Transforming Systems Engineering through Model Centric Engineering

Sponsors: NAVAIR and ARDEC

By

Dr. Mark Blackburn

10th Annual SERC Sponsor Research Review

November 8, 2018

FHI 360 CONFERENCE CENTER

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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

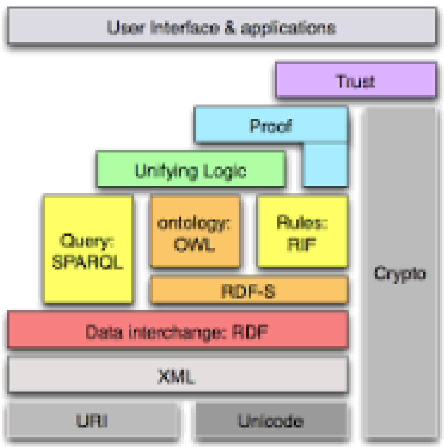
RT-195
- Mark Blackburn (PI), Stevens
- Mary Bone - Stevens
- Ralph Giffin - Stevens
- Bob Hathaway- Stevens
- Benjamin Kruse - Stevens
- Russell Peak – Georgia Tech.
- Stephen Edwards – Georgia Tech.
- Adam Baker (Grad) – Georgia Tech.
- Marlin Ballard (Grad) – Georgia Tech.
- Donna Rhodes - MIT
- Mark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

Overview and Accomplishments

- Perspectives and status RT-170/195 - NAVAIR
  - Systems Engineering Transformation (SET) Framework
    - A new operational paradigm between government and industry
  - Using a prototype Collaborative Authoritative Source of Truth
  - Surrogate pilot experiment(s) for assessing/refining the SET Framework
    - Developed methods for linking Mission models, System models, and SOW Evaluation models & Surrogate contractor refinement of system models to formalize source selection – and more
  - Navy and DoD Ontology Suite (not discussed)
- Perspectives and status RT-168 – ARDEC
  - Prototype an Interoperability and Integration Framework (IoIF) to formalize Decision Framework concept using SysML, Semantic Web Technologies (SWT), Decision Ontology, OpenMBEE with Visualizations
  - Uses cases applying Multidisciplinary Design Analysis and Optimization (MDAO) for Graphical CONOPS, Mission, and System levels trades

Research Thrusts

Semantic Web Technologies



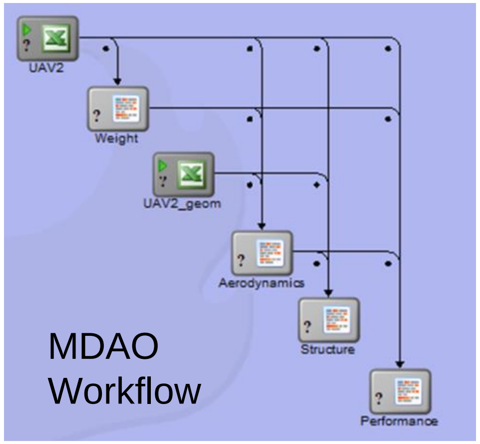
Enforces **Modeling Methods**

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

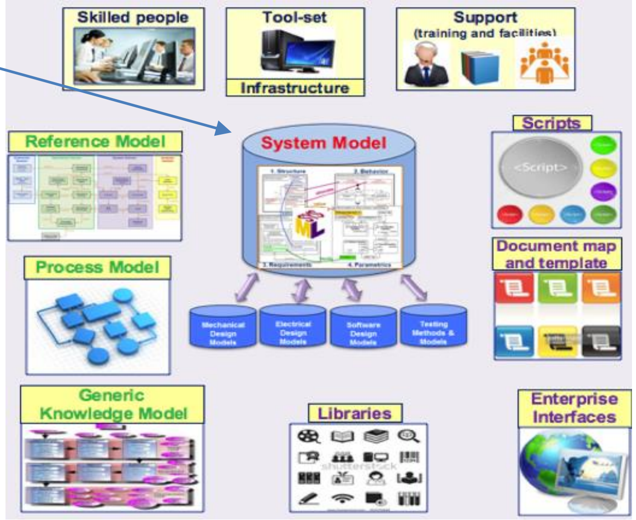
Multidisciplinary Design, Analysis and Optimization MDAO



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

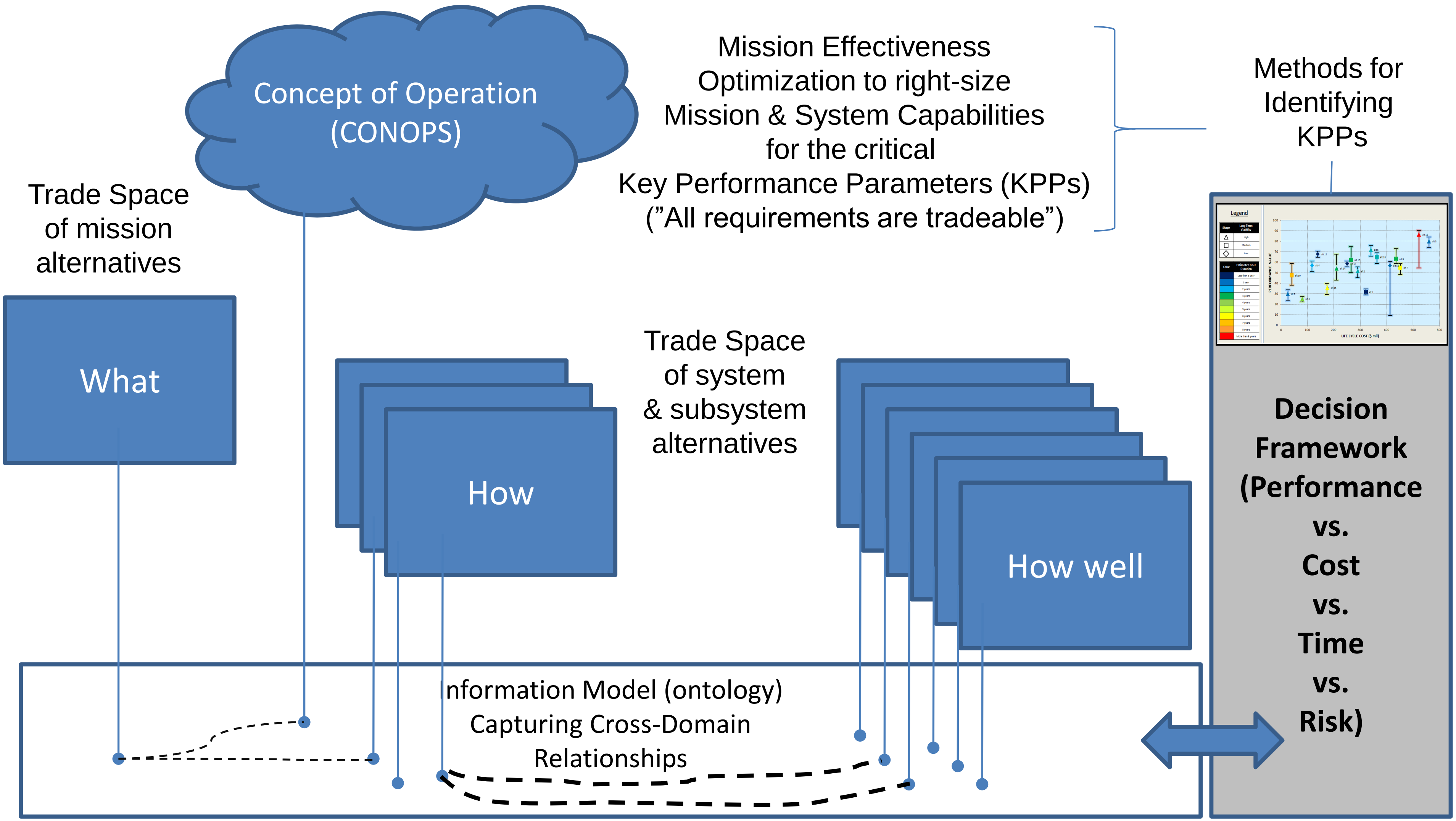
Provides optimization analysis **Across Domains** to support KPP and alternatives trades at mission, system, & subsystem levels

Integrated Modeling Environment



ARDEC Research Examples & Interoperability and Integration Framework (IoIF)

Perspectives on Characterizing Challenges of Research Space

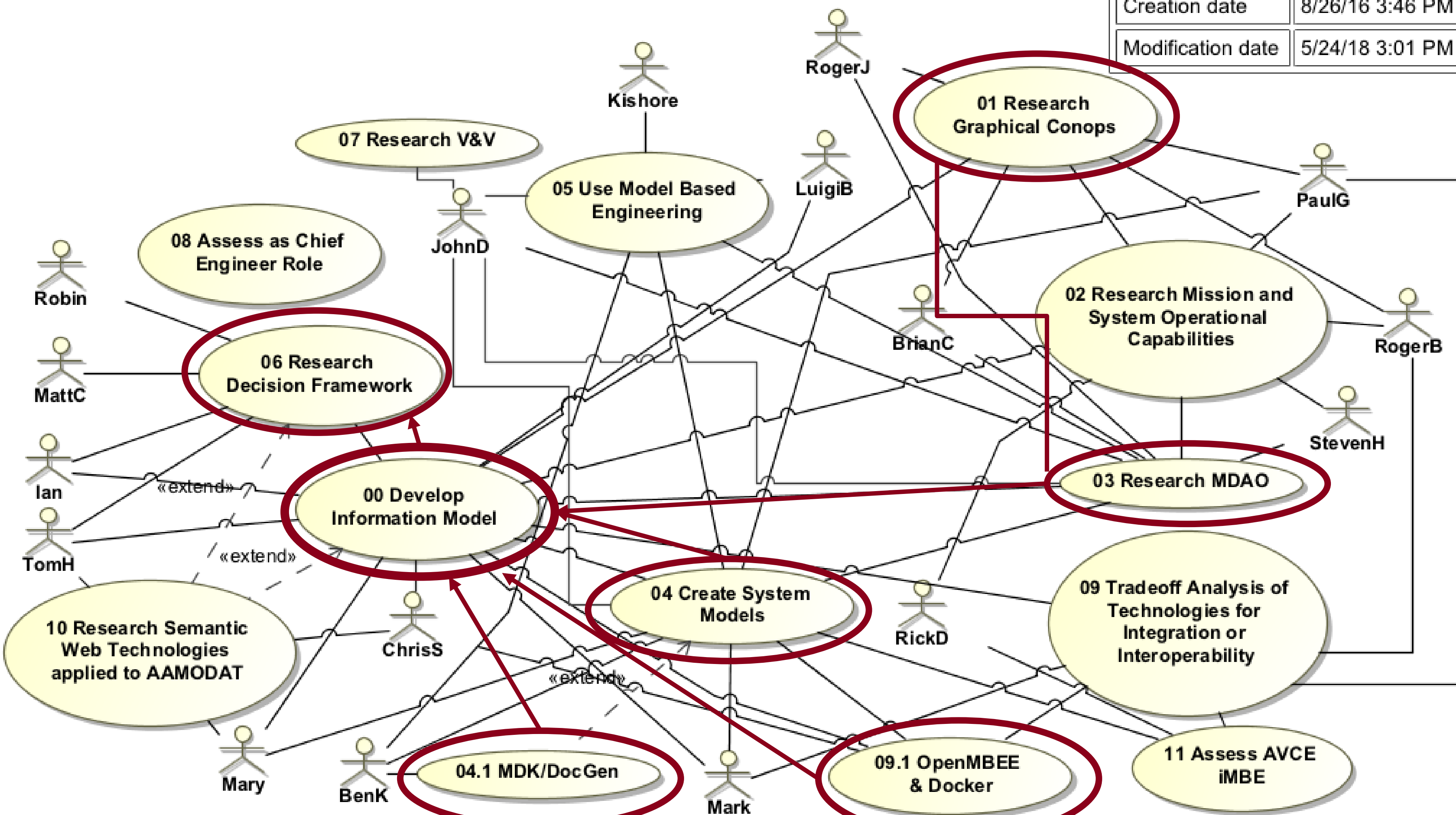


Reasoning about completeness and consistency of information across domains

ARDEC RT-168 Use Case Perspective and Team

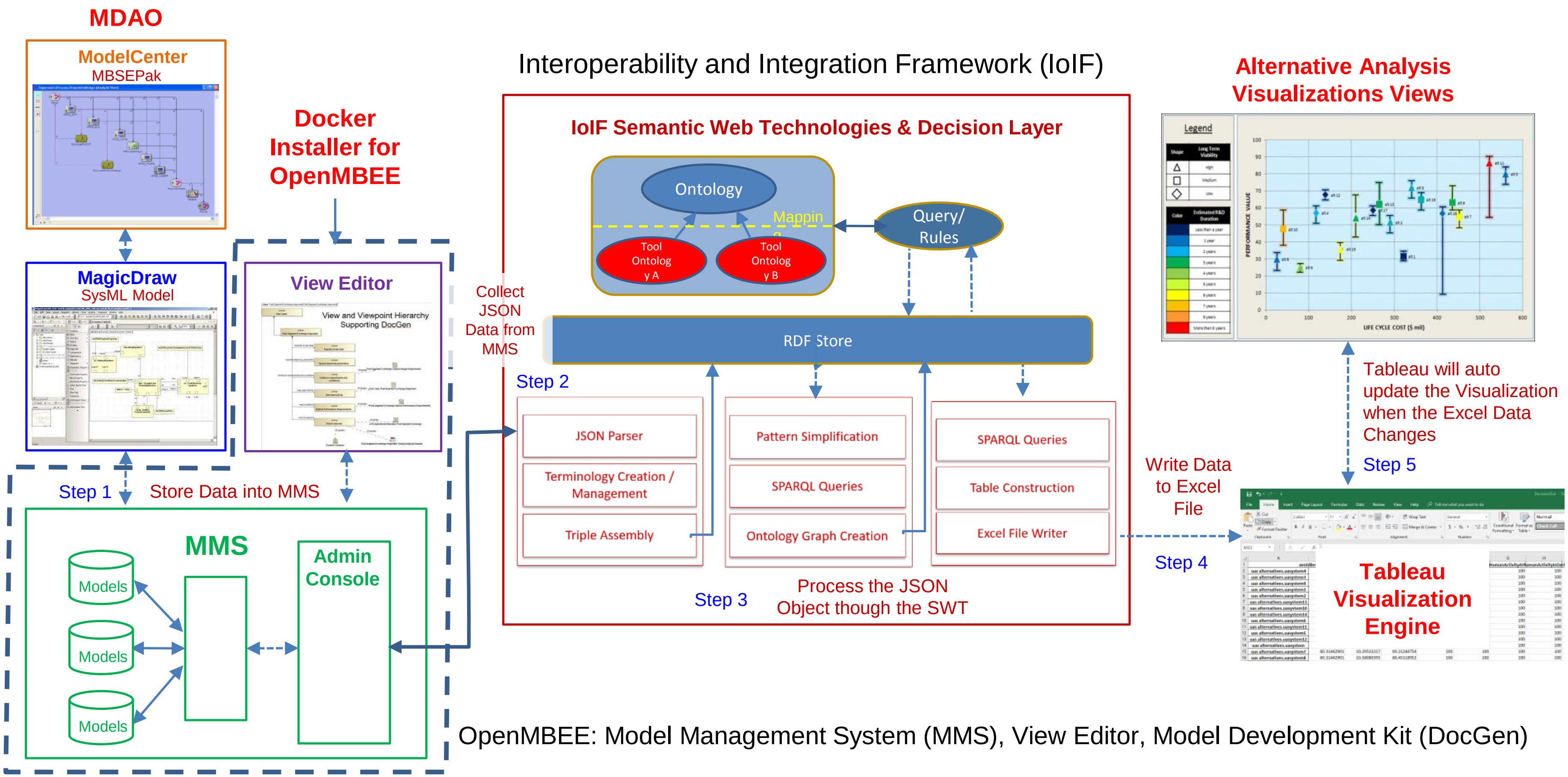
Phase II Completed in August 2018

Diagram name	ResearchUseCases
Author	blackburnmr
Creation date	8/26/16 3:46 PM
Modification date	5/24/18 3:01 PM



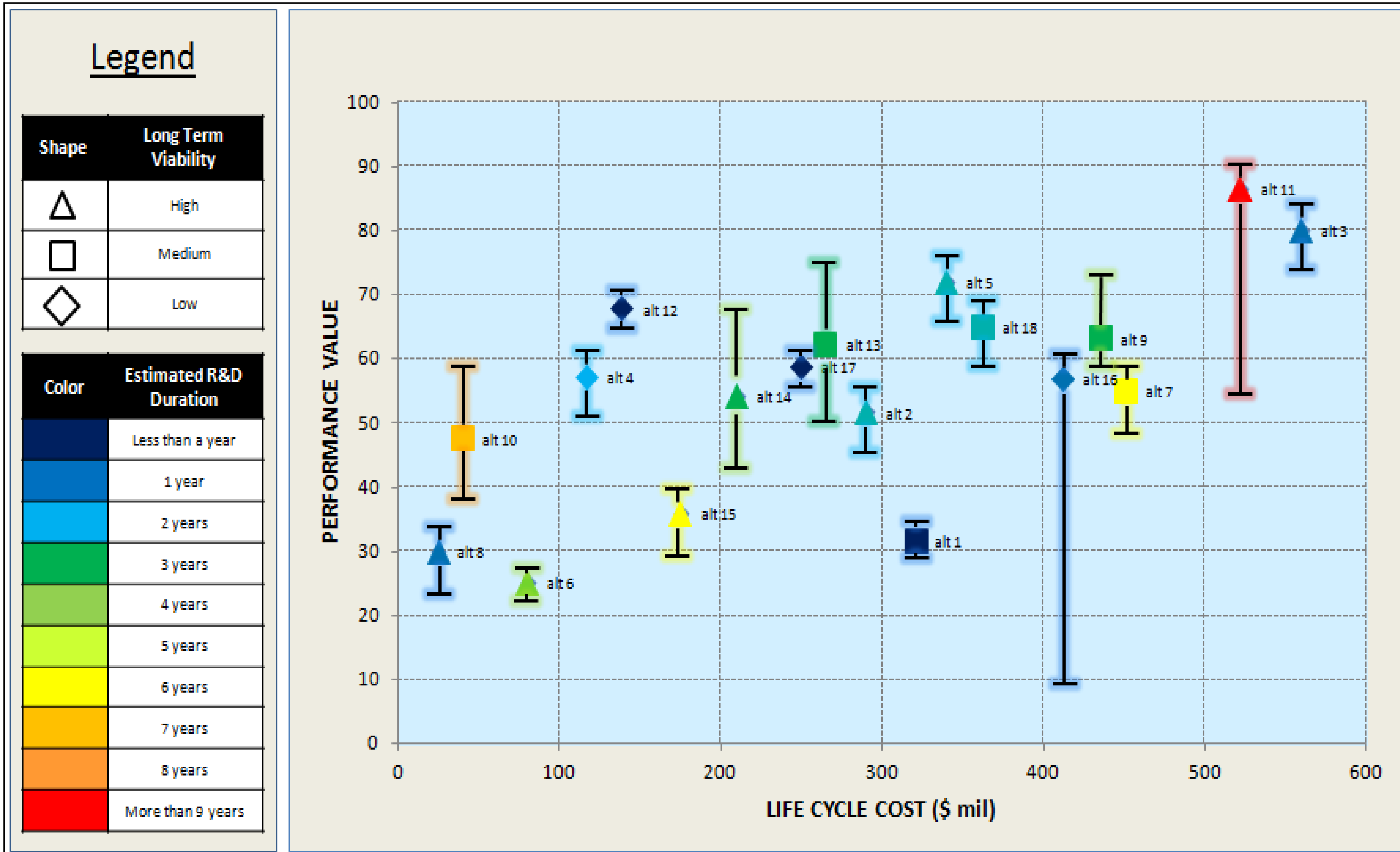
Interoperability and Integration Framework (IoIF) using Semantic Web Technologies

- Uses OpenMBEE, SysML Models and ModelCenter (MDAO) and a Decision Ontology to support Visualization of Tradespace



RDF: Resource Description Framework
SPARQL: Query Language for RDF

Visualizing Alternatives – Value Scatterplot with Assessing Impact of Uncertainty*



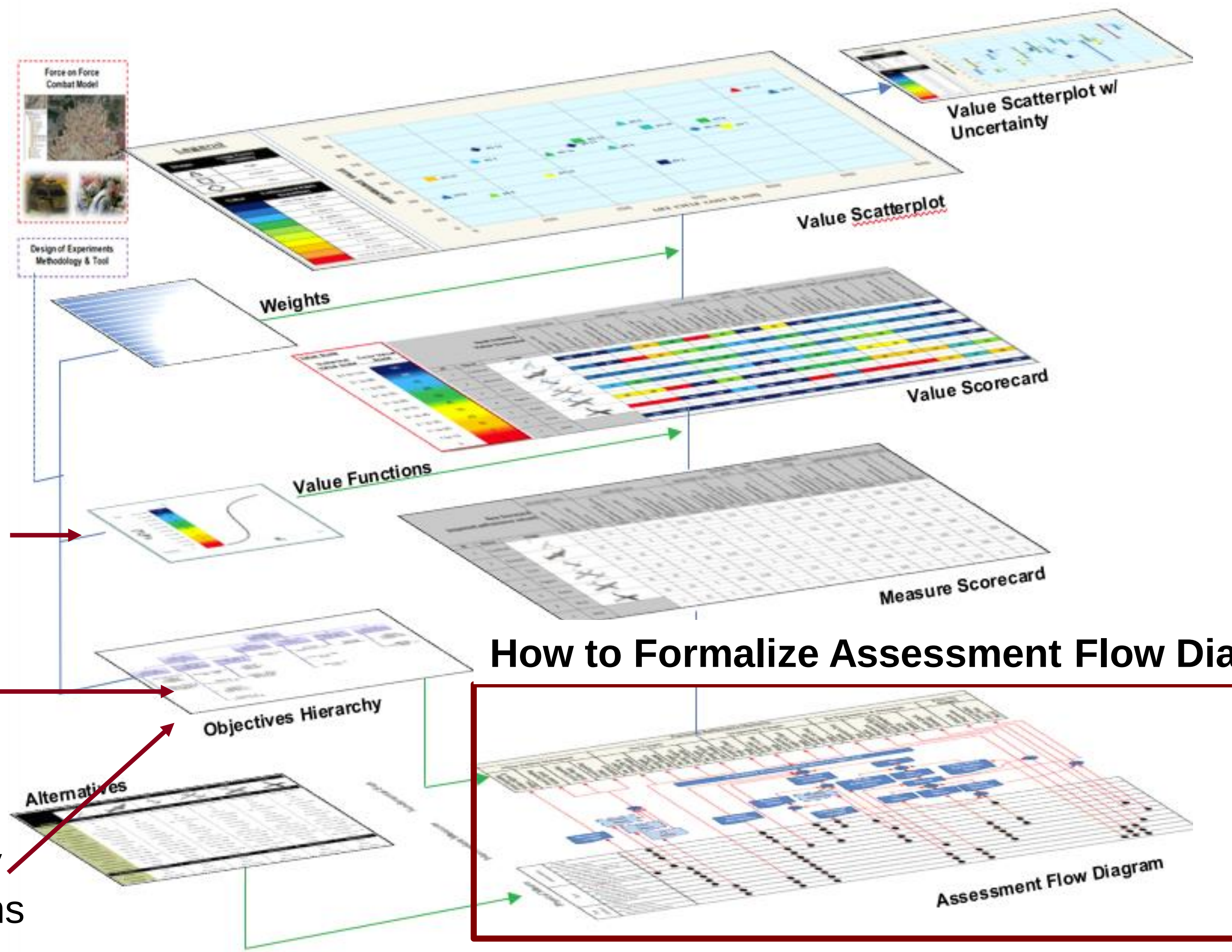
Cilli, M. Seeking Improved Defense Product Development Success Rates Through Innovations to Trade-Off Analysis Methods, Dissertation, Stevens Institute of Technology, Nov. 2015.

Decision Support Model Construct

Value Functions

Identify KPPs

Objective Hierarchy of Decisions



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

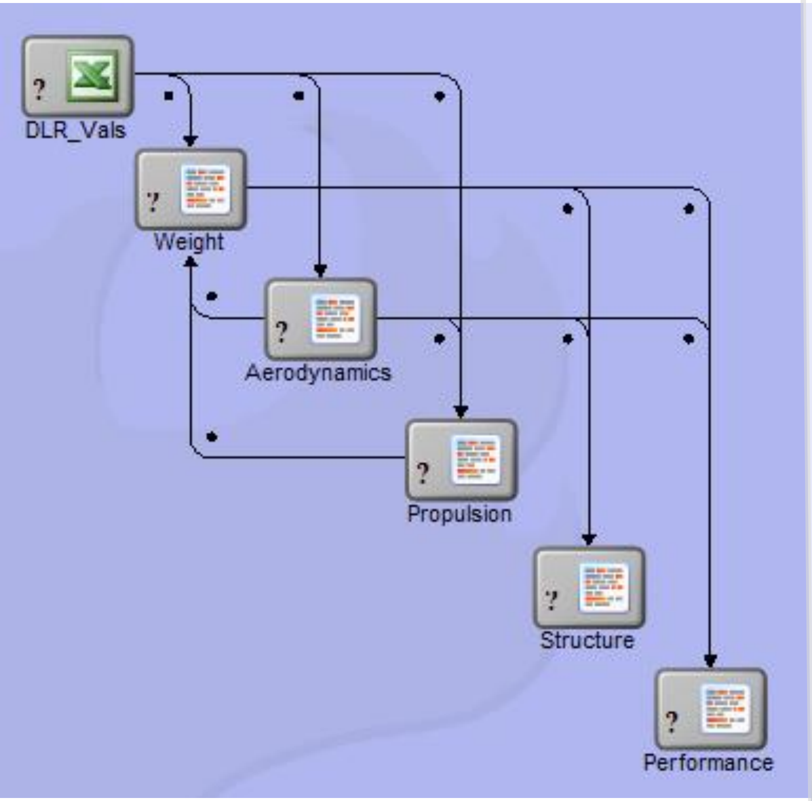
Formalized Assessment Flow Diagram of Decision Framework using ModelCenter/MBSEPak

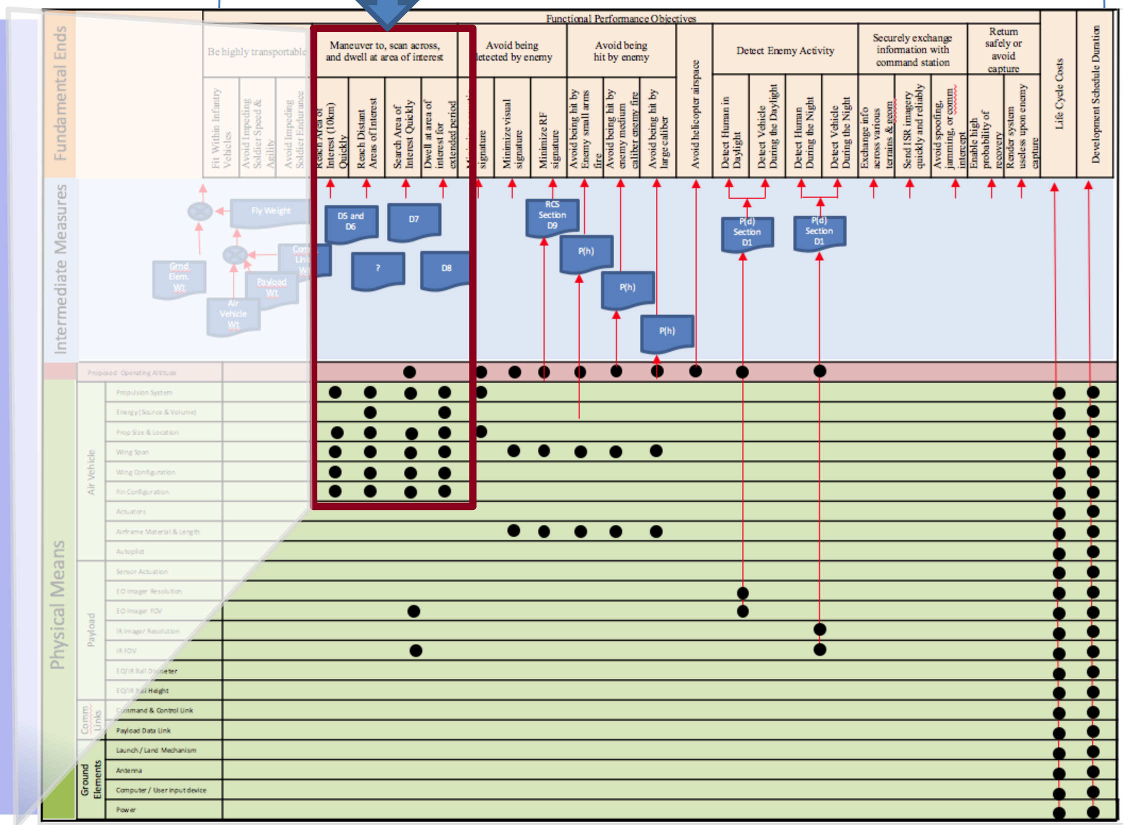
✓Can MDAO represent Assessment Flow Diagram (AFD)? YES

✓Does AFD characterize needed MDAO workflows? YES

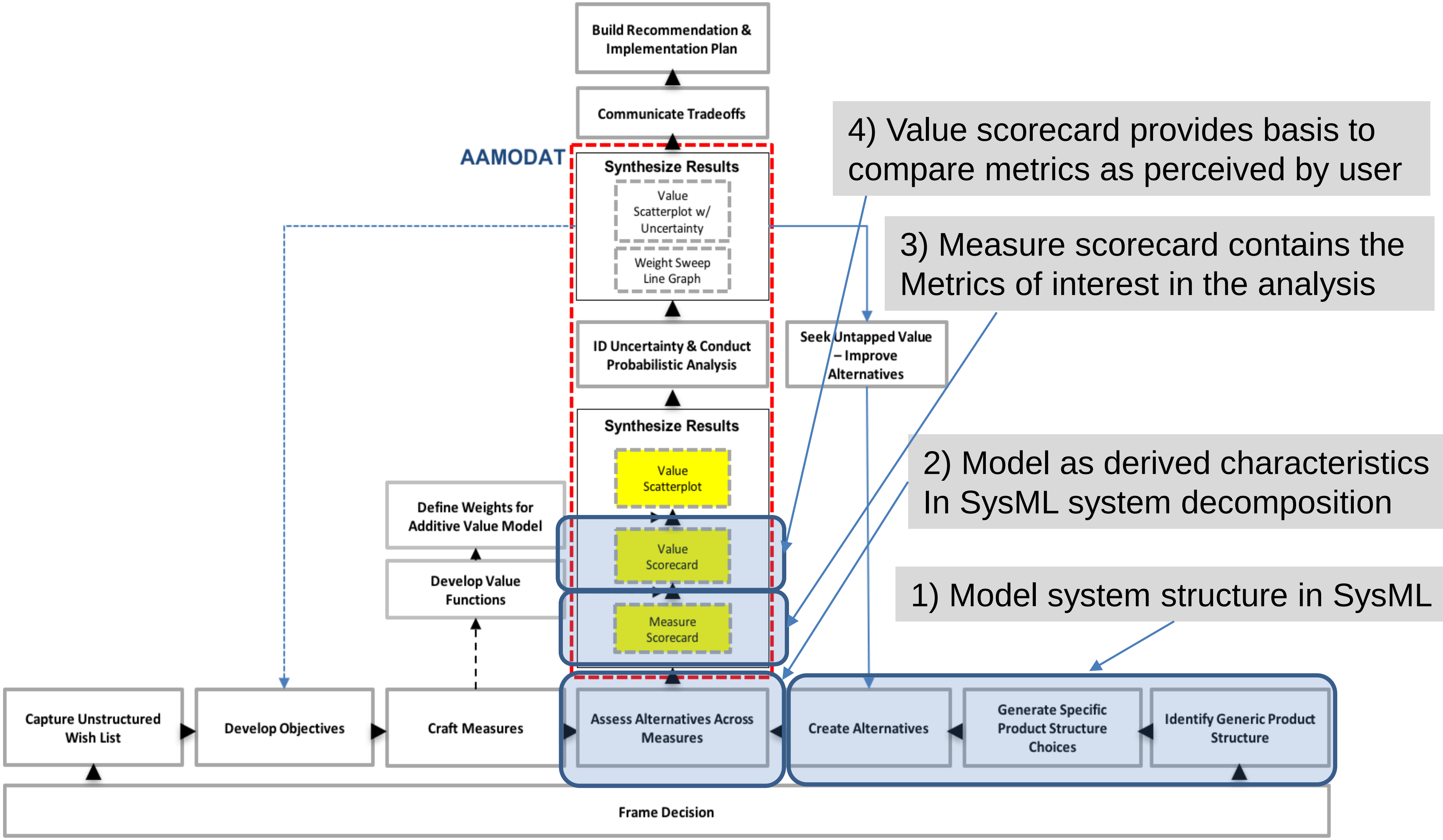
Key Performance Function
(Key Performance Parameter [KPP])

MDAO Workflow for KPP





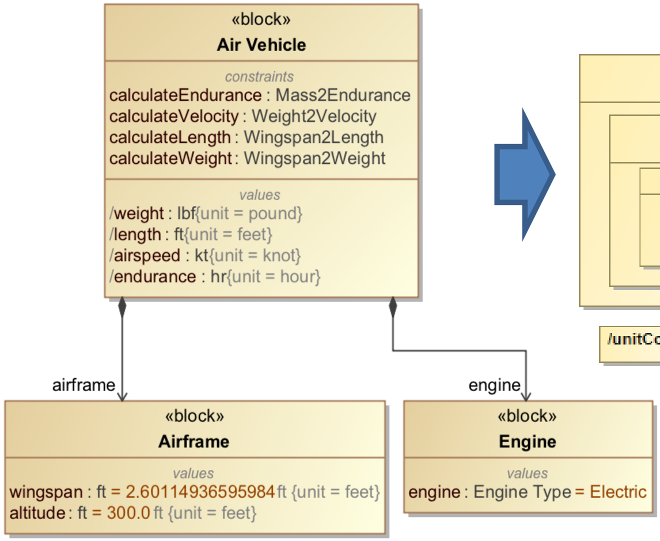
Steps to Formalize Decision Support Model Construct using SysML and ModelCenter



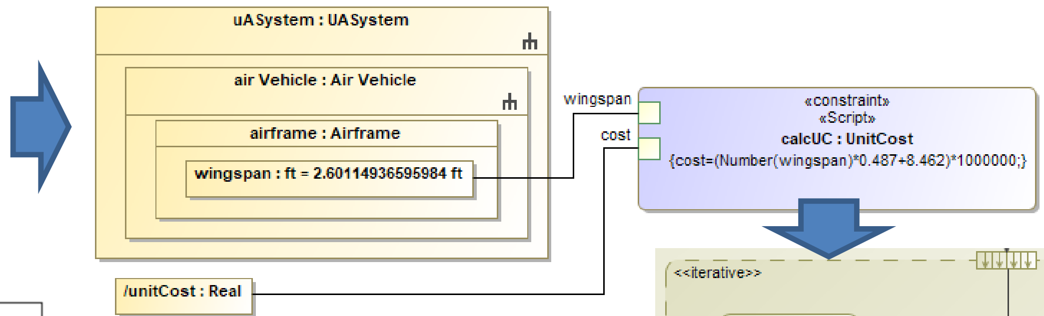
Cilli, M. Seeking Improved Defense Product Development Success Rates Through Innovations to Trade-Off Analysis Methods, Dissertation, Stevens Institute of Technology, Nov. 2015.

UAS model in SysML (by John Dzielski)

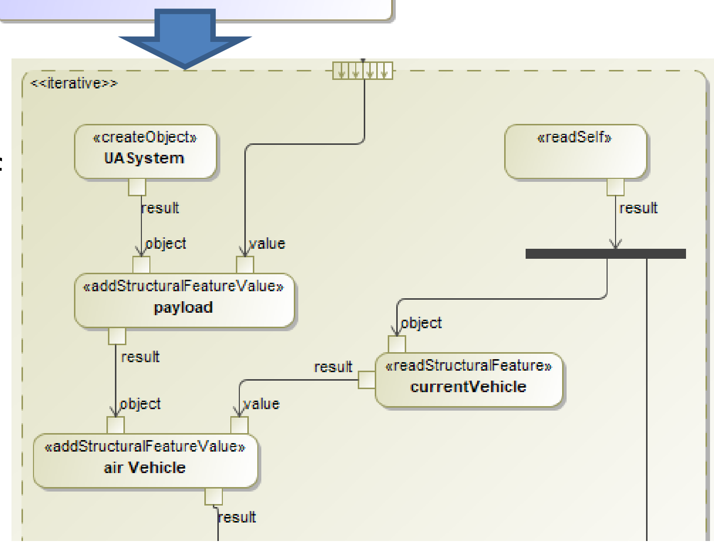
- Design Variables/Attributes in Block Hierarchy



- Parametrics



- Generation of Alternatives

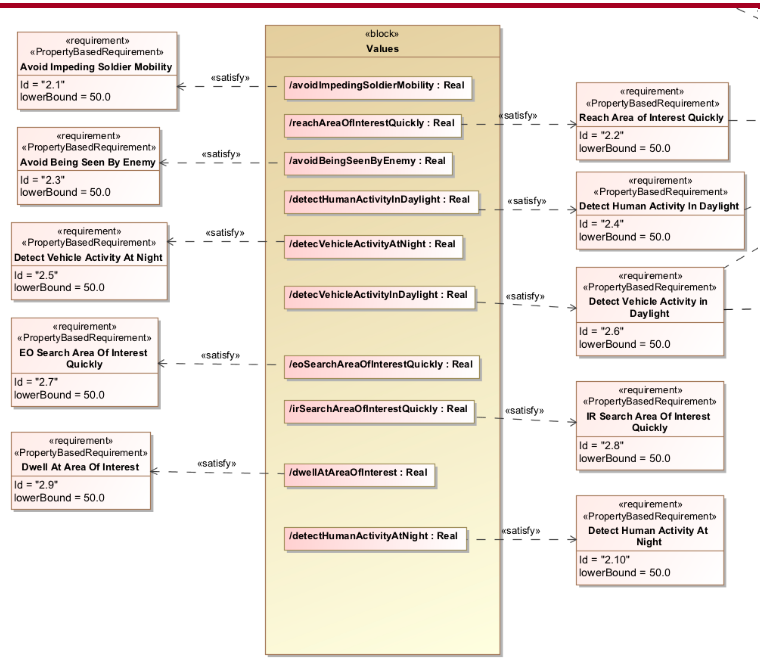


- Resulting UAS Instances

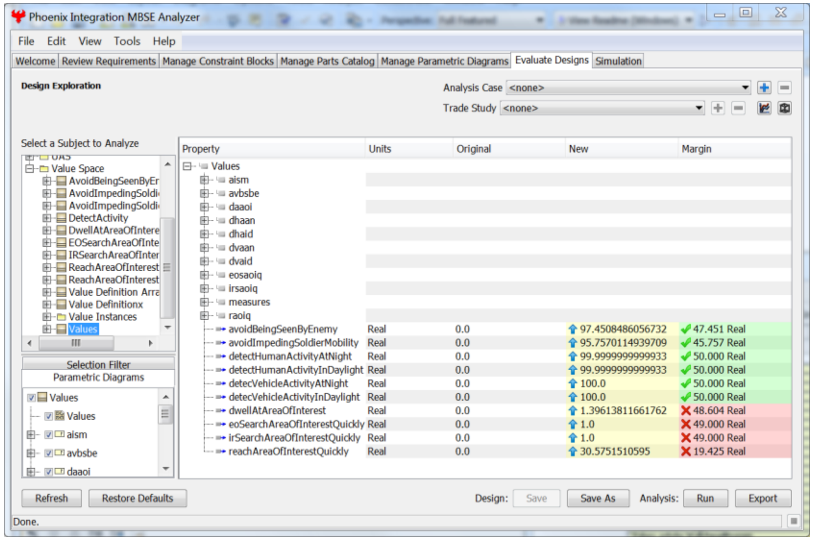
More details provided in Webinar

Applications for Three Research Use Cases in Model Centric Engineering using ModelCenter and MBSEPak at:
https://www.phoenix-int.com/applications-three-research-use-cases-model-centric-engineering-using-modelcenter-mbse-analyzer/

Simulations of Model Constraints Checks Bounds on Values as Requirements

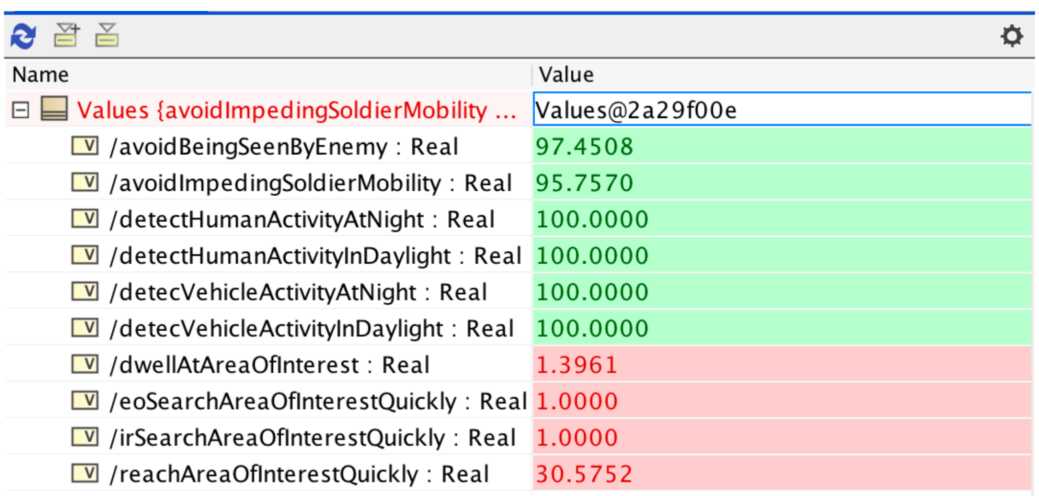


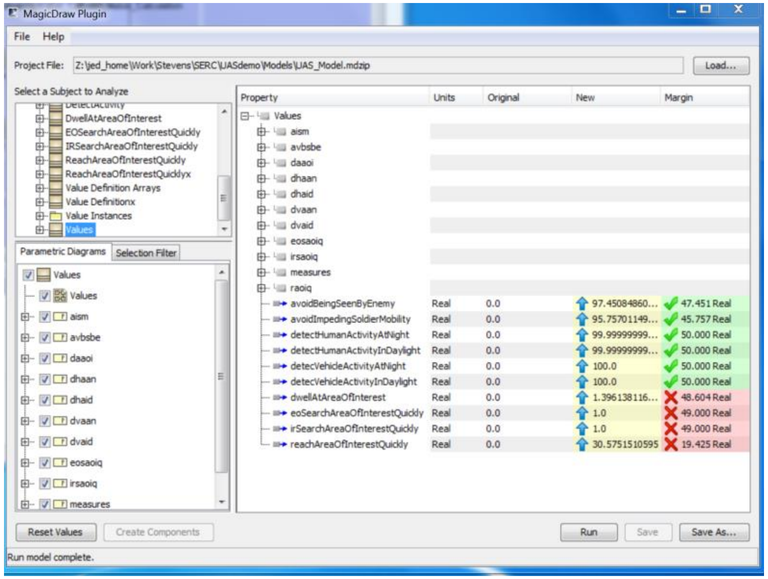
MBSEPak from within MagicDraw



MBSEPak from within Model Center

Cameo Simulation Toolkit

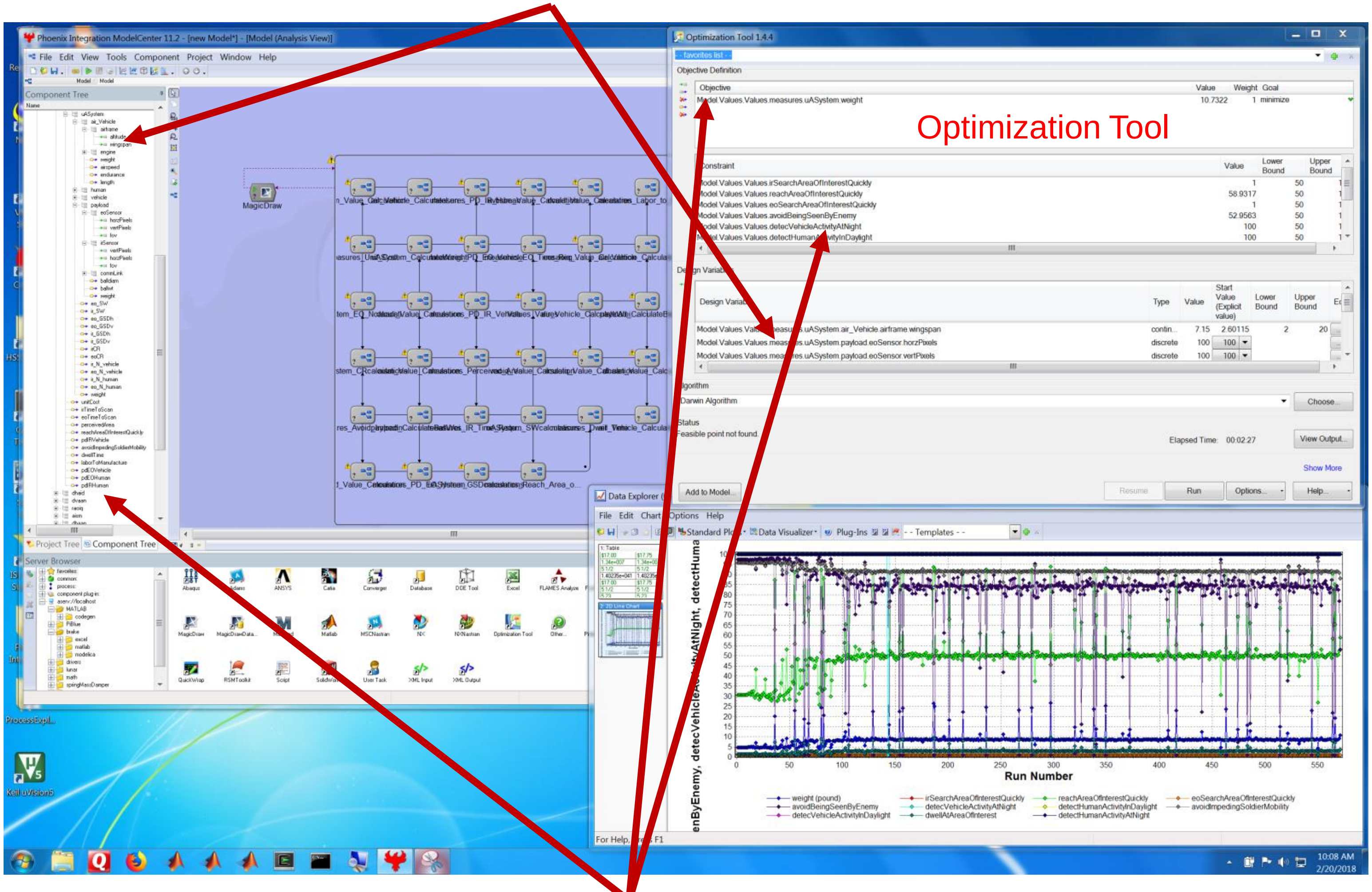




Mark R. Blackburn, PhD,

SysML Model Transformed using MBSEPak into ModelCenter for MDAO

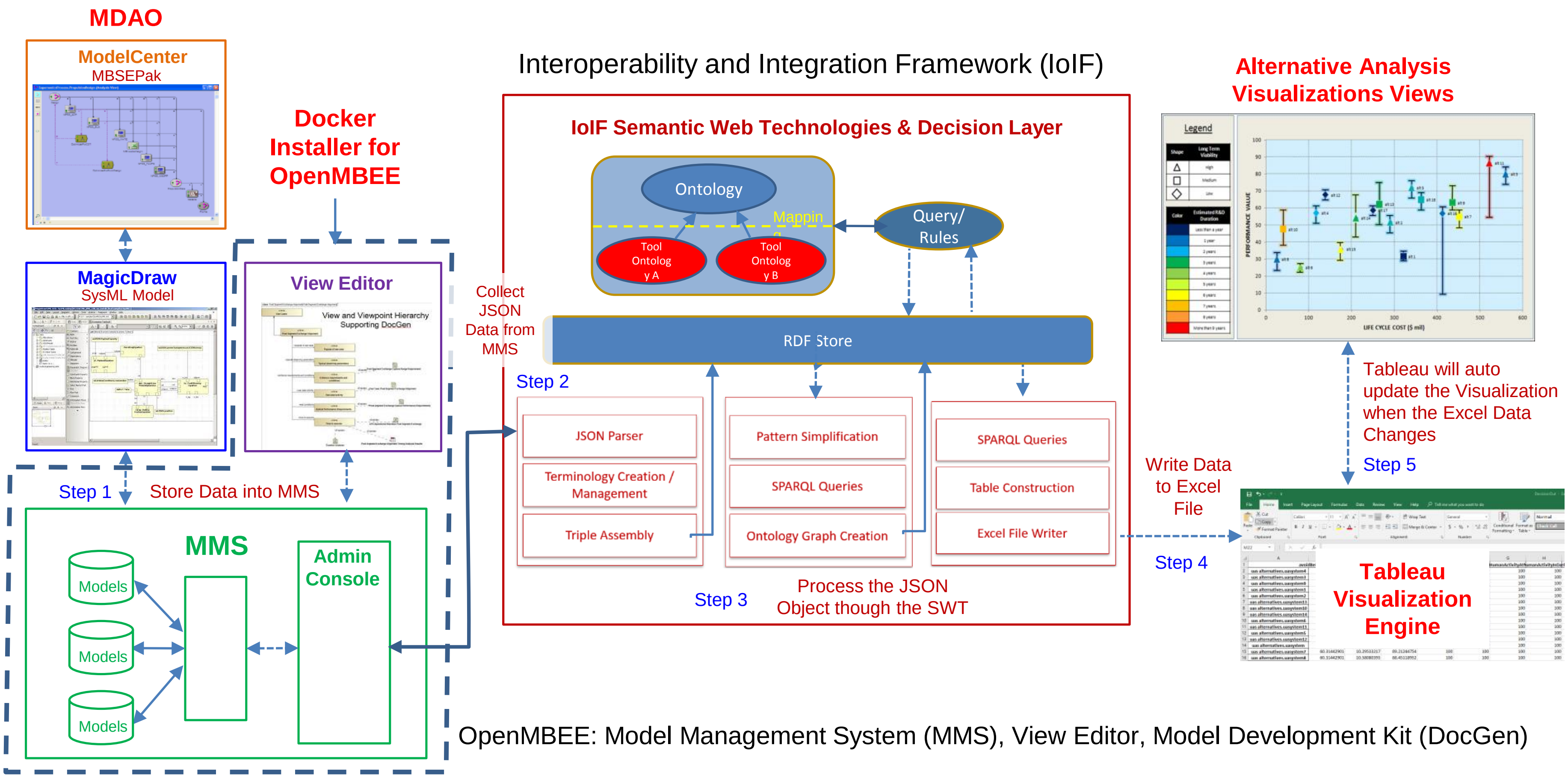
Independent Variables (are Design Variables)



Dependent Variables -- Values (are Constraints/Objectives)

Interoperability and Integration Framework (IoIF) using Semantic Web Technologies

- Uses OpenMBEE, SysML Models and ModelCenter (MDAO) and a Decision Ontology to support Visualization of Tradespace



RDF: Resource Description Framework
SPARQL: Query Language for RDF

Emergence of FDA Process from Open Biomedical Ontologies (OBO) Parallels Decision Ontology

- OBO foundational to solving the human genome
- Basic Formal Ontology (BFO) foundational to developing interoperable ontologies

Analogous to Decision Framework

Basic Formal Ontology (BFO)

RELATION TO TIME / GRANULARITY	CONTINUANT				OCCURRENT
	INDEPENDENT		DEPENDENT		
ORGAN AND ORGANISM	Organism (NCBI Taxonomy)	Anatomical Entity (FMA, CARO)	Organ Function (FMP, CPRO)	Phenotypic Quality (PaTO)	**Biological Process** (GO)
CELL AND CELLULAR COMPONENT	Cell (CL)	**Cellular Component** (FMA, GO)	Cellular Function (GO)		
MOLECULE	Molecule (ChEBI, SO, RnaO, PrO)		**Molecular Function** (GO)		Molecular Process (GO)

FDA (Decision Process)

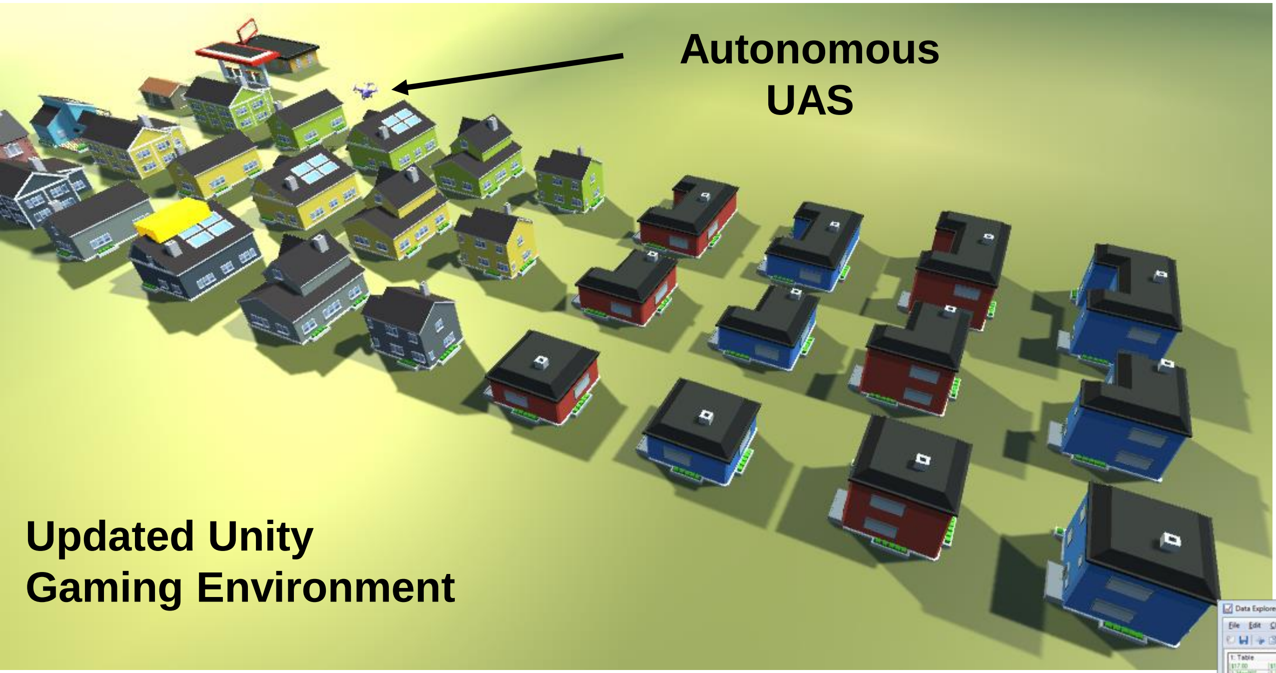
Original OBO (Open Biomedical Ontologies) Foundry

(Gene Ontology in yellow)

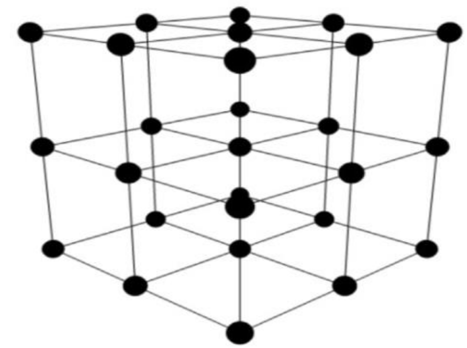
Barry Smith – Engineering Ontology Landscape, March 22, 2018

Graphical CONOPS with Unity Gaming Engine Exposes Mission-level Parameters

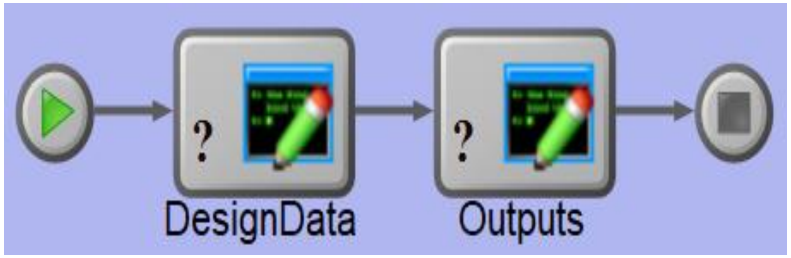
Graphical CONOPS Simulation with MDAO tools Exercises DoE Space ‘Headlessly’

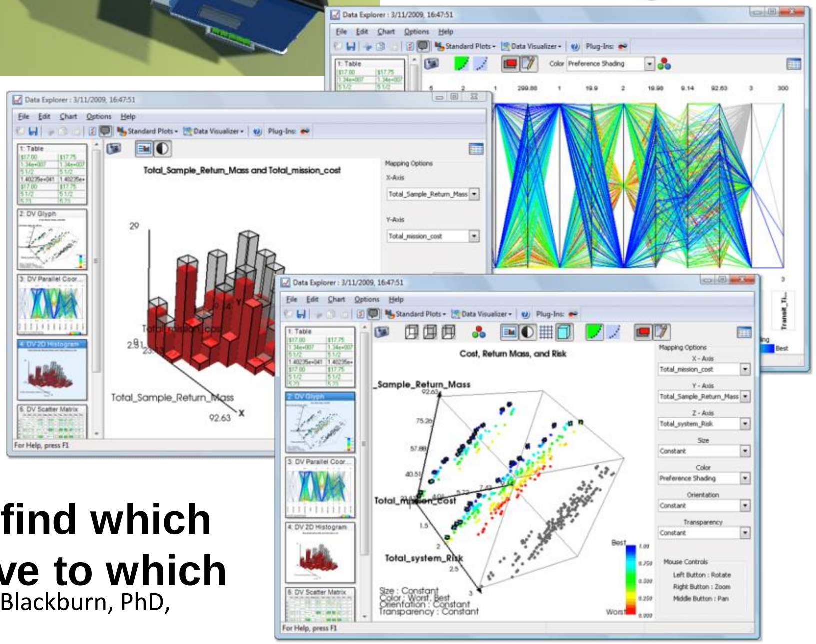


1000s of runs to cover Design of Experiments vs. 10s that could be run manually



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





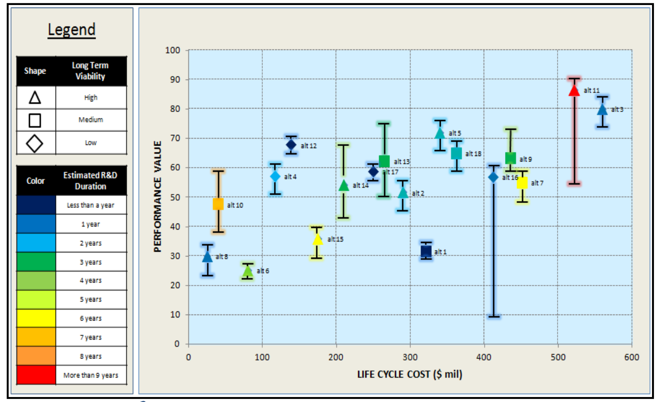
Brian Chell and Roger Jones

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

Future: Mission Capabilities Alternative Analysis of Composable System Alternatives using IoIF

- Ontologies provide representations to enable AI/Machine Learning

Mission/CONOPS

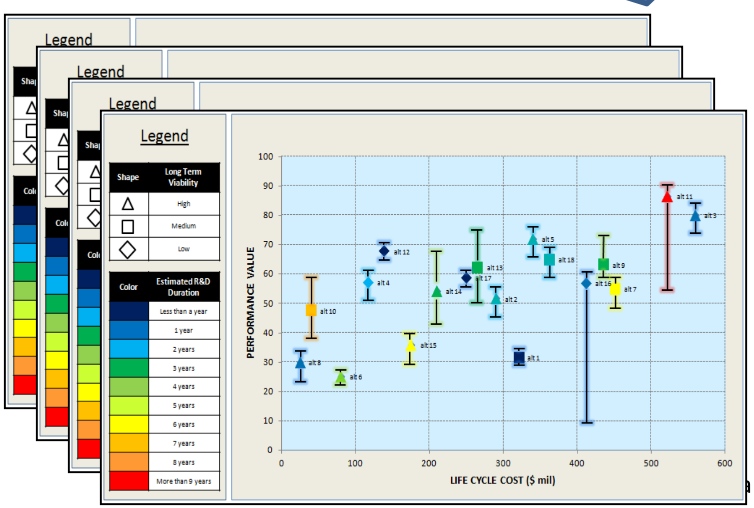


Mission Capabilities for Tradespaces incorporating Territory, Tactics and Terrain Scenarios

2) Inverse design optimization problem

3) Connection of the forward problem and the inverse problem through feedback control?

System Tradespaces of Candidate Solutions that could support Mission Capabilities



4) New: design optimization in a learning system and in multiple learning systems

response to changing aspect of Tactics, Terrain and Territory

response to Red Team

1) Forward design optimization problem

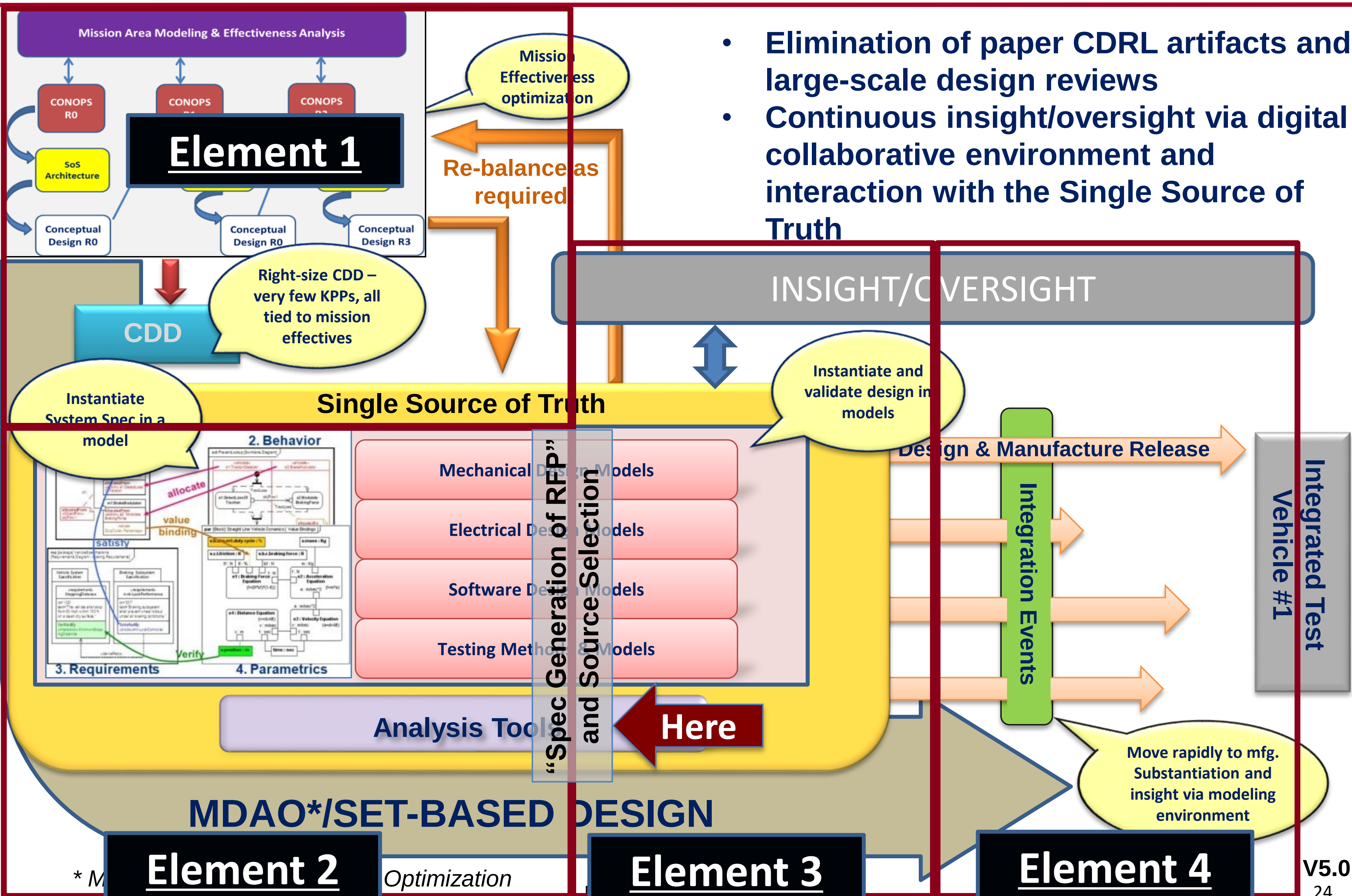
Surrogate Pilot for NAVAIR
SE Transformation Framework Experiments

NAVAIR SERC Research Historical Perspective

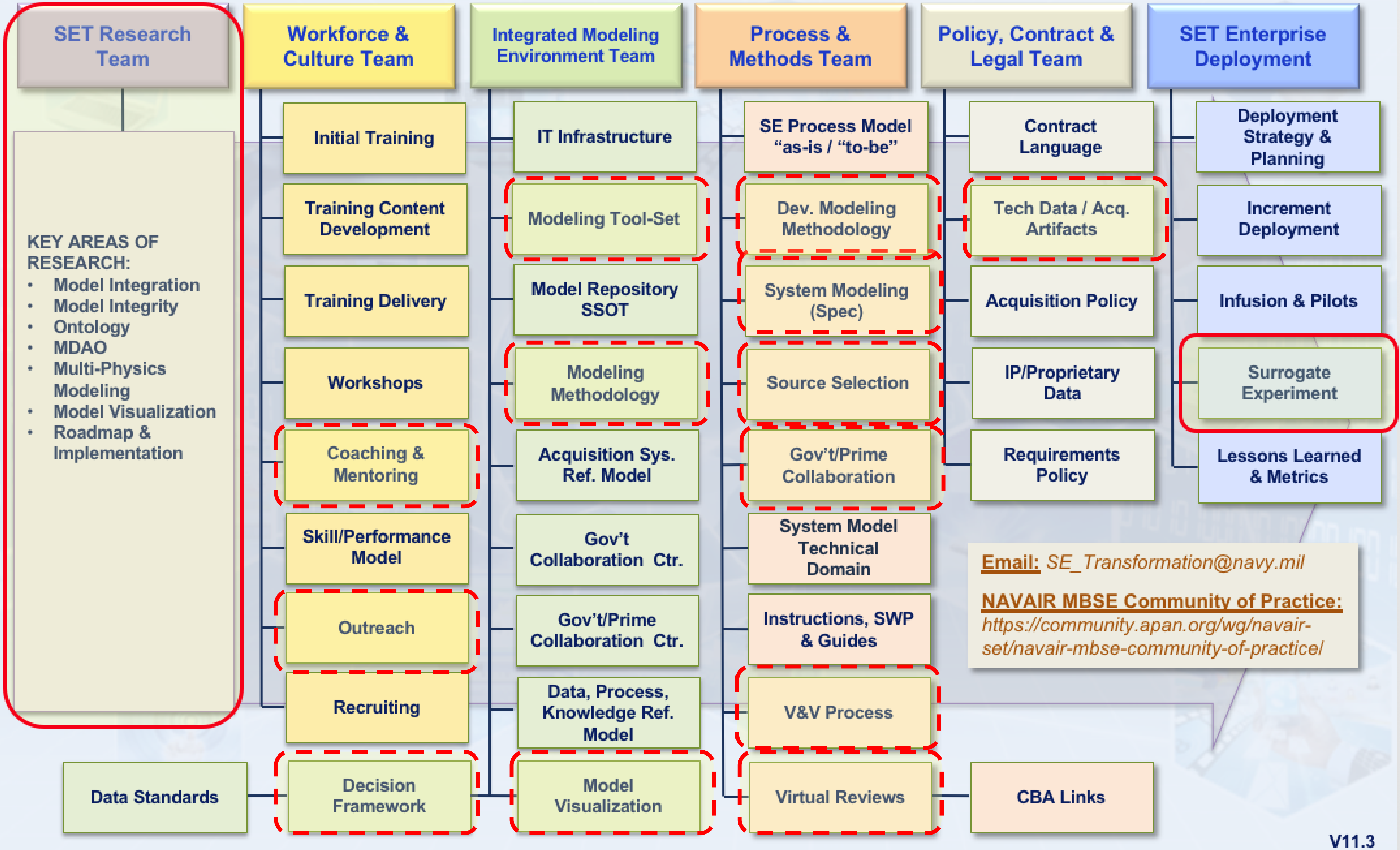
- 2013-2015: Global Scan of Most Holistic approaches to MCE/DE
- 2015: NAVAIR leadership decides they must move quickly to keep pace with other organizations that adopted MCE
- 2016: NAVAIR leadership – Accelerate Systems Engineering Transformation (SET) based on new **SET Framework** Concept
- 2017: Systematic planning of six (6) SET Functional Areas
- 2017 - late: **Surrogate Pilot Experiments kickoff** to Characterize, Assess and Refine SET Framework approach to Model-based Acquisition using new operational paradigm between government and industry
- 2018 – now: Awaiting Request for Proposal (RFP) Response from Surrogate Contractor

Surrogate Pilot focus is on ***Characterizing, Assessing, and Refining*** SET Framework

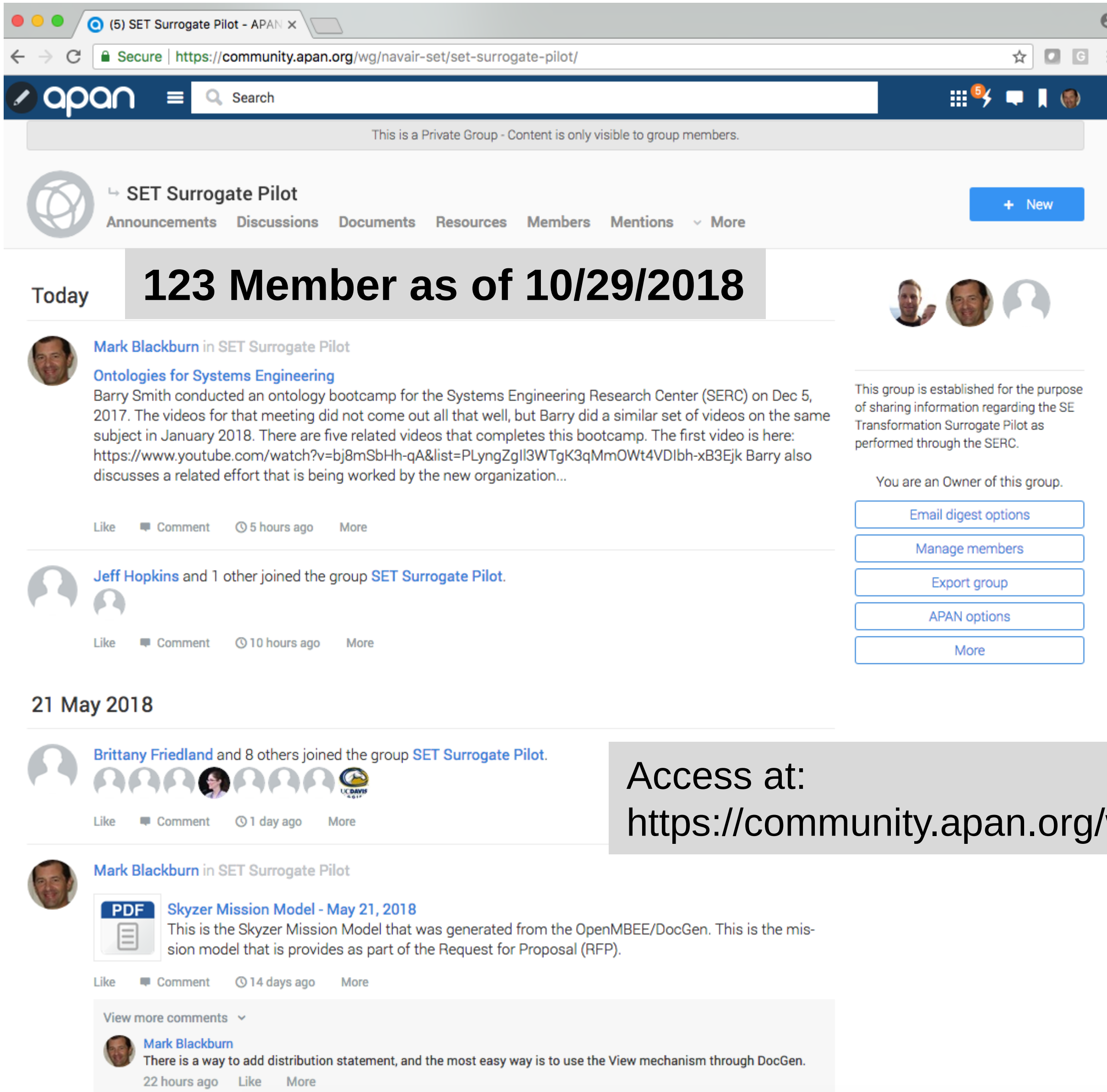
- **Elimination of paper CDRL artifacts and large-scale design reviews**
- **Continuous insight/oversight via digital collaborative environment and interaction with the Single Source of Truth**



SET Functional Areas



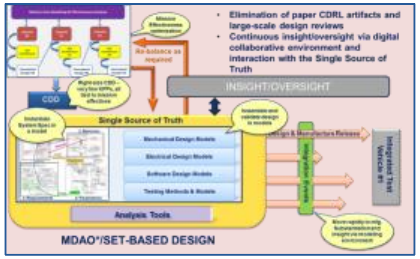
Continuous Updates of Discussion Threads Provided on Public All Partners Network (APAN.org)



123 Member as of 10/29/2018

Access at:
https://community.apan.org/wg/navair-set/set-surrogate-pilot/

Use Cases for Surrogate Pilot and Experimental System (Skyzer)



Surrogate Pilot Use Cases (UC) → Collaboration in Authoritative Source of Truth UC

Objectives to Assess SE Framework

How we Collaborate in AST

Skyzer is Experimental System using Authoritative Source of Truth (AST)

- Project Plan UC
- Mission Model UC ← Uses ← System Model UC ← Uses ← Contractor(s) System Model(s) UC
- Contractor Design Model UC
- Source Selection UC & Models

Mission Models
System Models
Evaluation Model
Based on Standards

→ RFI

RFP

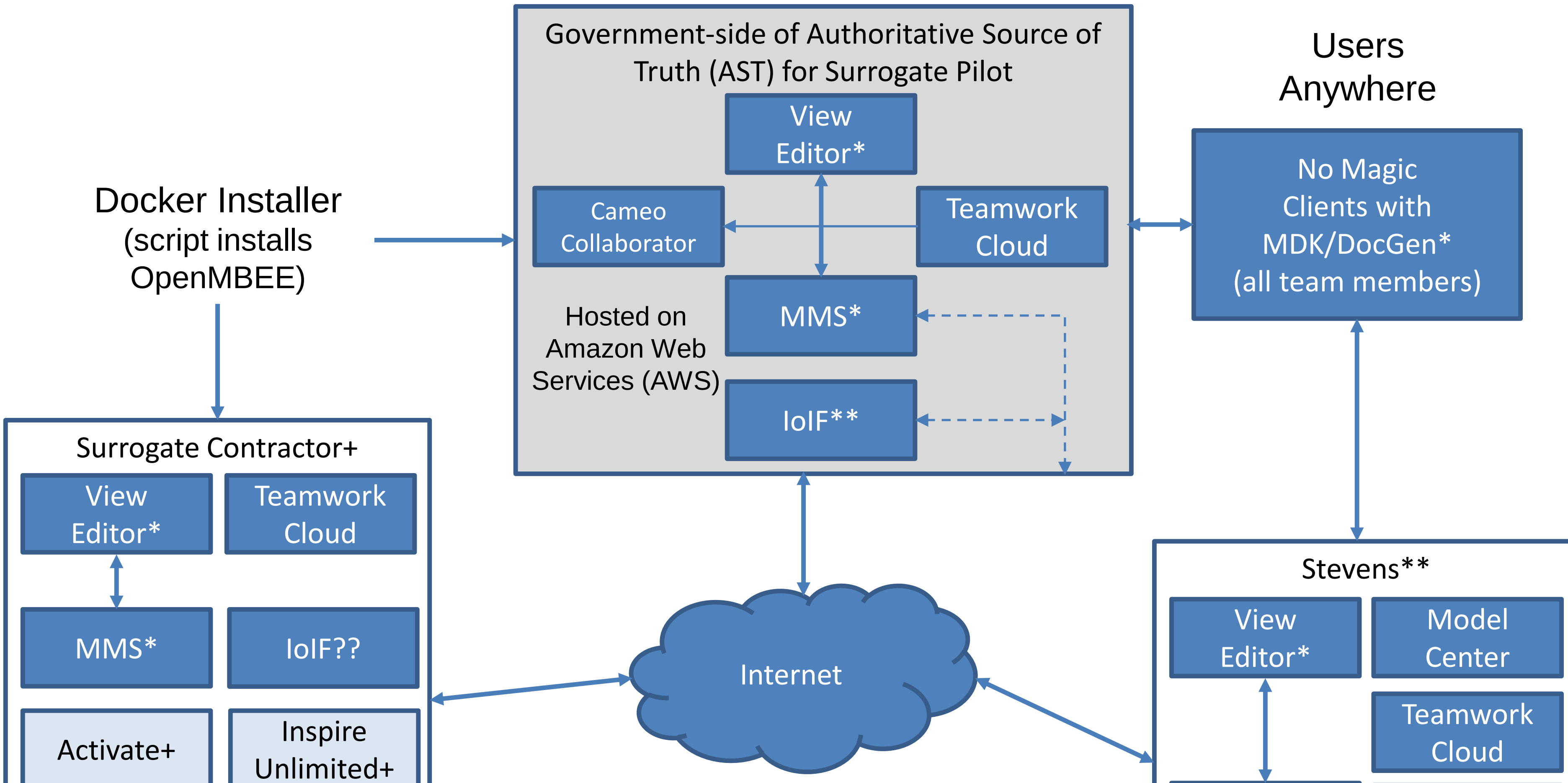
GFI

Proposal Extends GFI

Proposal for Design Models must be able to demonstrate aspects for Producability Decisions involving **Multi-physics**

RFI: Request for Information
RFP: Request for Proposal
GFI: Government Furnished Information (e.g. models)

Elements of Authoritative Source of Truth for Government/Industry Collaboration

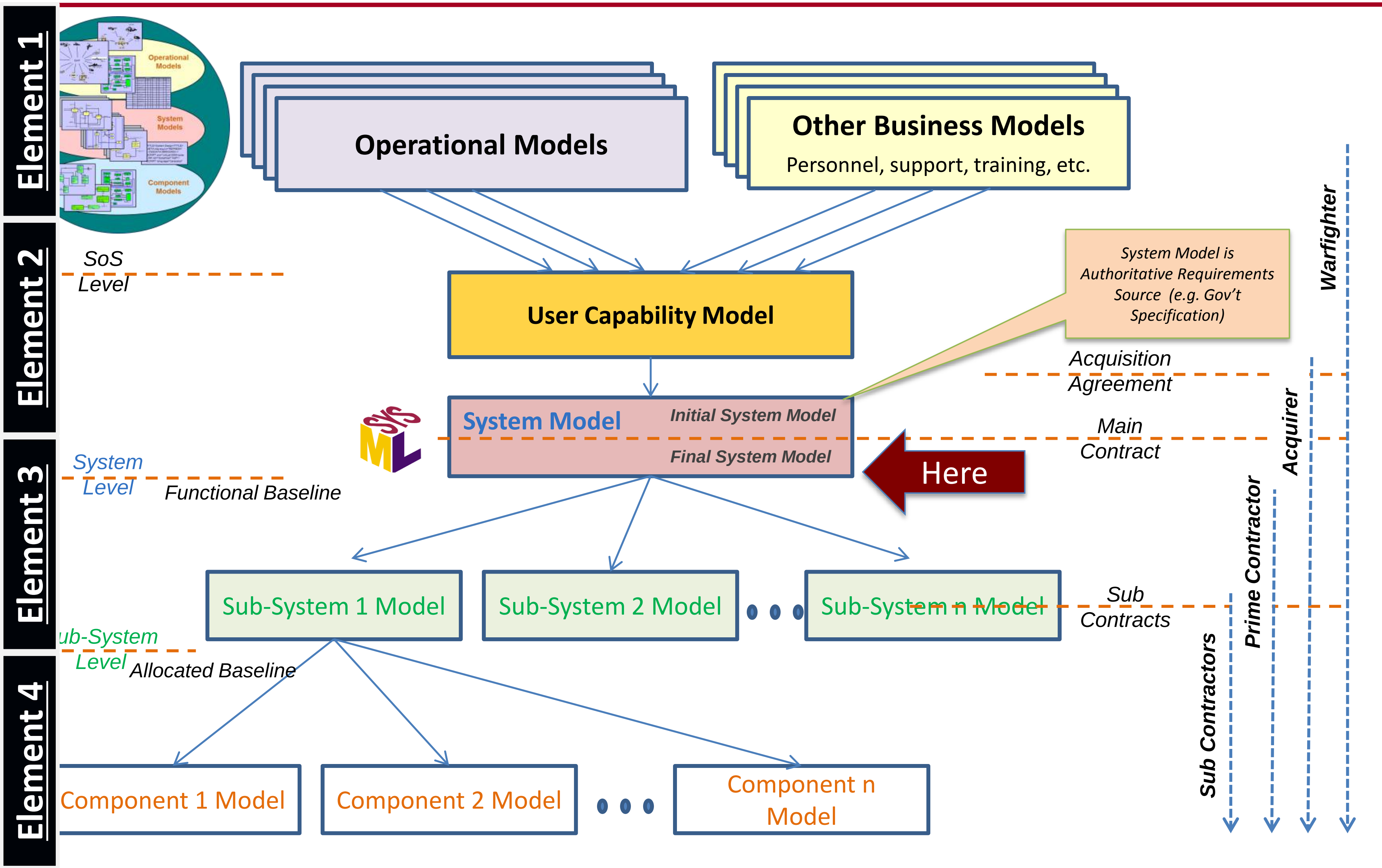


OpenMBEE*

- Model Management System (MMS)
- View Editor
- Model Development Kit (MDK)/DocGen

**Integration and Interoperability Framework

Skyzer Demonstrates Formalizing the Use of Models for the SET Framework Elements

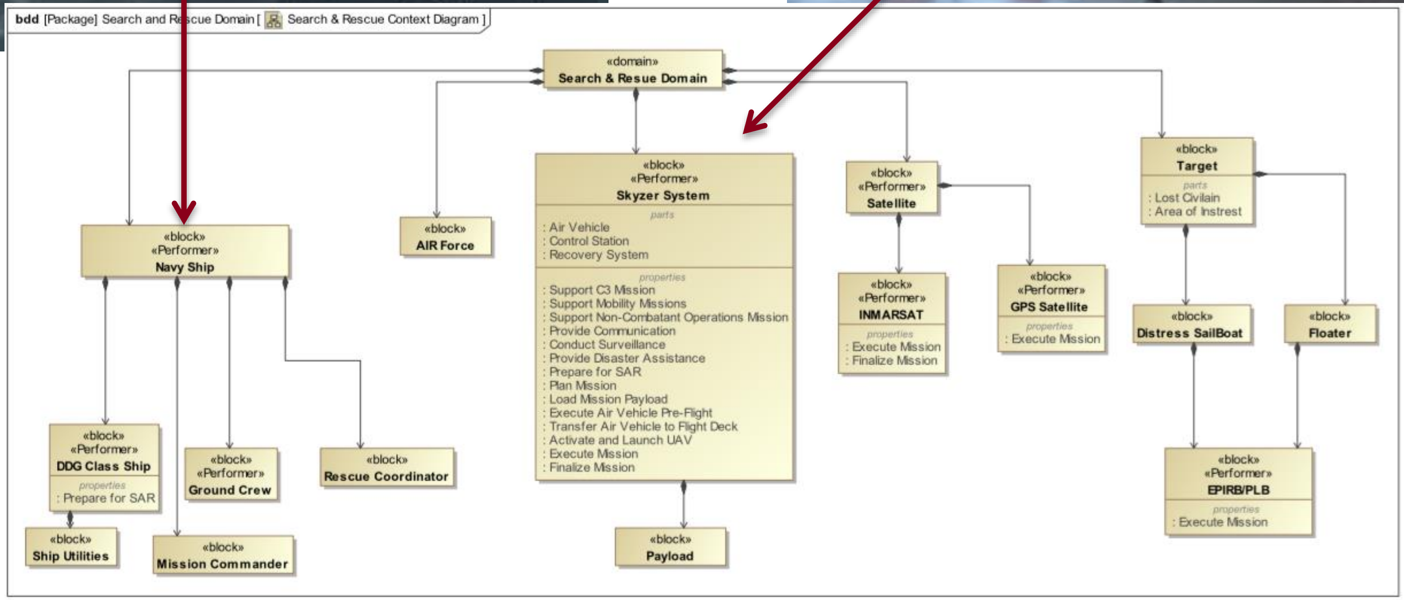


Surrogate Pilot Scenario: Skyzer UAS

Graphical CONOPS Scenario:

Search & Rescue

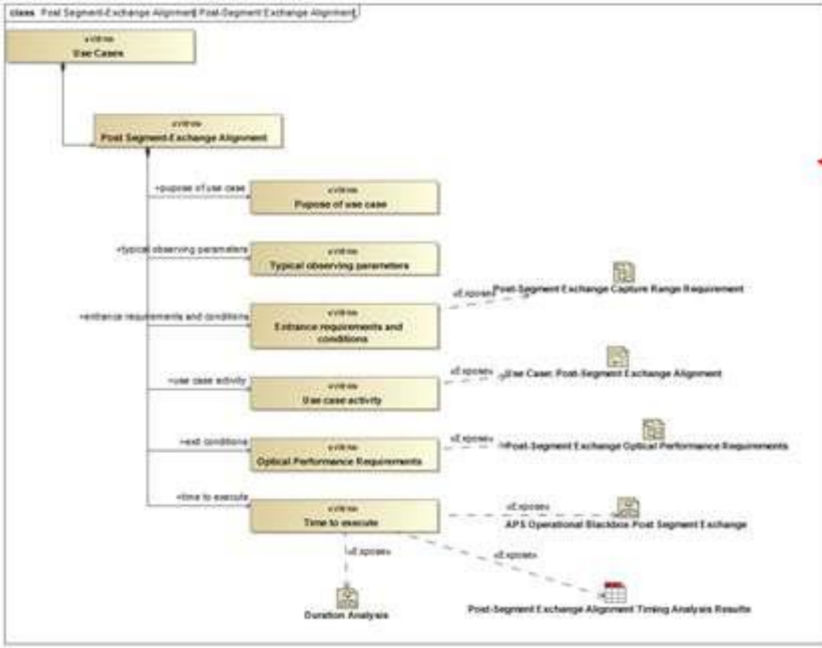
Airfoil designation for a similar Bell tilt-rotor



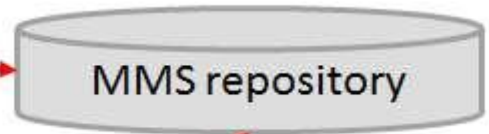
Skyzer System & Mission Models developed using SysML

Leverage Capabilities of OpenMBEE as Part of Integrated Modeling Environment (IME)

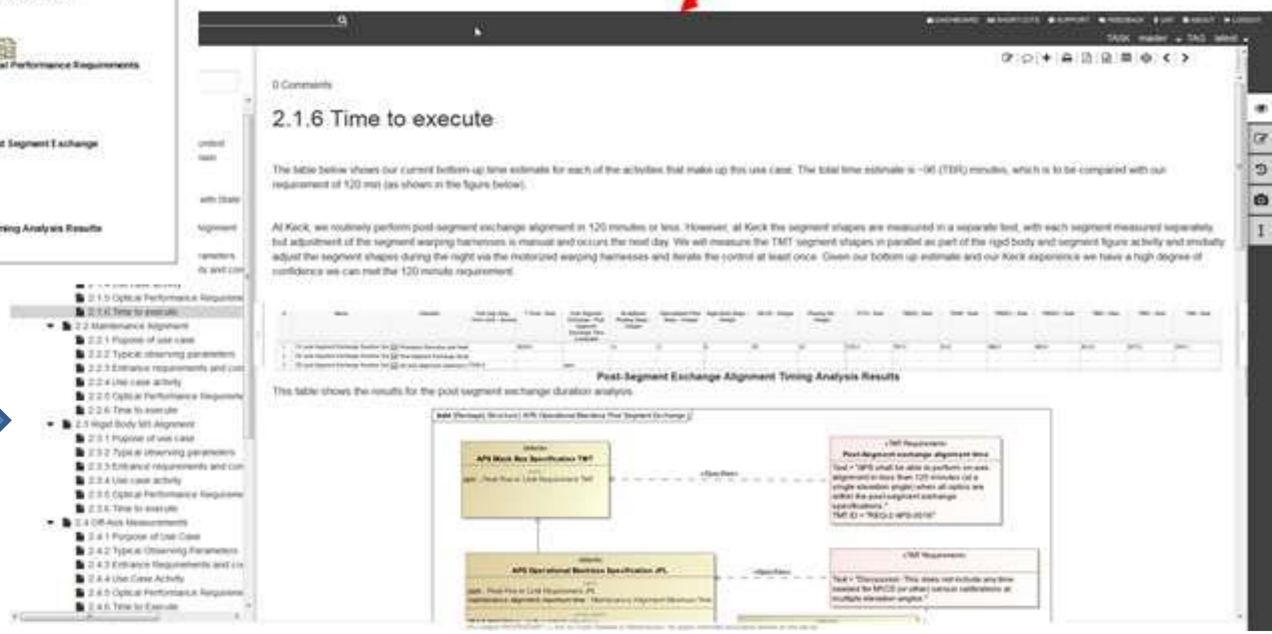
Model Development Kit/DocGen
View and Viewpoint Hierarchy



Model Management System



View Editor



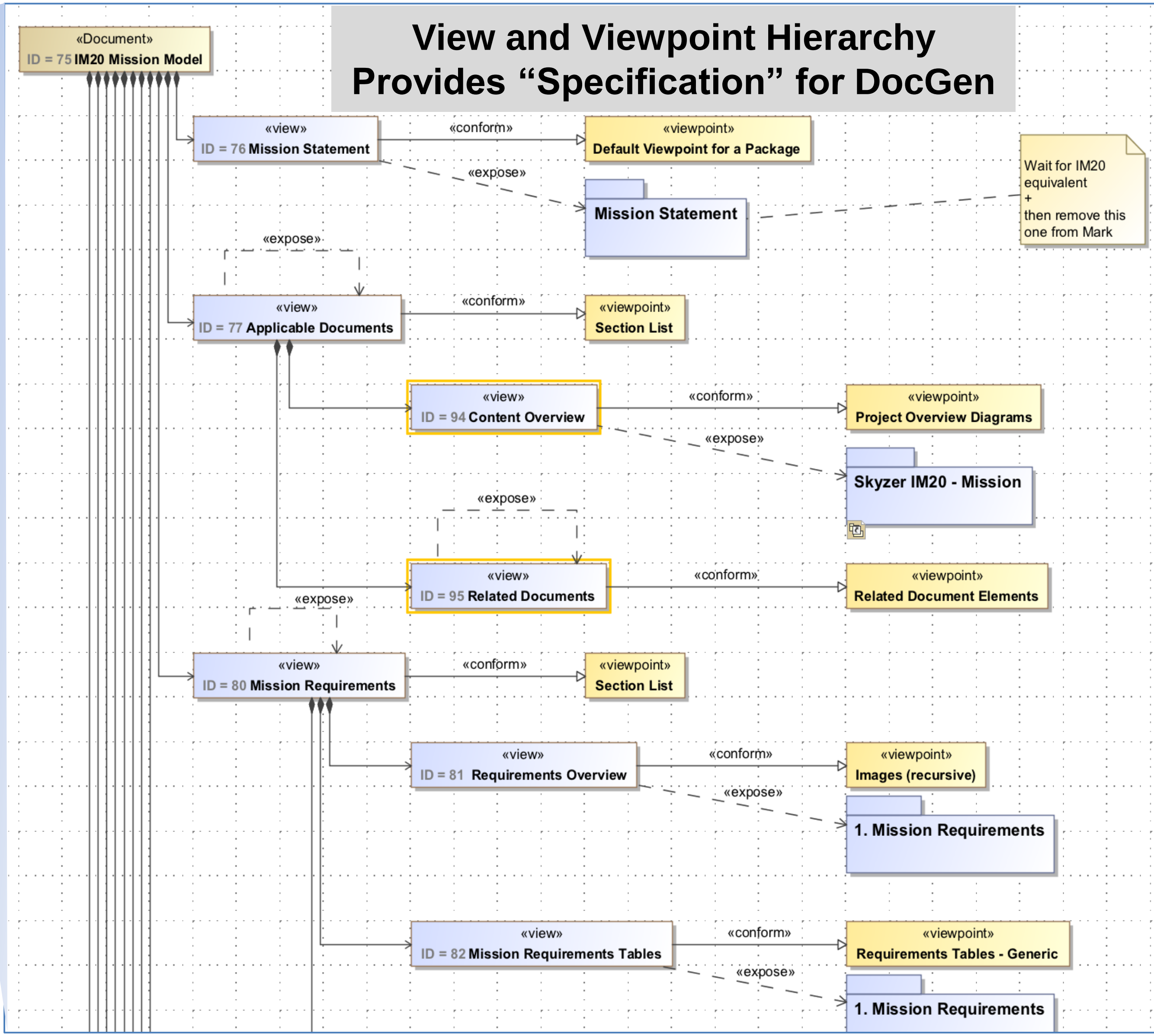
Visualization in View Editor

Mission Model Generated View Aligned with Integrated Capability Framework

Navy Integration and Interoperability

Integrated Capability Framework

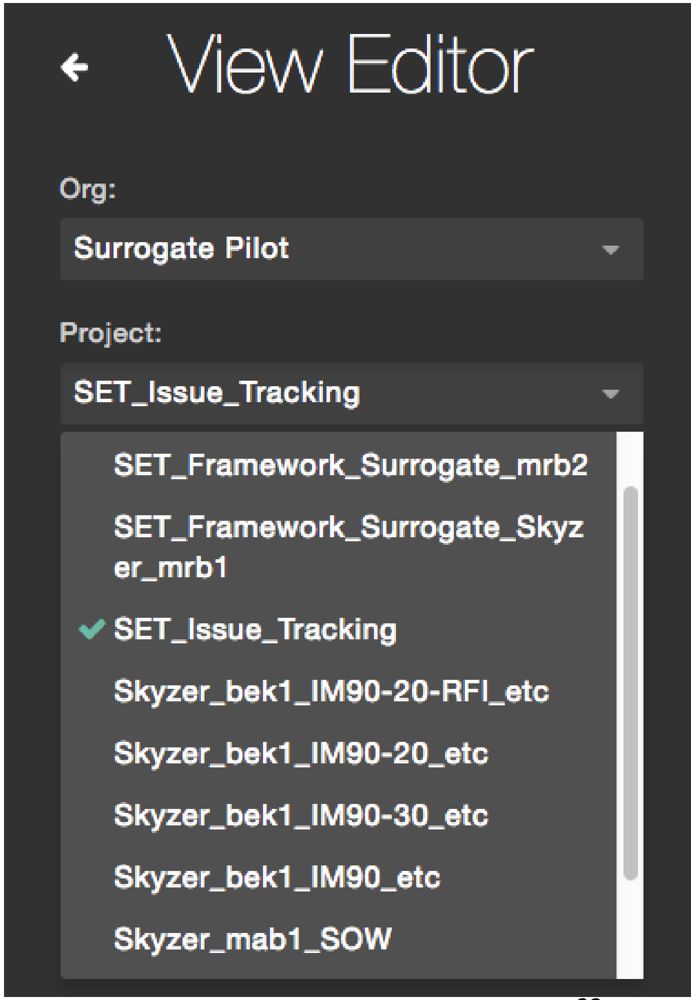
Operational Concept Document



Elements of the Request for Proposal (RFP)

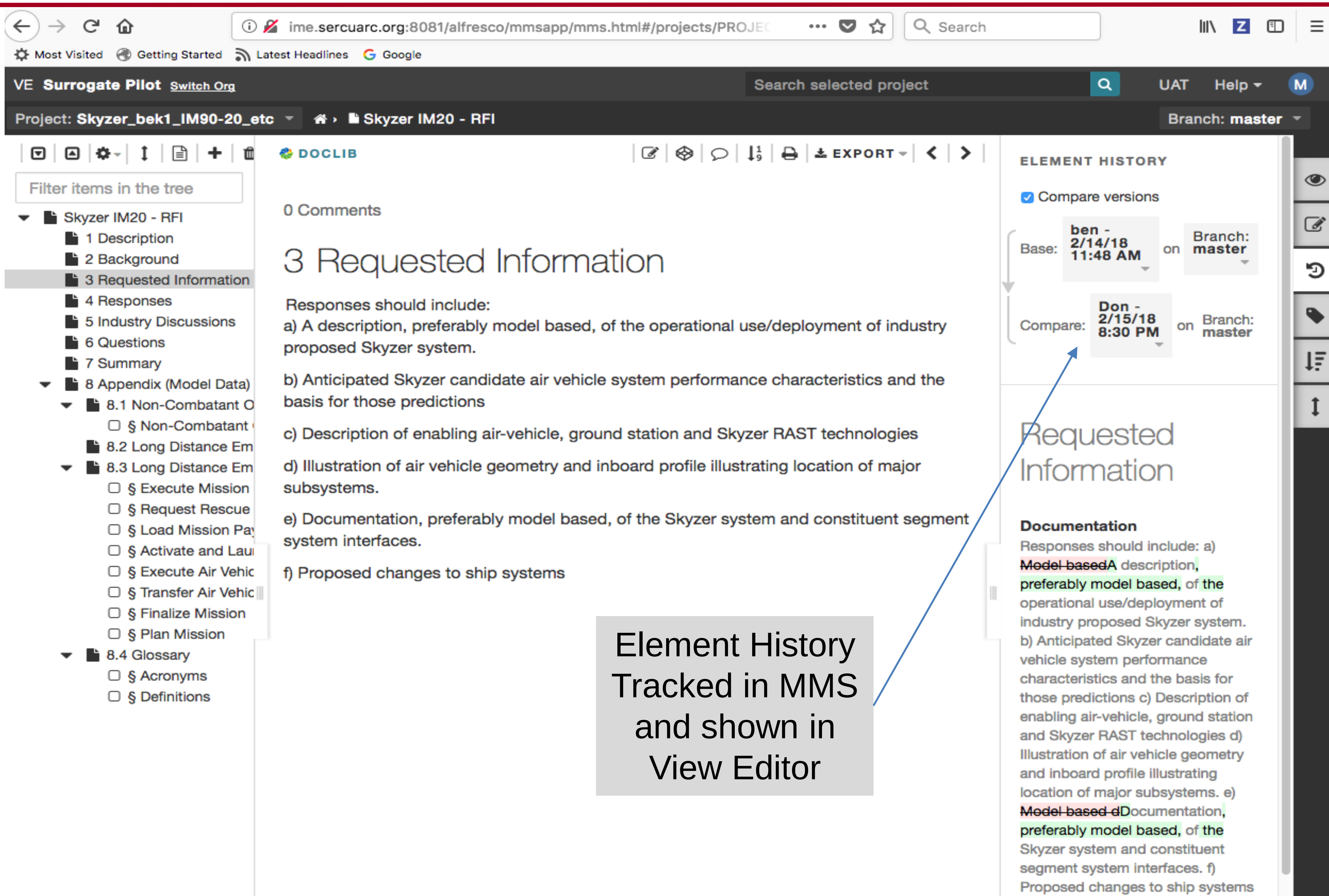
- Skyzer Mission Model & View (IM90-20 on AWS, pdf in APAN)
- Skyzer System Model & View (IM90-30 on AWS, pdf in APAN)
- Skyzer System Model as Government Furnished Information (GFI) (on APAN)
- Statement of Work (SOW) Model and View
- Section L & M Model and Views
  - Technical evaluation
- Evaluation Model (GFI) and View
  - Computes Margins for KPPs
- Issue tracking in View Editor on AWS
- Official Release: July 9th, 2018 tagged in MMS and Teamwork Cloud

- Log in instructions to examine the models are available on APAN

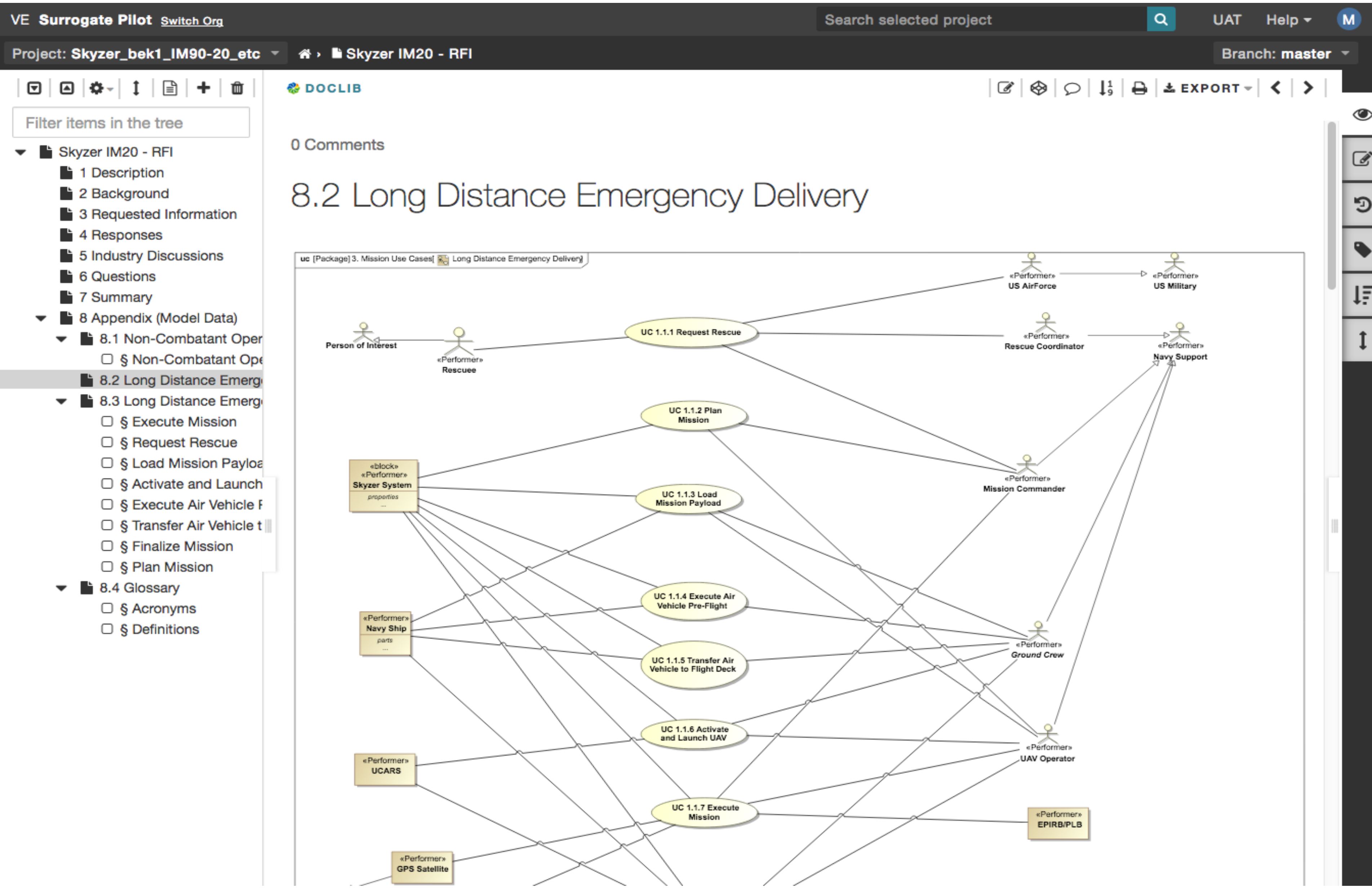


AWS: Amazon Web Service

View Editor Allows Updates to Skyzer Mission Model in Web Browser



View Editor Can Display Model Elements Such as Skyzer RFI Mission Model Use Cases

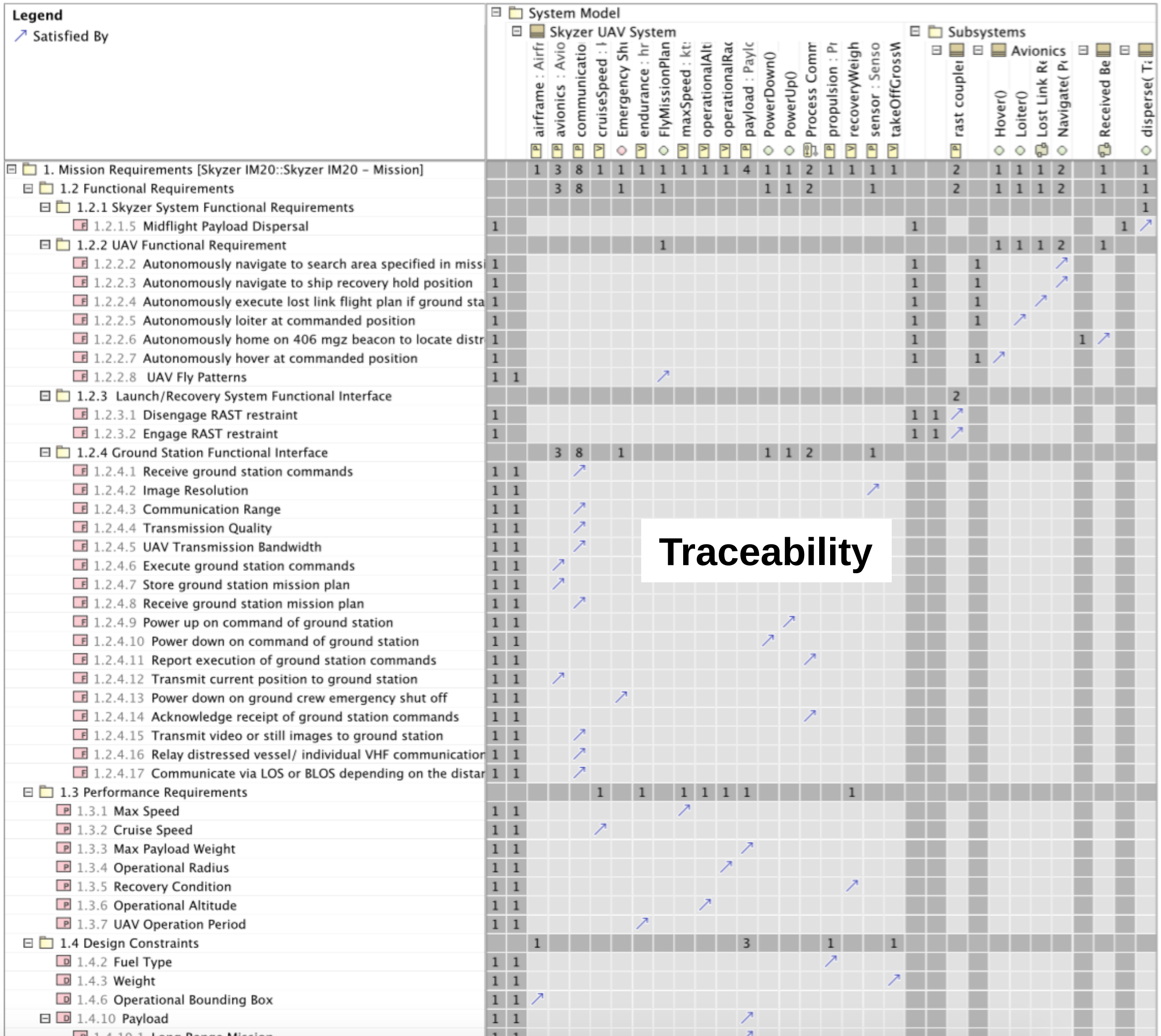


Skyzer Mission and System Requirements Traceability in Skyzer System Model

Figure 6.1. Requirements Satisfiability

System Requirements

Mission Requirements



SYSTEMS ENGINEERING RESEARCH CENTER

STEVENS INSTITUTE of TECHNOLOGY THE INNOVATION UNIVERSITY

Align with Goals of the Digital Engineering Strategy

Future Research Areas	G1. Formalize the development, integration and use of models to inform enterprise and program decision making.	G2. Provide an enduring authoritative source of truth.	G3. Incorporate technological innovation to link digital models of the actual system with the physical system in the real world.	G4. Establish a supporting infrastructure and environment to perform activities, collaborate and communicate across stakeholders.	G5. Transform a culture and workforce that adopts and supports DE across the lifecycle.
Cross-discipline integration of models to address the heterogeneity of the various tools and environments using semantic technology	X	X	X	X	X
High Performance Computing (HPC) advancements such as; 1) supporting organizing and analyzing "Big Data" and 2) being able to program in parallel to take advantage of HPC capabilities, are needed to support the DE effort	X	X	X	X	
Model integrity to ensure trust in the model predictions by understanding and quantifying margins and uncertainty	X	X	X	X	X
Modeling methodologies that can embed demonstrated best practices and provide computational technologies for real-time training within digital engineering environments	X		X	X	X
Model composability to understand the possibilities, constraints and rulesets for composition of multiple models	X		X		
Human-model task allocation to understand what activities are best performed by human decision makers and what can effectively be automated or augmented with model intelligence					X
Workforce development to understand what is needed to educate model developers, users and decision makers to work in a DE environment					X
MCE acquisition to understand the needed changes to acquisition and security when developing in the new DE environment	X	X		X	X

Decision Making

Authoritative Source of Truth

Technological Innovation Link Digital Models to Physical systems

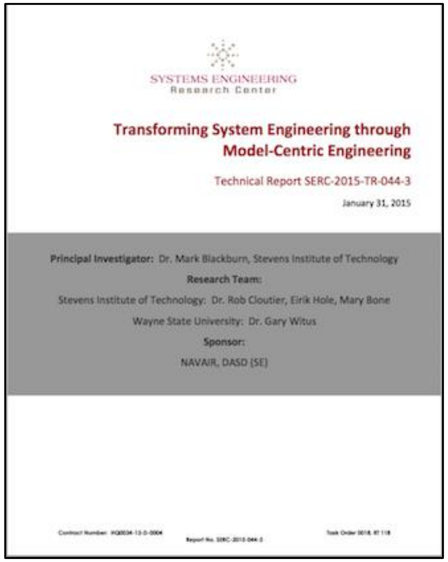
Collaborative Infrastructure and Environment

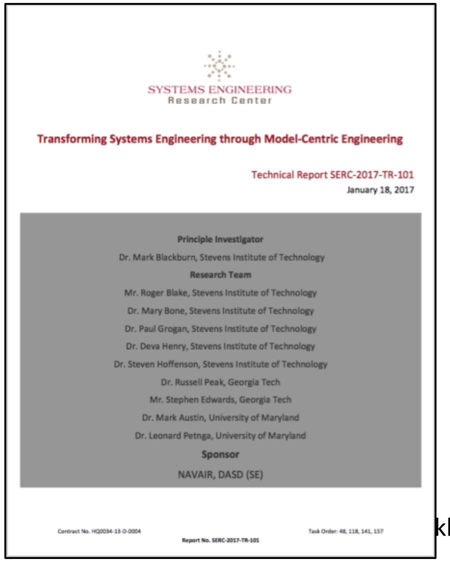
Transform Culture and Workforce in DE lifecycle

Historical Perspectives and Resources

- Resources
  - Technical reports link: https://sercuarc.org/researcher/?id=121&Mark-Blackburn
  - Comprehensive briefing: http://www.markblackburn.com/MBSE/SERC_SE_Transformation_Big_Picture_7_31_2017_v8.pdf

NAVAIR: RT-141 Phase I & II – Global Scan Advanced Approaches	NAVAIR: RT-157 Phase III – SE Transformation (SET) Initiated	ARDEC: RT-168 Phase I & II - Synergistic Research	NAVAIR: RT-170 Phase IV - SET Planned and in Execution


SYSTEMS ENGINEERING
Research Center
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)


SYSTEMS ENGINEERING
Research Center
Transforming Systems Engineering through Model-Centric Engineering
Technical Report SERC-2017-TR-101
January 18, 2017
Principle Investigator
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SYSTEMS ENGINEERING RESEARCH CENTER
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
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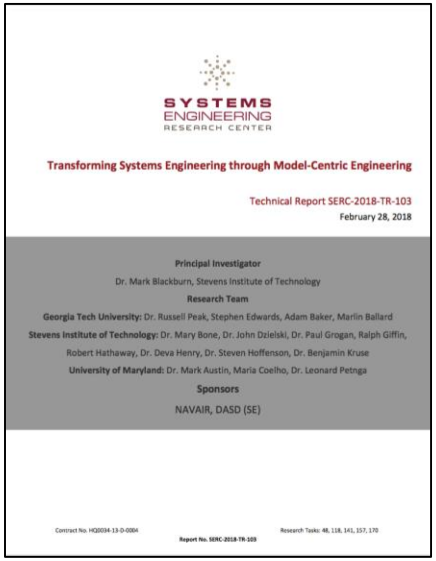
University of Southern California: Todd Richmond, and Edgar Evangelista
Sponsor:
U.S. Army Armament Research, Development and Engineering Center (ARDEC), Office of the Deputy Assistant Secretary of Defense for Systems Engineering (ODASD(SE))


SYSTEMS ENGINEERING RESEARCH CENTER
Transforming Systems Engineering through Model-Centric Engineering
Technical Report SERC-2018-TR-103
February 28, 2018
Principal Investigator
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Thank you!

Dr. Mark Blackburn

Senior Research Scientist

Member of SERC Research Council

Member of Leadership Team for OpenMBEE Collaboration Group

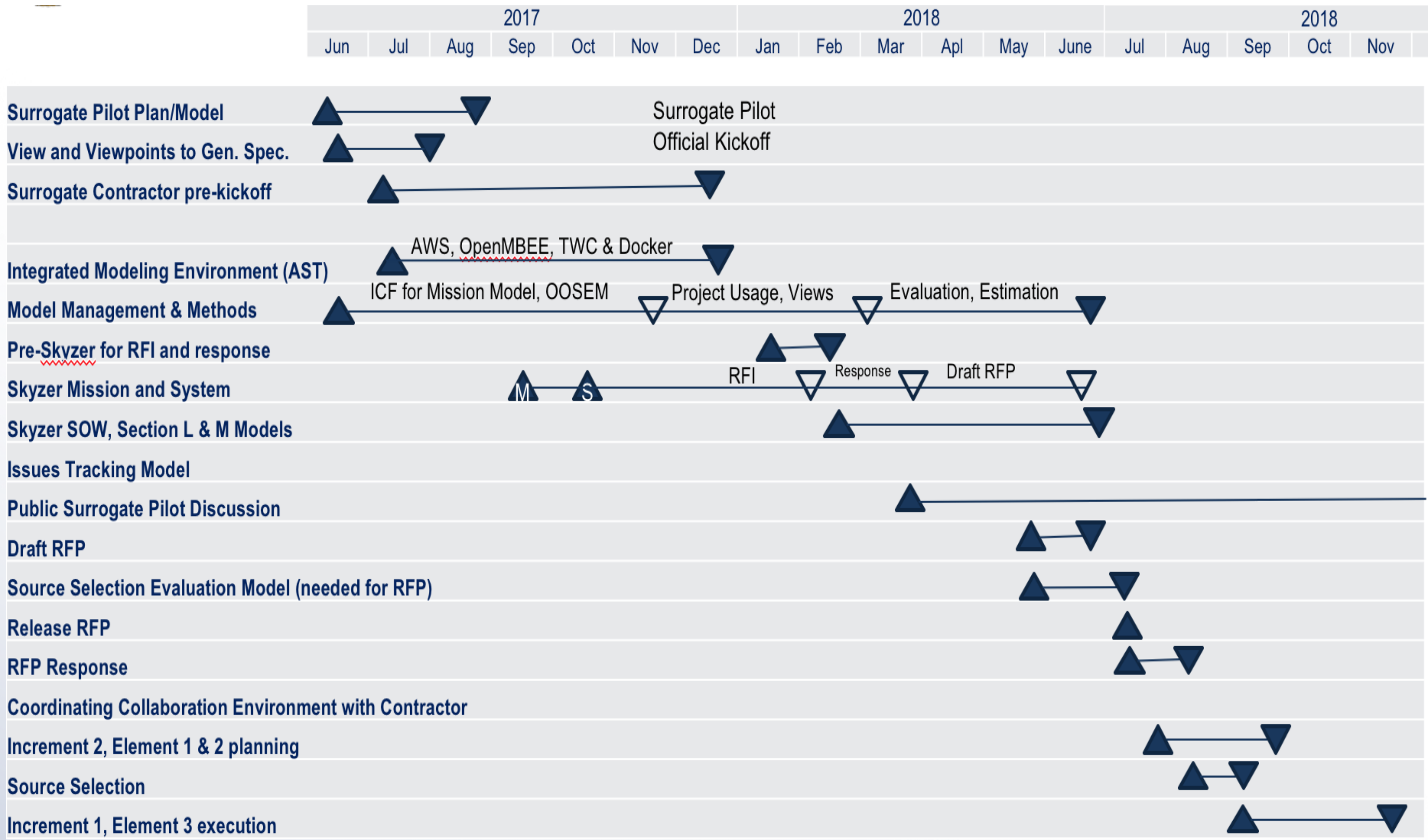
Member of Semantic Technologies for Systems Engineering Initiative

School of Systems & Enterprises

Systems Engineering Research Center

Stevens Institute of Technology

Time Line of Surrogate Pilot Experiments



Project Usages

- Project Usages of Skyzer Mission Model in the Skyzer System Model to trace mission requirements to system requirements
  - Skyzer System Model has several Project Usages, such as the Project Usage of the Mission Model (IM20)
  - Allows System model to create traceability linkages from system information (e.g., behavior in state machine and activity diagrams) in the Skyzer System model to the Skyzer Mission requirements
  - Requirements table is automatically generated
  - Provides significantly more rationale through analysis for requirements
    - Some behaviors have simulations that allow reviewers to understand broader implications through these dynamic views of a simulated model
  - If Mission requirements are updated, this will be immediately visible in the System model, which may then need to be modified to address those changes in the mission model.
- Reuse Model Libraries of DocGen Viewpoints
  - Collected and developed a number of Viewpoints (mechanism for extracting information from models to produce documents)
  - Standardizing on Viewpoints adds uniformity to the generated specification. In addition, this means that very few modelers need to create or know how to create viewpoints.
  - As part of the OpenMBEE, NASA/JPL developed an implementation for View and Viewpoints are part of the Model Development Kit/DocGen [59], which is extensively used to generate stakeholder-relevant views from all of the models used in the surrogate pilot
- Project Usages of Evaluation Model and Estimation Model
  - Our team is also working on an Evaluation Model to be used for Source Selection

Lessons Learned Examples (1/2)

- We have had to take “short-cuts” to get through experimental process
- Establish infrastructures for IME tools and AST as early as possible
- Technically feasible to develop everything as a model
- Establish model management practices early
- Project Usages Technologies valuable for Model Modularization, Reuse, partitioning work, linking GFI to RFP responder models, etc.
  - Uses cases and benefits on APAN
- Requirement management can be done directly in models
- Don’t provide mission model for RFI – too confusing
  - Do use Views of mission model for appropriate context
  - Need some type of evaluation criteria for a model-based RFI
- Simulating Virtual Industry Days was useful
- Modeling provided a means to simplify SOW with emphasis in providing tool agnostic modeling information
- Iterations (agile-esk) very useful – is there anything “illegal" with doing this
  - How would it work in a competition?

Lessons Learned Examples (2/2)

- Standardize on DocGen Viewpoints to makes Views look consistent
  - We have a library of Viewpoints
- Use Glossary Capability in modeling clients to fully define terms
- Issue tracking necessary and formalized as a model
- Agreed on using a stereotype (or Tag) for identifying Key Performance Parameters (KPP)
- Industry MBSE RFI suggested use of parametrics, which has been developed into an Evaluation Model (part of Section L)
  - Can be distributed as GFI for Section L to ensure contractor model characterizes performance for KPPs
- Team SME with modelers: SME may supply mission scenario and constraints in non-modeling representations
- Use SME Stakeholders to define relevant Views
  - Provides a means from transitioning from Doc-based to Model-based
  - Program leadership will make an approval decision based on model generated report
  - Only modeler will likely know/understand what is in entire model
  - Need to address potential of unintentional data leak can enable a protest