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Systems Engineering Research Center (SERC)

Applications for Three Research Use Cases in Model Centric Engineering using ModelCenter and MBSEPak

Presented by:

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Stevens Institute of Technology

Georgetown University

University of Massachusetts

University of Southern California

Research Sponsor:

US Army-ARDEC and US Navy-NAVAIR

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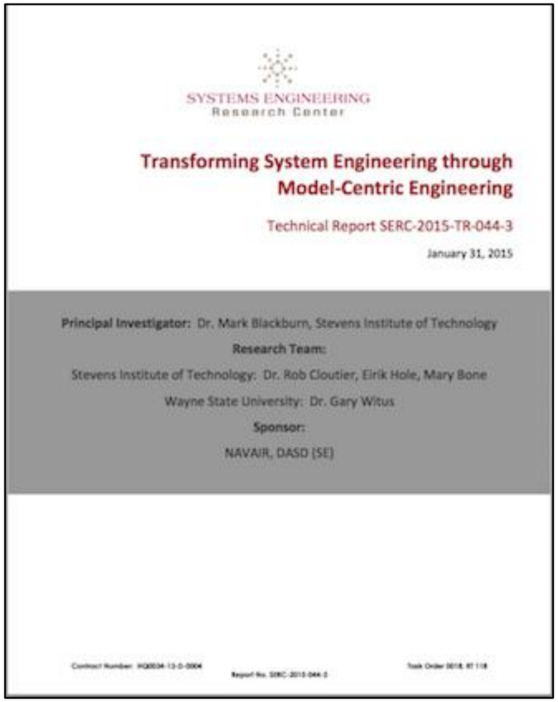
Outline

- Historical perspective and resources
- Context for research use cases
- Use cases:
  1. Developing Multidisciplinary Design, Analysis and Optimization (MDAO) workflows for Key Performance Parameter (KPPs) examples at system level
  2. ModelCenter integrated with a Graphical Concept of Operation (CONOPS) example using Unity gaming engine at the mission level
  3. ModelCenter and MBSEPak, with MagicDraw SysML to formalize the concept of an Assessment Flow Diagram, which is part of a recent PhD Decision framework and process

Historical Perspectives and Resources

- Resources
  - Technical reports link: http://www.sercuarc.org/researcher-profile/mark-blackburn/
  - Comprehensive briefing: http://www.sercuarc.org/publications-papers/presentation-systems-engineering-transformation-through-model-centric-engineering-past-why-present-what-and-future-how/

NAVAIR: RT-141
Phase I Summary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Transforming System Engineering through Model-Centric Engineering

Technical Report SERC-2015-TR-044-3

January 31, 2015

Principal Investigator: Dr. Mark Blackburn, Stevens Institute of Technology

Research Team:

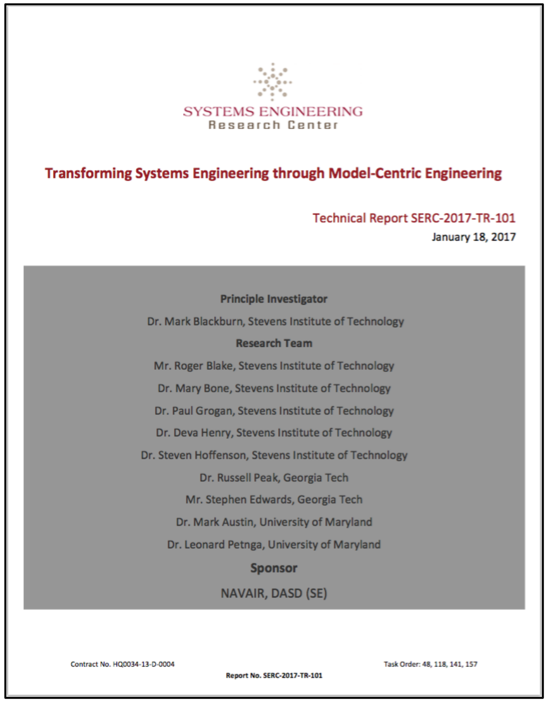
Stevens Institute of Technology: Dr. Rob Cloutier, Eirik Hole, Mary Bone

Wayne State University: Dr. Gary Witus

Sponsor:

NAVAIR, DASD (SE)

NAVAIR: RT-157
Phase II – SET Initiated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Transforming Systems Engineering through Model-Centric Engineering

Technical Report SERC-2017-TR-101

January 18, 2017

Principle Investigator

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Research Team

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Dr. Paul Grogan, Stevens Institute of Technology

Dr. Deva Henry, Stevens Institute of Technology

Dr. Steven Hoffenson, Stevens Institute of Technology

Dr. Russell Peak, Georgia Tech

Mr. Stephen Edwards, Georgia Tech

Dr. Mark Austin, University of Maryland

Dr. Leonard Petnga, University of Maryland

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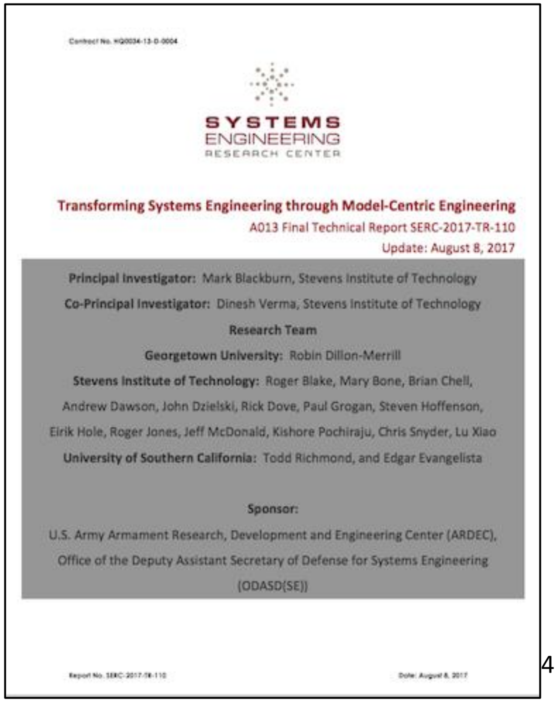
Contract No. HQ0034-13-D-0004 Report No. SERC-2017-TR-101 Task Order: 48, 118, 141, 157

ARDEC: RT-168
Synergistic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Transforming Systems Engineering through Model-Centric Engineering

A013 Final Technical Report SERC-2017-TR-110

Update: August 8, 2017

Principal Investigator: Mark Blackburn, Stevens Institute of Technology

Co-Principal Investigator: Dinesh Verma, Stevens Institute of Technology

Research Team

Georgetown University: Robin Dillon-Merrill

Stevens Institute of Technology: Roger Blake, Mary Bone, Brian Chell, Andrew Dawson, John Dzielski, Rick Dove, Paul Grogan, Steven Hoffenson, Eirik Hole, Roger Jones, Jeff McDonald, Kishore Pochiraju, Chris Snyder, Lu Xiao

University of Southern California: Todd Richmond, and Edgar Evangelista

Sponsor:

U.S. Army Armament Research, Development and Engineering Center (ARDEC), Office of the Deputy Assistant Secretary of Defense for Systems Engineering (ODASD(SE))

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Research Tasks and Collaborator Network

RT-48
- Mark Blackburn (PI), Stevens
- Rob Cloutier (Co-PI) - Stevens
- Eirik Hole - Stevens
- Gary Witus – Wayne State

RT-118
- Mark Blackburn (PI), Stevens
- Rob Cloutier - Stevens
- Eirik Hole - Stevens
- Gary Witus – Wayne State

RT-141
- Mark Blackburn (PI), Stevens
- Mary Bone - Stevens
- Gary Witus – Wayne State

RT-157
- Mark Blackburn (PI), Stevens
- Mary Bone - Stevens
- Roger Blake - Stevens
- Mark Austin – Univ. Maryland
- Leonard Petnga – Univ. of Maryland

RT-170
- Mark Blackburn (PI), Stevens
- Mary Bone - Stevens
- Deva Henry - Stevens
- Paul Grogan - Stevens
- Steven Hoffenson - Stevens
- Mark Austin – Univ. of Maryland
- Leonard Petnga – Univ. of Maryland
- Maria Coelho (Grad) – Univ. of Maryland
- Russell Peak – Georgia Tech.
- Stephen Edwards – Georgia Tech.
- Adam Baker (Grad) – Georgia Tech.
- Marlin Ballard (Grad) – Georgia Tech.

RT-168 – Phase I & II
- **Mark Blackburn (PI), Stevens**
- Dinesh Verma (Co-PI) – Stevens
- Ralph Giffin
- Roger Blake - Stevens
- Mary Bone – Stevens
- Andrew Dawson – Stevens (Phase I)
- Rick Dove
- **John Dzielski, Stevens**
- Paul Grogan - Stevens
- Deva Henry – Stevens (Phase I)
- Bob Hathaway - Stevens
- **Steven Hoffenson - Stevens**
- Eirik Hole - Stevens
- **Roger Jones – Stevens**
- Benjamine Kruse - Stevens
- Jeff McDonald – Stevens (Phase I)
- Kishore Pochiraju – Stevens
- Chris Snyder - Stevens
- Gregg Vesonder – Stevens (Phase I)
- Lu Xiao – Stevens (Phase I)
- **Brian Chell (Grad) – Stevens**
- Luigi Ballarinni (Grad) – Stevens
- Harsh Kevadia (Grad) – Stevens
- Kunal Batra (Grad) – Stevens
- Khushali Dave (Grad) – Stevens
- Rob Cloutier – Visiting Professor
- Robin Dillon-Merrill – Georgetown Univ.
- Ian Grosse – Univ. of Massachucetts
- Tom Hagedorn – Univ. of Massachusetts
- Todd Richmond – Univ. of Southern California (Phase I)
- Edgar Evangelista – Univ. of Southern California (Phase I)

RT-176
- Kristin Giammaro (PI) – NPS
- Ron Carlson (Co-PI), NPS
- Mark Blackburn (Co-PI), Stevens
- Mikhail Auguston, NPS
- Rama Gehris, NPS
- Marianna Jones, NPS
- Chris Wolfgeher, NPS
- Gary Parker, NPS

RT-195
- Mark Blackburn (PI), Stevens
- Mary Bone - Stevens
- Ralph Giffin - Stevens
- Bob Hathaway- Stevens
- Benjamin Kruse - Stevens
- Russell Peak – Georgia Tech.
- Stephen Edwards – Georgia Tech.
- Adam Baker (Grad) – Georgia Tech.
- Marlin Ballard (Grad) – Georgia Tech.
- Donna Rhodes - MIT
- Mark Austin – Univ. Maryland
- Maria Coelho (Grad) – Univ. Maryland

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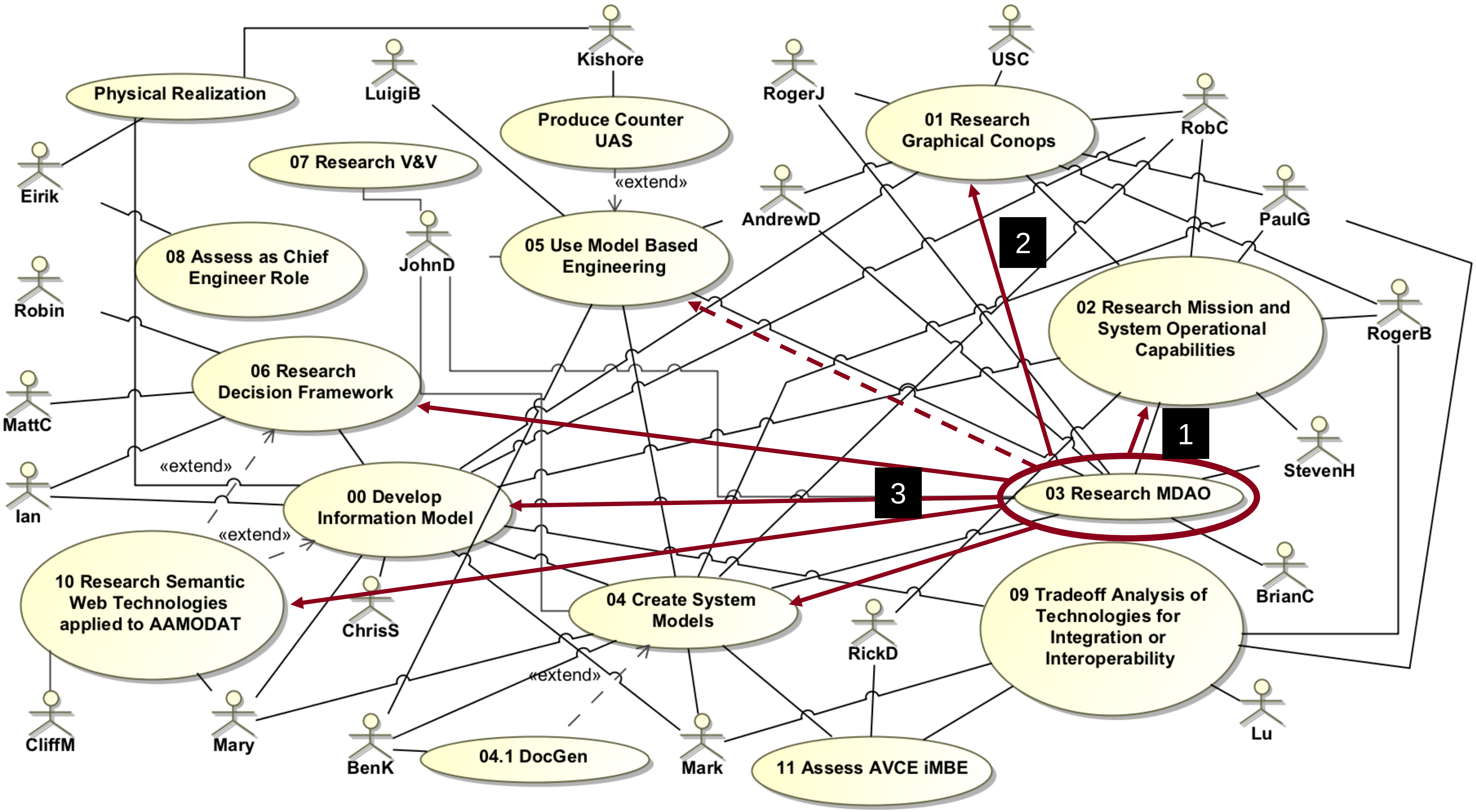
RT-168 Use Case Perspective and Team



Research Thrusts

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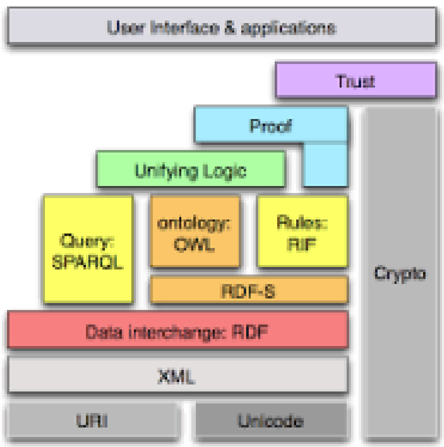
Semantic Web Technologies



Enforces **Modeling Methods**

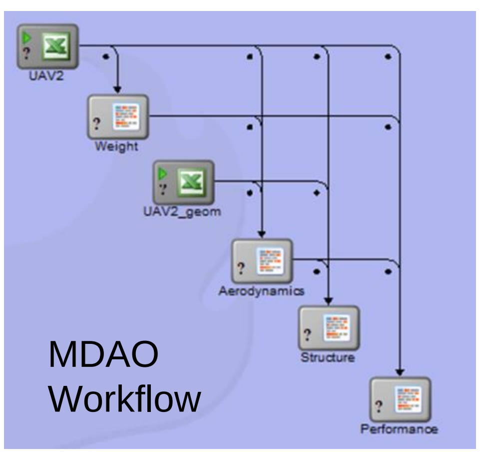
Underlying technologies
for reasoning about completeness
and consistency **Across Domains** in modeling
tool agnostic way

Modeling Methodologies

Guides proper usage to ensure **Model Integrity** (trust in model results) for decision making

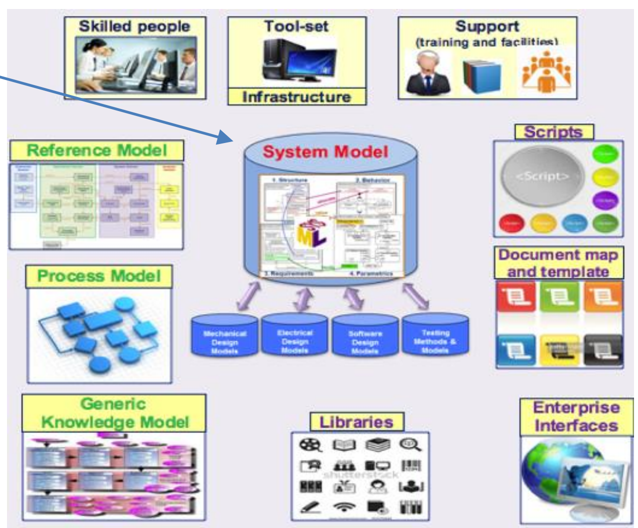
Digital System Model:
Single Source of Truth
(*Authoritative Source of Truth)*

Multidisciplinary Design, Analysis and Optimization (MDAO)



Provides optimization analysis
Across Domains
to support KPP
and alternatives trades
at mission, system,
& subsystem levels

Integrated Modeling Environment



Key Performance Parameter (KPP)

- Performance attributes of a system considered critical to the development of an effective military capability.
- Example:
  - Predator shall have an endurance of 40 hours
  - Possibly with other constraint:
    - And carry 340kg of multiple payloads including video cameras, laser designators, communications
  - Meet some availability and cost objectives

http://www.airforce-technology.com/features/featurethe-top-10-longest-range-unmanned-aerial-vehicles-uavs/featurethe-top-10-longest-range-unmanned-aerial-vehicles-uavs-5.html

Use Case #1:

Developing Multidisciplinary Design, Analysis and Optimization (MDAO) workflows for Key Performance Parameter (KPPs) examples at system level

Steven Hoffenson & Brian Chell

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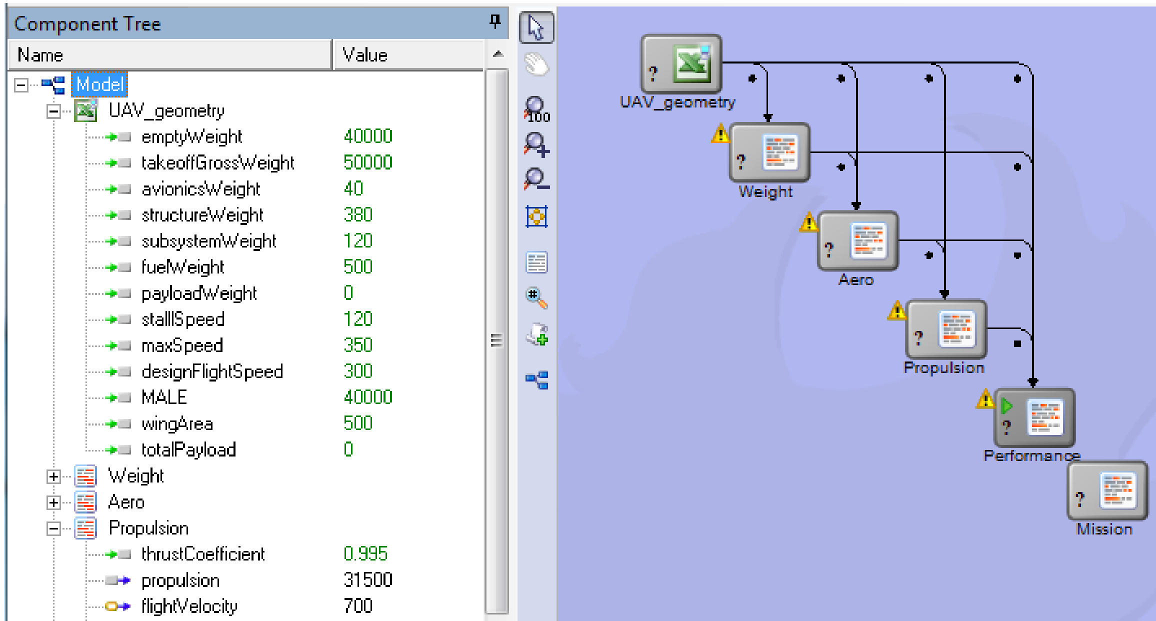
Use Case #1

- Developed MDAO workflow for example of KPP (range) using UAV Weight, Aero, Propulsion, Performance, which links back to system model to illustrate method:
  - — Defining sequence of workflows (scenarios)
  - — Identifying a set of inputs and outputs (parameters)
  - — Define a Design of Experiments (DoE) and use analyses such as sensitivity analysis and visualizations to understand the key parameter to scope
  - — Use Optimization using solvers with key parameters and define different (key objective functions – on outputs) to determine set of solutions (results often provided as a table of possible solutions)
  - — Use visualizations to understand relationships of different solutions
  - — Concept applicable at mission, system and subsystems

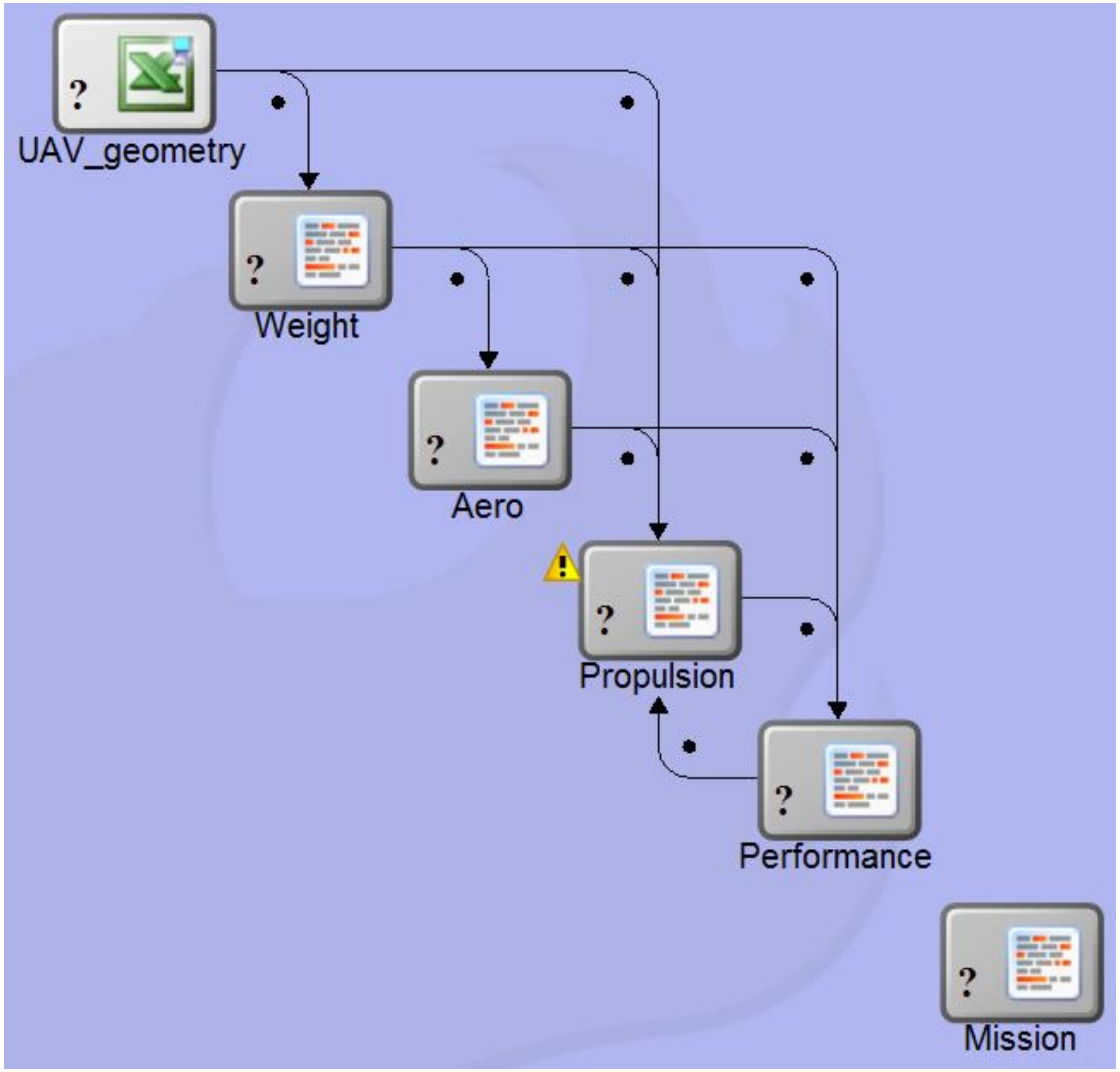


Brian Chell and Steven Hoffenson

SYSTEMS ENGINEERING Research Center

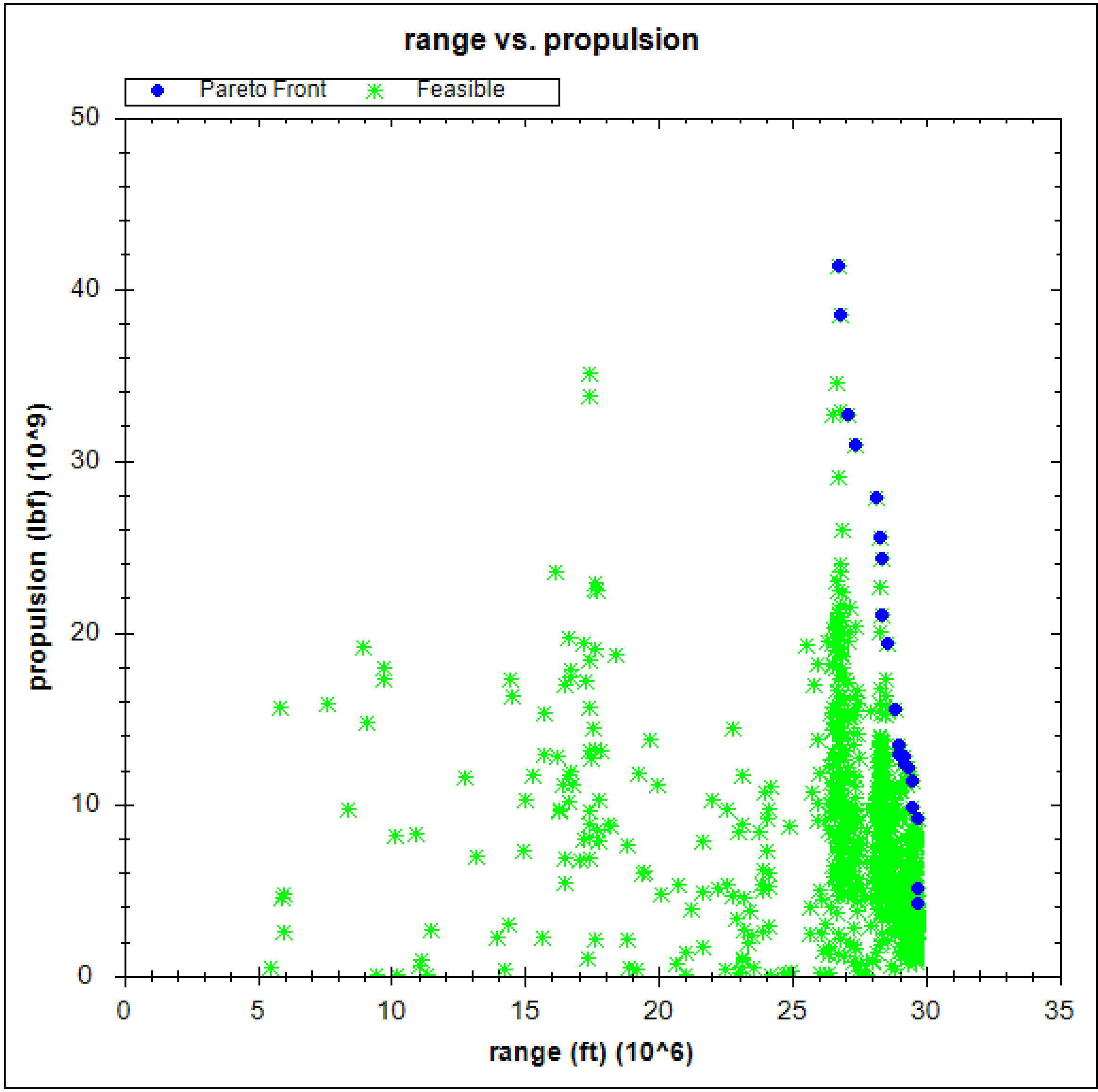
Initial model

- Fixed-wing UAV model
- Equation-based
- Currently links 5 equation-based models
  - Geometry
  - Weight
  - Aerodynamics
  - Propulsion
  - Performance
- Later work
  - Used more advanced, simulation-based models
  - Add mission capabilities

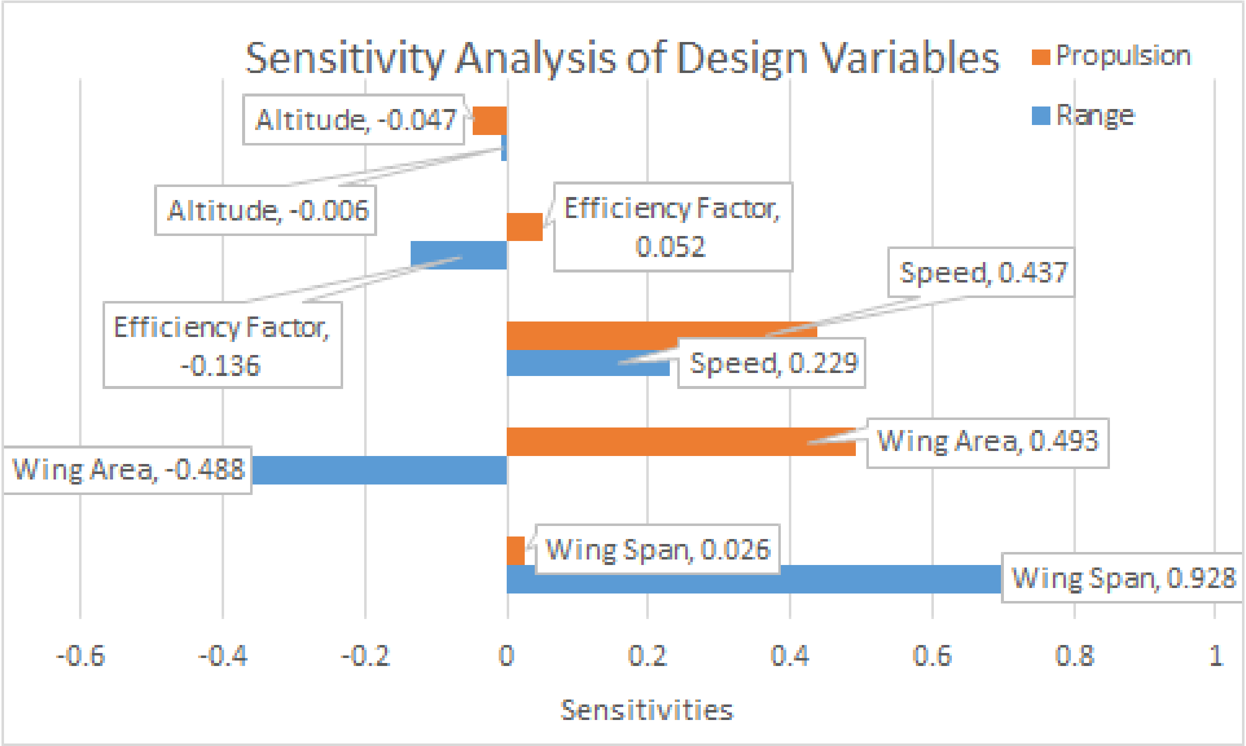


Initial results

- Bi-objective optimization using NSGA-II algorithm:
  - Maximize range
  - Maximize propulsion
- 5 design variables
  - Wing area (ft^2)
  - Wing span (ft)
  - Altitude (ft)
  - Speed (knots)
  - Efficiency factor
- Pareto frontier shows trade-off between range and propulsion
  - How much range would you have to give up to increase the propulsion by some amount?



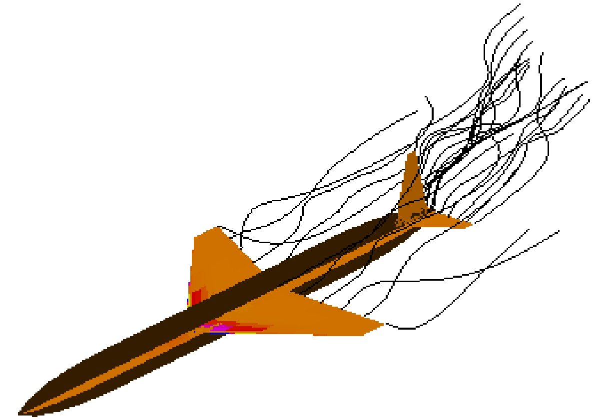
Sensitivity of Objectives to Design Variables



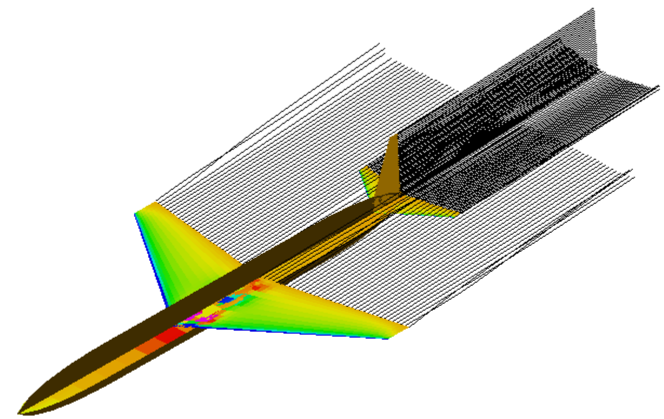
- Wing area is the variable that exhibits the clearest trade-off
- Wing span has the largest effect on range, but does not present a trade-off between these objectives

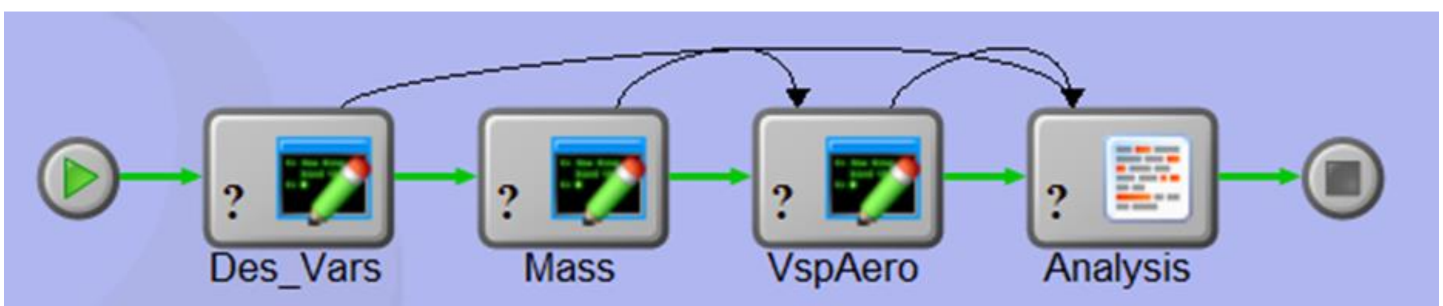
Other Models Examples using Workflow in ModelCenter

- UAV Geometry
  - Easy to change



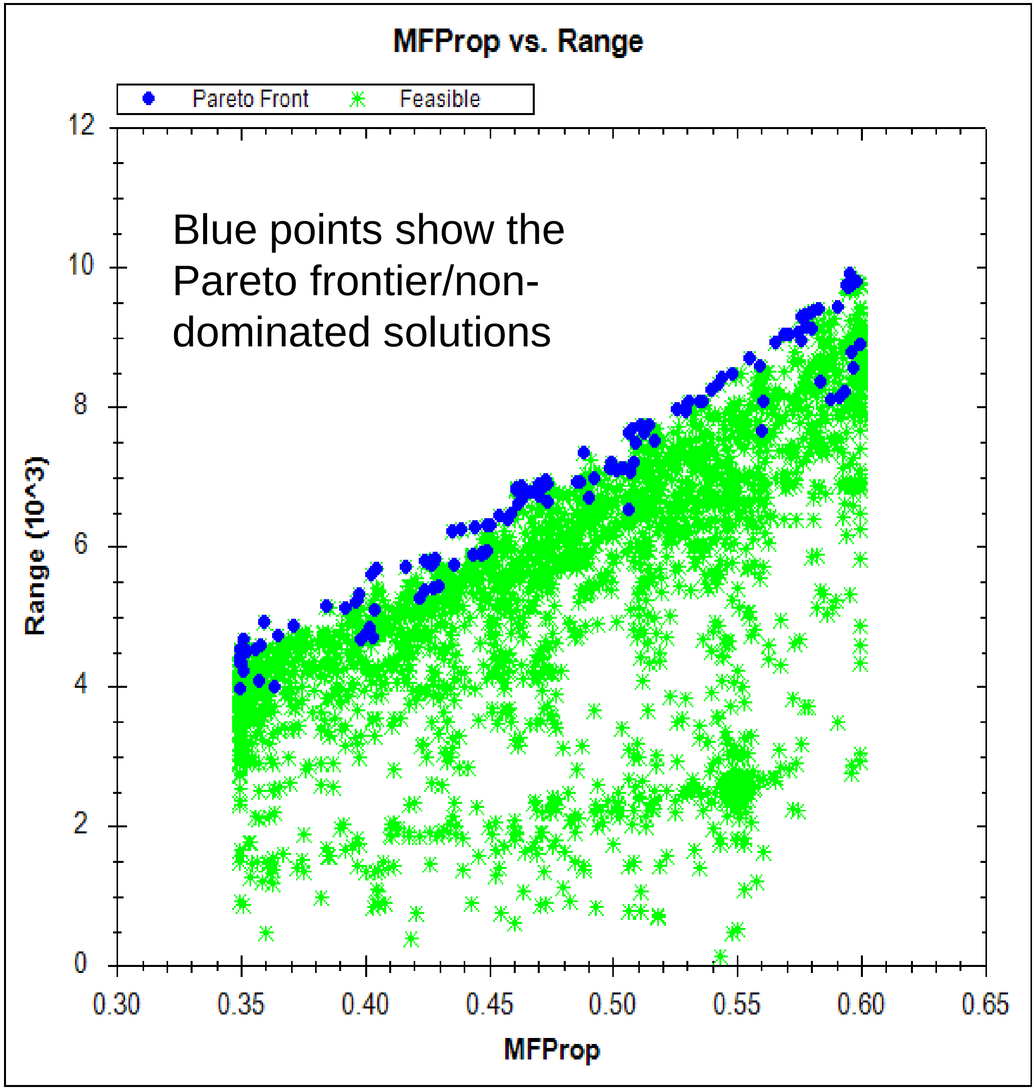
- Simulation-based Model
  - OpenVSP geometry and VSPAero CFD tool wrapped into ModelCenter
  - Adjusts geometry and flight conditions for MDAO
  - About 1 minute per run





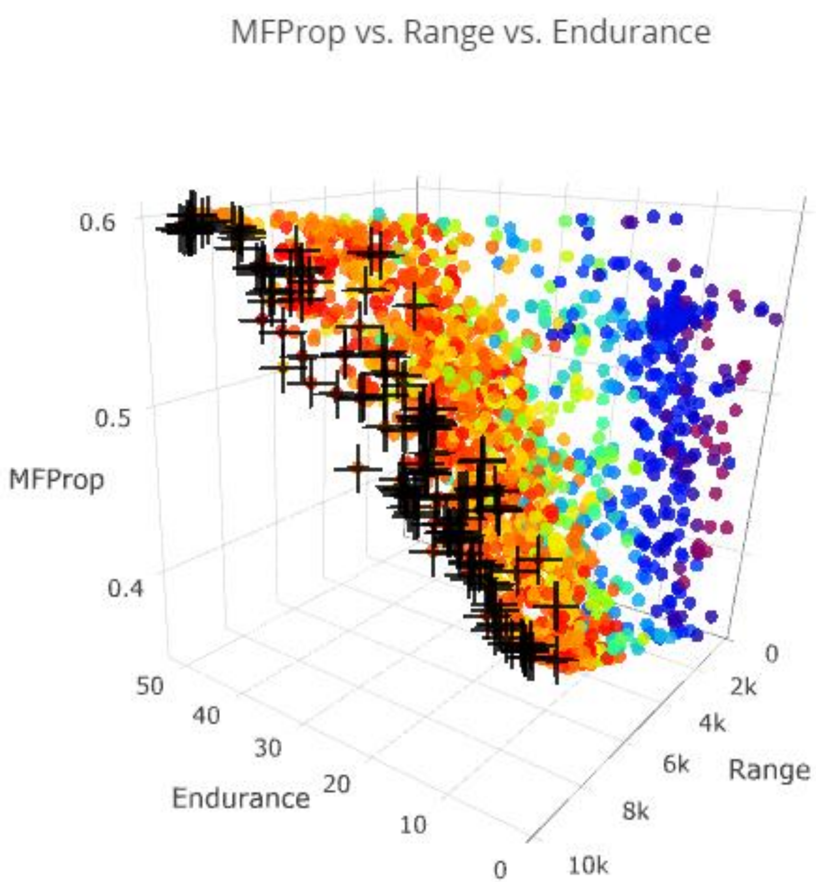
Optimization

- Tri-objective optimization using Darwin algorithm:
  - Maximize range
  - Maximize endurance
  - Minimize fuel mass fraction
  - ~2600 runs in ~2 days
- 9 design variables
  - Fuel mass fraction
  - Wing span
  - Average wing chord
  - Tail span
  - Average tail chord
  - Tail Y-rotation
  - Wing X-location
  - Airspeed
  - Angle of Attack

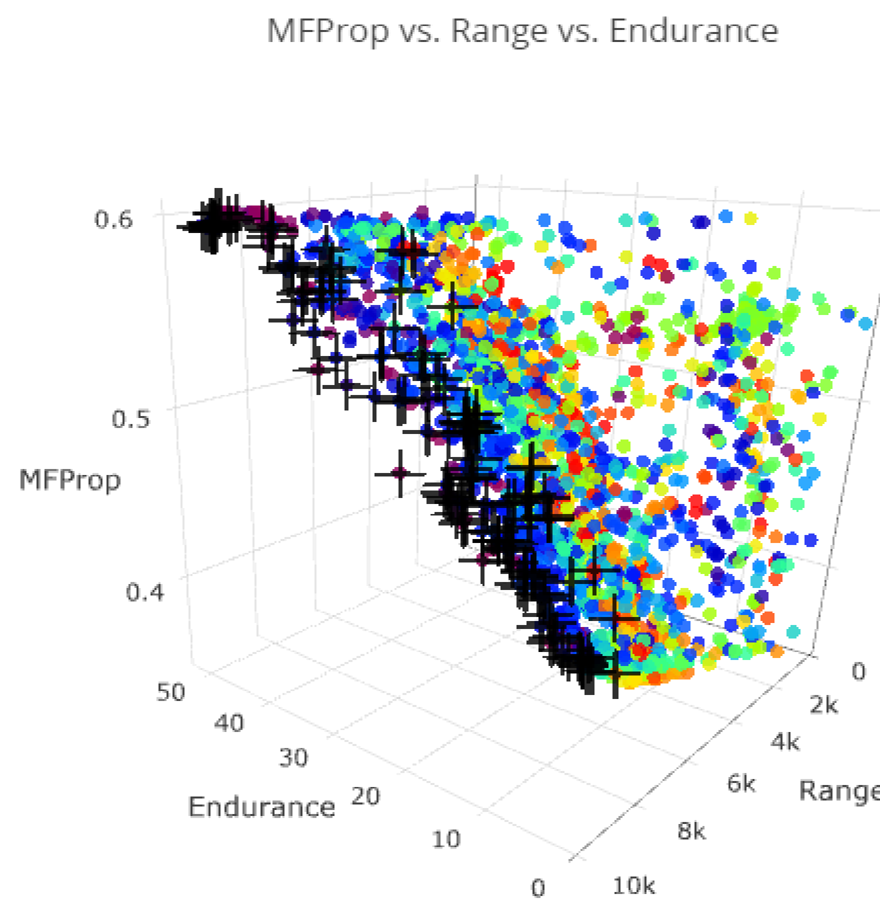


Range (mi) vs. Fuel Mass Fraction

Optimization Visualizations



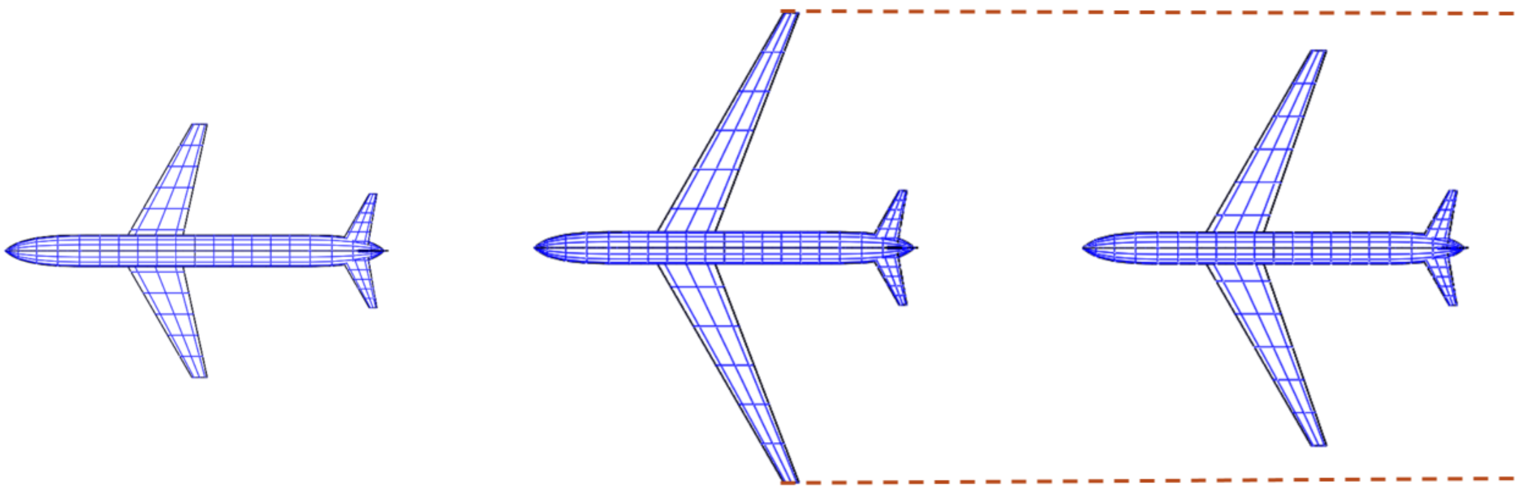
Colors Represent Angle of Attack



Colors Represent Mach # (airspeed)

Update of Fixed-Wing Model to Include CFD and FEA

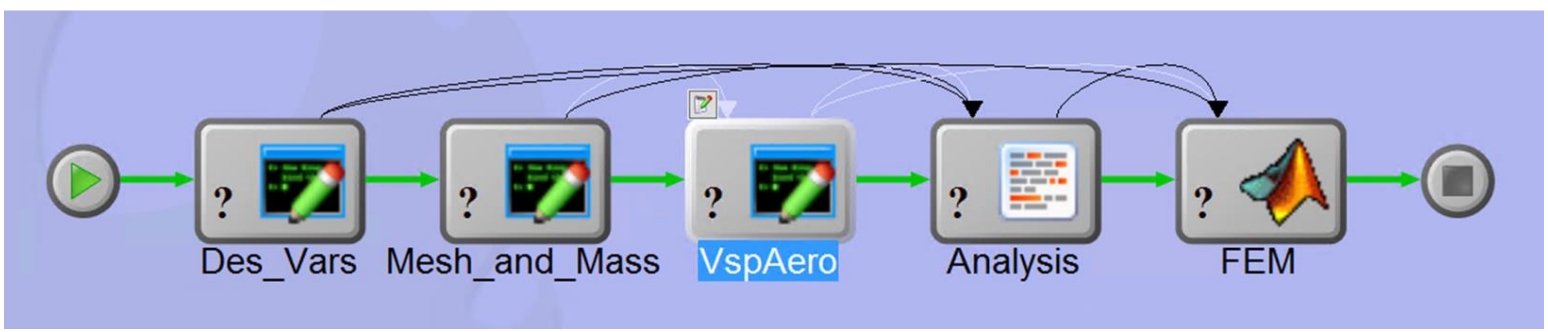
- Update: Finite Element Analysis constrains wing



Initial Inputs

Optimization with CFD but without FEA

Optimization with CFD and FEA

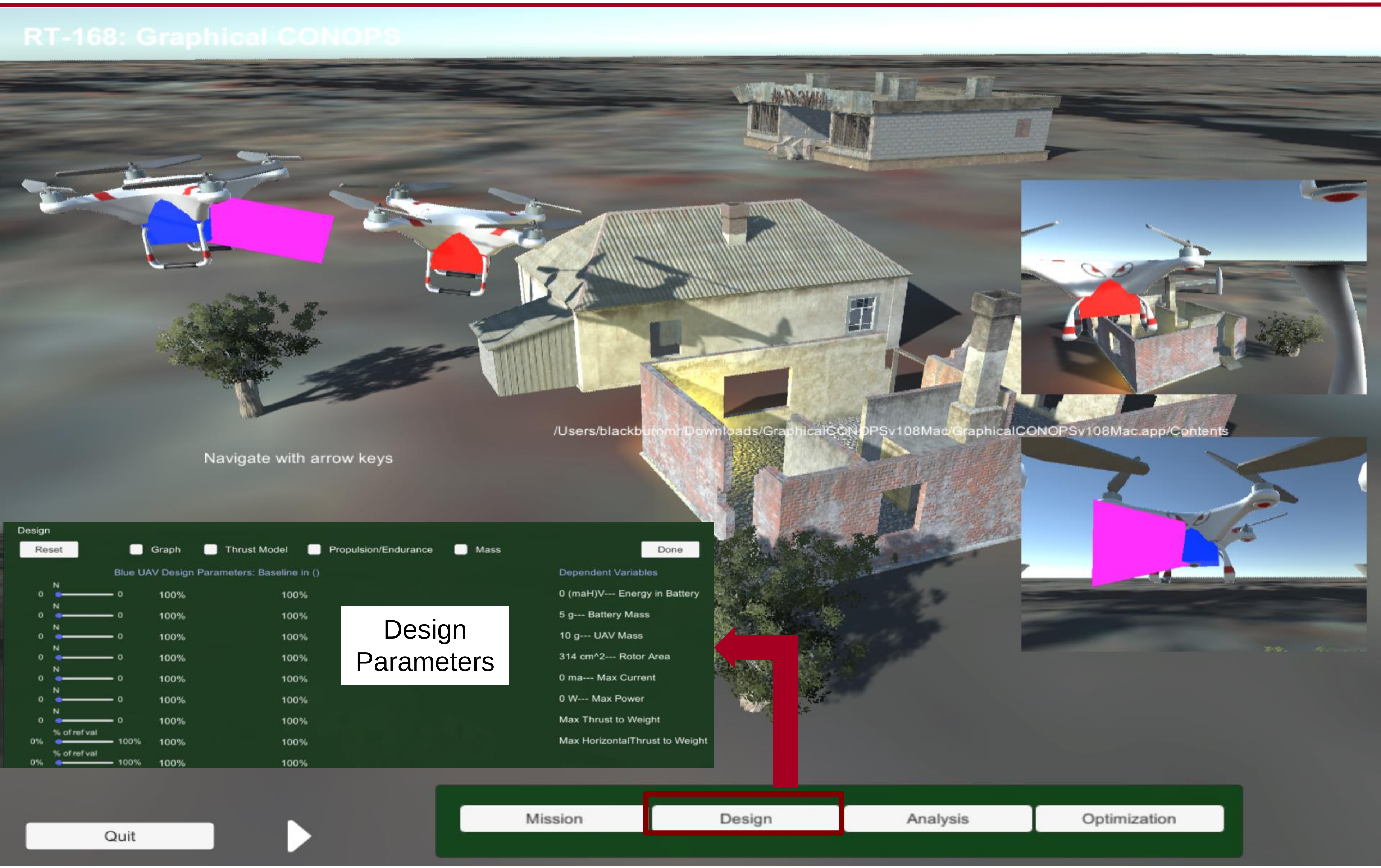


Use Case #2:

ModelCenter Integrated with a Graphical Concept of Operation (CONOPS) example using Unity gaming engine at the mission level

Roger Jones & Brian Chell

Use Case #2 - Base Capability: Graphical CONOPS with Unity Gaming Engine



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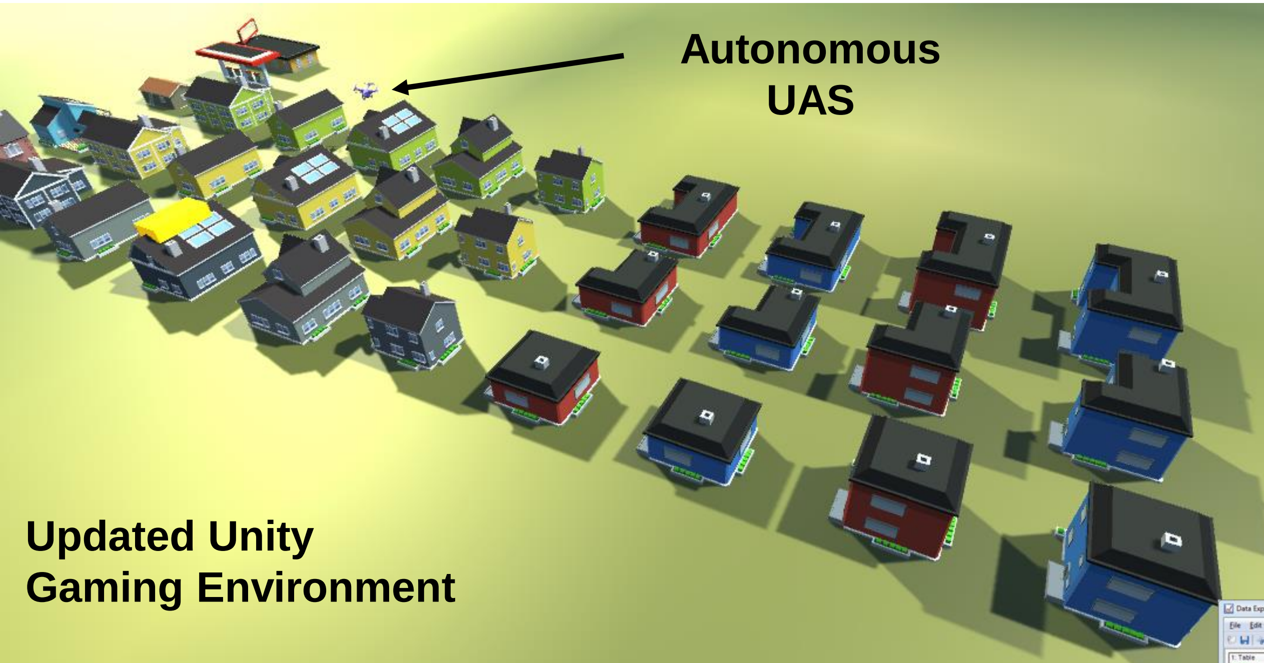
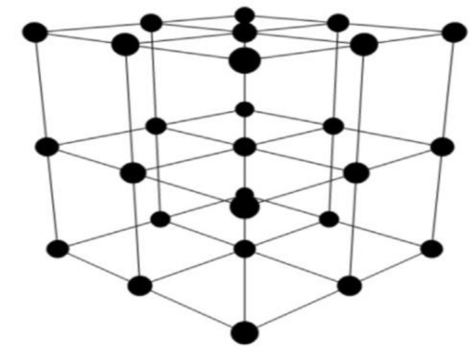
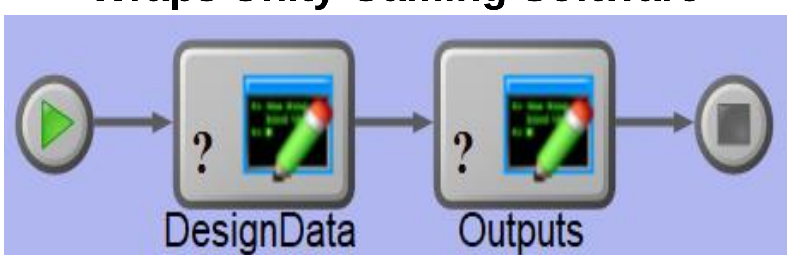
Use Case #2: Integration of Graphical CONOPS Simulation with MDAO tools

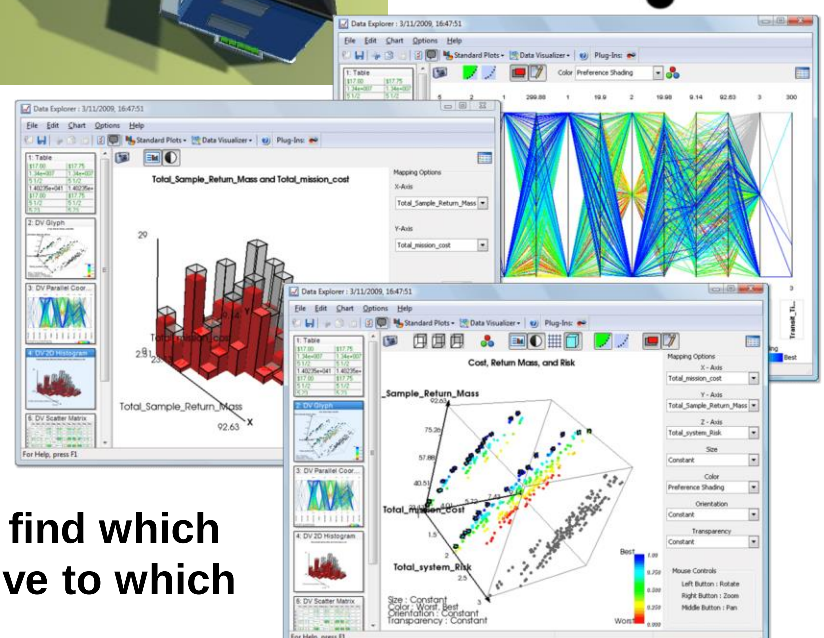


1000s of runs to cover Design of Experiments vs. 10s that could be run manually



Headless (no humans in loop) ModelCenter Workflow Wraps Unity Gaming Software





Sensitivity Analysis – to find which outputs are most sensitive to which input variables

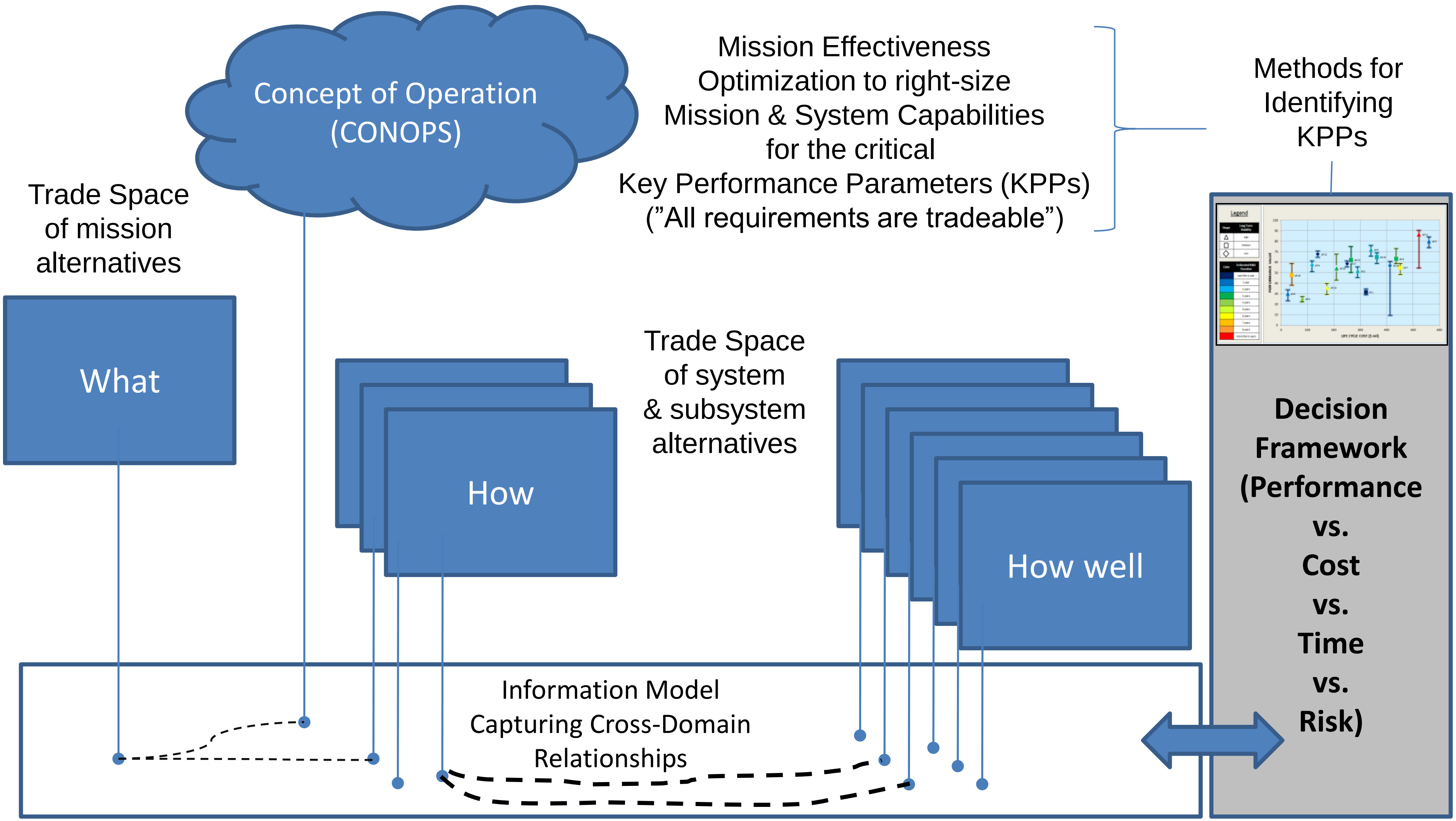
Brian Chell and Roger Jones

Use Case #3:

ModelCenter and MBSEPak, with MagicDraw SysML to formalize the concept of an Assessment Flow Diagram, which is part of a recent PhD Decision framework and process

John Dzielski & Matt Cilli

Perspectives on Characterizing Challenges of Research Space



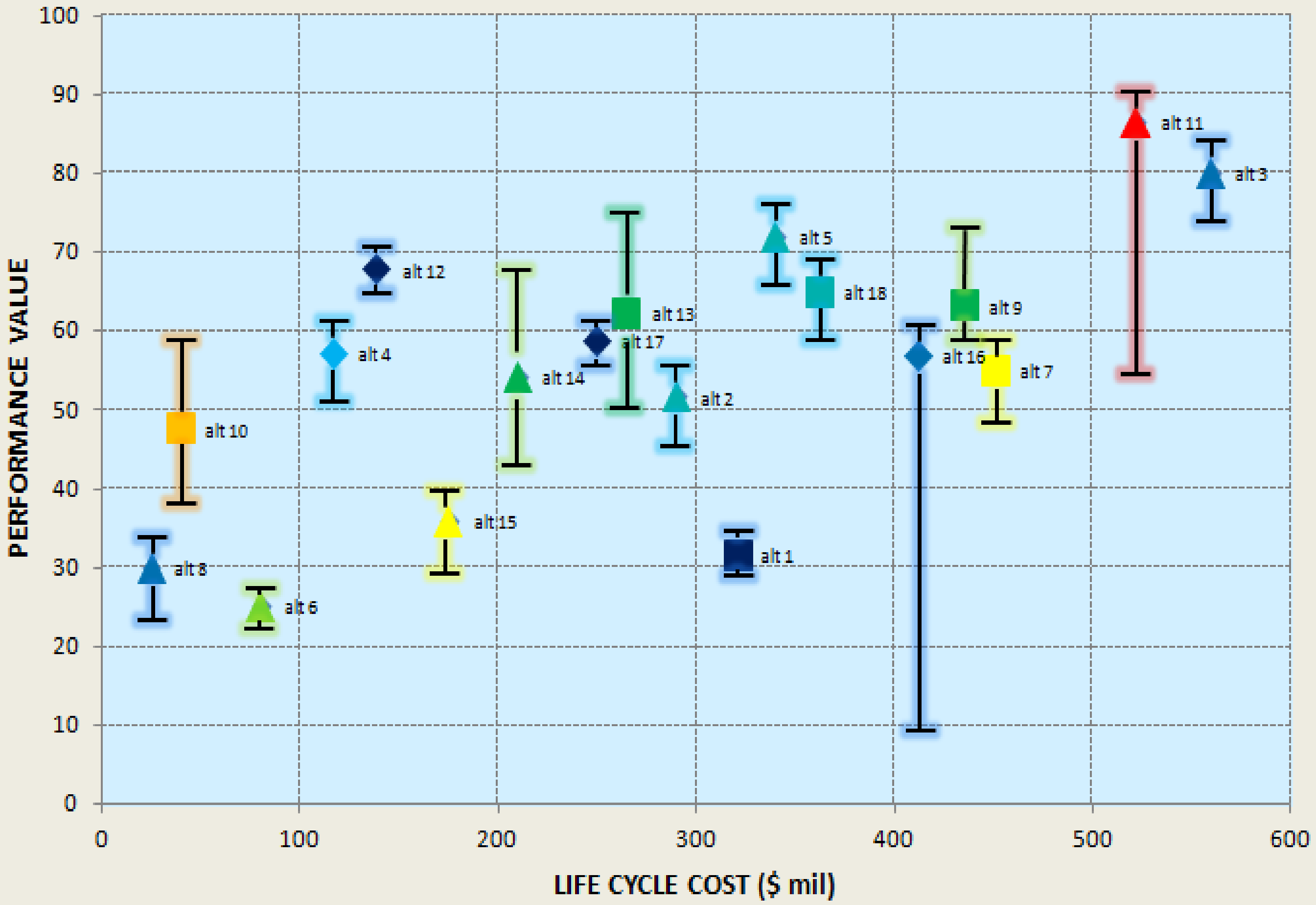
Reasoning about completeness and consistency of information across domains

Visualizing Alternatives – Value Scatterplot with Assessing Impact of Uncertainty*

Legend

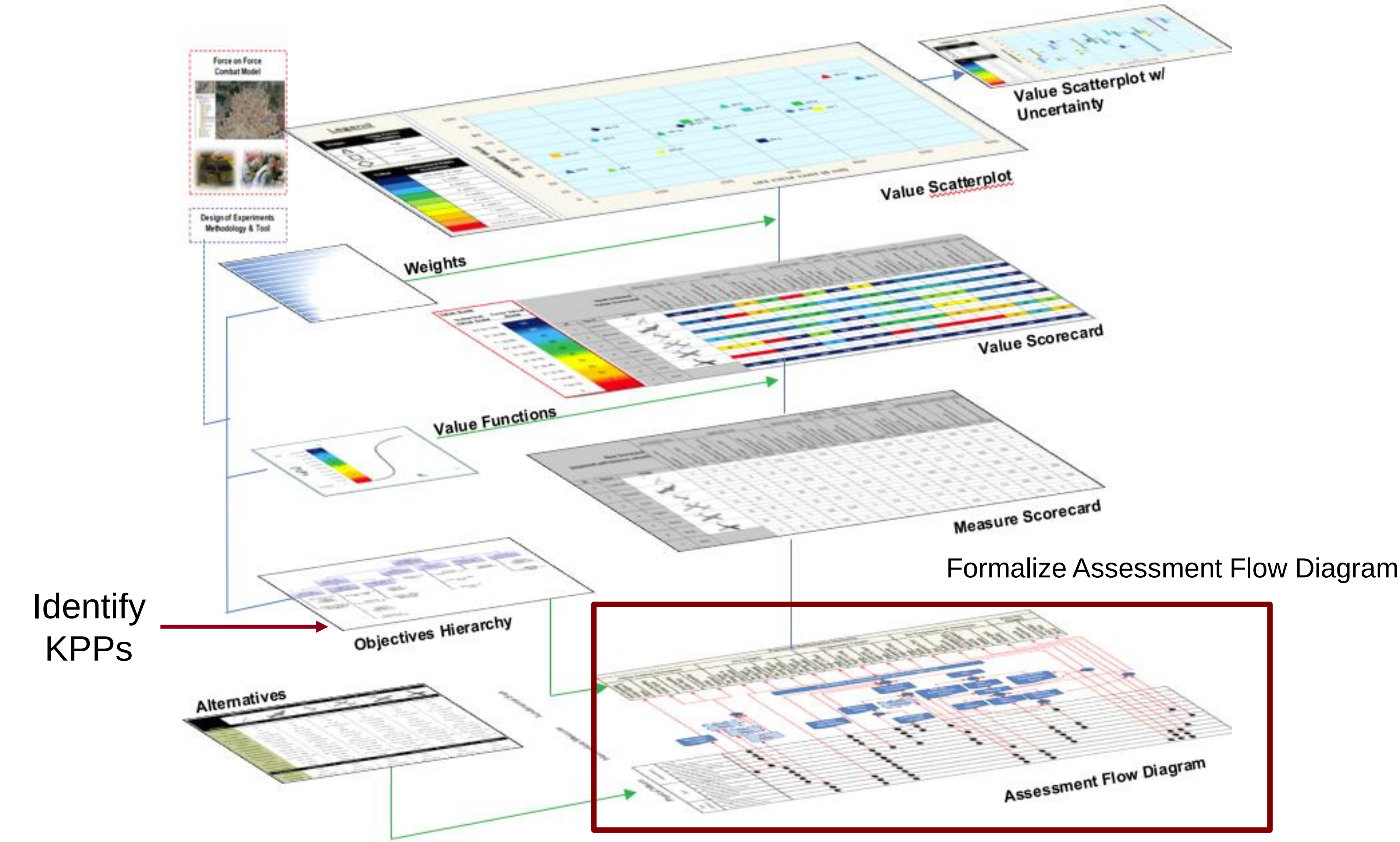
Shape	Long Term Viability
△	High
□	Medium
◇	Low

Color	Estimated R&D Duration
Dark navy	Less than a year
Blue	1 year
Light blue	2 years
Green	3 years
Light green	4 years
Yellow-green	5 years
Yellow	6 years
Gold	7 years
Orange	8 years
Red	More than 9 years



Cilli, M. Seeking Improved Defense Product Development Success Rates Through Innovations to Trade-Off Analysis Methods, Dissertation, Stevens Institute of Technology, Nov. 2015.

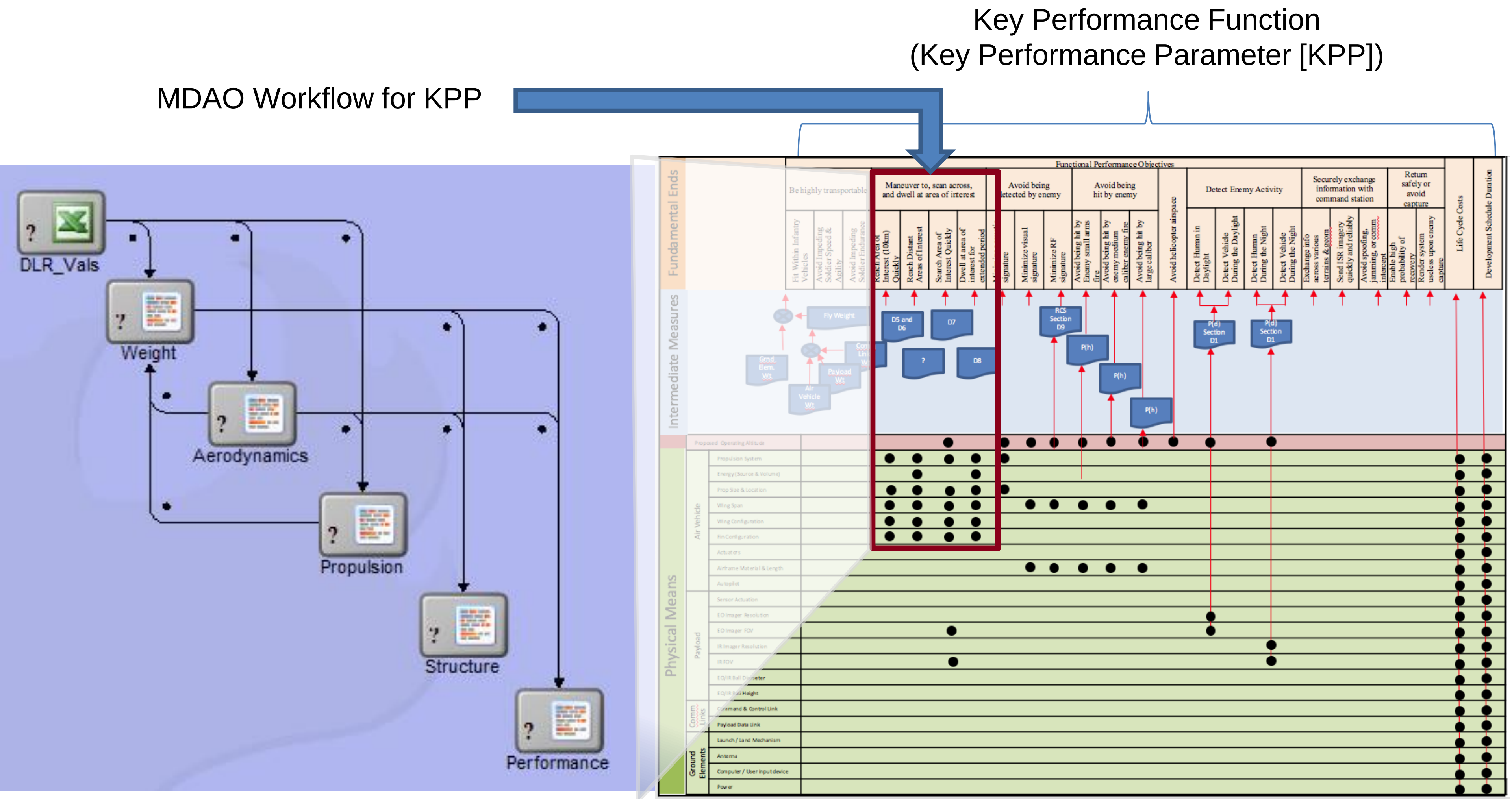
Decision Support Model Construct



Cilli, M. Seeking Improved Defense Product Development Success Rates Through Innovations to Trade-Off Analysis Methods, Dissertation, Stevens Institute of Technology, Nov. 2015.

Formalize Assessment Flow Diagram of Decision Framework using ModelCenter/MBSEPak

- Can MDAO represent Assessment Flow Diagram?
- Does AFD characterize needed MDAO workflows?



Overview

- Describe the decision support model (DSM) conceptually
- Example of DSM in context of a surveillance drone
- Show how example can be mapped to a SysML model
- Demonstrate different ways to use SysML model with MBSEPak

Steps to Formalize Decision Support Model Construct using SysML and ModelCenter

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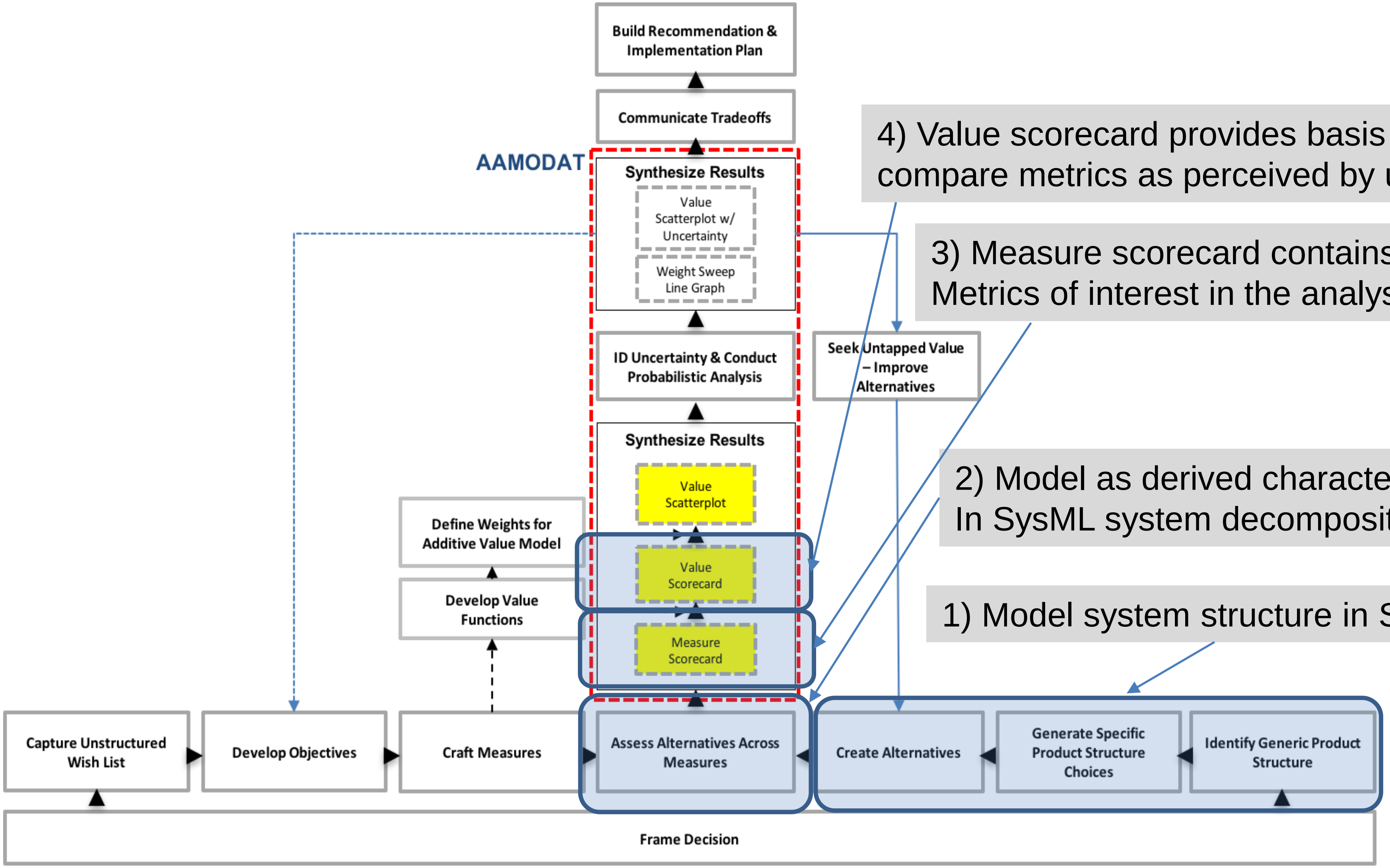

4) Value scorecard provides basis to compare metrics as perceived by user

3) Measure scorecard contains the Metrics of interest in the analysis

2) Model as derived characteristics In SysML system decomposition

1) Model system structure in SysML

Cilli, M. Seeking Improved Defense Product Development Success Rates Through Innovations to Trade-Off Analysis Methods, Dissertation, Stevens Institute of Technology, Nov. 2015.

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Decision Support Tool uses Spreadsheet Data to Indicate Structure, Characteristics, and Alternatives

Decision Support Tool
developed with integrated worksheets

D7 | fx 2.60114936595984

			Physical Design Choice - Air Vehicle			Physical Design Choice - Payload					
ID#	Short name	Sensor Group	Wingspan	Engine Type	Operating Altitude (ft.)	EO Imager Pixels Horizontal	EO Imager Pixels Vertical	EO FOV	IR Pixels Horizontal	IR Pixels Vertical	IR FOV
1	E_span_2.6_alt_300_sensor_grp_1	1	2.6	E	300	100	100	3	100	100	3
2	E_span_5_alt_300_sensor_grp_2	2	5.0	E	300	120	100	3	100	100	3
3	E_span_5_alt_300_sensor_grp_3	3	5.0	E	300	120	100	3	100	100	3
4	E_span_6.8_alt_300_sensor_grp_4	4	6.8	E	300	120	120	3	120	120	3
5	E_span_7.5_alt_300_sensor_grp_5	5	7.5	E	300	240	240	4	240	240	3
6	E_span_8.1_alt_300_sensor_grp_6	6	8.1	E	300	360	360	5	240	240	4
7	E_span_9.6_alt_300_sensor_grp_7	7	9.6	E	300	400	300	5	360	240	4
8	E_span_10.5_alt_300_sensor_grp_8	8	10.5	E	300	480	360	5	300	300	4
9	P_span_2.1_alt_300_sensor_grp_9	9	2.1	P	300	320	240	3	160	120	3
10	P_span_4.6_alt_300_sensor_grp_10	10	4.6	P	300	540	360	4	240	180	4
11	P_span_5.5_alt_300_sensor_grp_11	11	5.5	P	300	780	600	6	320	240	5
12	P_span_6.7_alt_300_sensor_grp_12	12	6.7	P	300	960	840	7	320	240	6
13	P_span_7.9_alt_300_sensor_grp_13	13	7.9	P	300	960	720	8	480	320	7
14	P_span_8.6_alt_300_sensor_grp_14	14	8.6	P	300	1280	840	9	320	240	9
15	P_span_9.3_alt_300_sensor_grp_15	15	9.3	P	300	1080	720	10	512	480	10
16	P_span_10.4_alt_300_sensor_grp_16	16	10.4	P	300	1280	720	15	512	360	15
17	E_span_2.9_alt_500_sensor_grp_1	1	2.9	E	500	100	100	3	100	100	3
18	E_span_4.2_alt_500_sensor_grp_2	2	4.2	E	500	120	100	3	100	100	3
19	E_span_5.7_alt_500_sensor_grp_3	3	5.7	E	500	120	100	3	100	100	3
20	E_span_6.8_alt_500_sensor_grp_4	4	6.8	E	500	120	120	3	120	120	3
21	E_span_7_alt_500_sensor_grp_5	5	7.0	E	500	240	240	4	240	240	3

Armament Analytics Multiple Objective Decision Analysis (AAMODAT)
(Excel-based Spreadsheet Instrument)

- Organization maps to a logical decomposition of UAS system into air vehicle and payload subsystems
- First columns correspond to attributes of alternatives
- Attributes correspond to design choices, characteristics derive from those choices
- Rows correspond to alternative designs (instances)

UAS System Decomposes into Air Vehicle and Payload Subsystems

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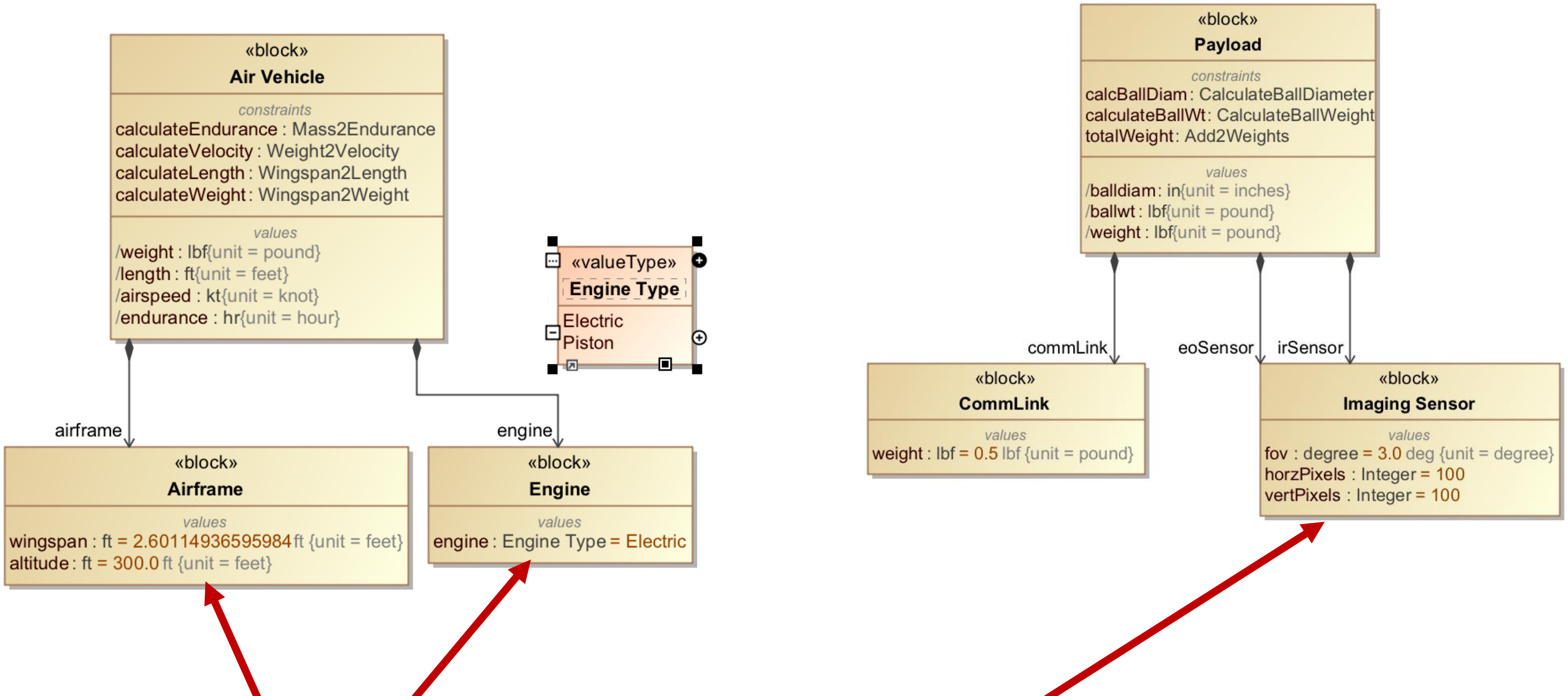
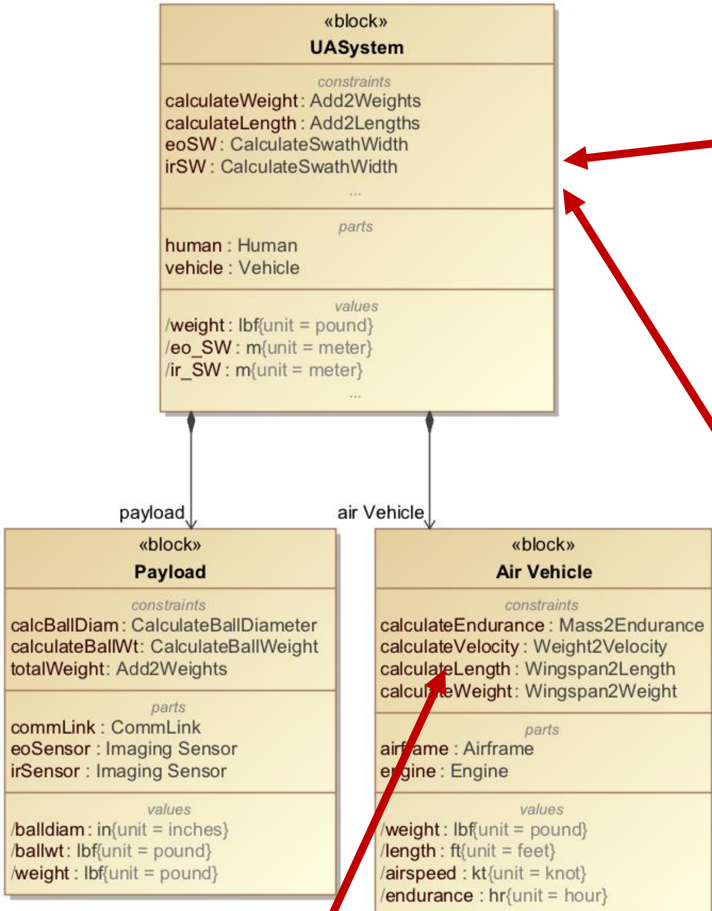


Physical Design Choice - Air Vehicle			Physical Design Choice - Payload					
Wingspan	Engine Type	Operating Altitude (ft.)	EO Imager Pixels Horizontal	EO Imager Pixels Vertical	EO FOV	IR Pixels Horizontal	IR Pixels Vertical	IR FOV
2.0	P	300	200	200	3	200	200	3
3.0	P	300	200	200	3	200	200	3
4.0	P	300	200	200	3	200	200	3
5.0	P	300	200	200	3	200	200	3
6.0	P	300	200	200	3	200	200	3
7.0	P	300	200	200	3	200	200	3

Armament Analytics Multiple Objective Decision Analysis (AAMODAT)
(Current implementation in Excel-based Spreadsheet Instrument)

UAS System Characteristics Depend on Attributes and Characteristics of Subsystems



- PAR diagrams for characteristics should be at lowest possible level of composition hierarchy
- Use of directed composition relationship ensures constraint relations execute in both MBSEPak and Cameo Simulation Toolkit (CST)

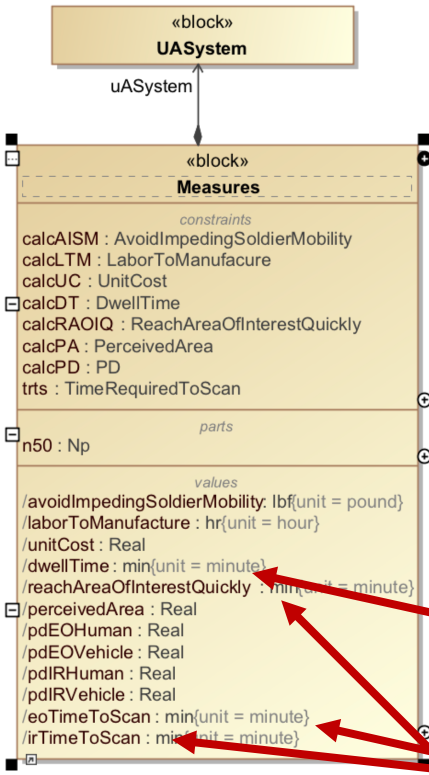
Pobability of Detection Intermediate Variables

human Bound	EO N_human Expected	EO N_human Upper Bound	EO N_vehicle Lower Bound	EO N_vehicle Expected	EO N_vehicle Upper Bound	IR N_human Lower Bound	I
.608	19.54	22.47	95.65	112.53	129.41	16.61	
.608	19.54	22.47	95.65	112.53	129.41	16.61	
.608	19.54	22.47	95.65	112.53	129.41	16.61	
.608	19.54	22.47	95.65	112.53	129.41	16.61	

System Characteristics (Intermediate Measures)

Weight (Lbs., Total sUAV)			Length (Ft., Air Vehicle)			Sensor Ball Dia. (Inches)			Weight (Lbs., Sensors)			Weight (Lbs., Comm Link)								
Lower Bound	Expected	Upper Bound	Lower Bound	Expected	Upper Bound	Lower Bound	Expected	Upper Bound	Lower Bound	Expected	Upper Bound	Lower Bound	Expected	Upper Bound	Lower Bound	Expected	Upper Bound	Lower Bound	Expected	Upper Bound
8.22	10.28	12.34	1.11	1.23	1.36	1.69	1.99	2.29	0.11	0.20	0.33	0.45	0.50	0.55	0.56	0.70	0.88	26.37	31.03	35.68
10.37	12.96	15.55	1.67	1.85	2.04	1.69	1.99	2.29	0.11	0.20	0.33	0.45	0.50	0.55	0.56	0.70	0.88	28.72	33.79	38.86
12.51	15.64	18.77	2.22	2.47	2.72	1.69	1.99	2.29	0.11	0.20	0.33	0.45	0.50	0.55	0.56	0.70	0.88	31.07	36.55	42.03
14.66	18.32	21.98	2.78	3.09	3.40	1.69	1.99	2.29	0.11	0.20	0.33	0.45	0.50	0.55	0.56	0.70	0.88	33.41	39.31	45.21

Measures are the Performance Metrics

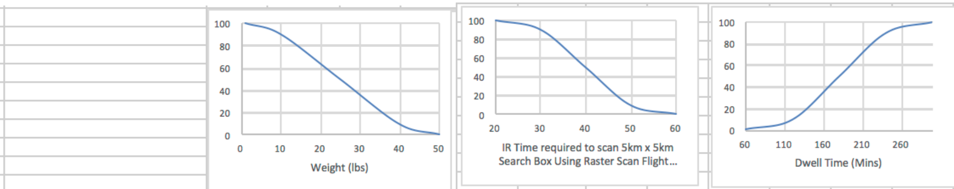


- Measures are calculated from design variables attributes and characteristics of UA System and its parts
- Measures can be represented by ranges or distributions of values

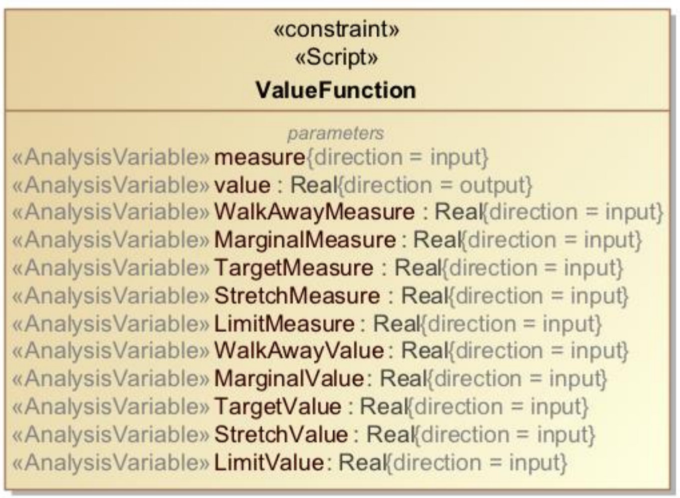
1.2 Maneuver to, scan across, and dwell at area of inte[illegible]															
1.2.1 Reach Area of Interest Quickly				1.2.2 Search Area of Interest Quickly								1.2.3 Dwell at area of interest for extended period			
Time required to fly 10km (Mins)				EO Time [illegible]ired to scan 5km x 5km Search Box Using Raster Scan Flight Pattern at proposed operating altitude				[illegible] required to scan 5km x 5km Search Box Using Raster Scan Flight Pattern at proposed				Dwell Time (Mins)			
more detail to follow				Assumes linear flight pattern				Assumes linear flight pattern				more detail to follow			
Lower Bound	Expected	Upper Bound	Rationale	Lower Bound	Expected	Upper Bound	Rationale	Lower Bound	Expected	Upper Bound	Rationale	Lower Bound	Expected	Upper Bound	Rationale
9.08	10.44	12.28		5342.003	5451.02	5560.043		5342.003	5451.02	5560.043		369.74	443.01	515.32	
8.34	9.59	11.28		4905.584	5005.70	5105.812		4905.584	5005.70	5105.812		401.82	480.10	557.49	
7.71	8.86	10.43		4535.087	4627.64	4720.192		4535.087	4627.64	4720.192		433.59	516.92	599.43	
7.17	8.24	9.70		4216.624	4302.68	4388.731		4216.624	4302.68	4388.731		465.13	553.54	641.19	
6.70	7.70	9.06		3939.952	4020.36	4100.767		3939.952	4020.36	4100.767		496.47	590.00	682.82	

SYSTEMS ENGINEERING Research Center

Value Functions are Monotonic Functions of Measures

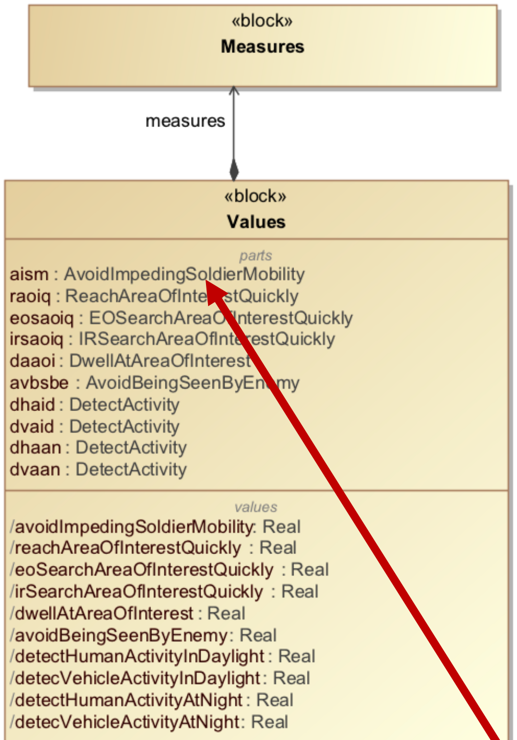


	x	v(x)	x	v(x)	x	v(x)
walkaway point	50	1	60	1	60	1
marginally acceptable	40	10	50	10	120	10
target value	25	50	40	50	180	50
stretch goal	10	90	30	90	240	90
meaningful limit	1	100	20	100	300	100

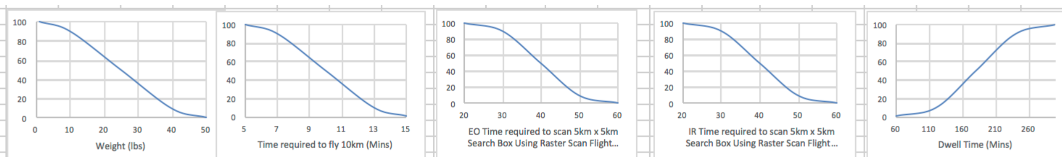


- Value functions characterize the utility of a calculated measure to one or more groups of stakeholders
- In UAS demo problem, values of the metrics correspond to:
  - Walkaway point (value = 1)
  - Marginally acceptable (10)
  - Target (50)
  - Stretch goal (90)
  - Meaningful limit (100)
- Value function implemented as linear interpolation

Values Normalize Measures to be Comparable



- Value weightings reflect importance of measures to stakeholders
- Different sets of weightings can reflect concerns of different stakeholders
- Uncertainty in measures and different value weights result in values having a range

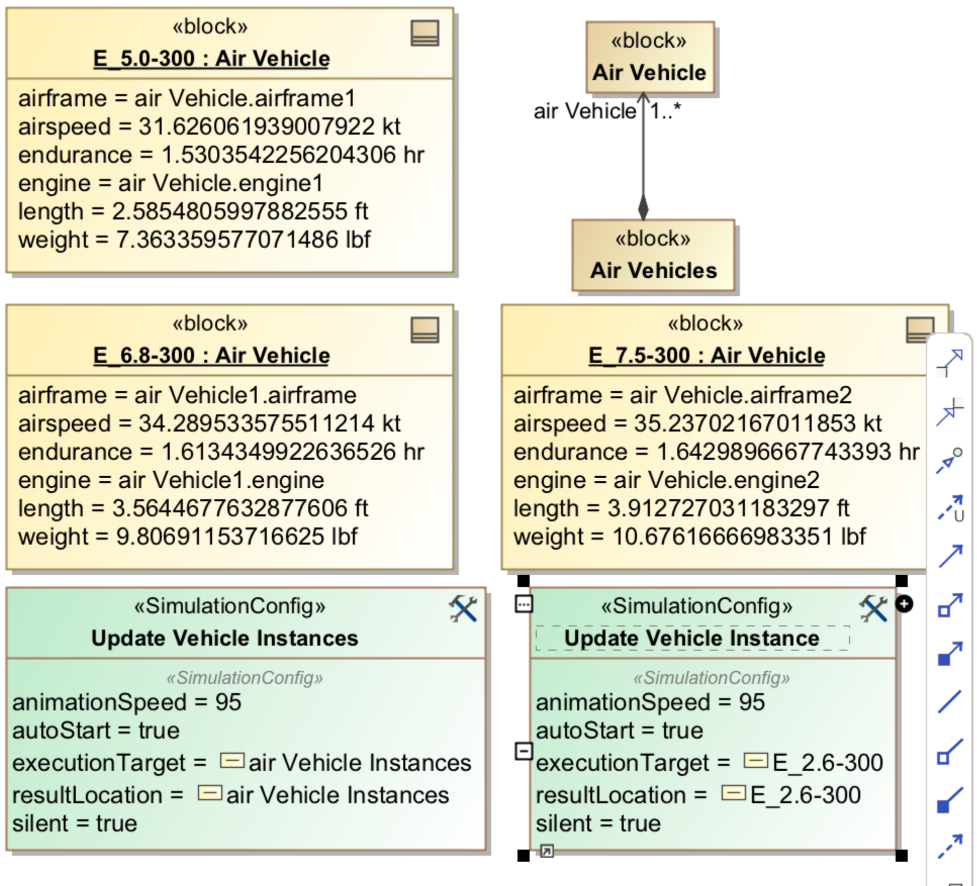


	x	v(x)	x	v(x)	x	v(x)	x	v(x)	x	v(x)
walkaway point	50	1	15	1	60	1	60	1	60	1
marginally acceptable	40	10	13	10	50	10	50	10	120	10
target value	25	50	10	50	40	50	40	50	180	50
stretch goal	10	90	7	90	30	90	30	90	240	90
meaningful limit	1	100	5	100	20	100	20	100	300	100

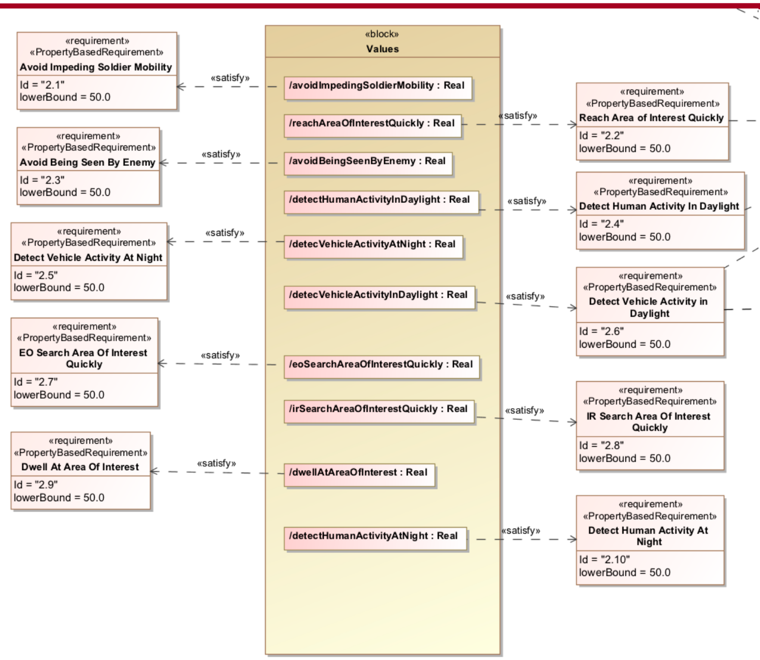
	1.1 Be Transportable				1.2 Maneuver to, scan across, and dwell at area of interest															
Fundamental Objective	1.1.1 Avoid Impeding Soldier Mobility				1.2.1 Reach Area of Interest Quickly				1.2.2 Search Area of Interest Quickly								.3 Dwell at area of interest for extended per			
Measure	Weight (lbs)				Time required to fly 10km (Mins)				EO Time required to scan 5km x 5km Search Box Using Raster Scan Flight Pattern at				IR Time required to scan 5km x 5km Search Box Using Raster Scan Flight Pattern at				Dwell Time (Mins)			
Value Space	more detail to follow				more detail to follow				Assumes linear flight pattern				Assumes linear flight pattern				more detail to follow			
	Lower Bound	Expected	Upper Bound	Rationale	Lower Bound	Expected	Upper Bound	Rationale	Lower Bound	Expected	Upper Bound	Rationale	Lower Bound	Expected	Upper Bound	Rationale	Lower Bound	Expected	Upper Bound	Rationale
		96.34				30.58				1.00				1.00				1.40		
		92.93				46.75				1.00				1.00				2.70		
		92.83				47.18				1.00				1.00				2.74		
		90.21				57.36				1.00				1.00				3.69		
		88.20				60.74				1.00				1.00				4.03		

Creating Instances in Magic Draw

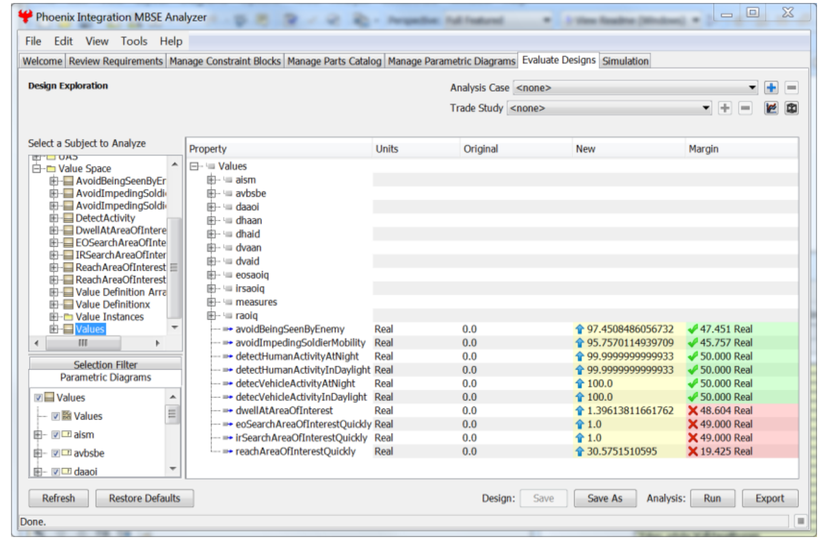
- PAR diagrams and constraints are not evaluated during creation of an instance
- Lists of a block type are used to update and save sets of instances



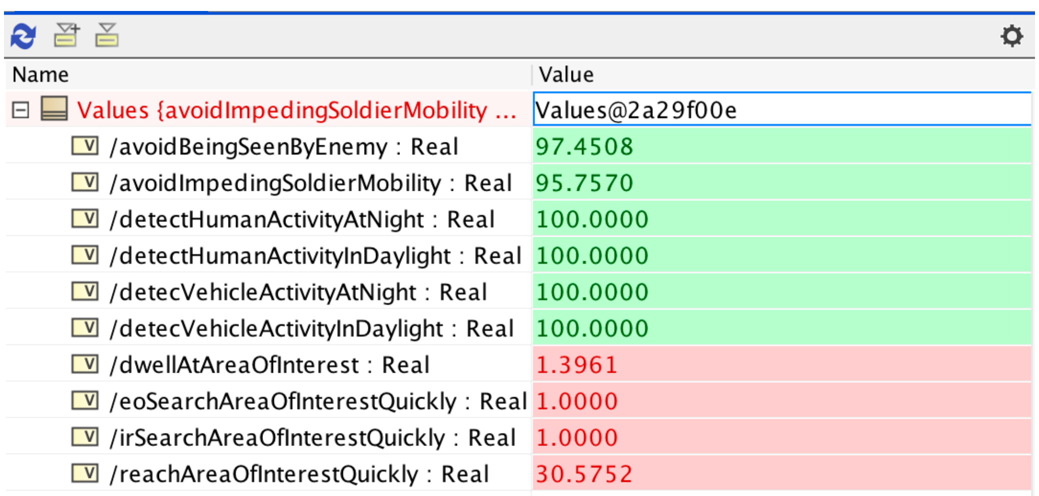
Model Bounds on Values as Requirements



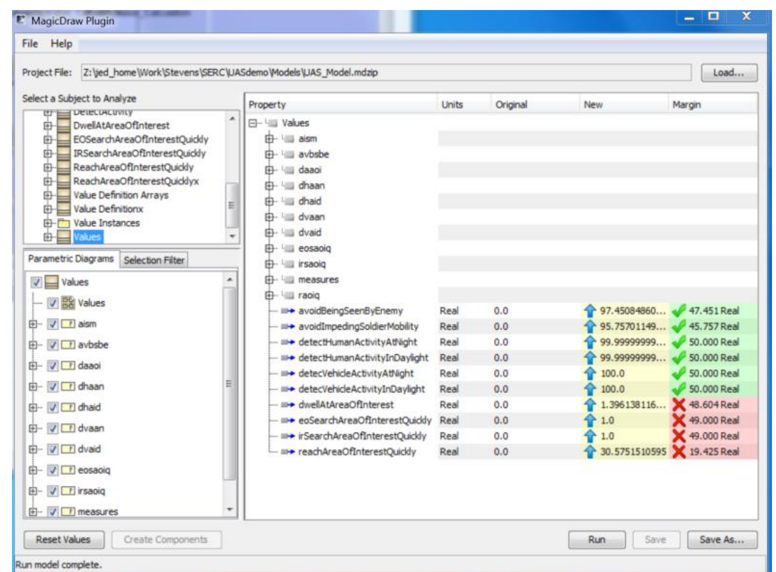
MBSEPak from within MagicDraw



Cameo Simulation Toolkit

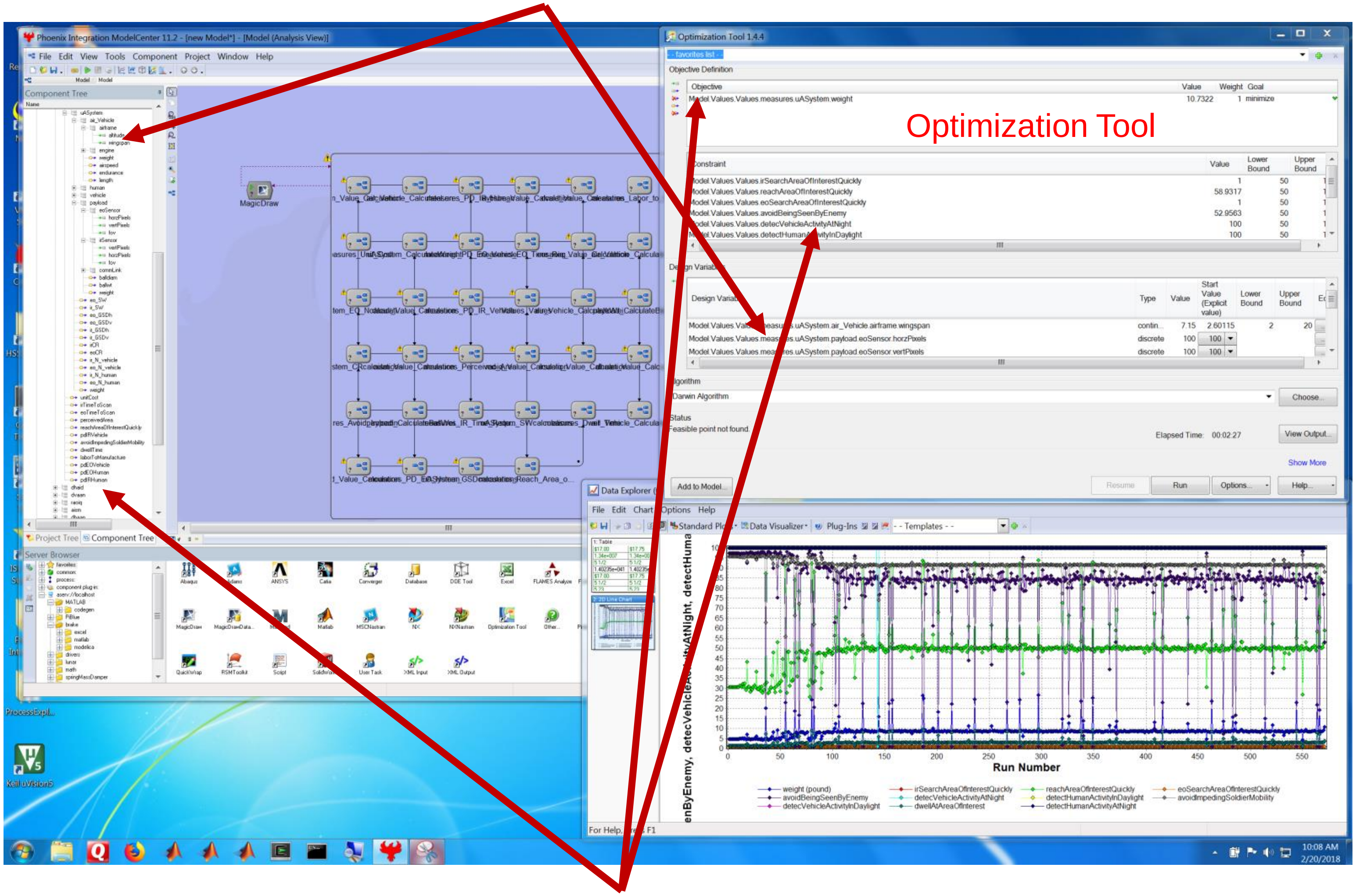


MBSEPak from within Model Center



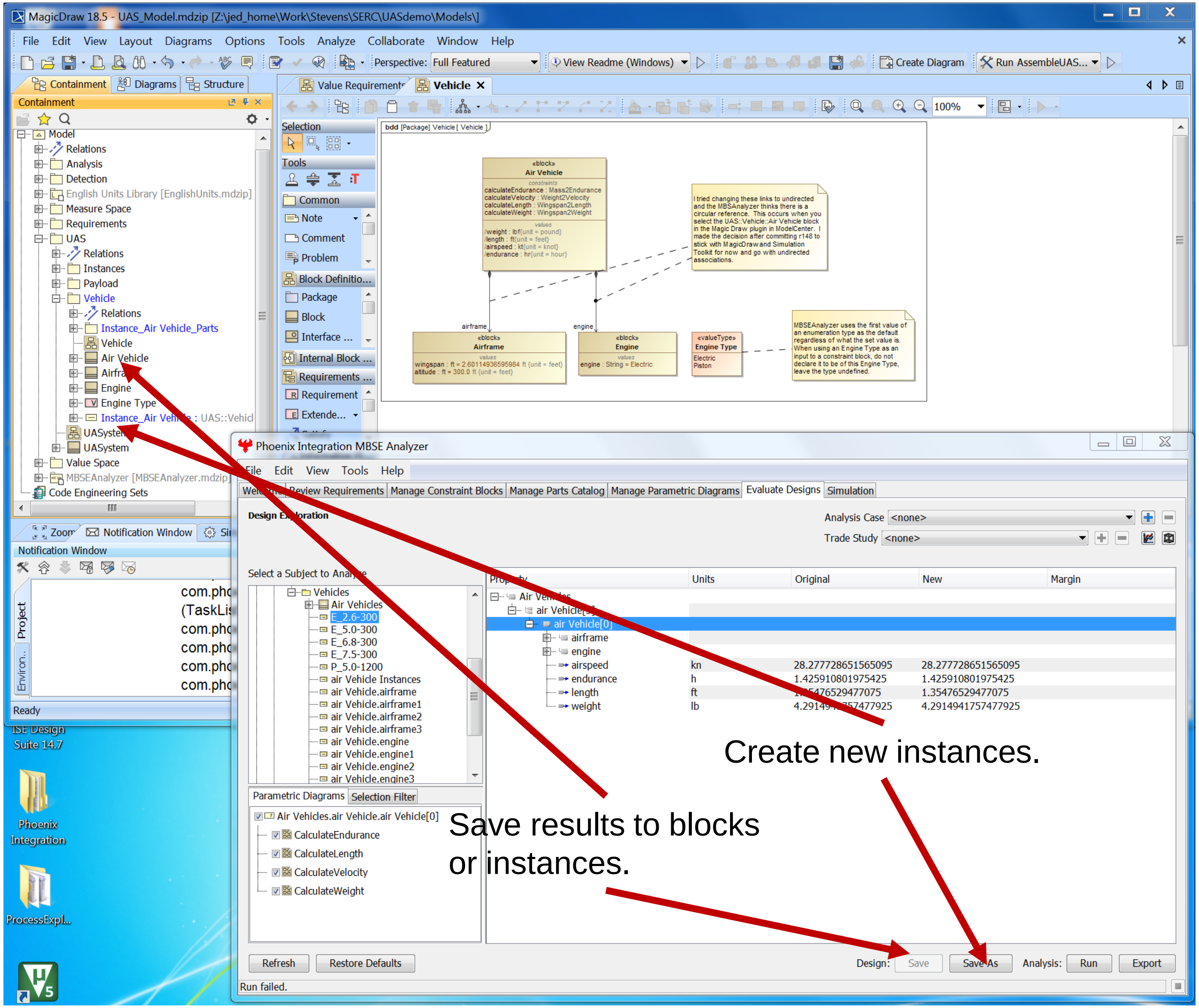
Analysis Model of UAS in Model Center: Workflow Can be a Constraint in SysML

Independent Variables (are Design Variables)



Dependent Variables -- Values (are Constraints/Objectives)

MBSEPak Used to Perform Trade-Studies & Design of Experiments & Save Results to Model



Summary

- Use case #1 shows method for using ModelCenter to create and MDAO workflows for assessing Key Performance Parameters at system-level
- Use case #2 shows method for integrating ModelCenter with Graphical CONOPS to do analysis of alternatives at mission-level
- Use case #3 shows approach to formalize a Decision Framework process in SysML with the MBSEPak to transform into workflows for ModelCenter
  - Lessons–learned: It is important to use appropriate method to model in SysML in order to get best results from MBSEPak transformation into ModelCenter