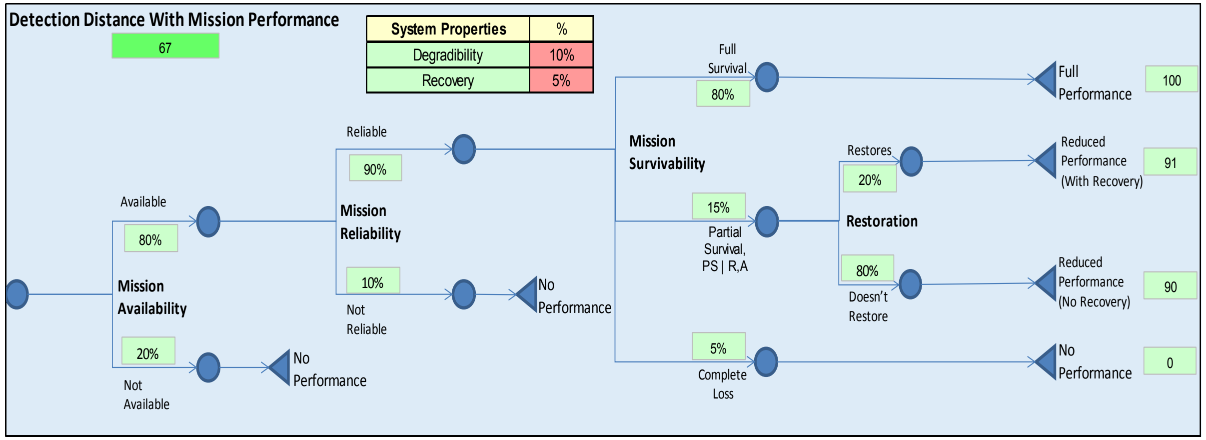
Engineered Resilient Systems with Value-Focused Thinking

Bottom Line Up Front

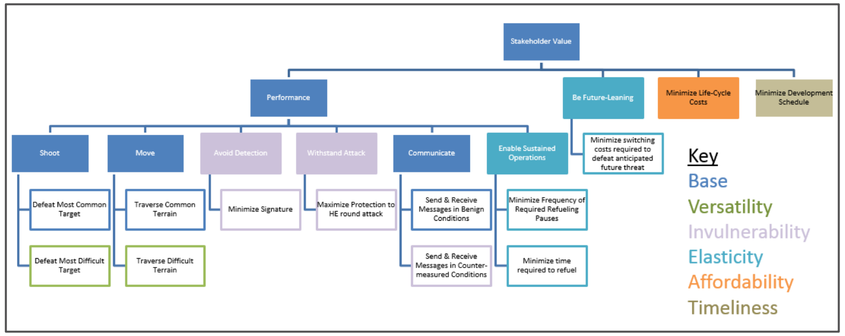
Resilience Opportunity Value



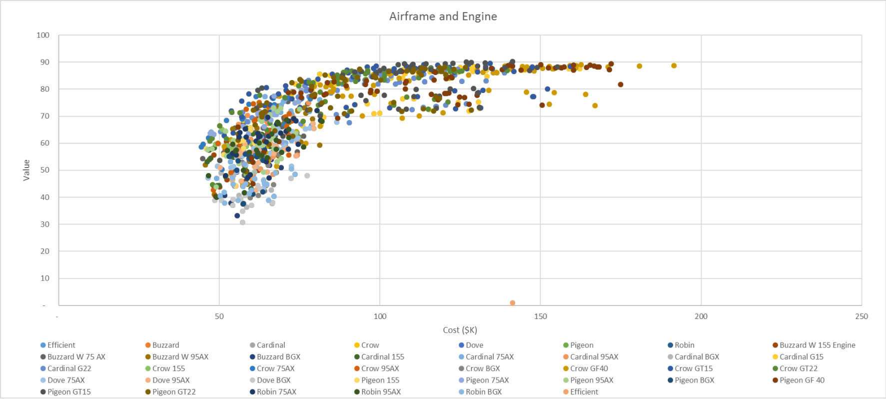
Resilience KPP



Include "Ilities" in Value Model



Set Based Design

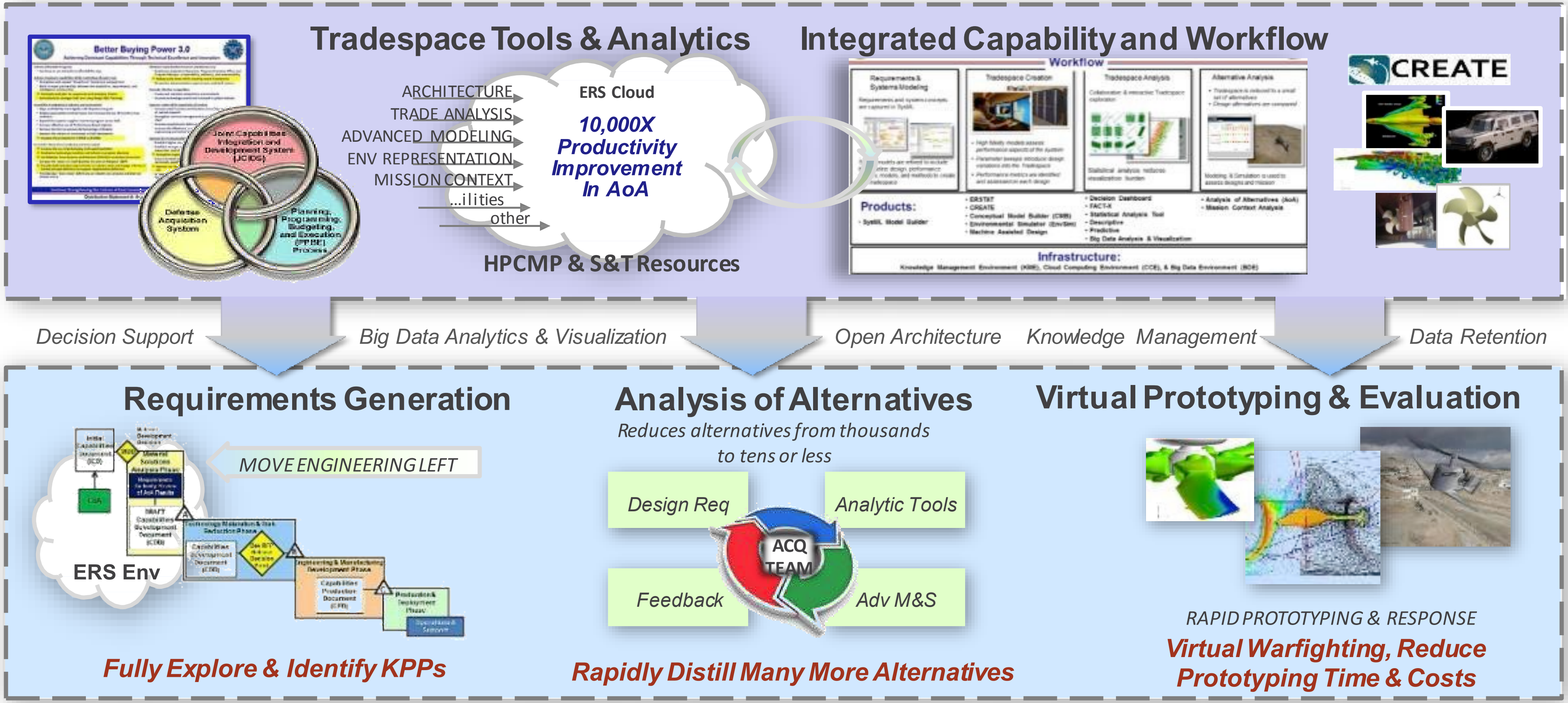


Overview

Introduction to Engineered Resilient Systems (ERS)	Capability Analysis with Requirements	Capability Analysis with Multiple Objective Decision Analysis (MODA) with Value Focused Thinking (VFT)	Recent ERS Research

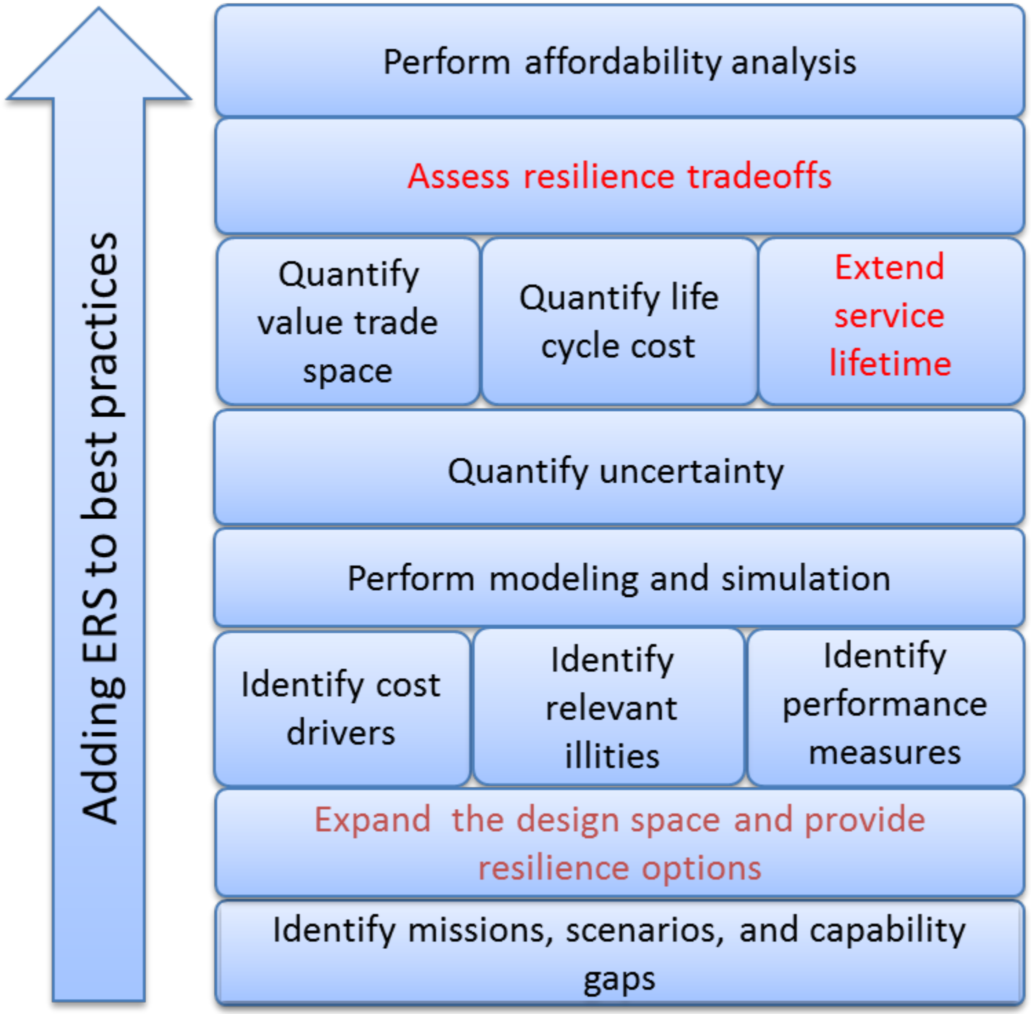
Engineered Resilient Systems

- ERS is a Department of Defense (DoD) program focusing on the effective and efficient design and development of resilient complex engineered systems.



Holland, J. P. (2015). Engineered Resilient Systems: Power of Advanced Modeling and Analytics in Support of Acquisition. NDIA 16th Science and Engineering Technology Conference. Springfield, VA.

Incorporating ERS into AoAs



ERS focuses on effectiveness and efficiency

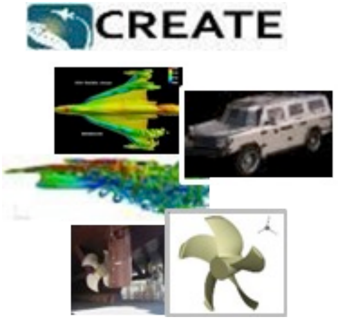
- MBSE
- MBE
- Trade-off analytics toolkits
- High performance computing

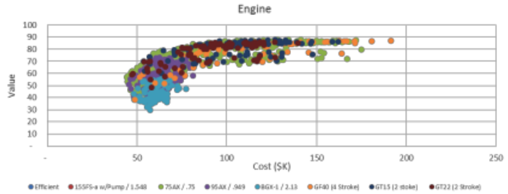
Small, C., Parnell, G., Pohl, E., Goerger, S., Cottam, B., Specking, E., & Wade, Z. (2017). Engineering Resilience for Complex Systems. *Conference on Systems Engineering Research.* Redondo Beach, CA: Springer International Publishing.

Incorporating ERS into AoAs

RAPID PROTOTYPING & RESPONSE

Virtual Warfighting, Reduce Prototyping Time & Costs



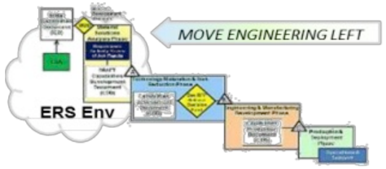


Set Based Design to expand the design space

Adding ERS to best practices

- Perform affordability analysis
- Assess resilience tradeoffs
- Quantify value trade space | Quantify life cycle cost | Extend service lifetime
- Quantify uncertainty
- Perform modeling and simulation
- Identify cost drivers | Identify relevant illities | Identify performance measures
- Expand the design space and provide resilience options
- Identify missions, scenarios, and capability gaps

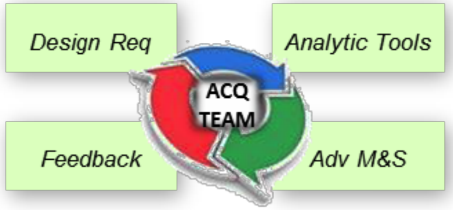
Requirements Generation



Fully Explore & Identify KPPs

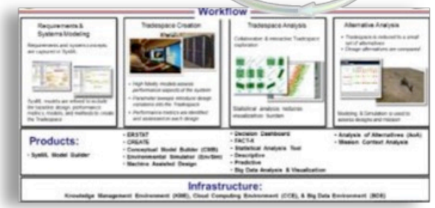
Analysis of Alternatives

Reduces alternatives from thousands to tens or less



Tradespace Tools & Analytics

HPCMP & S&T Resources



Integrated Capability and Workflow

Small, C., Parnell, G., Pohl, E., Goerger, S., Cottam, B., Specking, E., & Wade, Z. (2017). Engineering Resilience for Complex Systems. *Conference on Systems Engineering Research.* Redondo Beach, CA: Springer International Publishing.

Defining Resilience

- Many definitions of resilience in many domains.
- Most definitions emphasize means to obtain resilience.
- Seek definition without using means
  - "A resilient engineered system is able to successfully complete its planned mission(s) in the face of environmental and adversarial threats, and has capabilities allowing it to flexibly adapt to future missions with evolving threats."[2]

1) removes the "means" or the how to accomplish resilience from the definition and focuses on the "ends" or the desired outcomes
2) distinguishes between a platform resilience and a mission resilience.[2]

[1] S. R. Goerger, A. M. Madni, and O. J. Eslinger, "Engineered Resilient Systems: A DoD Perspective," *Procedia Computer Science*, vol. 28, pp. 865–872, 2014.
[2] B. Cottam, E. Specking, C. Small, G. S. Parnell, and E. A. Pohl, "Quantifying Resilience to Enable Engineered Resilient Systems: Task 1 Report," 2016.

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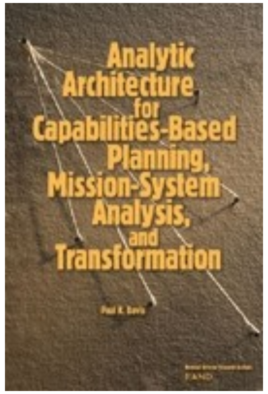
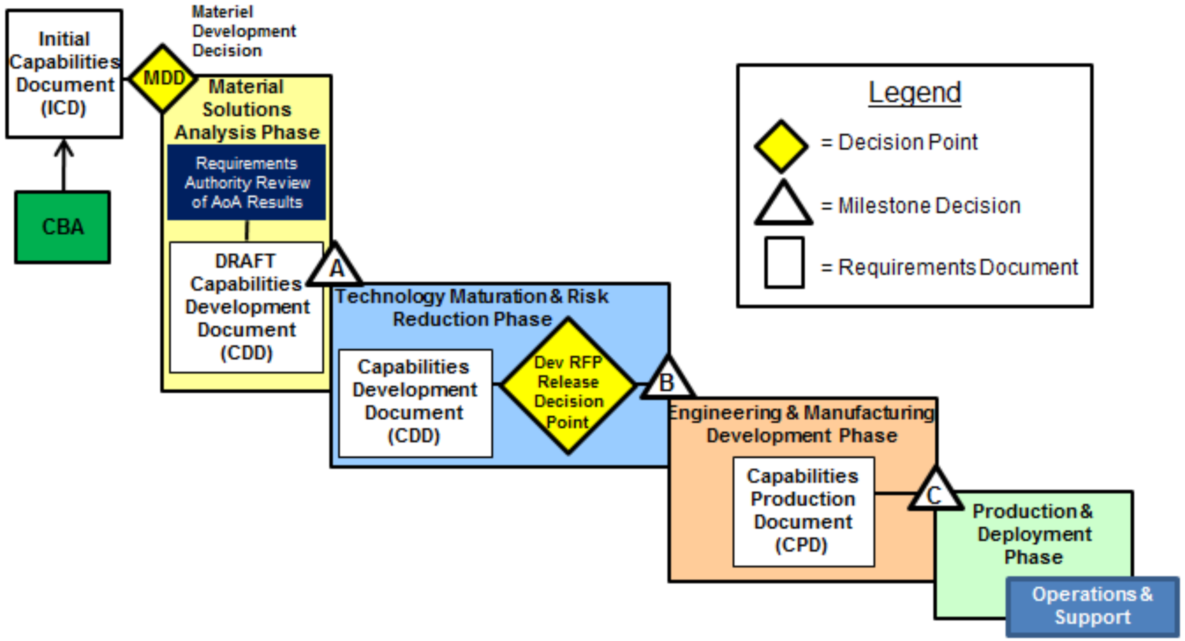
Capability Based Assessment



- Define the mission
- Identify capabilities required
- Determine the attributes/ standards of the capabilities
- Identify gaps
- Assess operational risk associated with the gaps
- Prioritize the gaps;
- Identify and assess potential non-materiel solutions
- Provide recommendations for addressing the gaps



DoD uses Capability Based Assessment.

http://www.acqnotes.com/acqnote/acquisitions/capabilities-based-assessment-cba

Requirements view

- The Capability Development Document (CDD) and Capability Production Document identify the KPPs and KSAs
- Key Performance Parameters (KPPs) are critical.
- If an attribute is important but not critical it is called a Key System Attribute (KSA)

Measure (attribute)	Threshold	Objective
Availability	80%	85%
Probability of Detecting Objects	88%	92%
etc.		

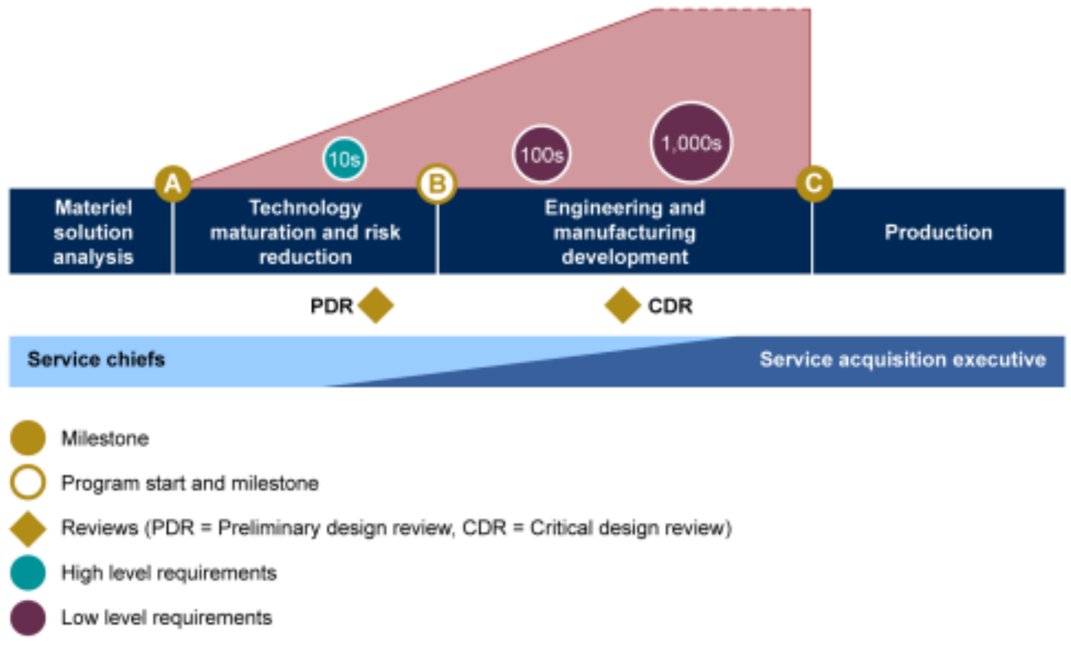
Long list of requirements do not provide a tradespace for affordability.

http://www.acqnotes.com/acqnote/acquisitions/key-perfrormance-parameter

Requirements

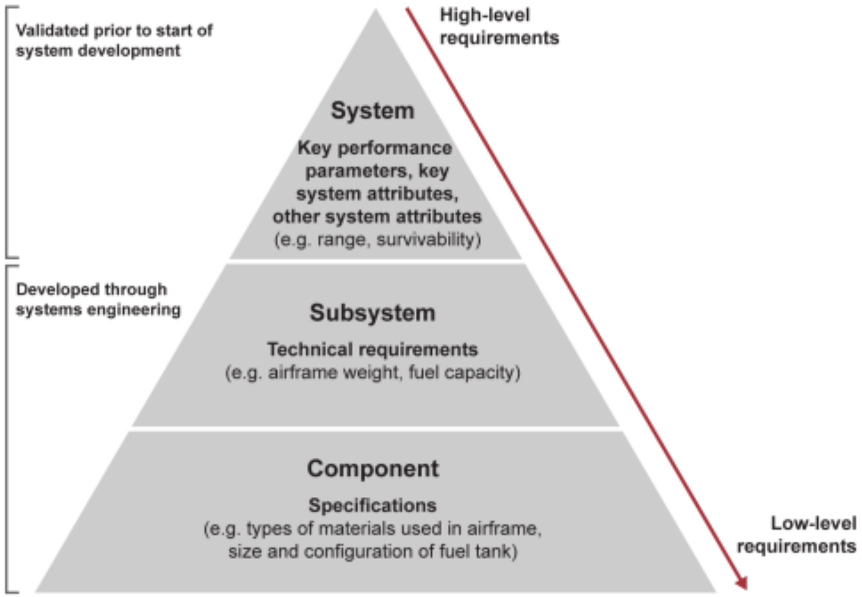
Army's Future Combat System, a large program that was intended to equip combat brigades with an advanced set of integrated systems, requirements were still being defined when the program was canceled beginning in 2009—after 6 years and $18 billion had been spent on initial system development.

Figure 3: Translation of High-Level Requirements into Low-Level Requirements Typically Occurs After Milestone B (Notional)



Source: GAO analysis of DOD policy and selected programs. | GAO-15-469

Figure 1: Notional Levels of Requirements for Weapon System Development



Source: GAO analysis of DOD policy and guidance. | GAO-15-469

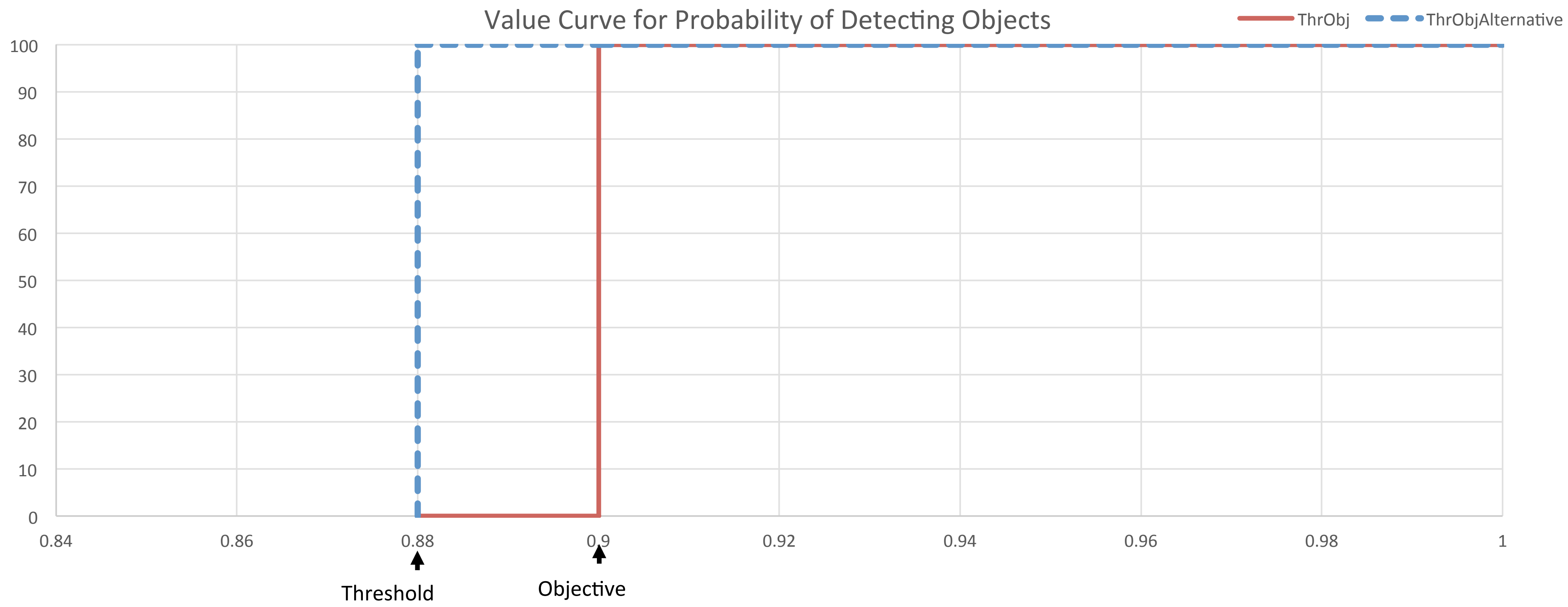
The program was approved to start system development with **7 key performance parameters.** In order to meet these key performance parameters—which did not change—the program ultimately translated them into **over 50,000 lower-level requirements** before it was canceled.

Requirements start small and grow to a long list.

Overview

Introduction to Engineered Resilient Systems (ERS)	Capability Analysis with Requirements	Capability Analysis with Multiple Objective Decision Analysis (MODA) with Value Focused Thinking (VFT)	Recent ERS Research

Apparent mathematics



- Only two points have value
- KPPs are more important than KSAs
- All KPPs are equal
- All KSAs are equal

Multiple Objective Decision Analysis

- Based on the additive value model, multiple objective decision analysis (MODA) analyzes decision based off of multiple objectives.

Keeney, R., & Raiffa, H. (1976). Decision with Multiple Objectives: Preference and Value Tradeoffs. New York: Wiley & Sons.

Total Value of the Alternative

$$v(x) = \sum_{i=1}^{n} w_i v_i(x_i)$$

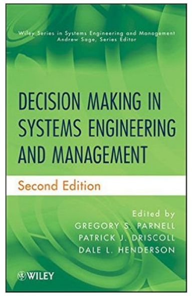
$$\sum_{i=1}^{n} w_i = 1$$

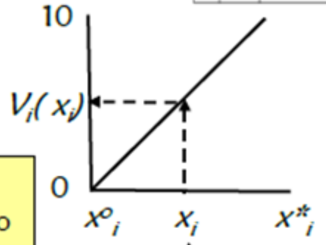
Normalized Swing weights sum to 1

Swing weights for each value measure *i* assess importance and variation

		Level of importance of the value measure		
		High	Medium	Low
Variation in measure ranges	High	3.1.1 Accuracy 100	3.2.1 Range 50	
	Medium	1.1.1 Speed of Platform 85	2.1.1 Thrust 45	1.1.2 % Grade 5
	Low	2.2.1 Number of Payloads 60	1.2.1 Number of People 20	

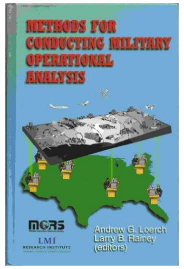
Parnell, G. S., Driscoll, P. J., & Henderson, L. D. (2011). *Decision Making in Systems Engineering and Management.* 2 Ed, John Wiley & Sons.





Value function for each measure *i*: assess returns to scale and provide a 'common currency' across all measures

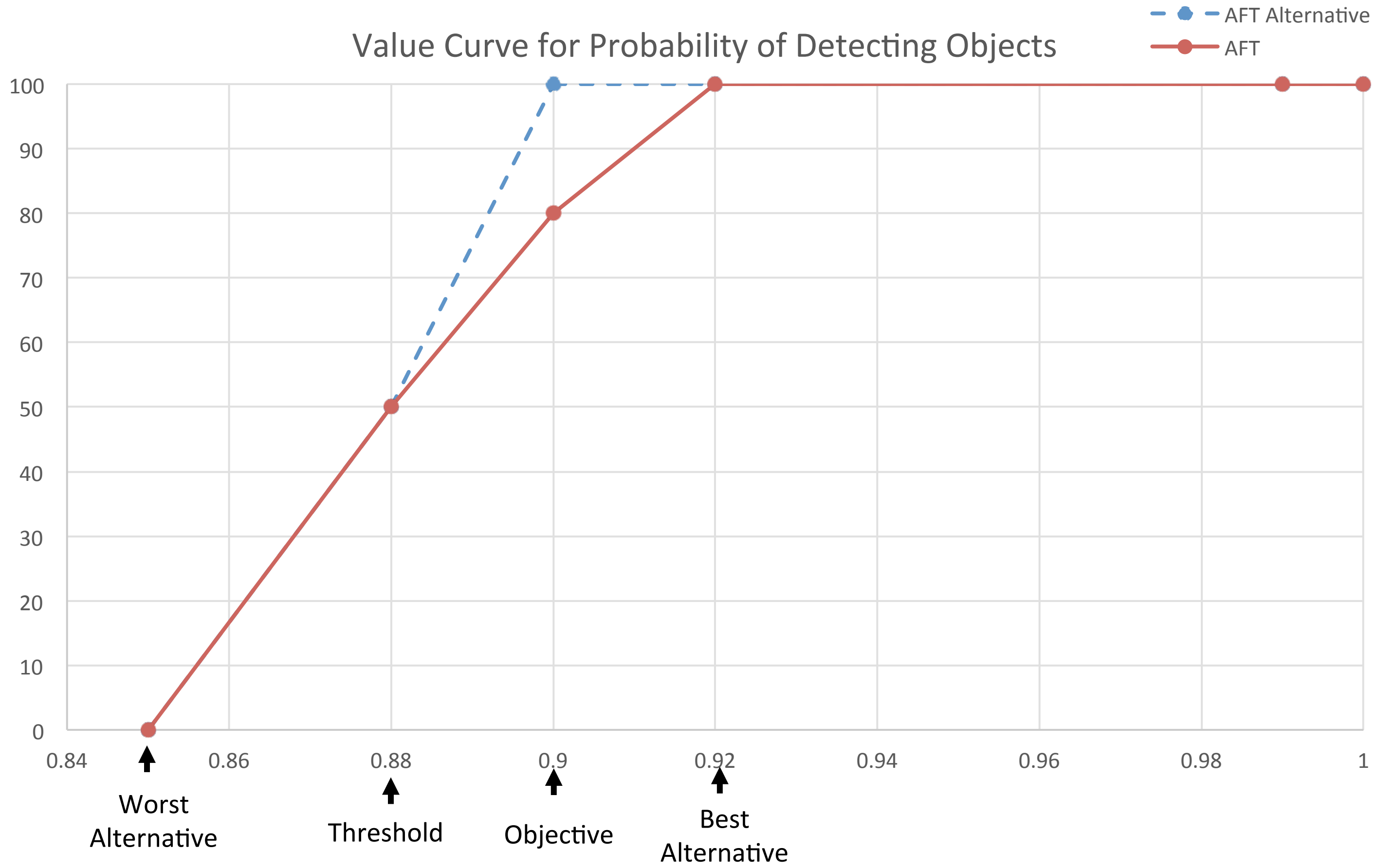
Score on value measure i



Parnell, G. S., Chapter 19, Value-Focused Thinking, *Methods for Conducting Military Operational Analysis, Military Operations Research Society*, Editors Andrew Loerch and Larry Rainey 2007, pp. 619-656.

Use value (utility) functions to define the single measure tradespace

Alternative-Focused Thinking (Local)

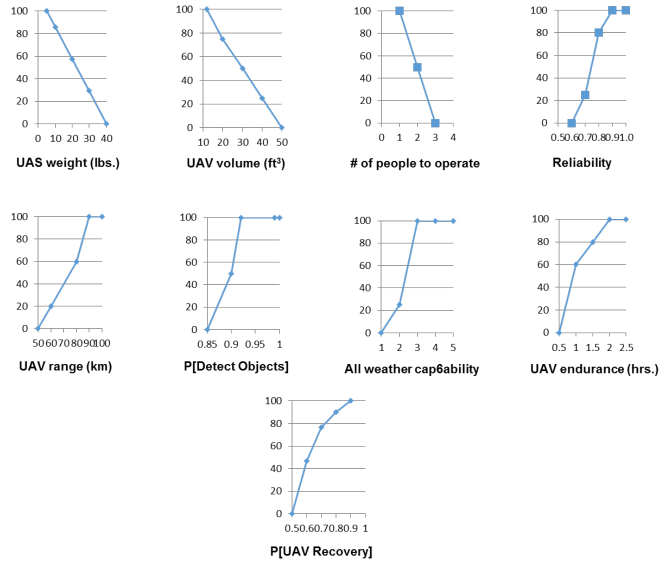


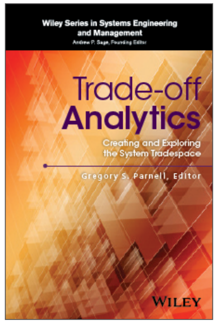
The value curve for each measure quantifies the value for the range of interest.

MODA: UAV example

- In MODA, each parameter has the value relationship graphed to create a value curve.

UAS weight (lbs.)		UAV volume (ft3)		# of people to operate		Reliability		UAV range (km)		P[Detect Objects]		All weather capability		UAV endurance (hrs.)		P[UAV Recovery]	
X	V	X	V	X	V	X	V	X	V	X	V	X	V	X	V	X	V
5	100	12	100	1	100	0.6	0	50	0	0.85	0	1	0	0.5	0	0.5	0
10	86	20	75	2	50	0.7	25	60	20	0.9	50	2	25	1	60	0.6	47
20	58	30	50	3	0	0.8	80	80	60	0.92	100	3	100	1.5	80	0.7	77
30	29	40	25			0.9	100	90	100	0.99	100	4	100	2	100	0.8	90
40	0	50	0			1.0	100	100	100	1	100	5	100	2.5	100	0.9	100





Modified from M. Cilli and G. Parnell, “Understanding Decision Management,” **Trade-off Analytics: Creating and Evaluating the Tradespace**, G. Parnell, Editor, Wiley & Sons, 2017

The value curve for each measure quantifies the value for the range of interest.

Swing Weight Matrix

- Using value curves and the ranges of variance, the swing weights are developed and determine the weight distributed to each measure.

	Mission Critical			Important			Useful		
	Measure	fi	wi	Measure	fi	wi	Measure	fi	wi
High Capability Gap	UAV endurance (hrs.)	100	0.28	All weather capability	50	0.14	P[UAV Recovery]	10	0.03
Medium Capability Gap	Reliability	80	0.22	UAV range (km)	40	0.11	UAV volume (ft3)	5	0.01
Small Capability Gap	P[Detect Objects]	50	0.14	UAS weight (lbs.)	20	0.06	# of people to operate	1	0.00

Swing weights determine the amount of value distributed to each measure

Value Scores

- Using the value curves, scores on the measures for each alternatives is converted to value scores.

Alternative Scores	UAS weight (lbs.)	UAV volume (ft3)	# of people to operate	Reliability	UAV range (km)	P[Detect Objects]	All weather capability	UAV endurance (hrs.)	P[UAV Recovery]
Cardinal	5	12	1	0.9	60	0.92	3	0.5	0.6
Buzzard	10	15	1	0.8	60	0.9	1	1	0.7
Crow	10	20	2	0.7	70	0.92	3	1	0.8
Pigeon	15	30	2	0.6	80	0.92	3	1.5	0.9
Robin	30	40	2	0.6	90	0.9	1	2	0.9
Hypothetical Best	5	12	1	0.9	90	0.92	3	2	0.9
Ideal	5	10	1	1	100	1	5	2.5	0.9

Alterative Value	UAS weight (lbs.)	UAV volume (ft3)	# of people to operate	Reliability	UAV range (km)	P[Detect Objects]	All weather capability	UAV endurance (hrs.)	P[UAV Recovery]
Cardinal	100	100	100	100	20	100	100	100	100
Buzzard	86	91	100	80	20	50	86	91	100
Crow	86	75	50	25	40	100	86	75	50
Pigeon	72	50	50	0	60	100	72	50	50
Robin	29	25	50	0	100	50	29	25	50
Hypothetical Best	100	100	100	100	100	100	100	100	100
Ideal	100	100	100	100	100	100	100	100	100

Normalized Value

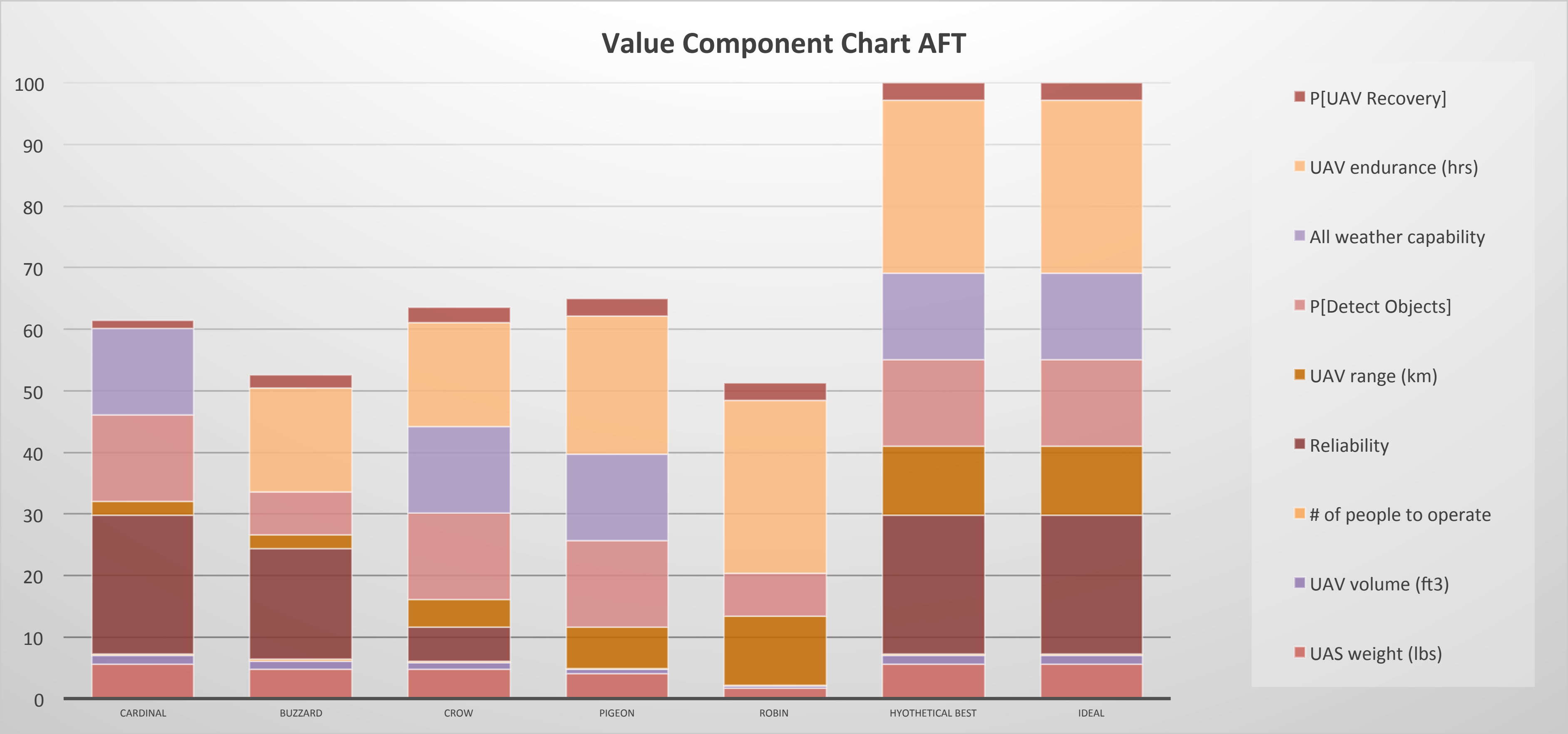
- Using the swing weight tables the value is normalized to account for the weights for each measure

Swing Weights	UAS weight (lbs.)	UAV volume (ft3)	# of people to operate	Reliability	UAV range (km)	P[Detect Objects]	All weather capability	UAV endurance (hrs.)	P[UAV Recovery]
Normalized Swing Weight, wi	0.056	0.014	0.003	0.225	0.112	0.140	0.140	0.281	0.028

wi * vi(xi)	UAS weight (lbs.)	UAV volume (ft3)	# of people to operate	Reliability	UAV range (km)	P[Detect Objects]	All weather capability	UAV endurance (hrs.)	P[UAV Recovery]
Cardinal	5.6	1.4	0.3	22.5	2.2	14.0	14.0	0.0	1.3
Buzzard	4.8	1.3	0.3	18.0	2.2	7.0	0.0	16.9	2.2
Crow	4.8	1.1	0.1	5.6	4.5	14.0	14.0	16.9	2.5
Pigeon	4.0	0.7	0.1	0.0	6.7	14.0	14.0	22.5	2.8
Robin	1.6	0.4	0.1	0.0	11.2	7.0	0.0	28.1	2.8
Hypothetical Best	5.6	1.4	0.3	22.5	11.2	14.0	14.0	28.1	2.8
Ideal	5.6	1.4	0.3	22.5	11.2	14.0	14.0	28.1	2.8

Alternative Value

- Summing the value across the measures according to the additive value model gives the value for each alternative

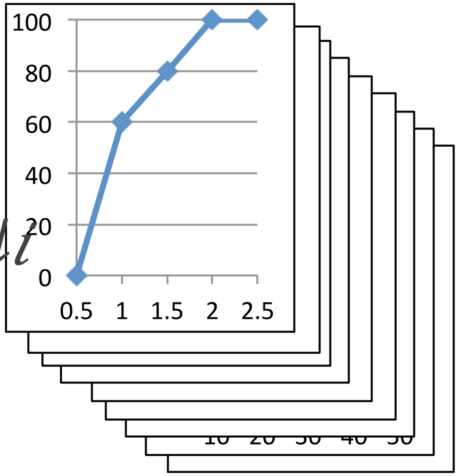


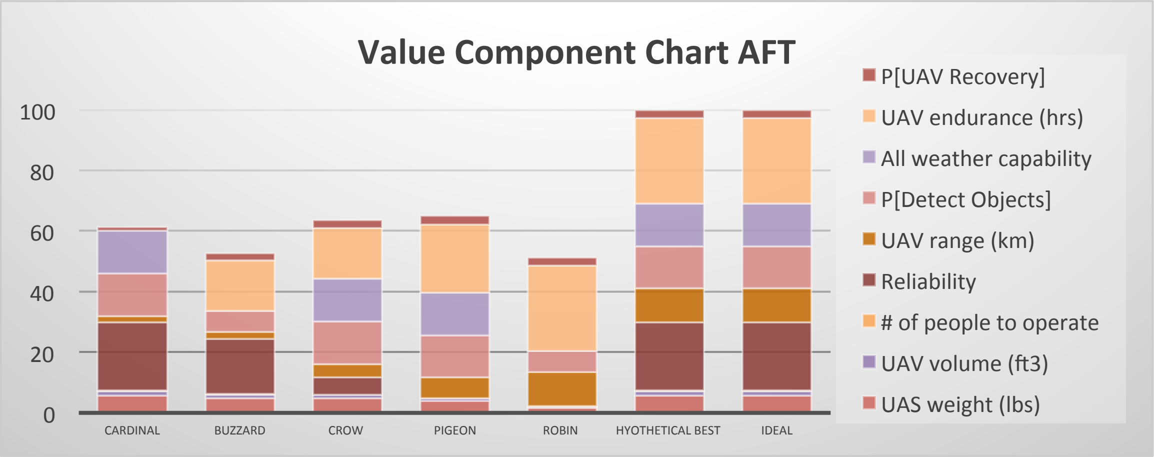
Value (utility) function using Alternative Focused Thinking (Local)

$$v(x_j)=\sum_{i=1}^{n} w_i v_i(x_{ij})$$

$$\sum_{i=1}^{n} w_i = 1$$

Keeney, R. & Raiffa, H. (1976). Decision with Multiple Objectives: Preference and Value Tradeoffs. New York: Wiley & Sons.

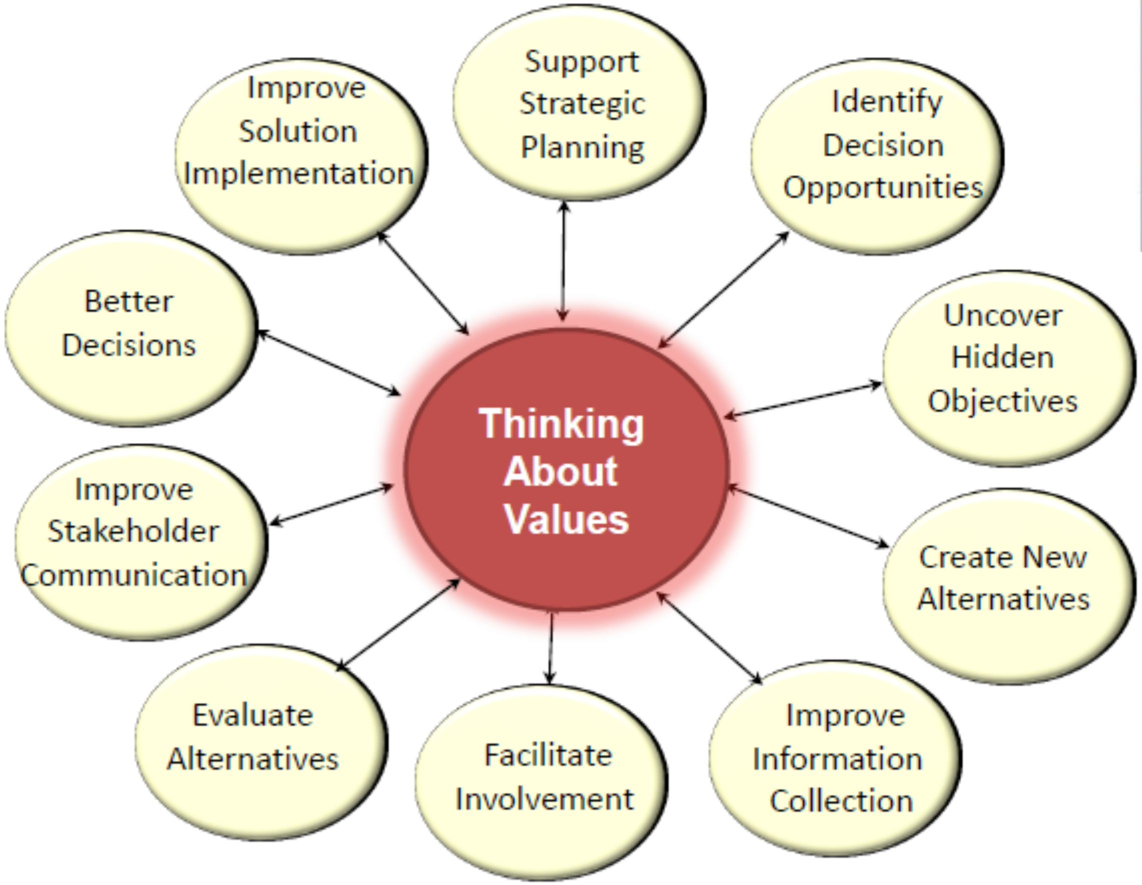




- Advantages
  - Quantitatively defines tradespace
  - Swing weights prioritize measures
  - Relatively easy to construct values curves and assess weights
  - Perform sensitivity analysis
- Disadvantages
  - Not aligned with capability based planning
  - Does not evaluate entire tradespace
  - Only accounts for known alternatives

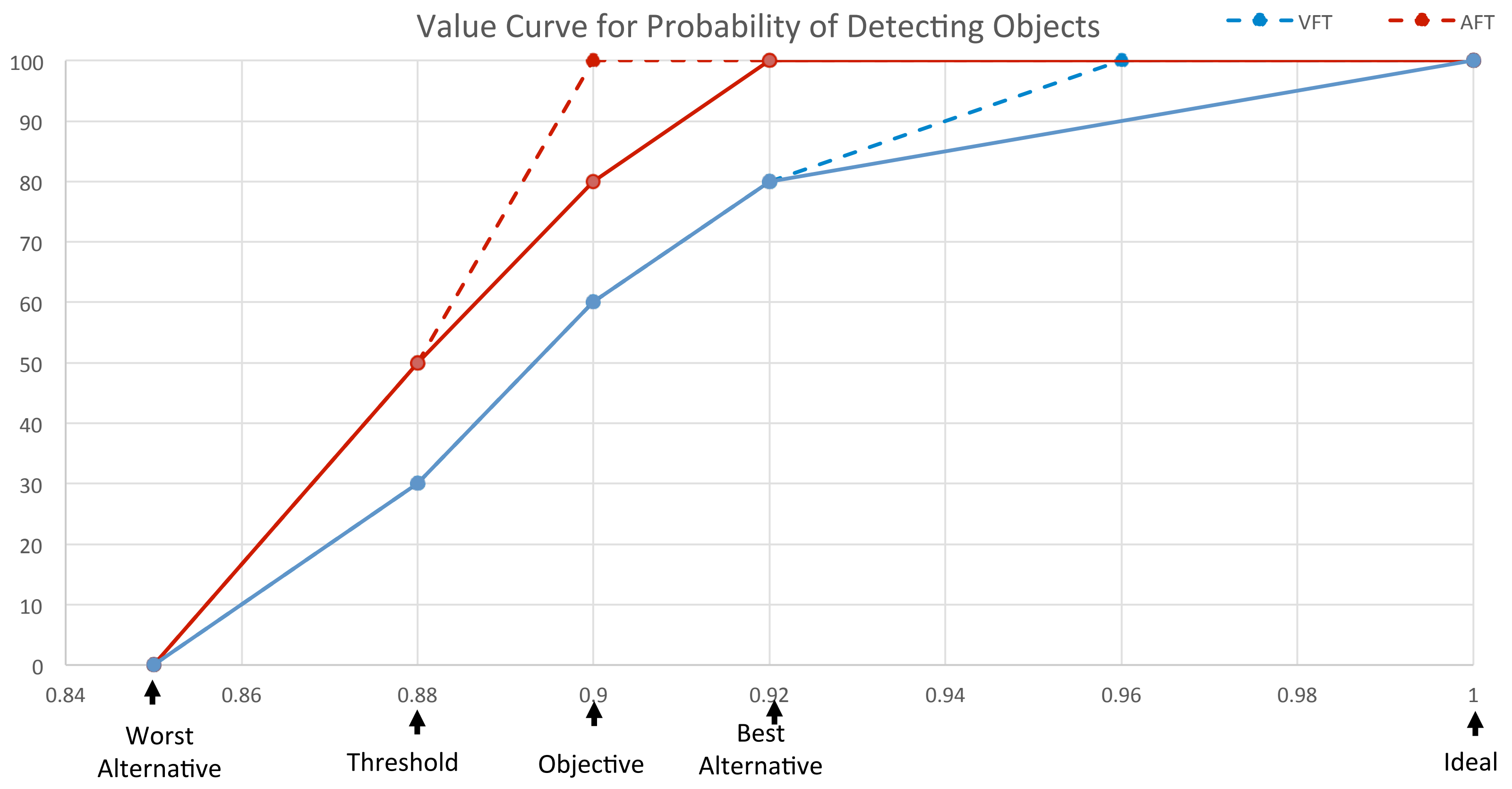
Benefits of Value-Focused Thinking

Modified from Keeney, R. L. (1992). *Value-Focused Thinking: A Path to Creative Decisionmaking.* Cambridge, MA: Harvard University Press.



Value-Focused Thinking has been used for Capabilities Based Assessments for platforms and mission chains.

Value (utility) function using Value-Focused Thinking (Global)

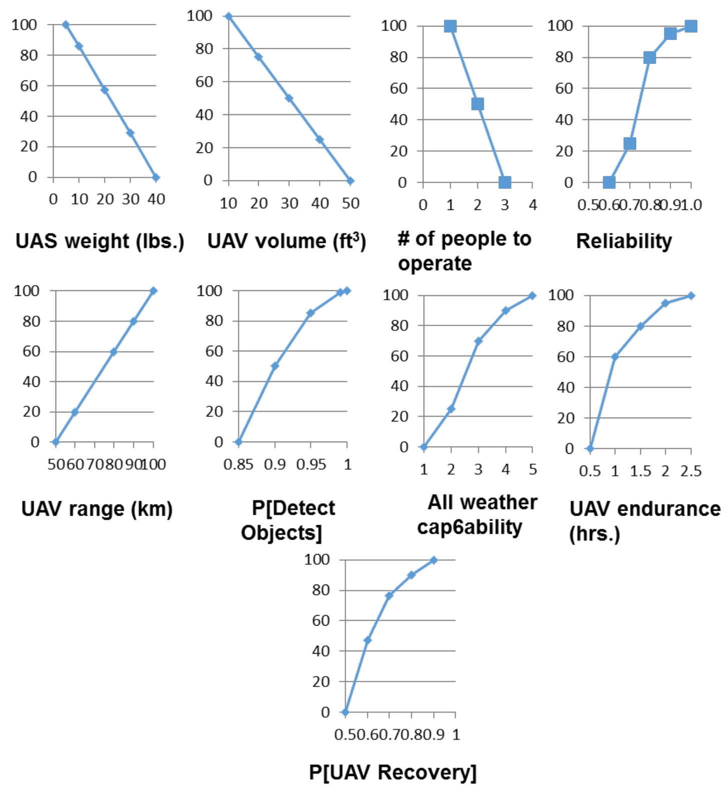


Using VFT increases the range of interest.

Changes in Value Curve

- Each value curve has an ideal which increases the tradespace

UAS weight (lbs.)		UAV volume (ft3)		# of people to operate		Reliability		UAV range (km)		P[Detect Objects]		All weather capability		UAV endurance (hrs.)		P[UAV Recovery]	
X	V	X	V	X	V	X	V	X	V	X	V	X	V	X	V	X	V
5	100	10	100	1	100	0.6	0	50	0	0.85	0	1	0	0.5	0	0.5	0
10	86	20	75	2	50	0.7	25	60	20	0.9	50	2	25	1	60	0.6	47
20	58	30	50	3	0	0.8	80	80	60	0.95	85	3	70	1.5	80	0.7	77
30	29	40	25			0.9	95	90	80	0.99	99	4	90	2	95	0.8	90
40	0	50	0			1.0	100	100	100	1	100	5	100	2.5	100	0.9	100

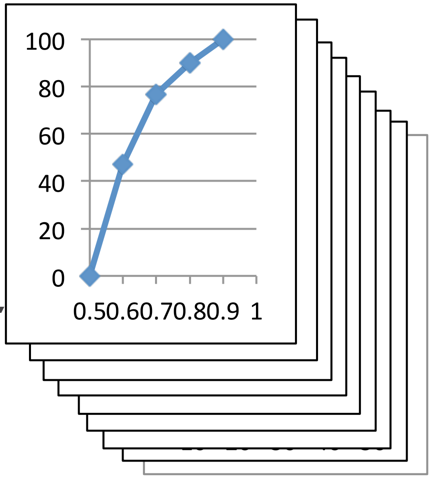


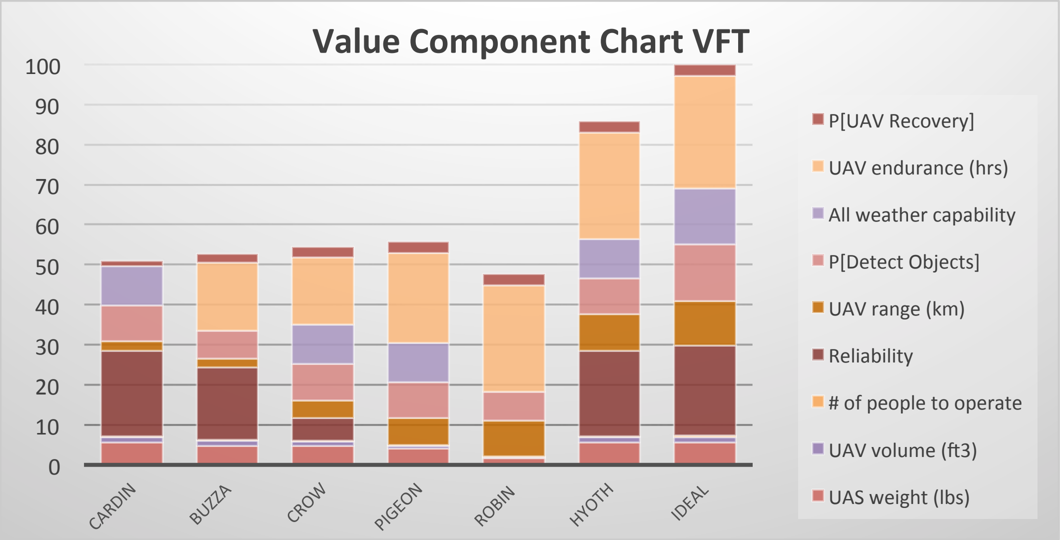
Multiple Objective Decision Analysis for Trade-off Analysis

Value Focused Thinking (Global)

$$v(x_j)=\sum_{i=1}^{n} w_i\, v_i(x_{ij})$$

$$\sum_{i=1}^{n} w_i = 1$$

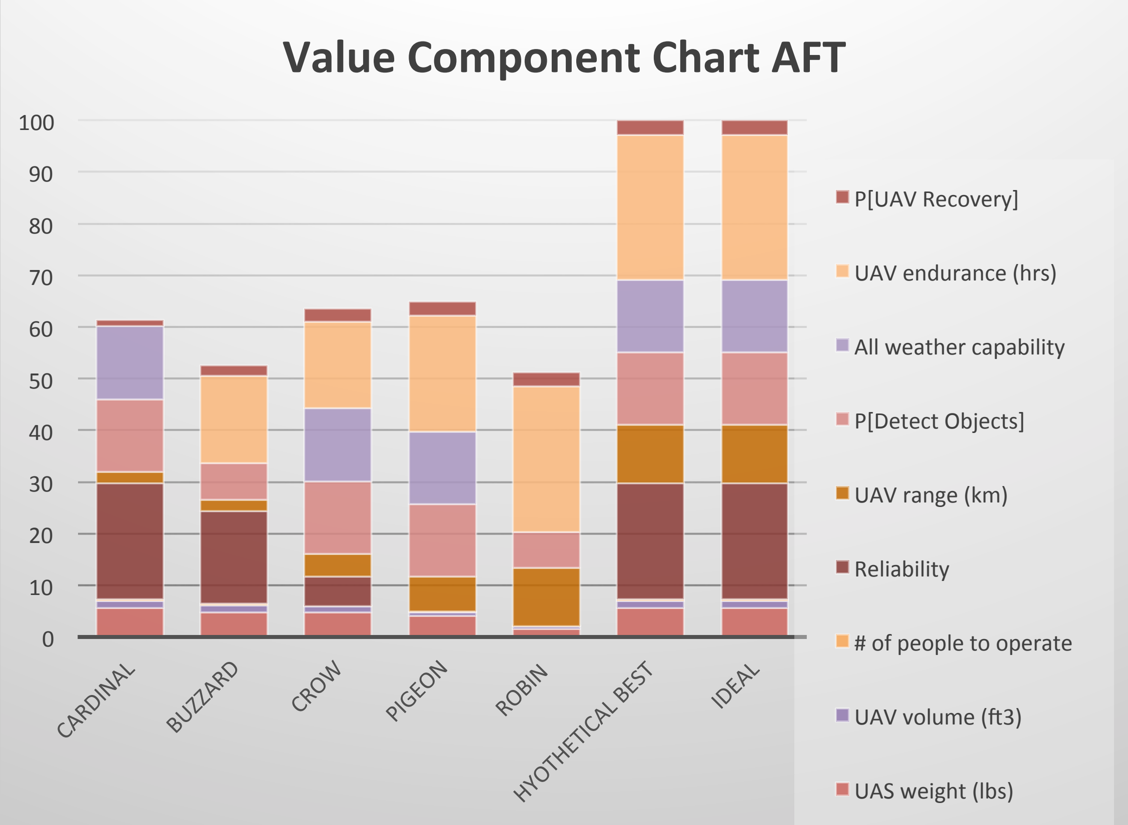


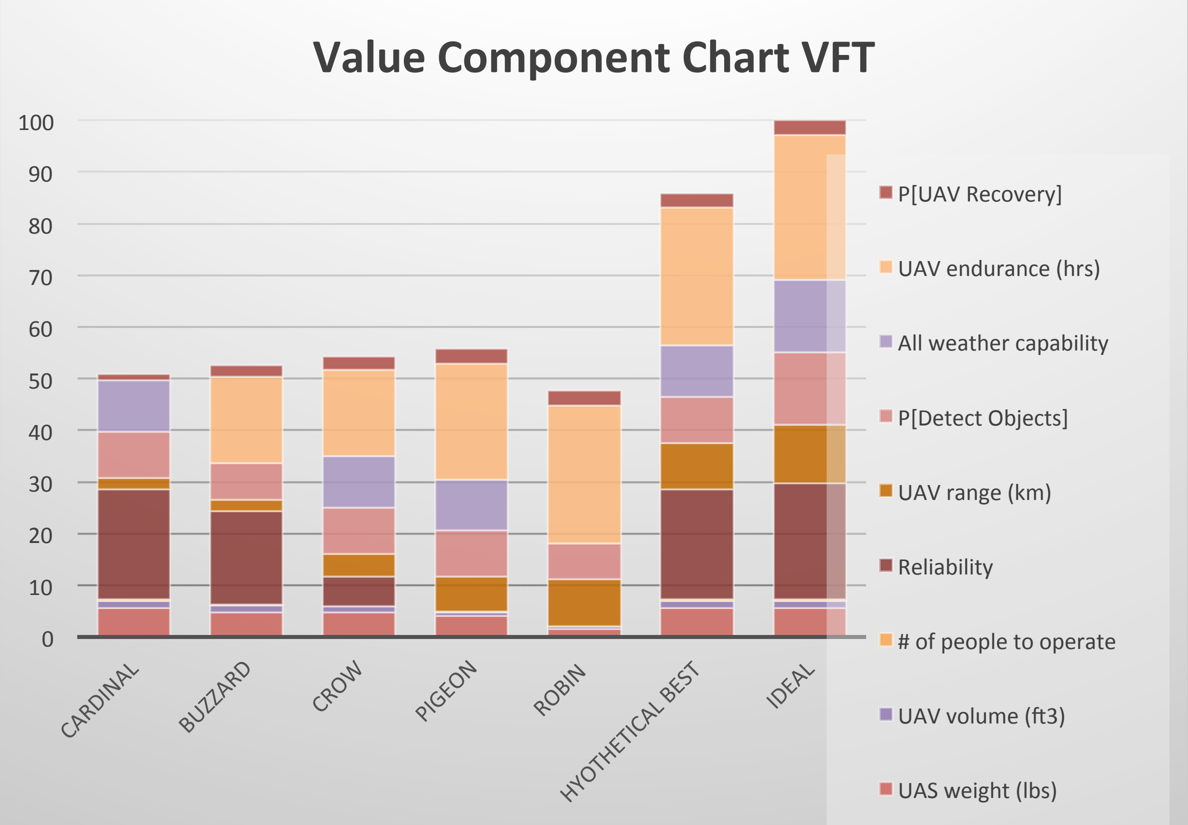


Keeney, R. L. (1992). *Value-Focused Thinking: A Path to Creative Decisionmaking.* Cambridge, MA: Harvard University Press.

- Advantages
  - Aligns with capability based assessment
  - Quantitatively defines tradespace
  - Swing weights prioritize measures (will be different than AFT)
  - Identifies value opportunities
- Disadvantages
  - More effort to identify ideal and construct value curve
  - May give value to unachievable tradespace

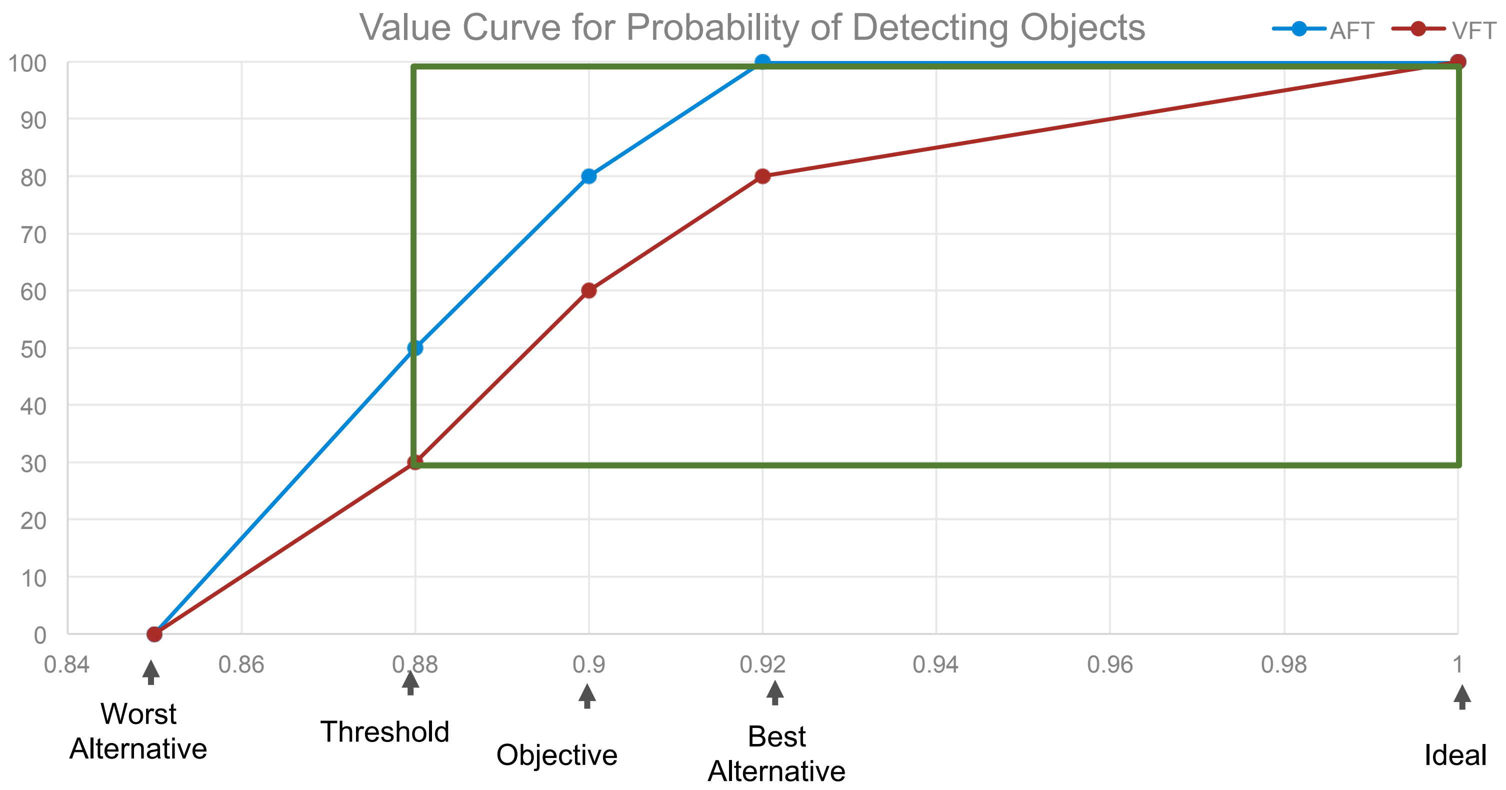
AFT vs VFT





- AFT tradespace focuses on the known alternatives.
- VFT tradespace aligns with Capabilities Based Assessment.
- Alternative preference may change with VFT since value curve and weights can change.

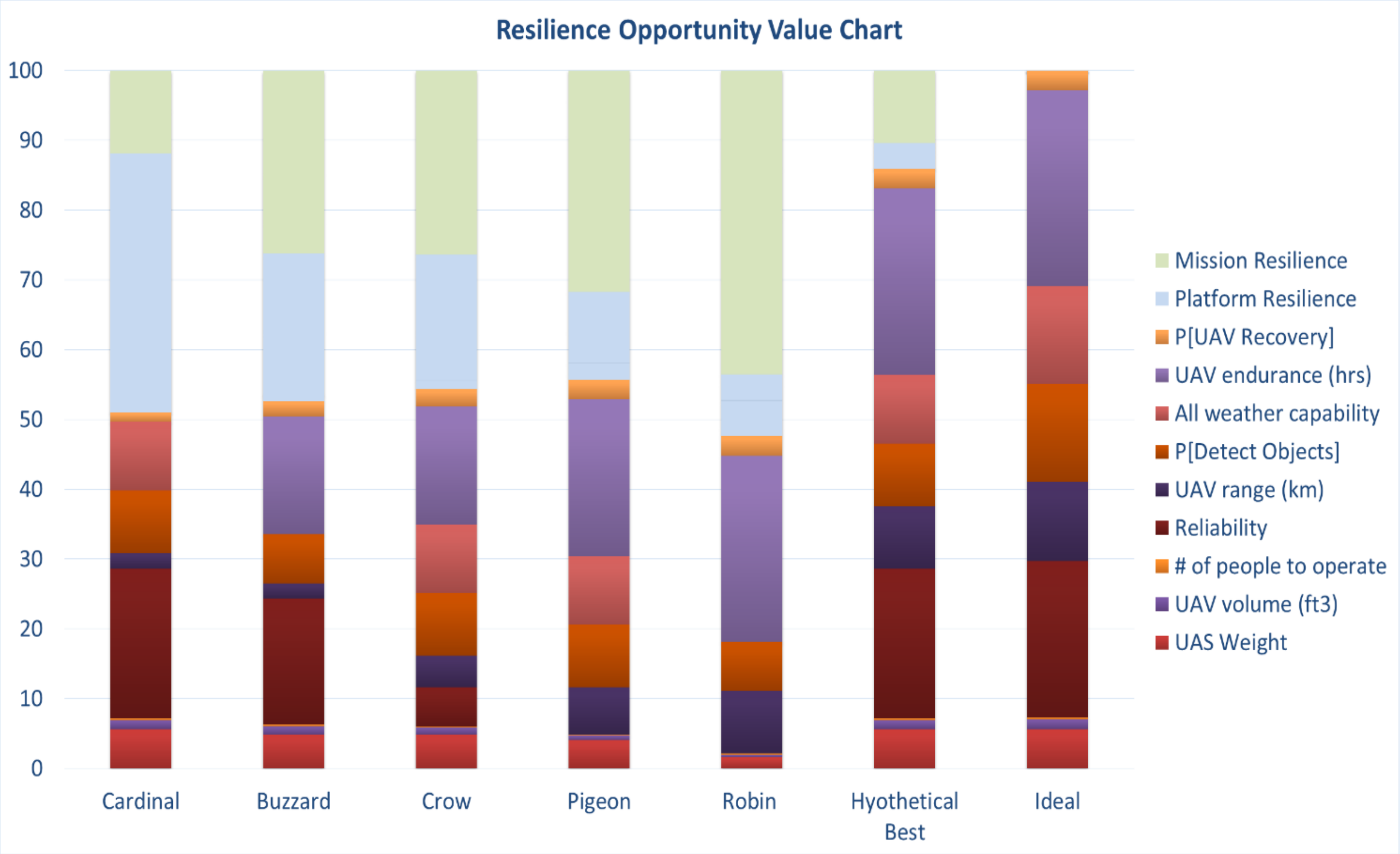
Value-Focused Thinking helps identify and quantify resilience



The additional performance and value in the green box provides mission and platform resilience.

Resilience opportunity chart for notional UAV example

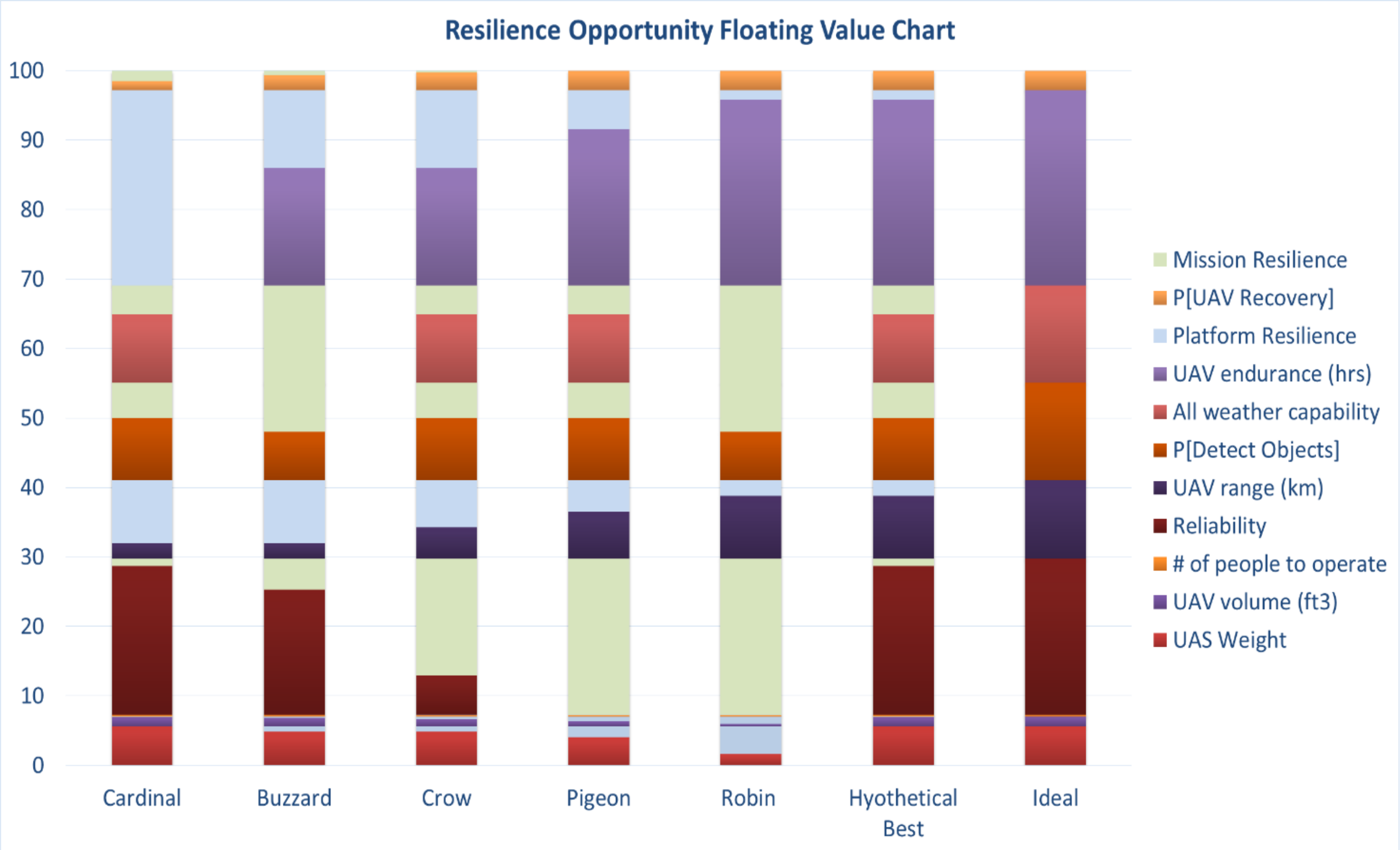
- Each value measure can be seen as mission or platform resilience
- The value gap represents the extra resilience we can add



Value component chart can identify opportunities to improve resilience.

Resilience opportunity floating value chart for notional UAV example

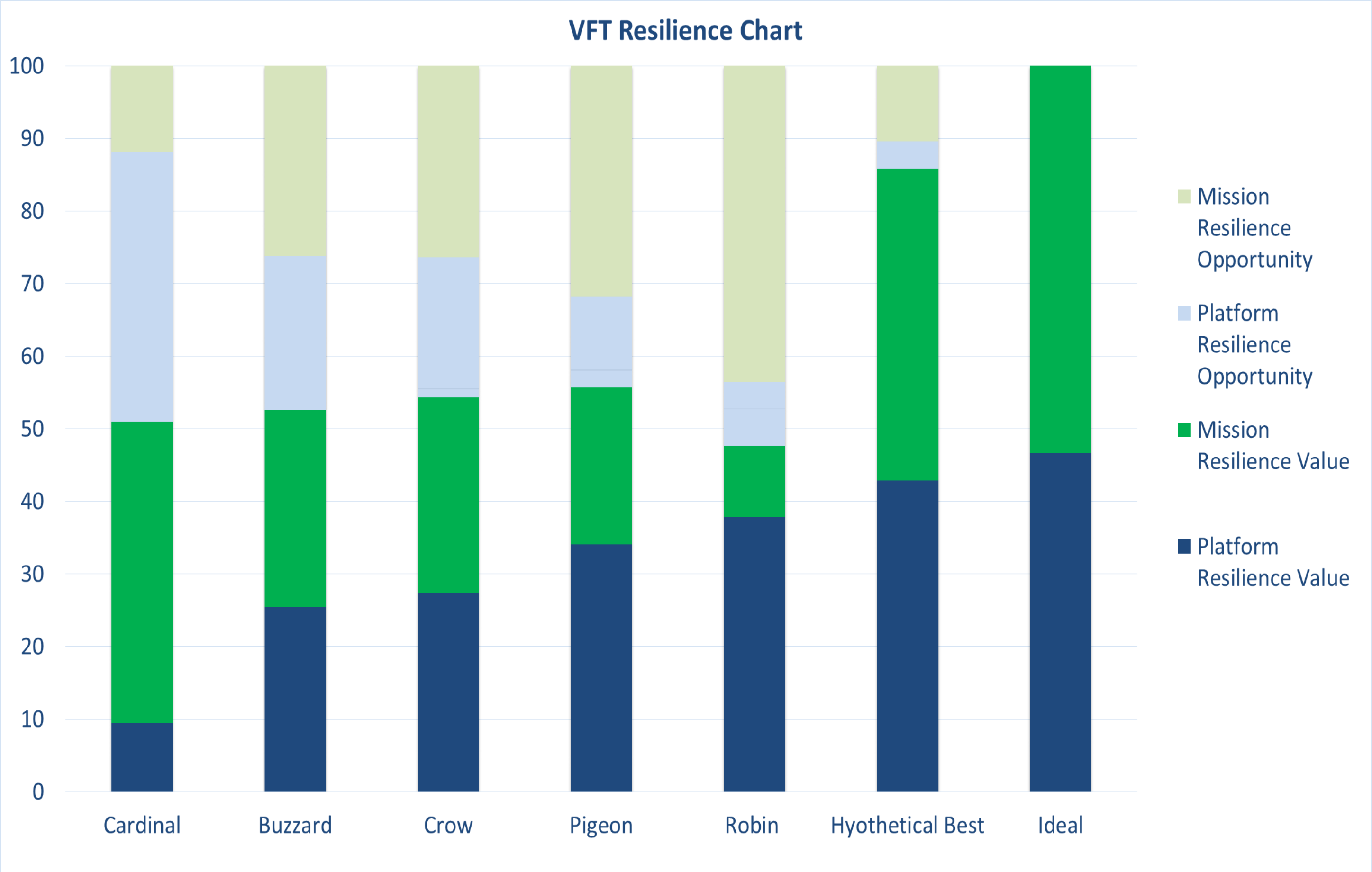
- The value above each measure are the resilience opportunities on that specific measure



Floating value chart can further identify specific opportunities to improve resilience.

Resilience value and opportunity chart for notional UAV example

- The value and opportunities of resilience can be shown using a resilience value and opportunity chart



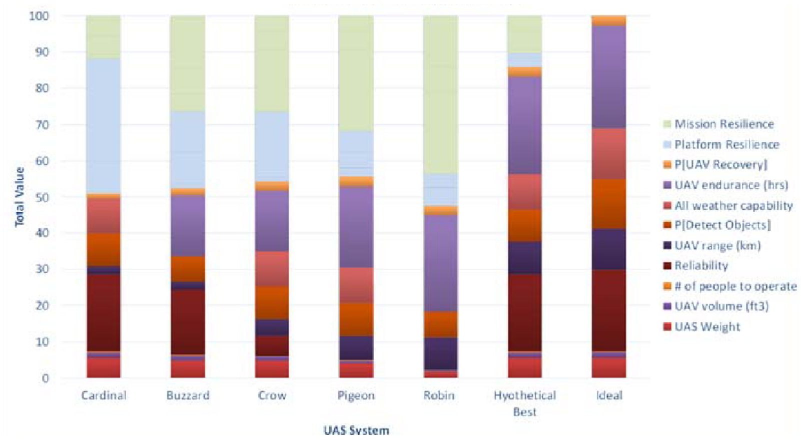
A resilience value and opportunity chart can identify resilience value in alternatives.

Overview

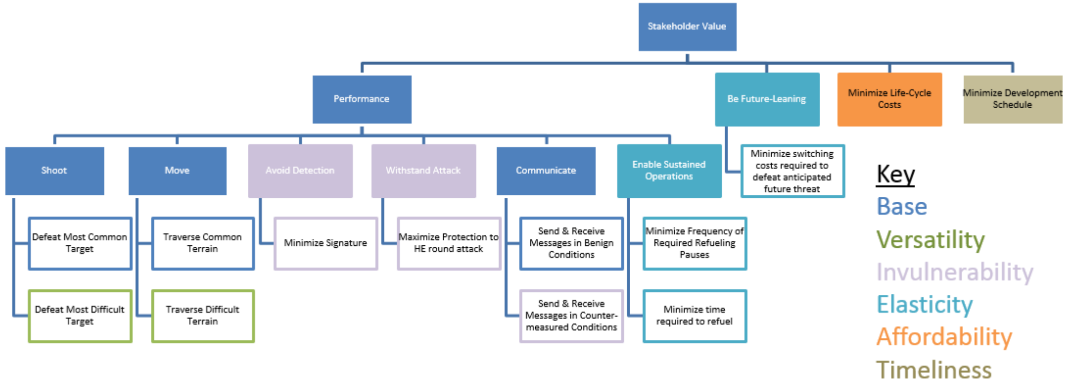
Introduction to Engineered Resilient Systems (ERS)	Capability Analysis with Requirements	Capability Analysis with Multiple Objective Decision Analysis (MODA) with Value Focused Thinking (VFT)	Recent ERS Research

Three Resilience MODA Methods

Resilience Opportunity Value[1]

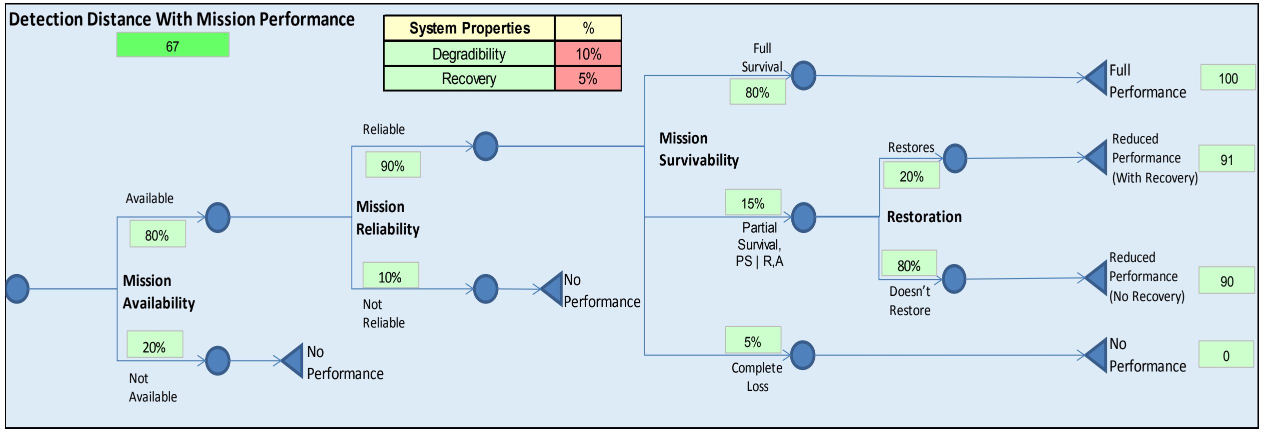


Include "Ilities" in Value Model[2]



Include resilience KPP calculation

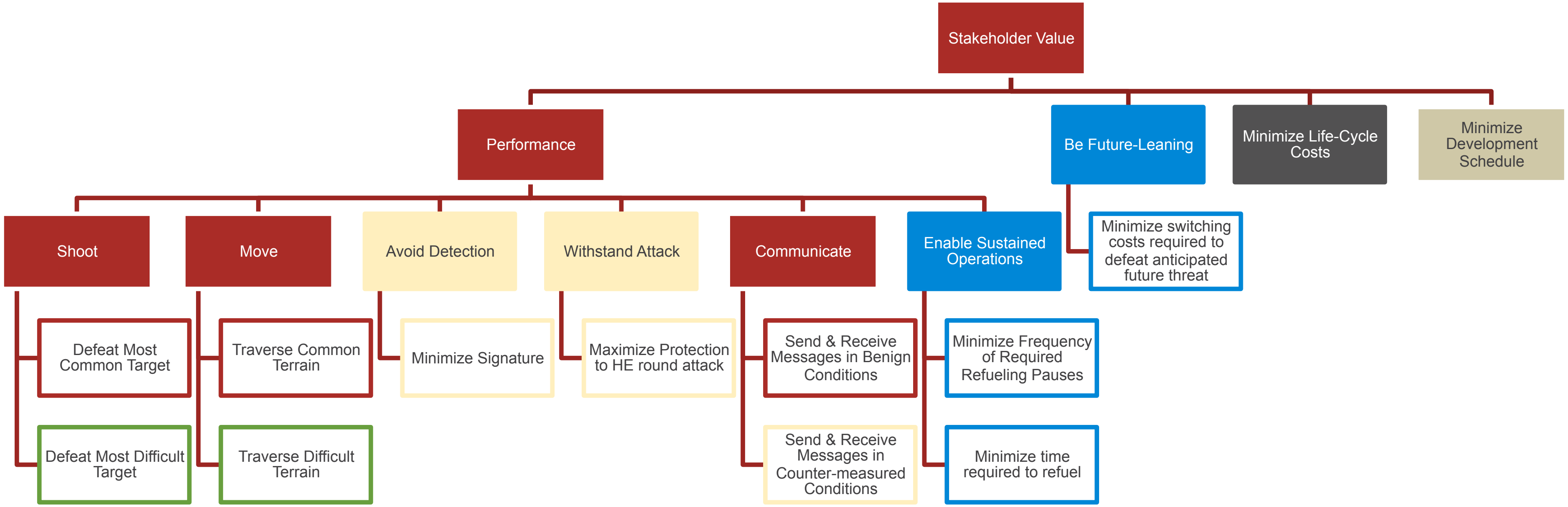
Method chosen depends upon complexity of problem and data availability.



[1] C. Small, G. Parnell, E. Pohl, S. Goerger, C. Cottam, E. Specking, and Z. Wade, "Engineered Resilient Systems with Value Focused Thinking," in 27th Annual INCOSE International Symposium, 2017.

[2] Modified from Dr. Matt Cilli, Army Armament Research and Development Engineering Center, Picatinny, NJ

Method 2: Include "ilities" in Value Model Example

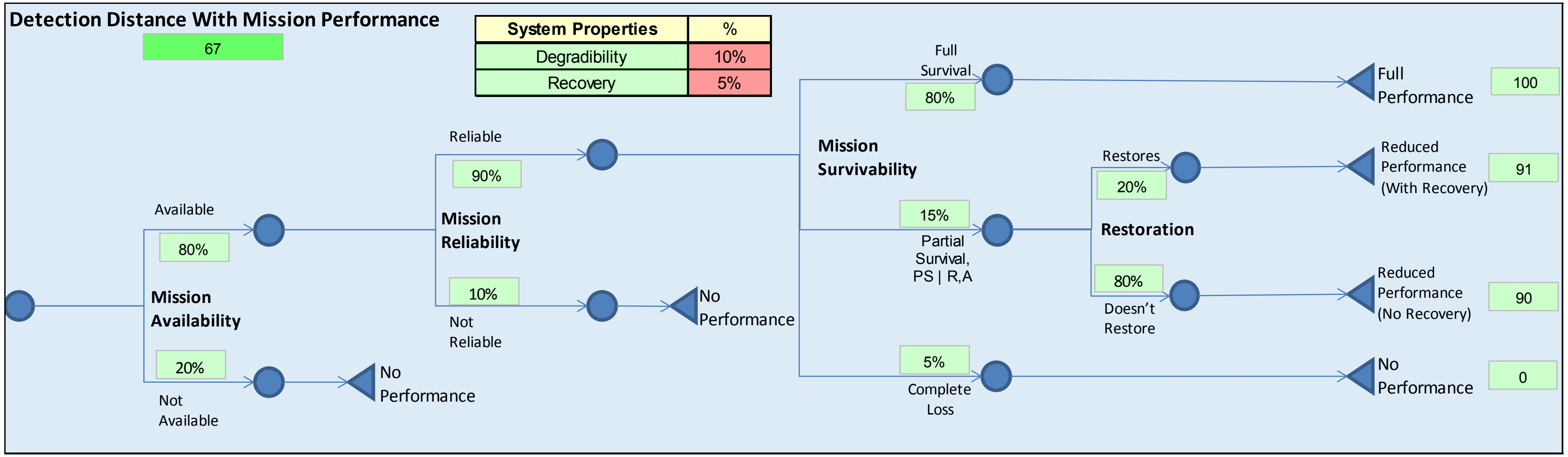


Key

Base	Elasticity
Versatility	Affordability
Invulnerability	Timeliness

Modified from Dr. Matt Cilli, Army Armament Research and Development Engineering Center, Picatinny, NJ

Method 3: Incorporate Resilience in all appropriate Key Performance Parameters (KPPs)



Expected ***Performance with Mission Resilience*** = 67

Assumes: Mission, Scenario, Threat=1

15.5% Increase in value (58 to 67)

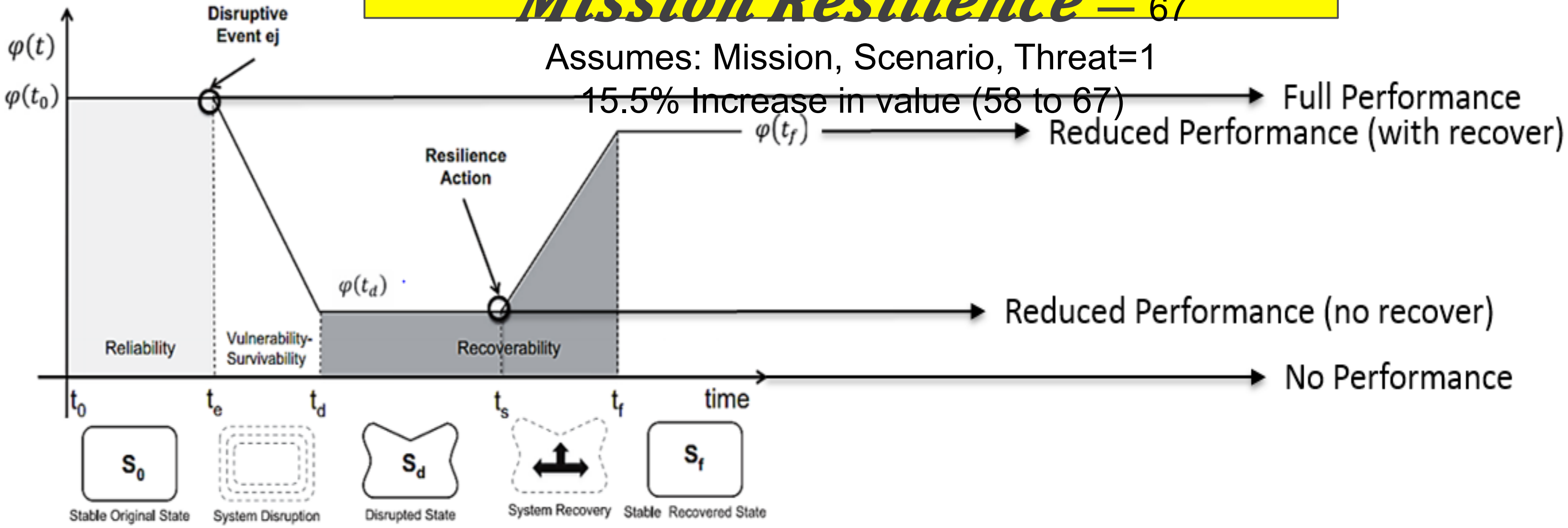
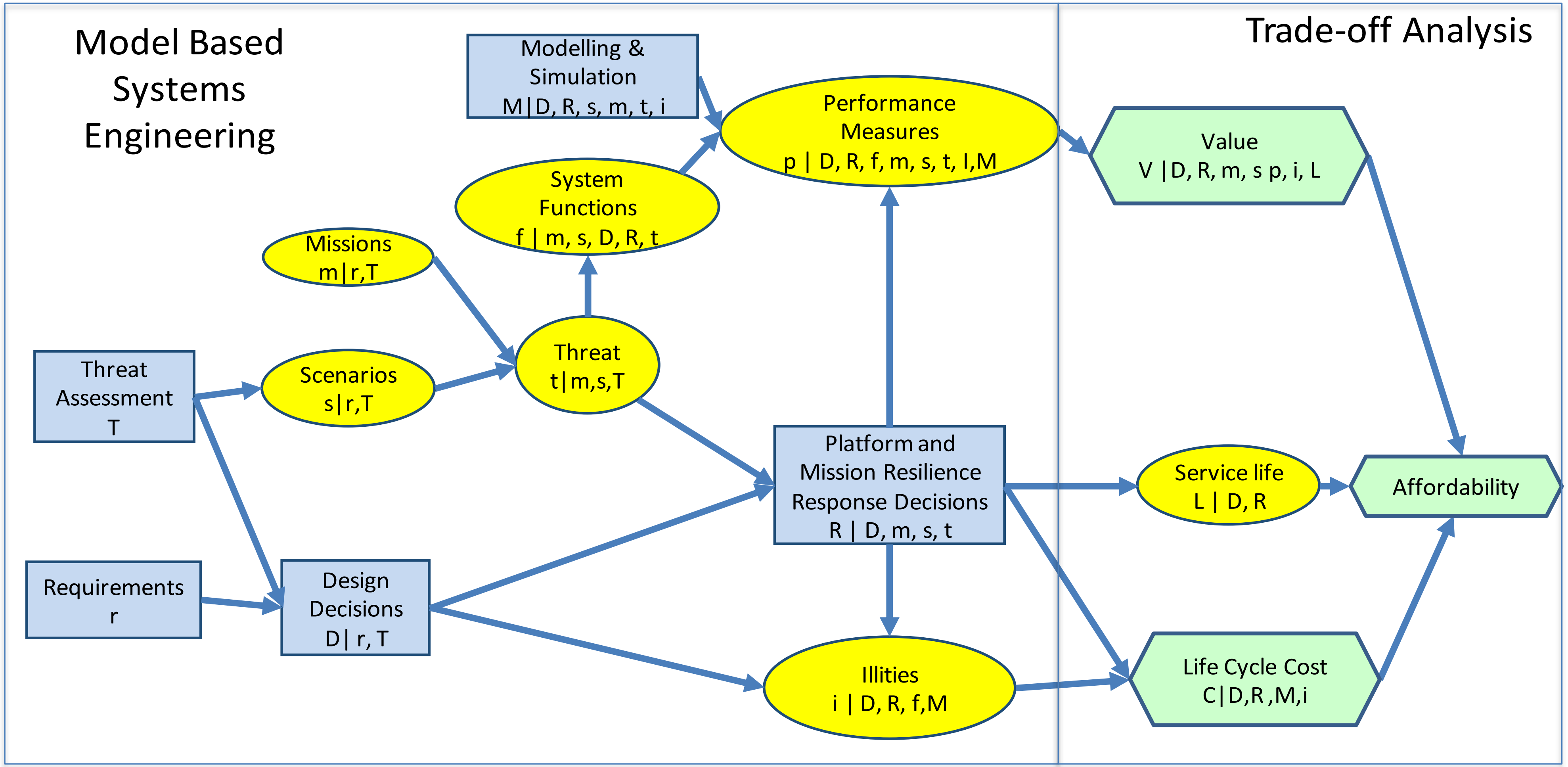


Illustration modified from Barker, K., Rocco, C. M., & Ramirez-Marquez, J. E (2013). Resilience Basec Network Component Importance Measures. Reliability Engineering & Systems Safety, 89-97.

ERS Influence Diagram

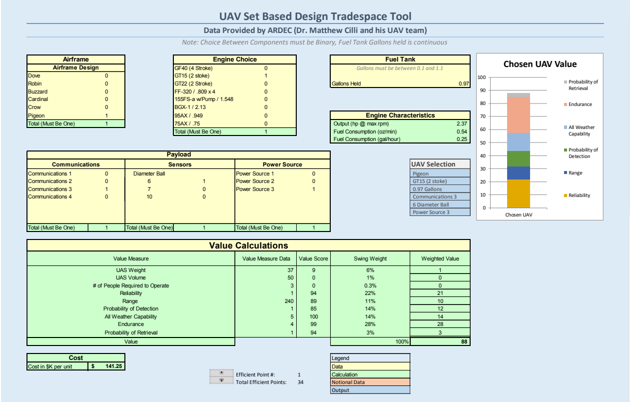
Small, C., Parnell, G., Pohl, E., Goerger, S., Cottam, C., Specking--, E., Wade, Z., “Engineering Resilience for Complex Systems,” 15th Annual Conference on Systems Engineering Research, Redondo Beach, CA, March 23-25, 2017



Provides context for ERS decision making. Influence diagram simplified using conditional notation.

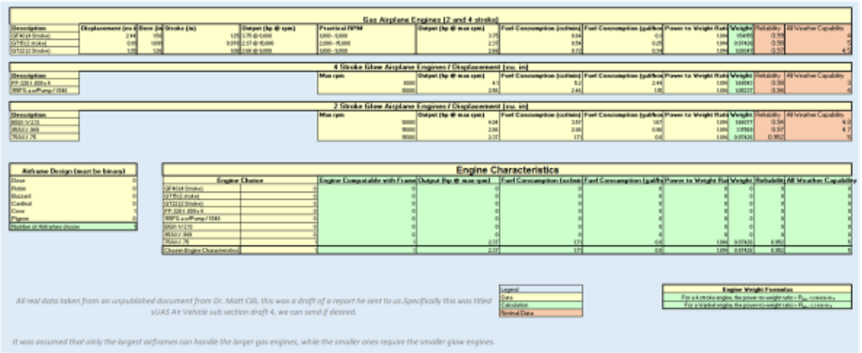
UAV Tradespace Tool Summary

Control Panel



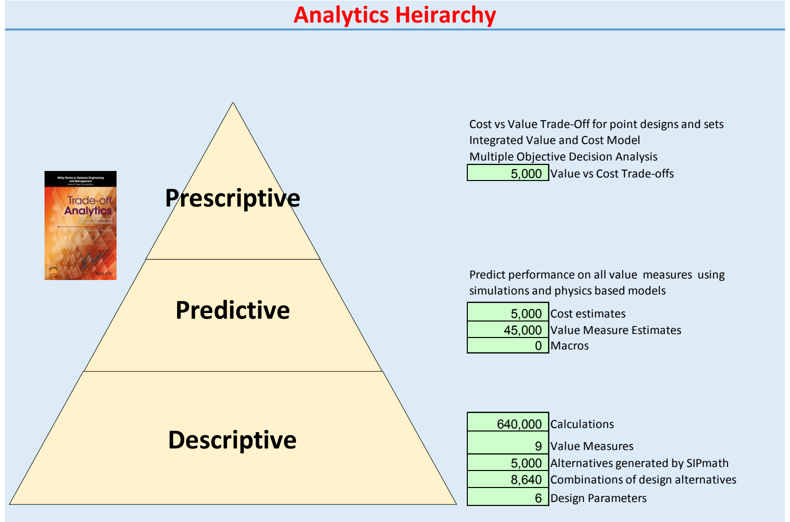
Using excel, we have created a tool that propagates design decisions through simultaneous calculations to assess value and cost.

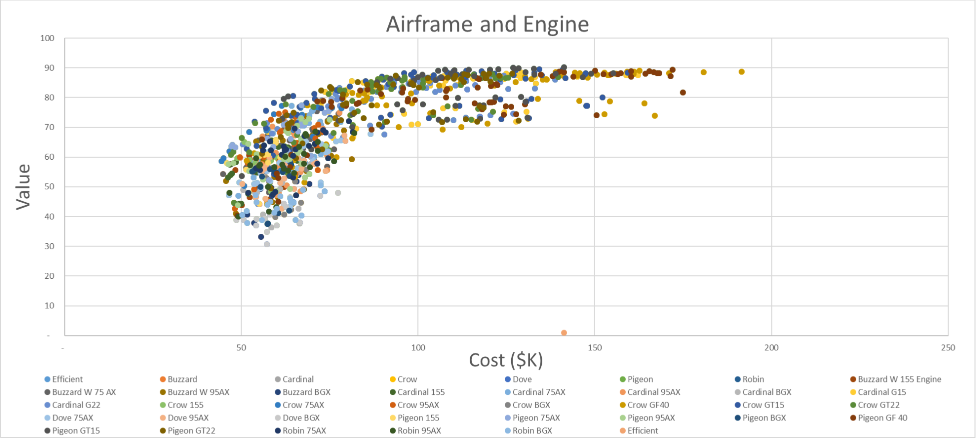
Engine Characteristics



For each of the discrete design decisions, Engine, Airframe, Sensors, Communications, Power Source, there is a page that uses the binary choice in the control panel to give the characteristics of each component.

Analytics Hierarchy





UAV data provided by Dr. Matt Cilli

UAV Trade-off Analysis Control Panel

UAV Set Based Design Tradespace Tool

Data Provided by ARDEC (Dr. Matthew Cilli and his UAV team)

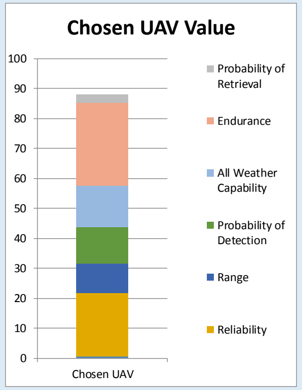
Note: Choice Between Components must be Binary, Fuel Tank Gallons held is continuous

Airframe	
Airframe Design	
Dove	0
Robin	0
Buzzard	0
Cardinal	0
Crow	0
Pigeon	1
Total (Must Be One)	1

Engine Choice	
GF40 (4 Stroke)	0
GT15 (2 stoke)	1
GT22 (2 Stroke)	0
FF-320 / .809 x 4	0
155FS-a w/Pump / 1.548	0
BGX-1 / 2.13	0
95AX / .949	0
75AX / .75	0
Total (Must Be One)	1

Fuel Tank	
Gallons must be between 0.1 and 1.1	
Gallons Held	0.97

Engine Characteristics	
Output (hp @ max rpm)	2.37
Fuel Consumption (oz/min)	0.54
Fuel Consumption (gal/hour)	0.25



Payload					
Communications		**Sensors**		**Power Source**	
Communications 1	0	Diameter Ball		Power Source 1	0
Communications 2	0	6	1	Power Source 2	0
Communications 3	1	7	0	Power Source 3	1
Communications 4	0	10	0		
Total (Must Be One)	1	Total (Must Be One)	1	Total (Must Be One)	1

UAV Selection
Pigeon
GT15 (2 stoke)
0.97 Gallons
Communications 3
6 Diameter Ball
Power Source 3

Value Calculations

Value Measure	Value Measure Data	Value Score	Swing Weight	Weighted Value
UAS Weight	37	9	6%	1
UAS Volume	50	0	1%	0
# of People Required to Operate	3	0	0.3%	0
Reliability	1	94	22%	21
Range	240	89	11%	10
Probability of Detection	1	85	14%	12
All Weather Capability	5	100	14%	14
Endurance	4	99	28%	28
Probability of Retrieval	1	94	3%	3
Value			100%	**88**

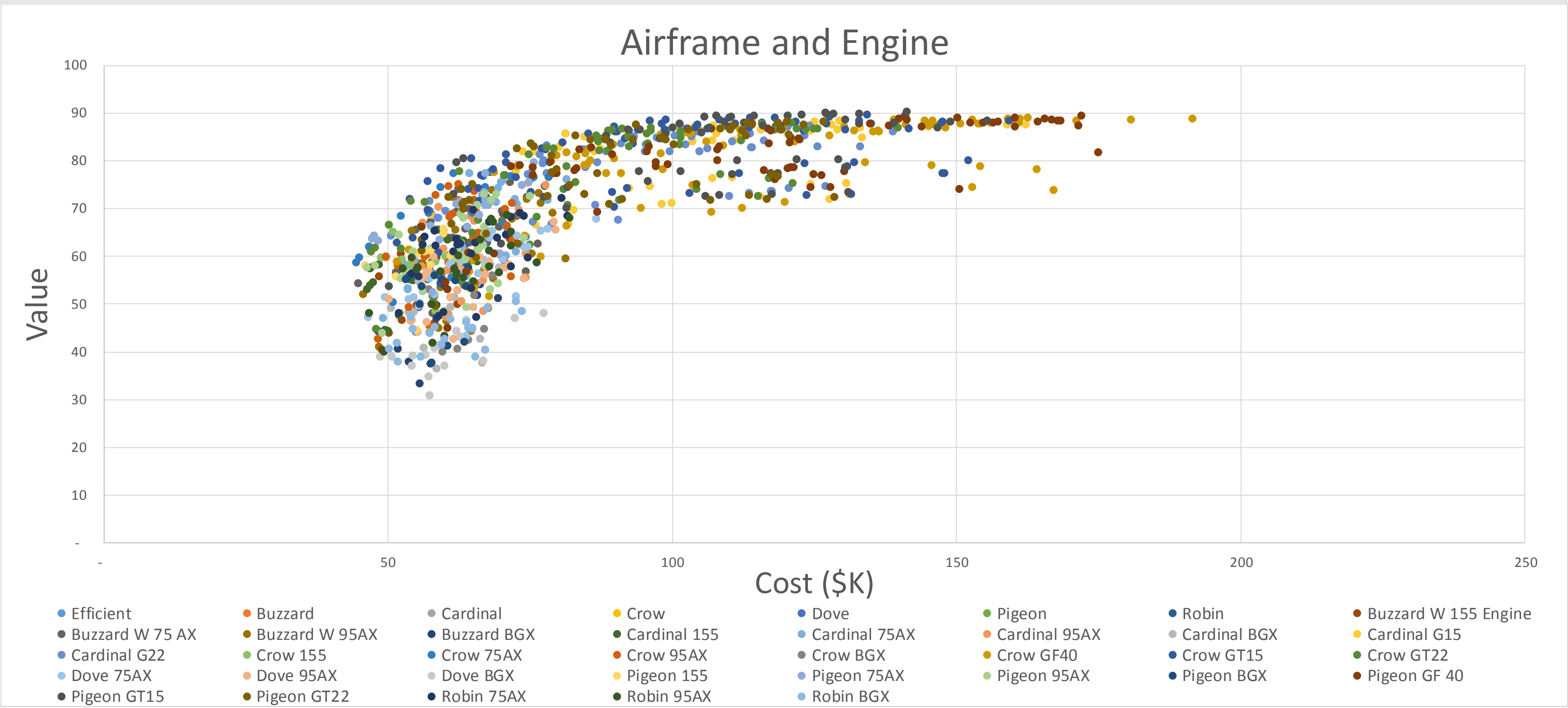
Cost		
Cost in $K per unit	$	141.25

Efficient Point #:	1
Total Efficient Points:	34

Legend
Data
Calculation
Notional Data
Output

Using excel, we have created a tool that propagates design decisions through simultaneous calculations to assess value and cost.

Point-Based to Set-Based Design

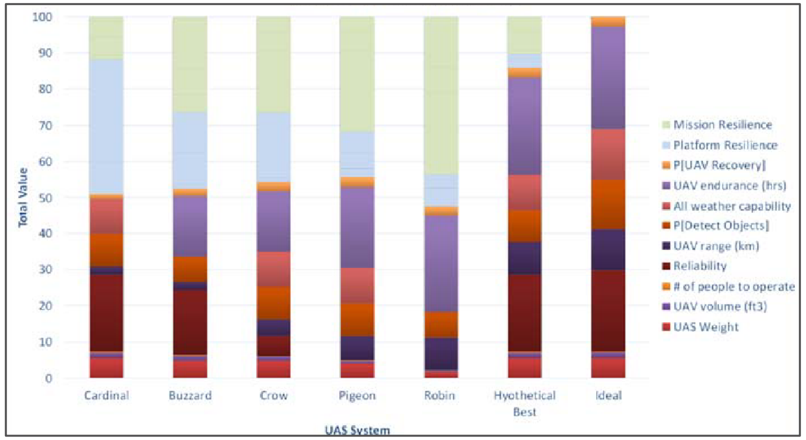


Savage, Sam, and Thomas Von Der Ohe. "SIPmath." SIPmath. Probability Management, Web. 13 Mar. 2017. <http://probabilitymanagement.org/sip-math.html>.

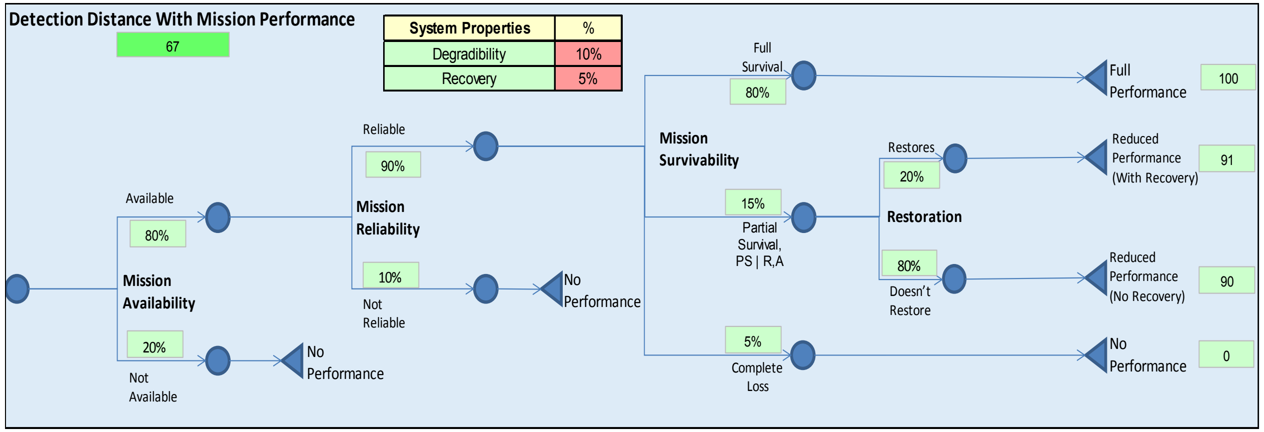
The model was adapted to perform set based design utilizing SIPmath, an open-source, Monte Carlo simulation add-in in Microsoft Excel from Probability Management. Each color represents a different notional airframe design alternative.

Summary

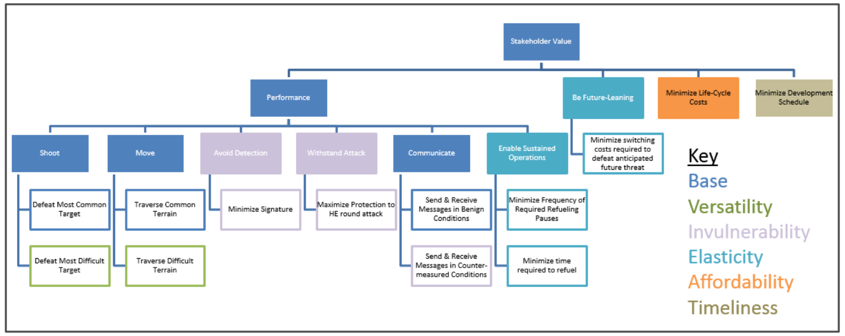
Resilience Opportunity Value



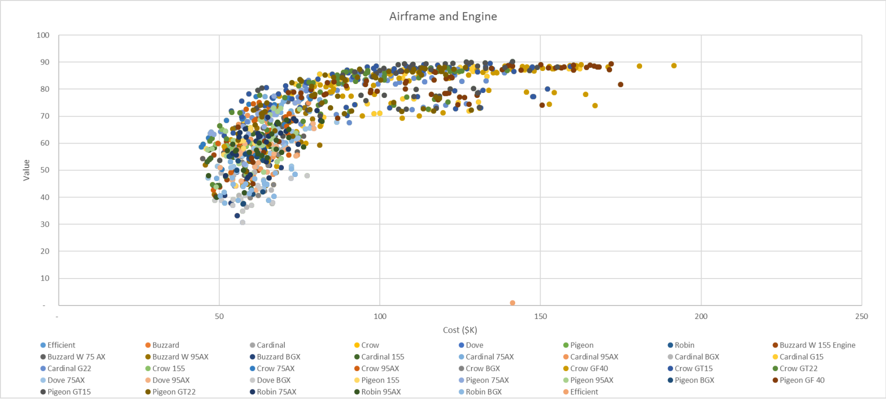
Resilience KPP



Include "Ilities" in Value Model



Set Based Design



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