SYSTEMS ENGINEERING Research Center

STEVENS INSTITUTE of TECHNOLOGY THE INNOVATION UNIVERSITY

Stevens Institute of Technology & Systems Engineering Research Center (SERC)

Systems Engineering Transformation through Model Centric Engineering

Presented by:

Dr. Mark R. Blackburn (PI)

With Contributing Sponsors (NAVAIR, ARDEC, DASD(SE))

With Contributing Researchers (RT-48, 118, 141, 157, 168, 170, 176)

November 8, 2017

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Outline

- Historical perspective and resources
- Perspectives and status RT-170 - NAVAIR
  - —Systems Engineering Transformation (SET) Framework for a new operational paradigm between government and industry
  - —Surrogate pilot experiment(s) for Executing the SET Framework that provides an experimentation environment for our research
- Perspectives and status RT-168 – ARDEC
  - —Sponsor’s vision for integrated Model-Based Engineering (iMBE) environment
  - —Research uses cases and a few examples of deliverables and demonstrations

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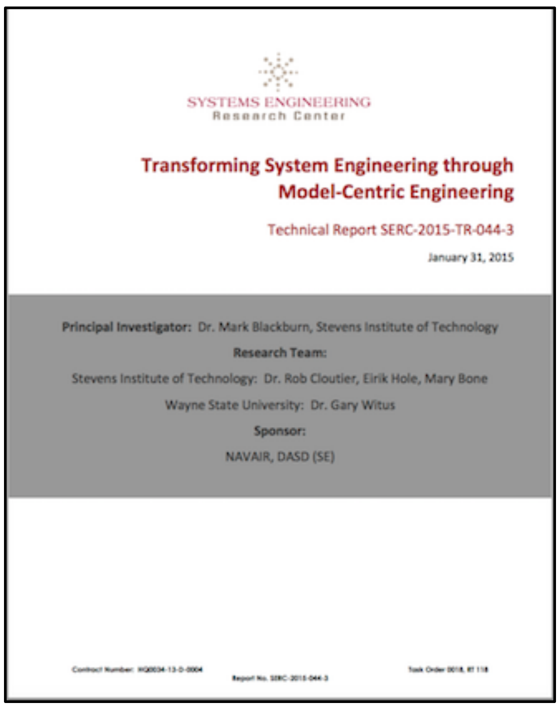
Historical Perspectives and Resources

- 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

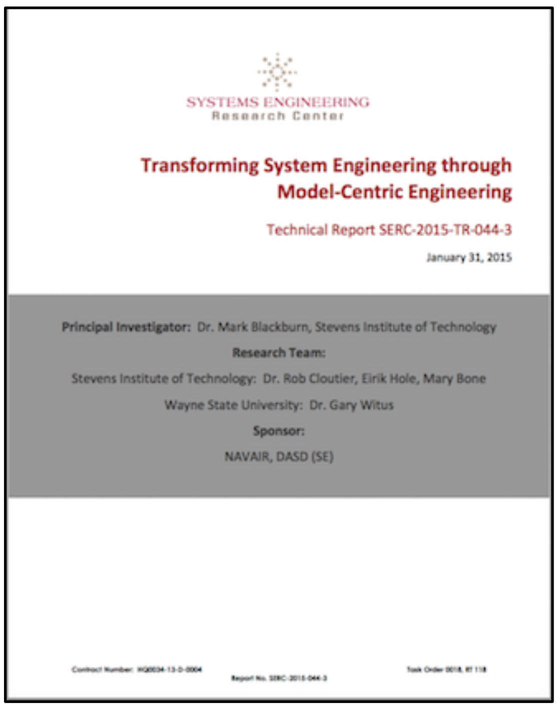
Wayne State University: Dr. Gary Witus

Sponsor:

NAVAIR, DASD (SE)

Contract Number: HQ0034-13-D-0004 Report No. SERC-2015-044-3 Task Order 0018, RT 118

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

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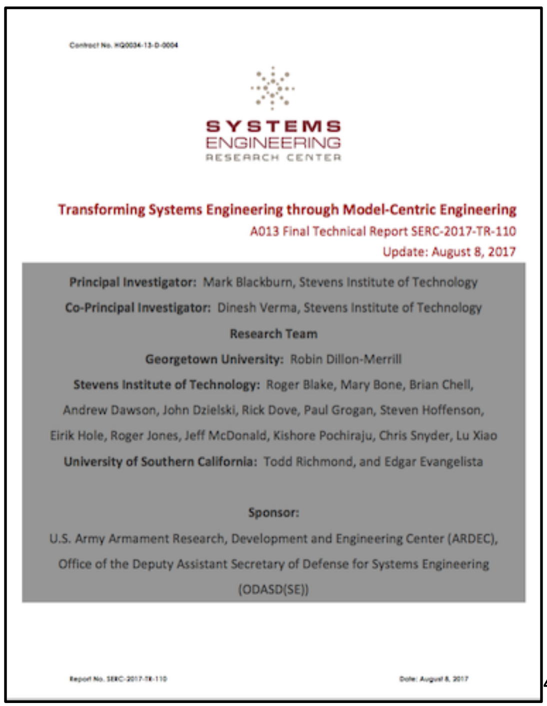
Contract Number: HQ0034-13-D-0004 Report No. SERC-2015-044-3 Task Order 0018, RT 118

ARDEC: RT-168
Synergistic


Contract No. HQ0034-13-D-0004

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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))

Report No. SERC-2017-TR-110 Date: August 8, 2017

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

Research Phase I: Model Based System Engineering (MBSE) versus Model-Centric Engineering (MCE)

- Over 30 organizational discussions "**tell us about most advanced and holistic approach**…":
  - Model-Based Engineering (MBE), Integrated Model-Centric Engineering, Interactive Model-Centric Systems Engineering (IMCSE), Model-Driven Development, Model-Driven Engineering (MDE), and even Model-Based Enterprise, which brings in more focus on manufacturability

- **MCE** characterizes the goal of integrating different model types with simulations, surrogates, systems and components at different levels of abstraction and fidelity across discipline throughout the lifecycle with manufacturability constraints

- SERC Research Supports **Digital Engineering** (DE) Thrust by DoD:
  - ***An integrated digital approach that uses authoritative sources of systems' data and models as a continuum across disciplines to support lifecycle activities from concept through disposal***

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Phase II: Systems Engineering Transformation Initiated at NAVAIR

- Organizations (with a few exceptions) were unwilling to share quantitative data, however
- Qualitative data in the aggregate suggests that **MCE technologies and methods are advancing and adoption is accelerating**

NAVAIR Executive Leadership Response:

- NAVAIR must move quickly to keep pace with other organizations that have adopted MCE
- NAVAIR must transform in order to perform effective oversight of primes that are using modern modeling methods for system development

March 2016: Change of Command has Accelerated the Systems Engineering Transformation and Broadened the Scope

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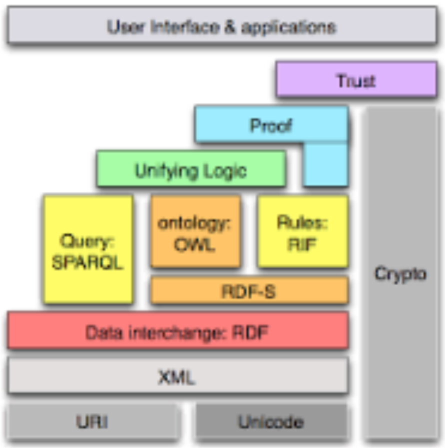
Current Research Trusts Investigated in Evolving Pilots

Semantic Web Technologies



Enforces **Modeling Methods**

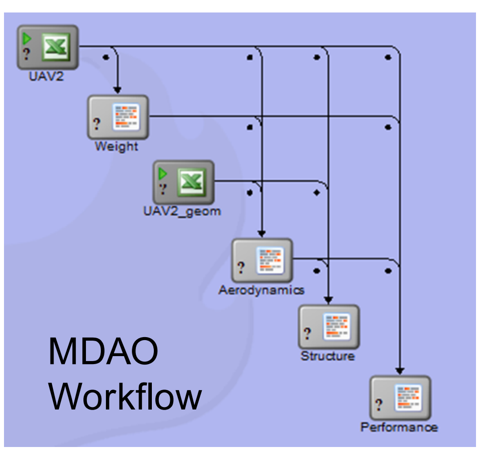
Underlying technologies for reasoning about completeness and consistency **Across Domains** in modeling tool agnostic way

Modeling Methodologies

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

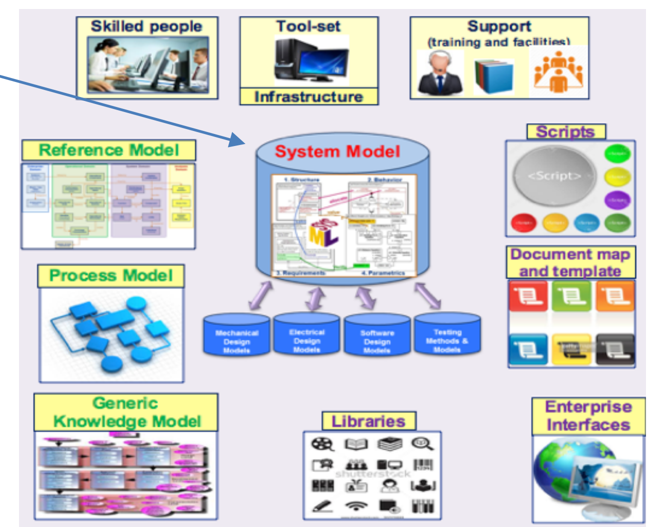
Digital System Model:
Single Source of Truth
(authoritative source of truth)

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



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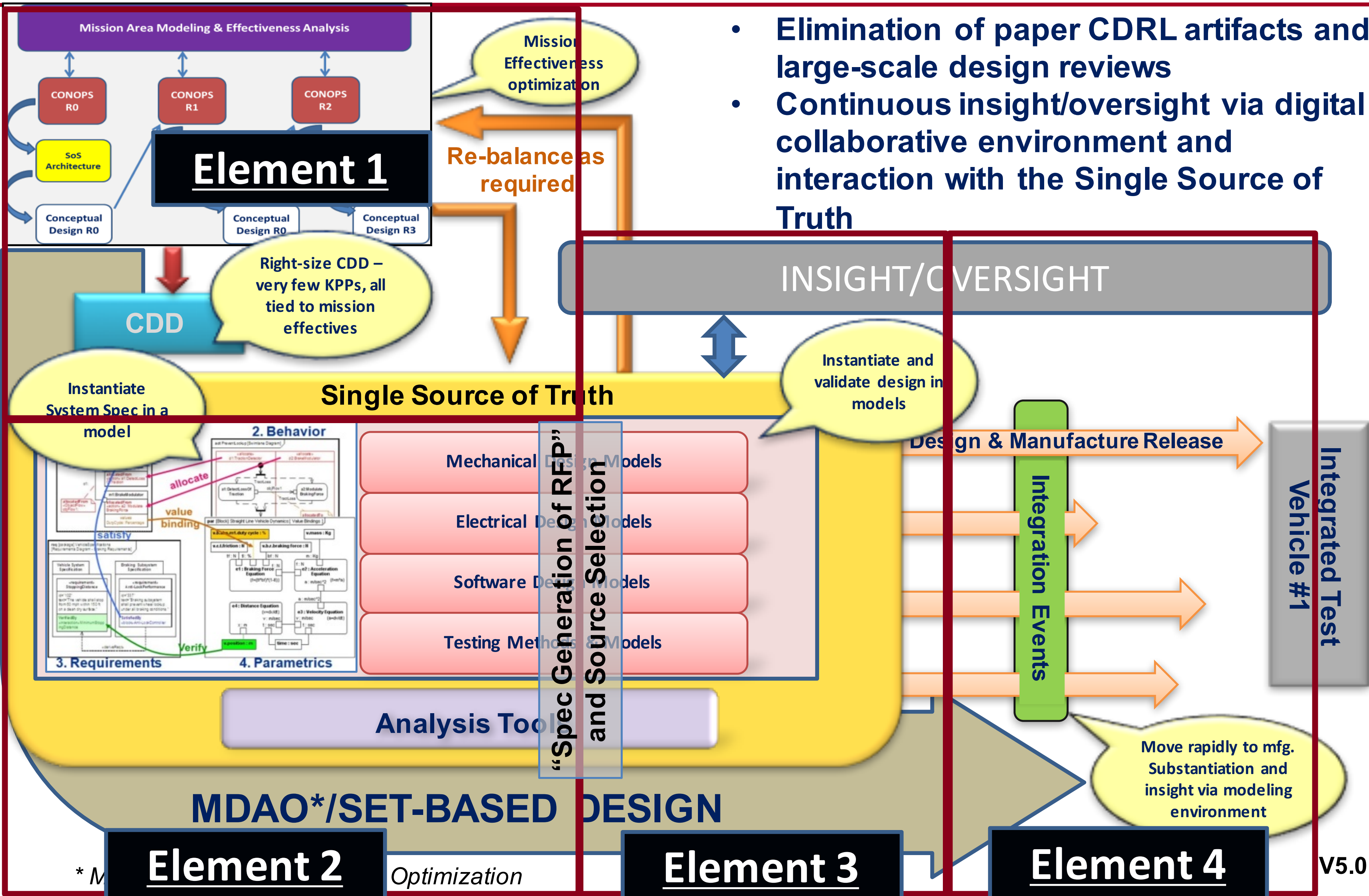
Surrogate Pilot focus is on *Execution* of SET Framework

- **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**



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Surrogate Pilot Overview

- Mission: Collaboration between Government and Industry in Model-based Acquisition under SET Framework
- Goal: Execute SET Framework to Assess, Refine, and Understand a New Paradigm for Collaboration in Authoritative Source of Truth (AST)
- Objectives (non exhaustive):
  - Formalize experiment to answer questions about executing SET framework using Surrogate Contractor (SC)
  - "Government team" creates mission, system (& other) models, "generates specification/RFP," & provides acquisition models to SC as Government Furnished Information (GFI)
  - SC refines GFI reflects corrections/innovations with physical allocation views with multi-physics-based Initial Balanced Design
  - Simulate continuous virtual reviews and derive new objective measures for assessing maturing design in AST
  - Demonstrate visualizations for real-time collaboration in AST
  - Demonstrate and document methods applied
  - Investigate challenging areas and research topics in series of pilots

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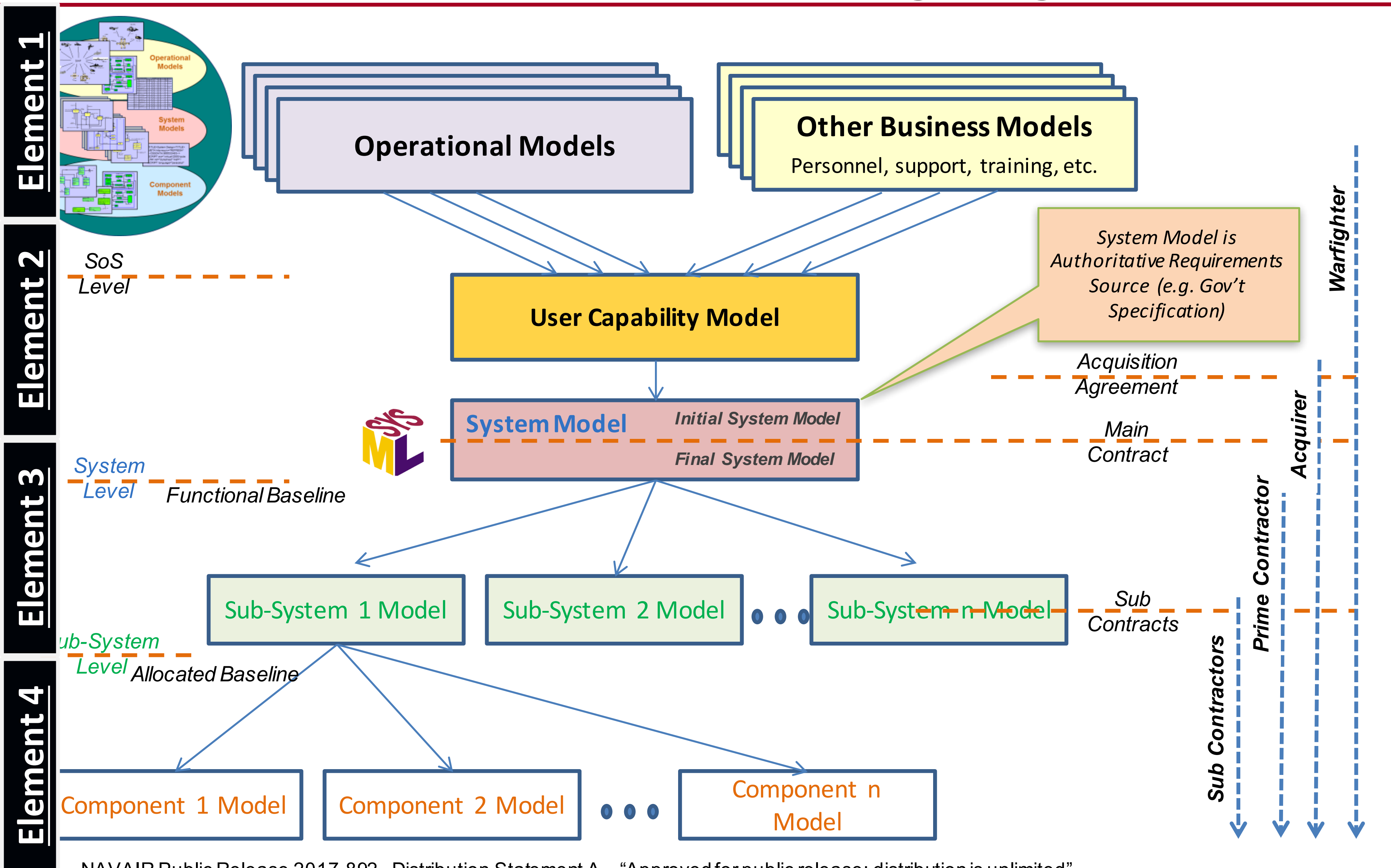
Formalizing the Use of Models… Creating a Digital Thread…



NAVAIR Public Release 2017-892. Distribution Statement A – "Approved for public release; distribution is unlimited"

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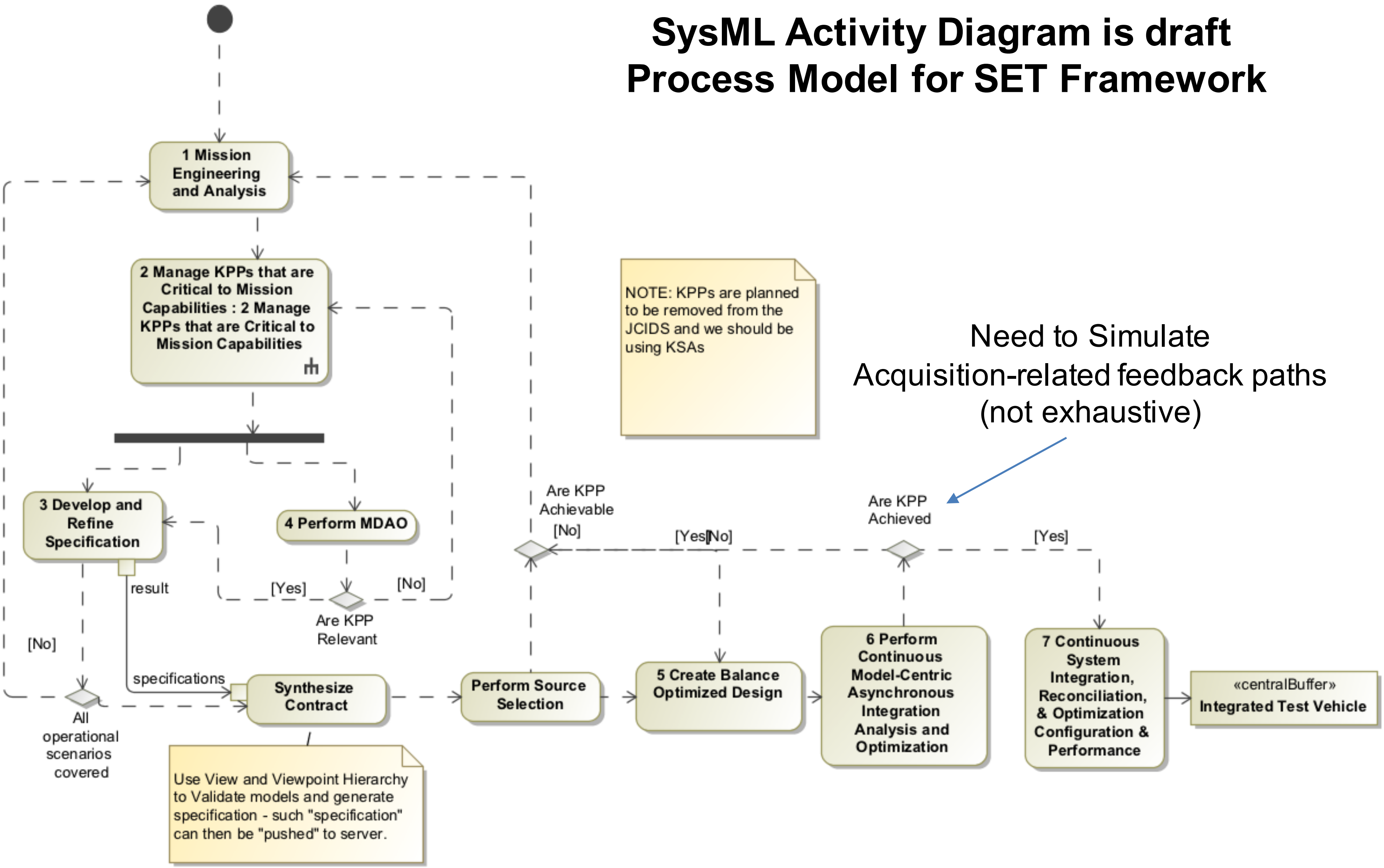
Example of Surrogate Questions (not exhaustive)

- Learning about new operational paradigm between government and industry in the **Execution** the SET Framework (NOT an air vehicle design)
- We are concerned with interactions (non-exhaustive):
  - Simulating prior to contract award (now)
  - Formalization of a "specification" for "Request for Proposal (RFP)" and methods for providing models to contractor
  - Simulating "Execution" of Oversight / Insight in AST per SET Framework for real-time collaboration in heterogeneous environments
  - **Simulating feedback back to mission engineering caused by specified objectives for unachievable Key Performance Parameters (KPP)**
  - Simulating approach for "faults in specification/model" detected after contract award
  - Simulating source selection – desirably as a dynamic simulations and V&V
  - Working with contracts/legal to get agreement on what a "specification" would be
  - Methods for modularizing model used to "generate specification"
  - Objective measures for evaluating evolving design maturity, with the reduction of risk
  - How will we use the Systems Engineering Technical Review (SETR) guide and checklist that NAVAIR uses? And, how will we make recommendations for its evolution
  - Use of Multidisciplinary Design, Analysis and Optimization (MDAO) at mission, systems, and subsystems (by surrogate contractor)

Formalize and Refine SET Framework

SysML Activity Diagram is draft Process Model for SET Framework



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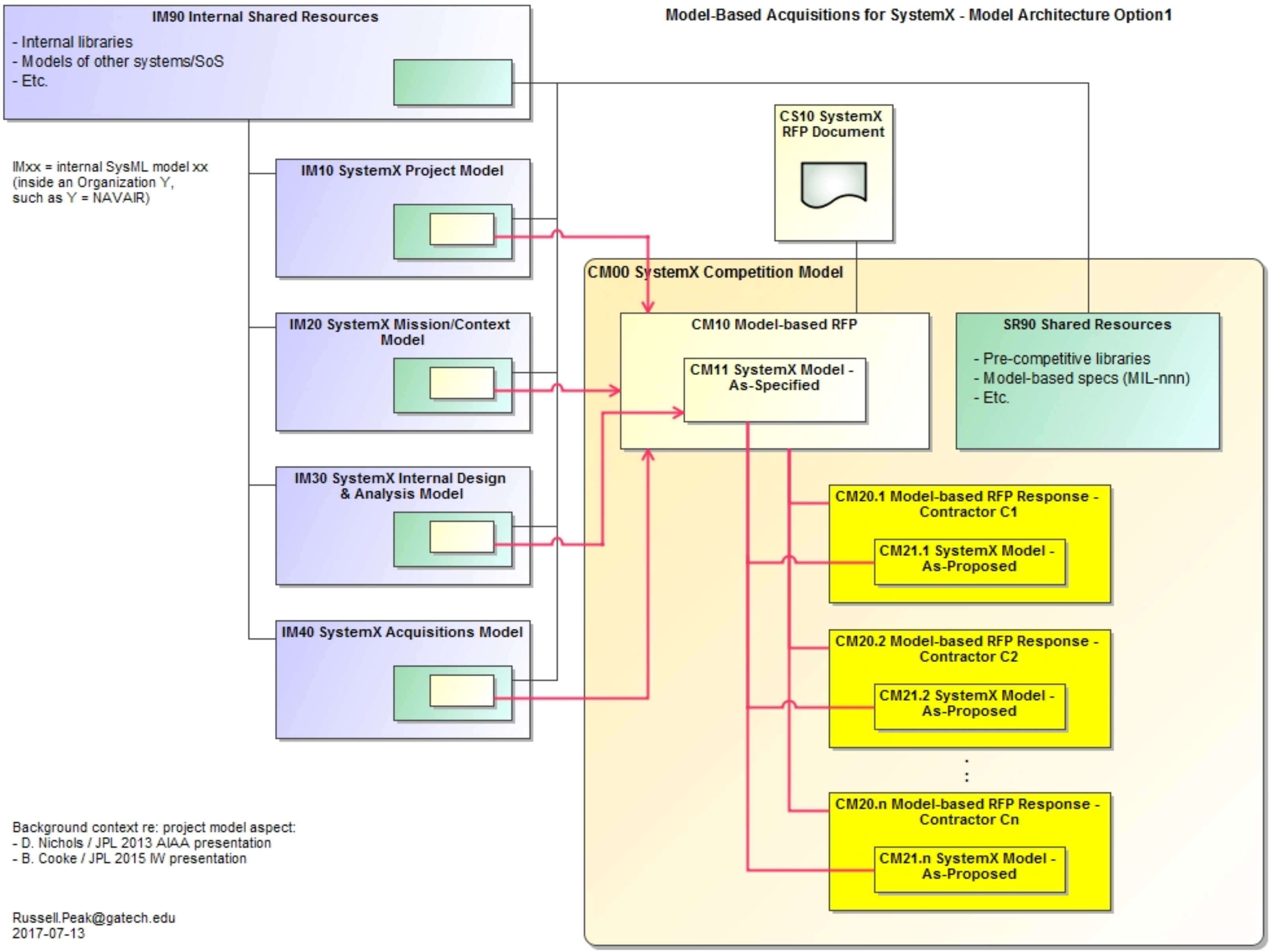
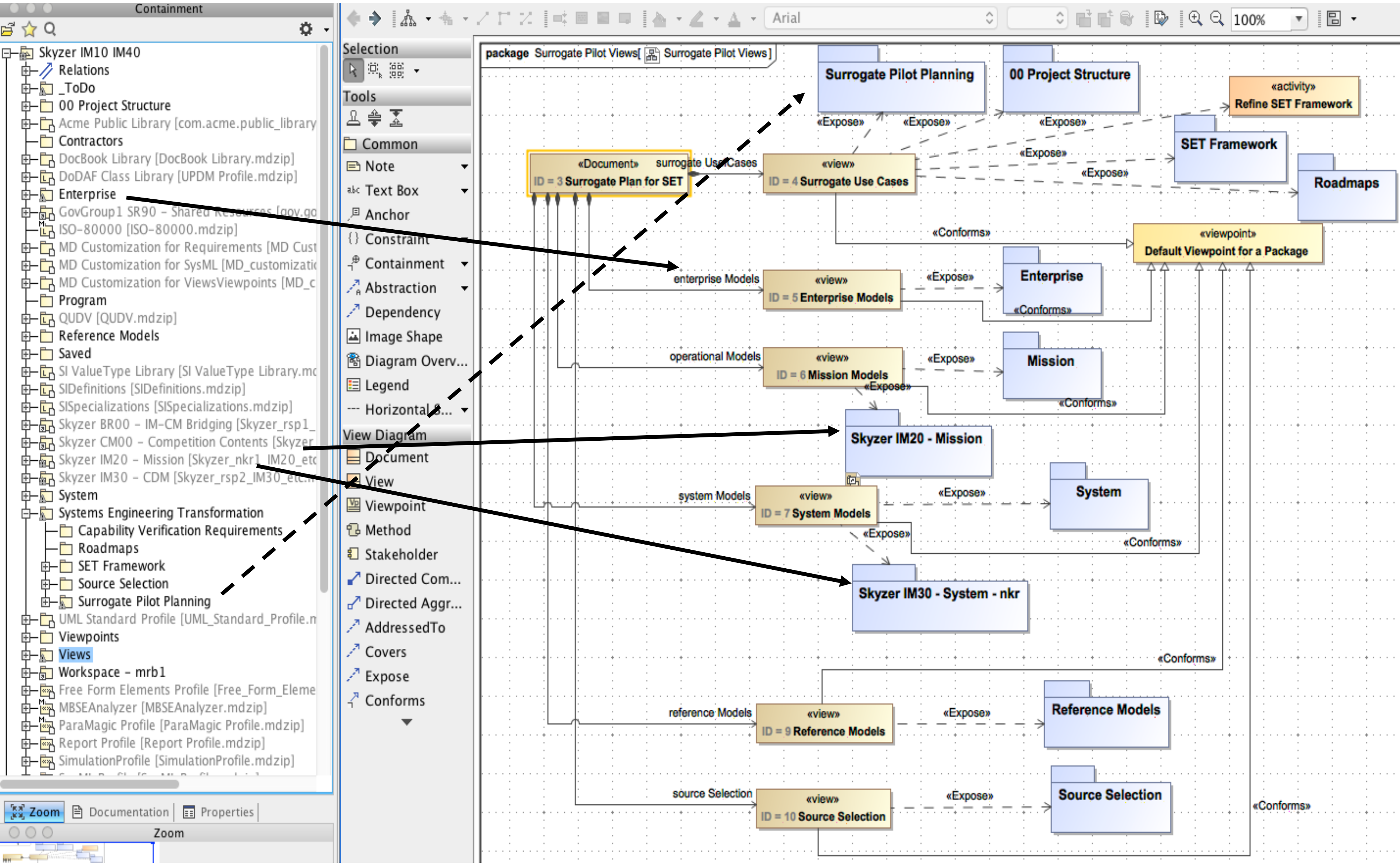
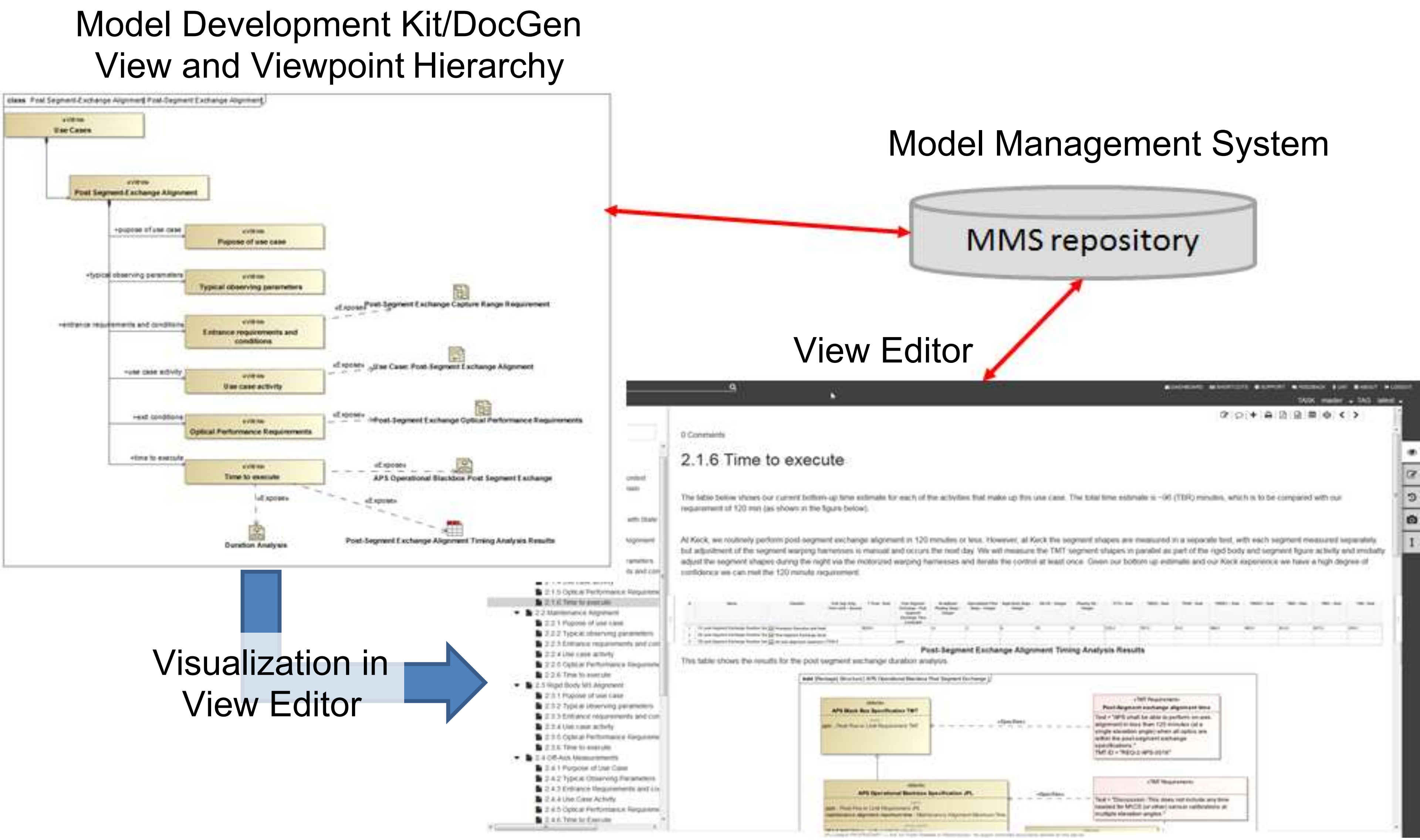
Methods for Partitioning of Work and Modularization of Models



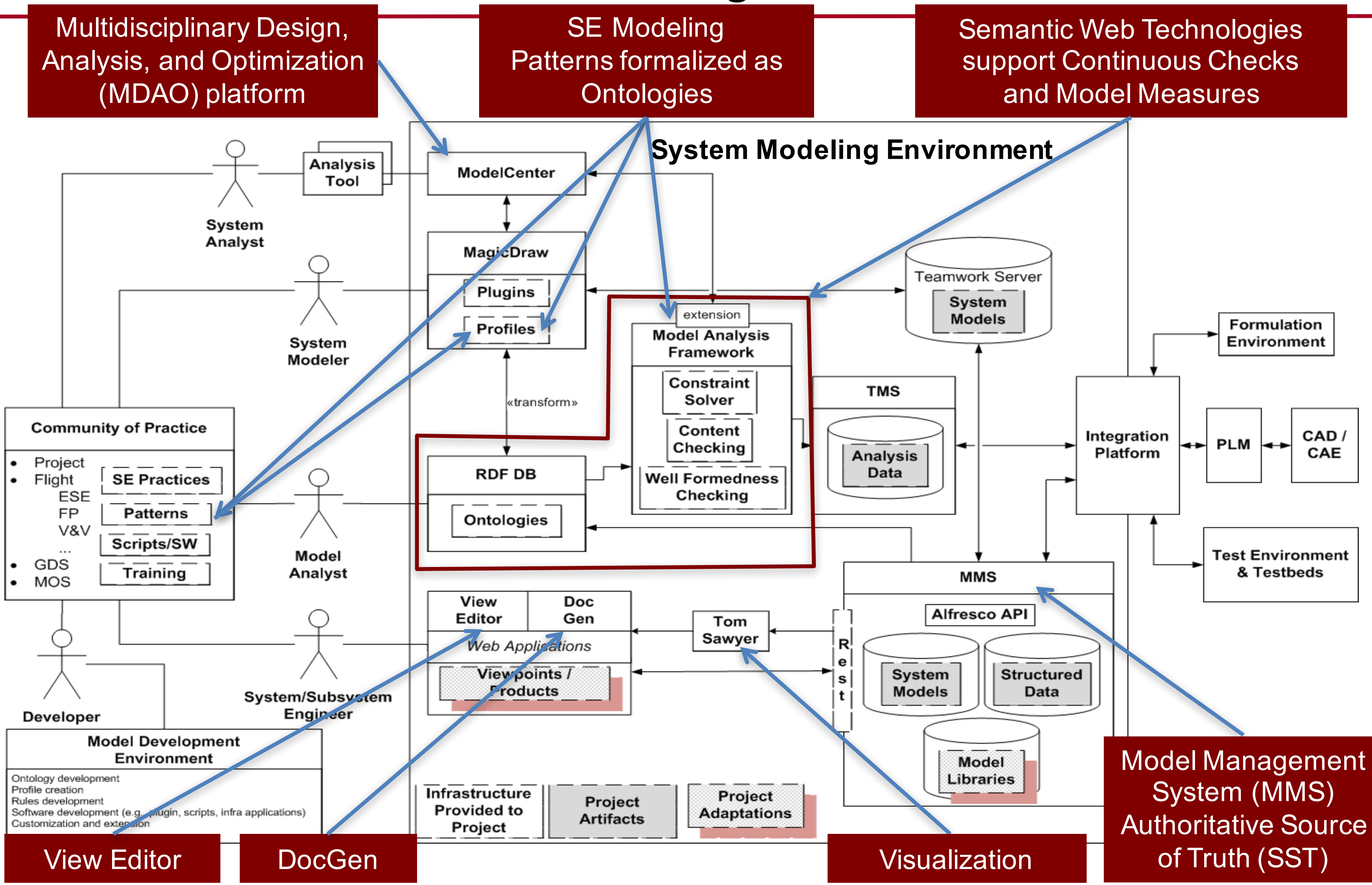
Using OpenMBEE Model Development Kit/DocGen for Generating Specification from Modularized Model



Open Model Based Engineering Environment (OpenMBEE)

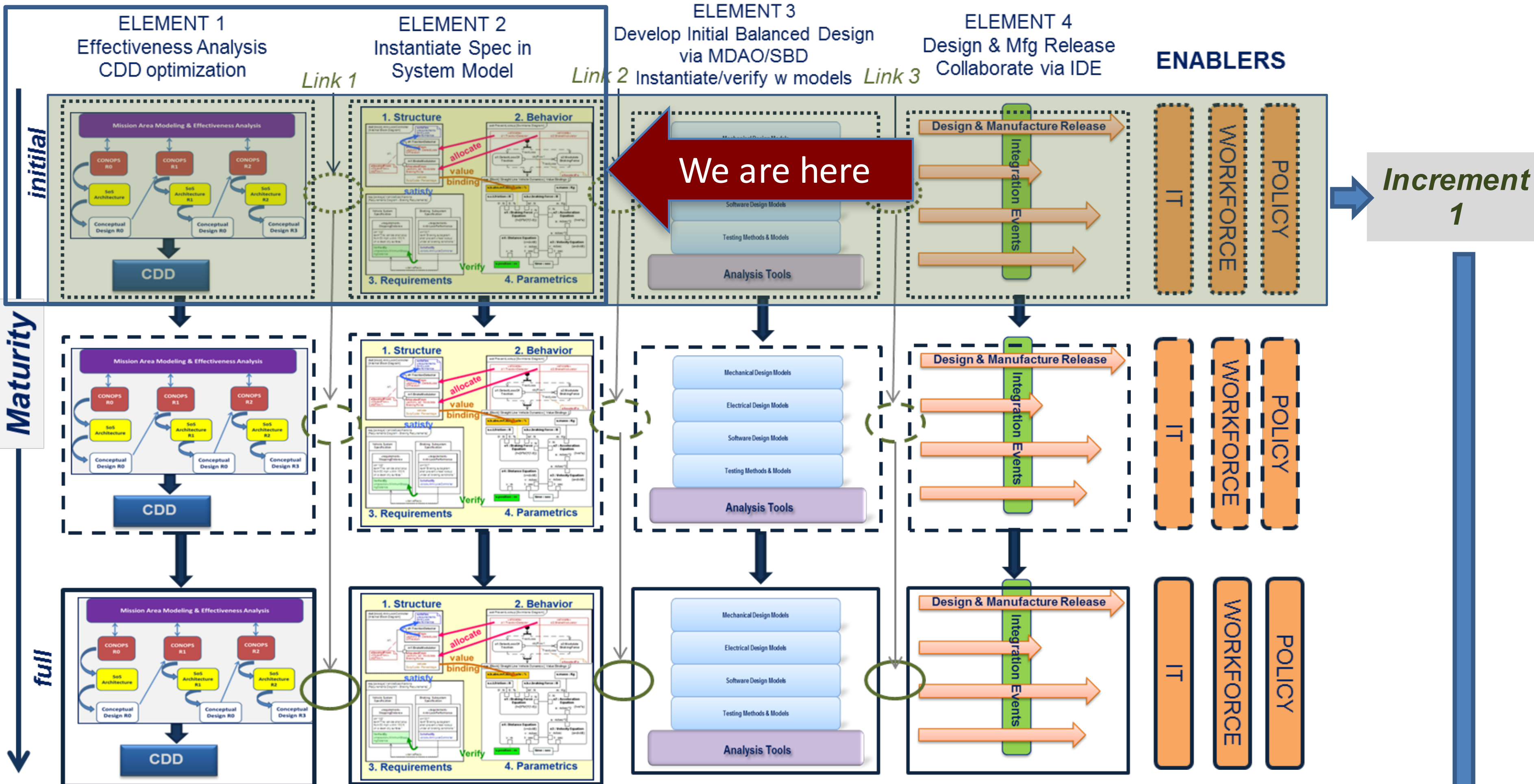


Surrogate Pilot Using OpenMBEE as Basis for Demonstrating Authoritative Source of Truth

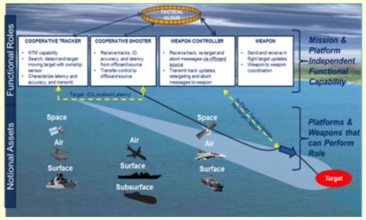


*An Integrated Model Centric Engineering (IMCE) Reference Architecture for a Model Based Engineering Environment (MBEE), NASA/JPL, Sept, 2014.

Where Are We:
Increment 1 and Elements 1 & 2



PILOTS



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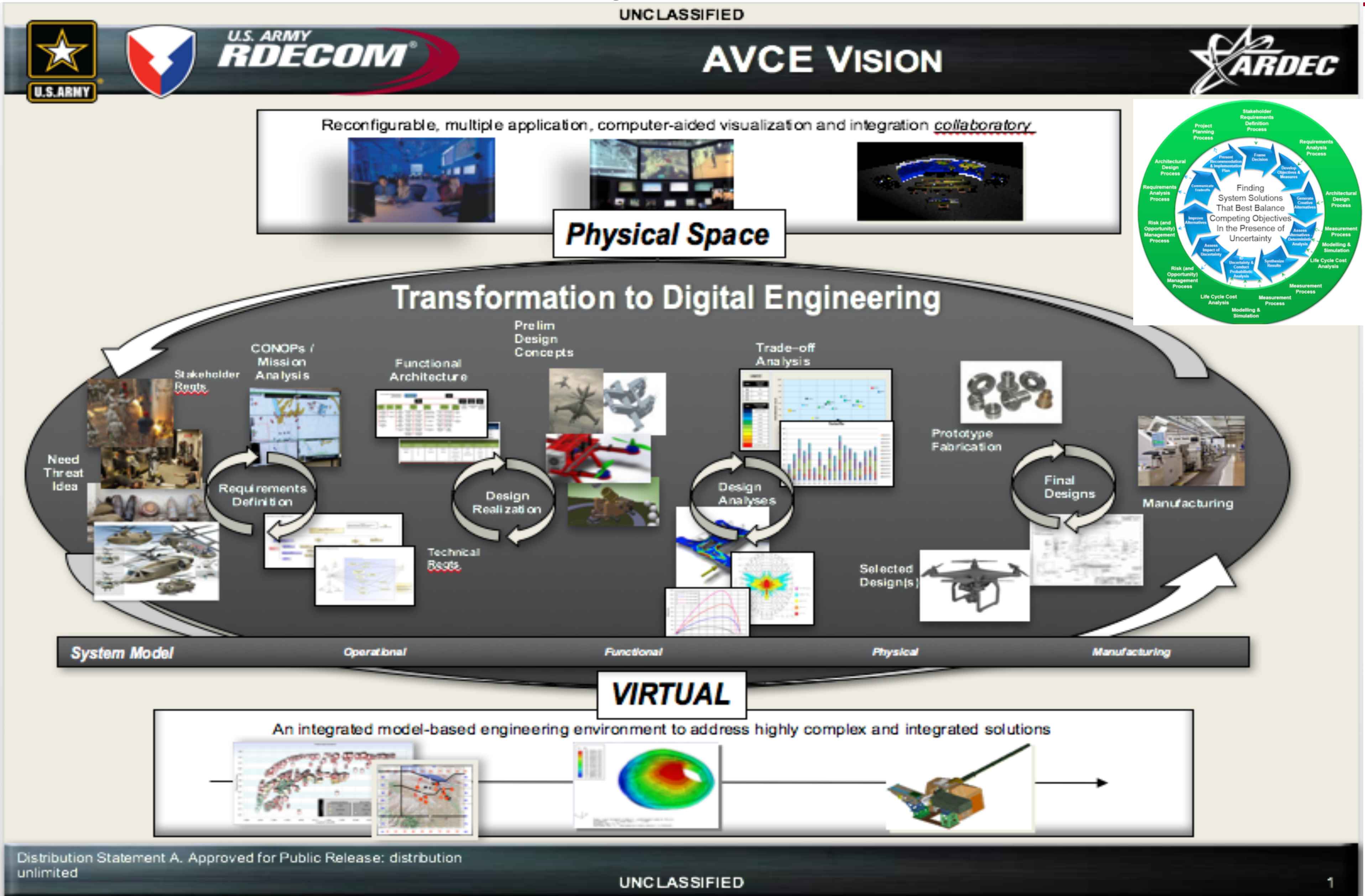
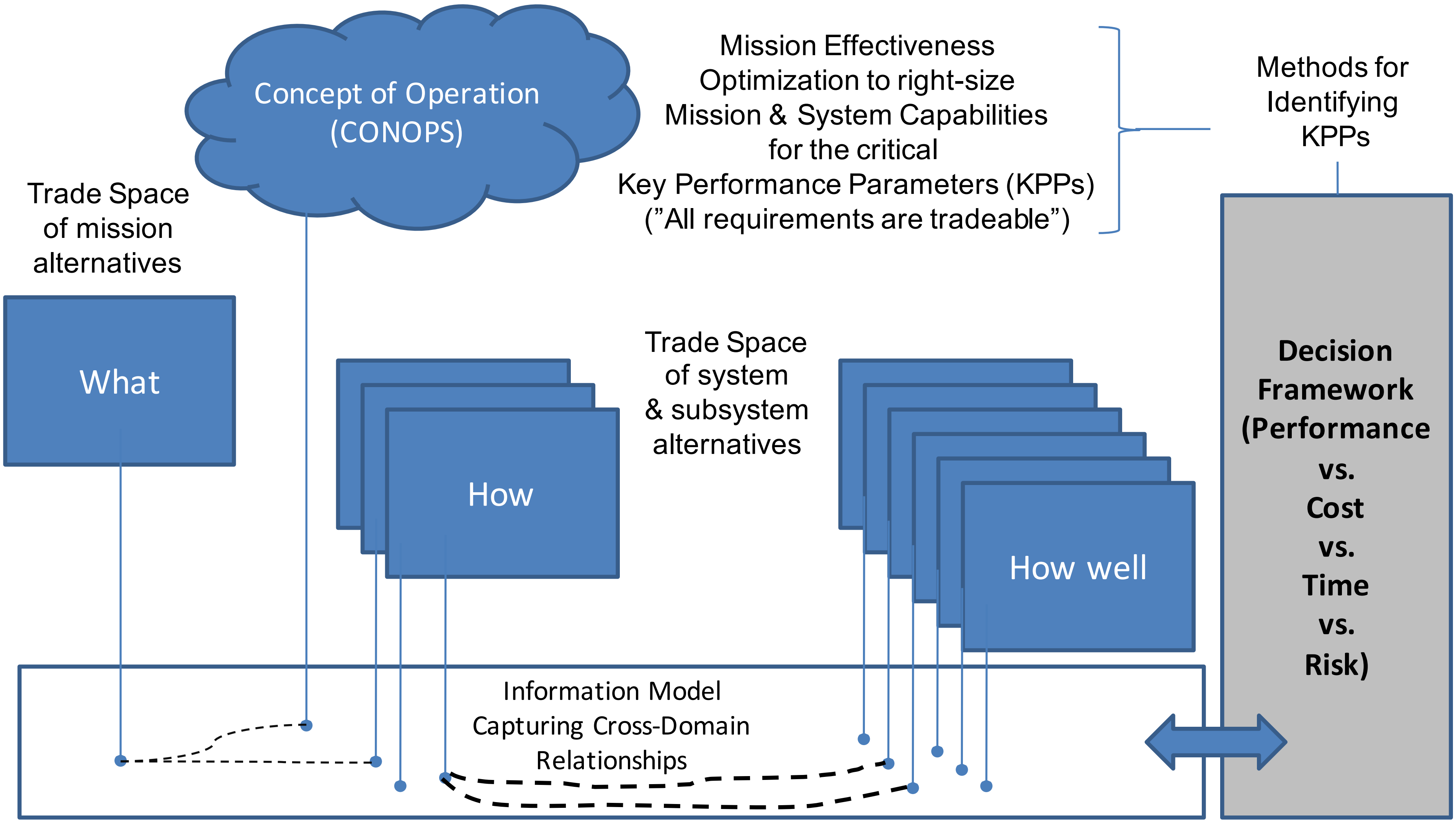
Our Research Efforts are Synergistic With Our ARDEC Sponsor and Other Collaborators



Perspectives on Characterizing Challenges of Research Space



Reasoning about completeness and consistency of information across domains

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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:
    - o 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

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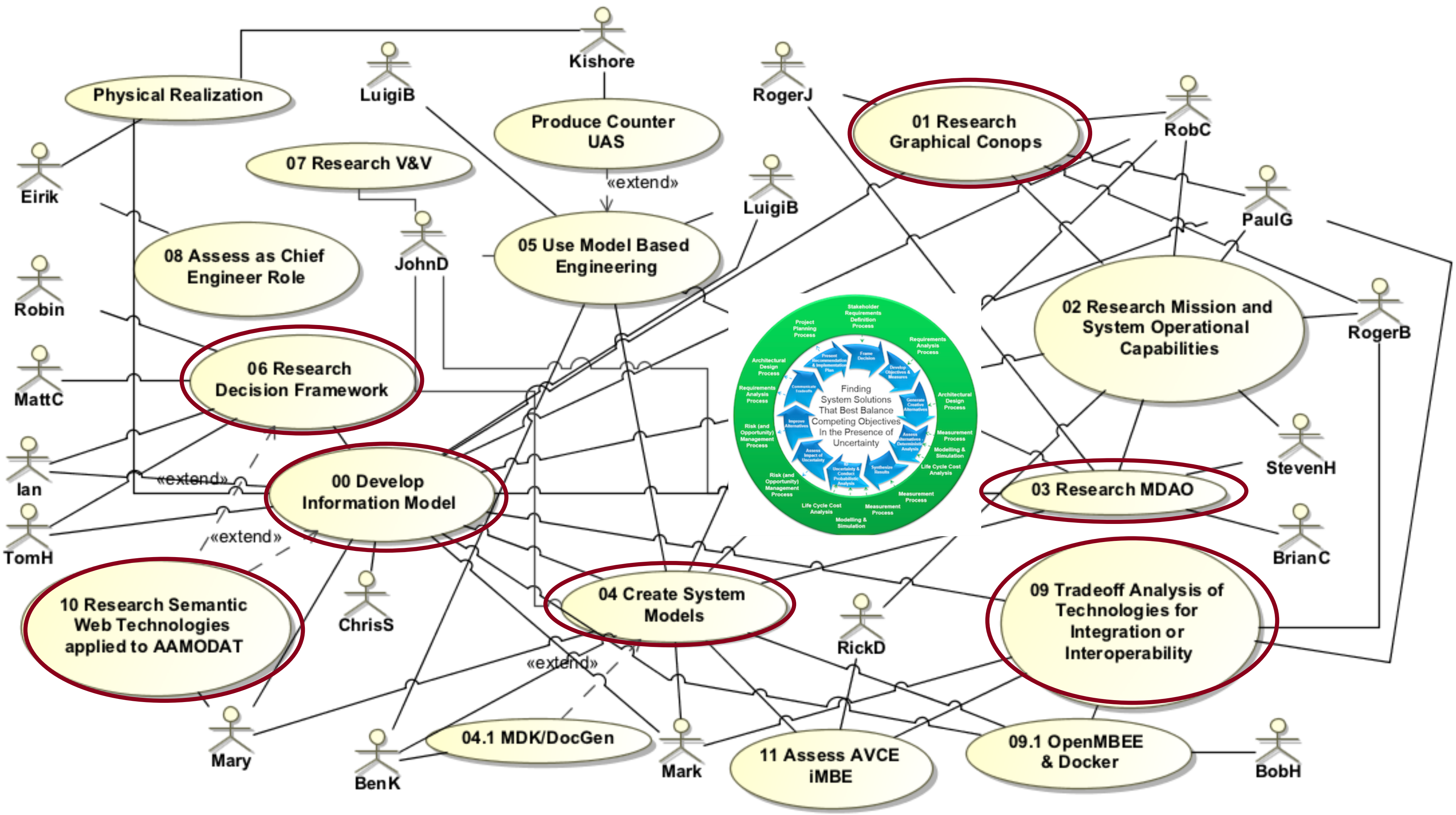
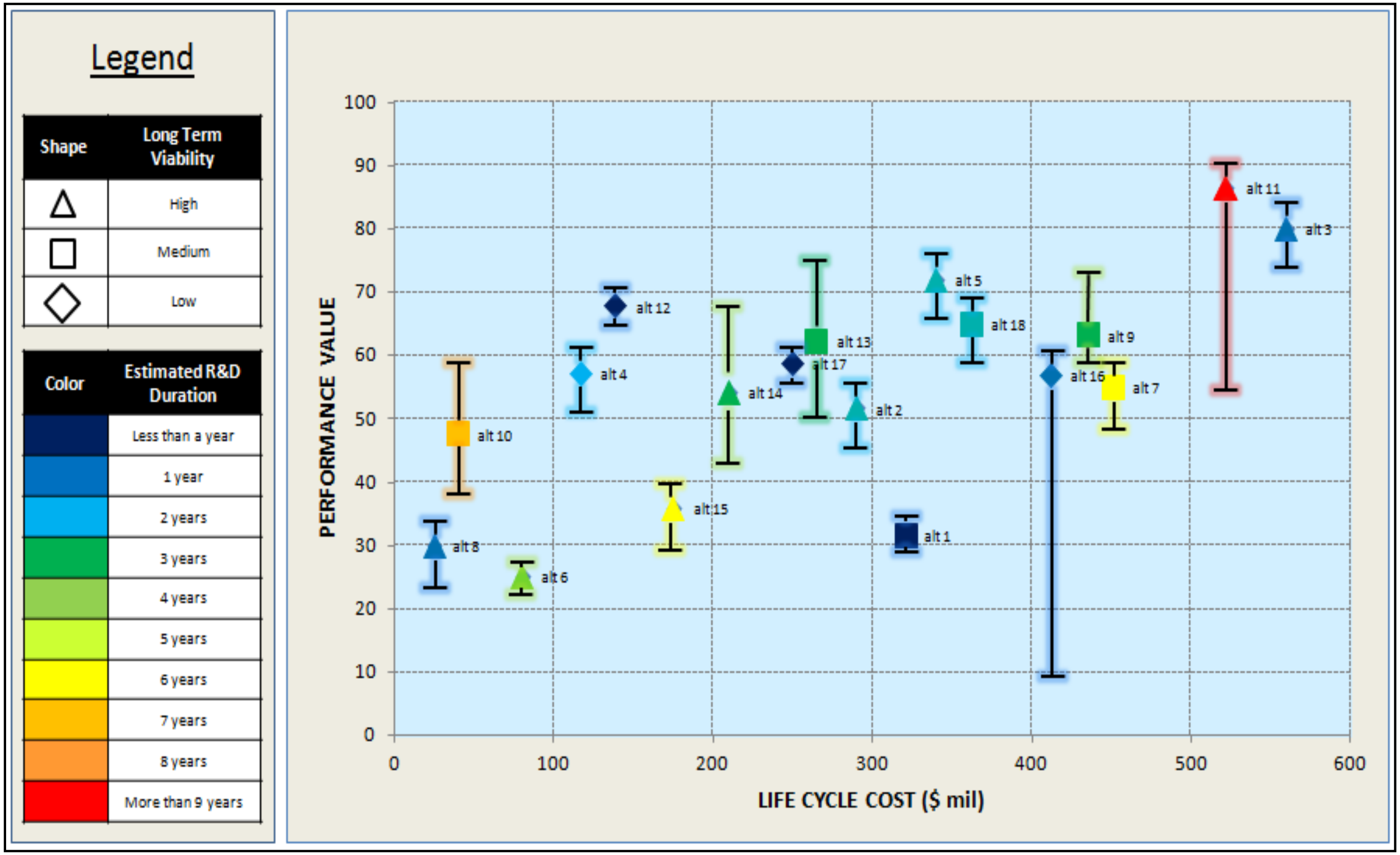
Example: Cross Domain Relationships Needed for System Trades, Analysis and Design

- Scenario Refueling UAV
- Valve – Cross-domain **Object**
- Mechanical **Domain**
  - Valve connects to Pipe
- Electrical **Domain**
  - Switch opens/closes Value
  - Maybe software
- Operator **Domain**
  - Pilot remotely send message to control value
- Communication **Domain**
  - Message sent through network
- Fire control **Domain**
  - Independent detection to shut off valve
- Safety **Domain**

RT-168 Use Case Perspective and Team

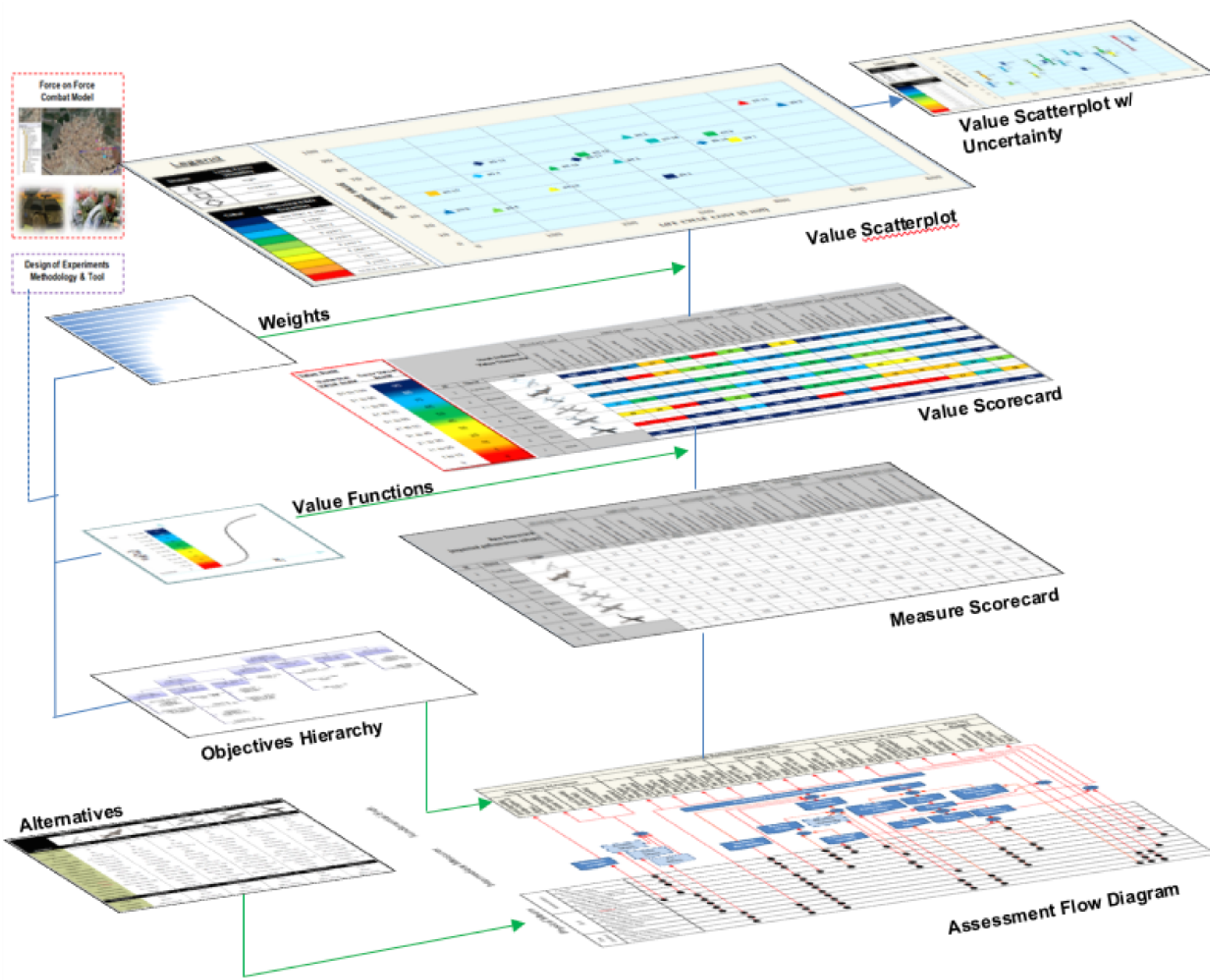


Decision Framework – Value Scatterplot of Trades with Assessing Impact of Uncertainty*



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

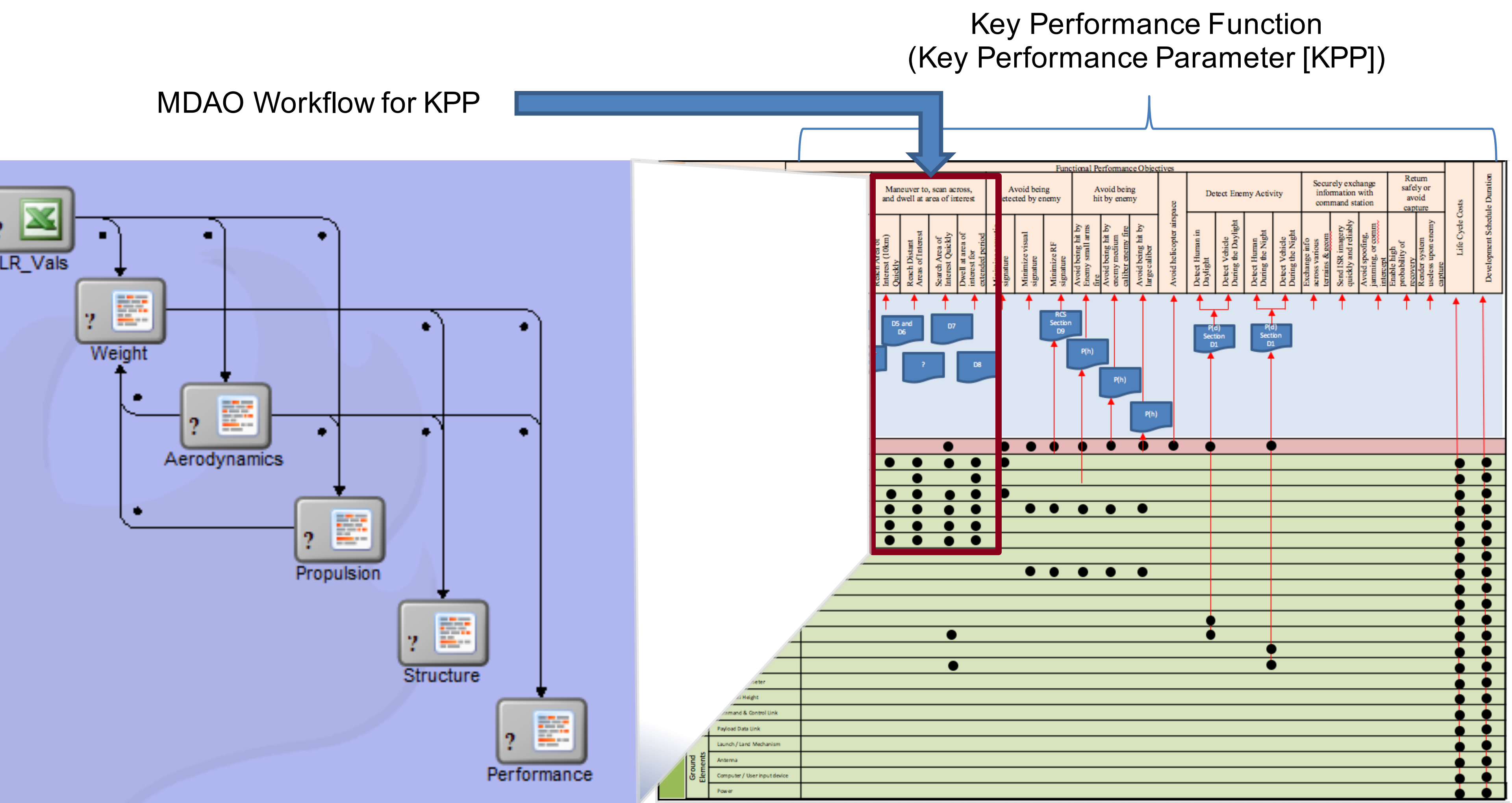
Decision Support Model Construct



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

Using MDAO for Assessment Flow Diagram of Decision Framework (AAMODAT)

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



Understanding Analysis Workflows and Methods for any Configured Workflows

Notional Example

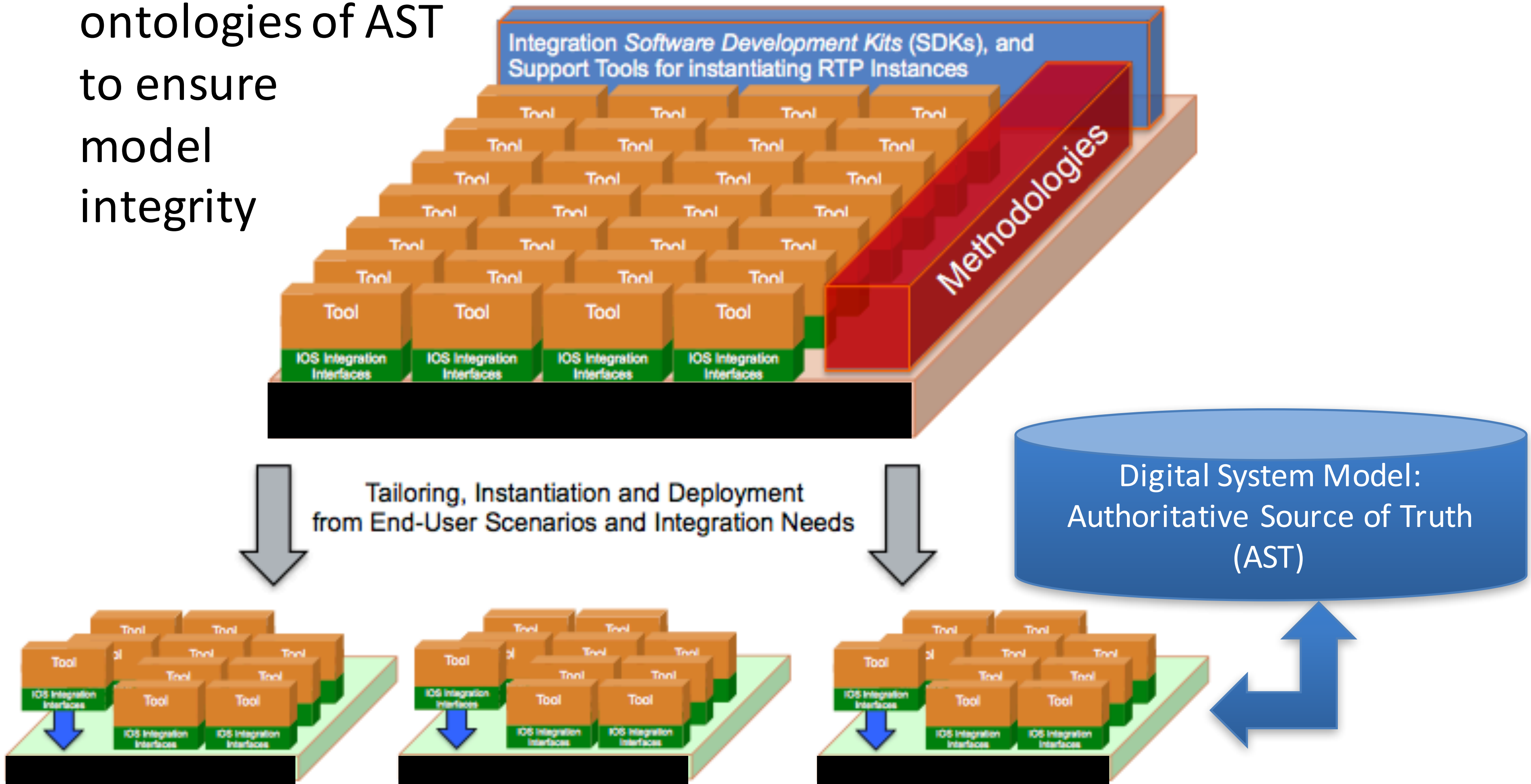
Prodas → CFD Muzzle Analysis

		Flow to the RIGHT -->		-->	-->		Flow to the RIGHT -->
TOOLS	Prodas	CASRED	CFD Muzzle Analysis	Terminal/ Systems Effects	IWARS	System/ Operational Effects	External Ballistics Effects
Prodas	Prodas		X	x		X	
CASRED		CASRED			X		
CFD Muzzle Analysis			CFD Muzzle Analysis			X	
Terminal/ Systems Effects		X		Terminal/ Systems Effects			X
IWARS			X		IWARS		
System/ Operational Effects		X				System/ Operational Effects	
External Ballistics Effects			X	X	X		External Ballistics Effects
	Flow to the <--- LEFT		<---	<---		Flow to the <--- LEFT	

CASRED ← Terminal/Systems Effects

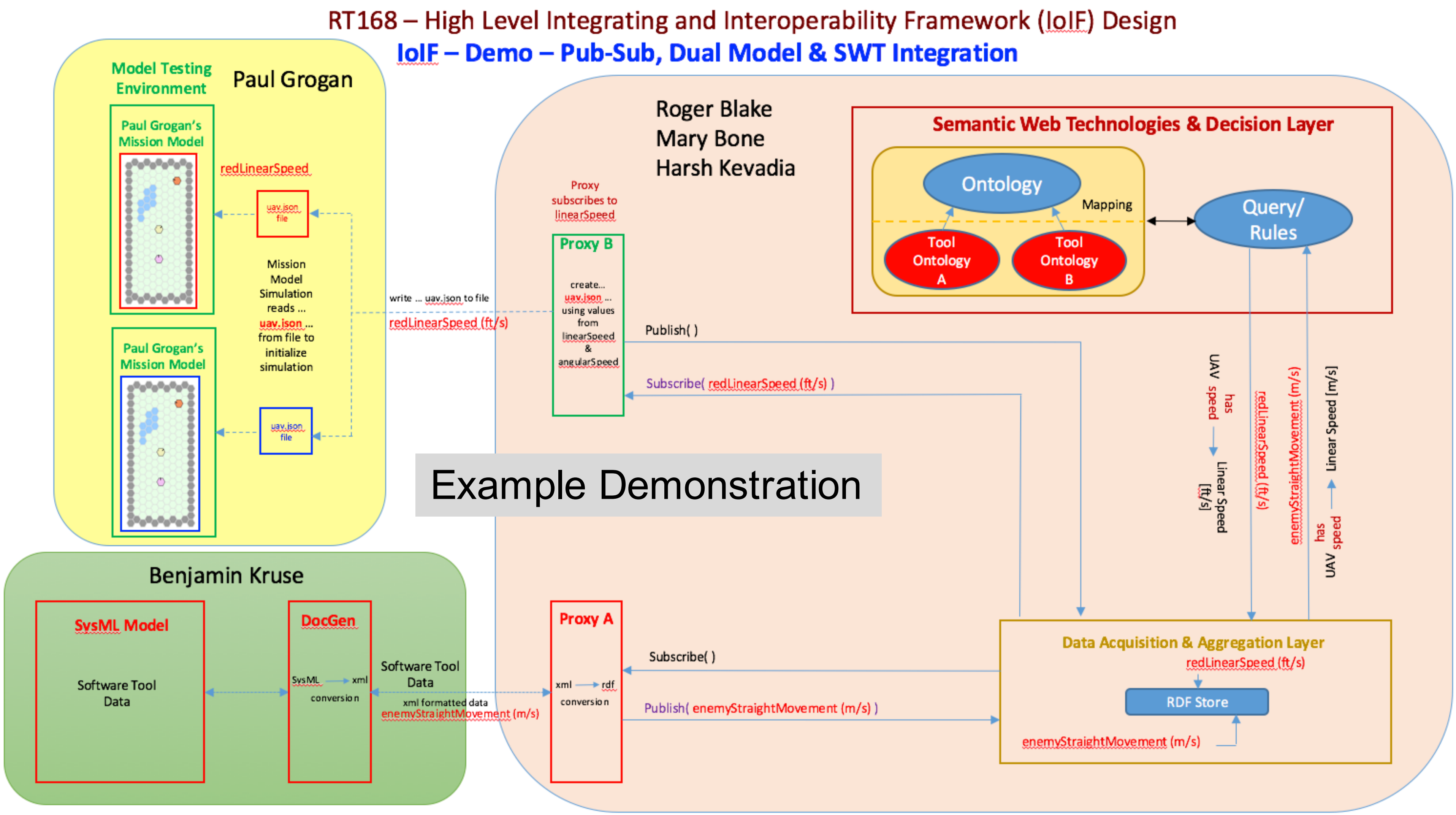
Methodologies are Critical Because Commercial Tools are Method Agnostic

Cross-domain **methodologies** ensure tool usage produces complete and consistent information compliant with ontologies of AST to ensure model integrity



Graphic Credit: CRitical SYSTem Engineering AcceLeration, Interoperability Specification (IOS) – V1 D601.021, ARTEMIS-2012-1-332830, 2014. SERC 168/170.

IoIF Uses SWT for Interoperability Among "Any" Type of MCE Capability



IoIF: Integration and Interoperability Framework
SWT: Semantic Web Technology

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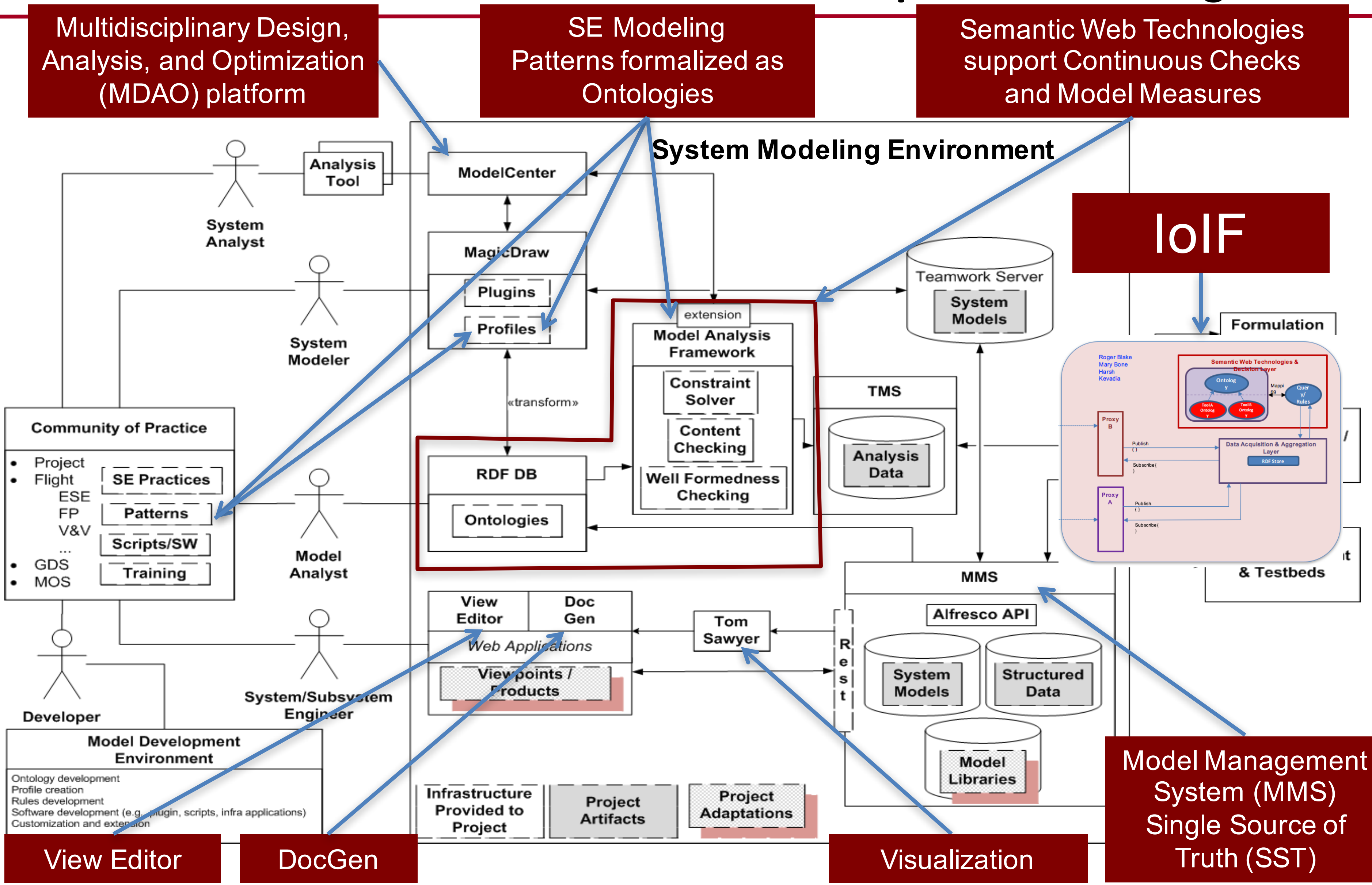
Planned CONCEPT for Integrating Technologies into OpenMBEE through IoIF



*An Integrated Model Centric Engineering (IMCE) Reference Architecture for a Model Based Engineering Environment (MBEE), NASA/JPL, Sept, 2014.

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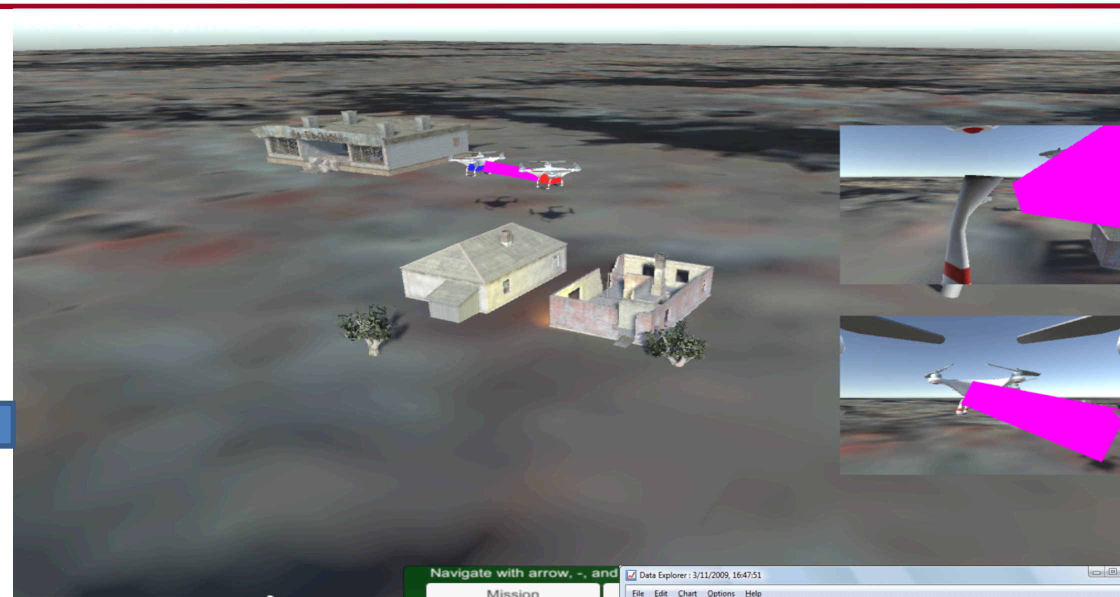
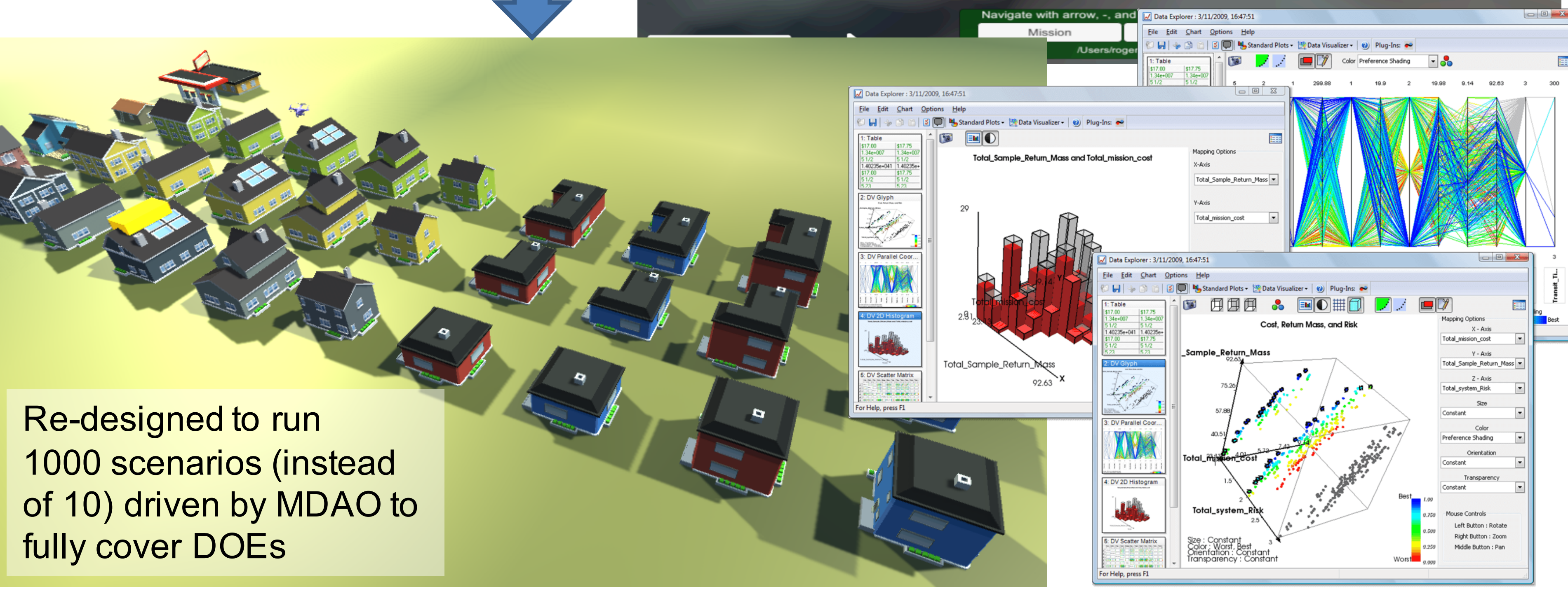
Explore Integration of Graphical CONOPS Simulation with MDAO tools

Fully interactive simulation of a blue UAS on a mission to located a treasure with an intelligent (AI) red UAS counterparty disrupting mission

<u>MDAO Methods</u>

- Design of Experiments (DOE)
- Sensitivity Analysis
- Optimize desired objectives





Re-designed to run 1000 scenarios (instead of 10) driven by MDAO to fully cover DOEs

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Collaborations

- SERC Collaborator: Georgia Tech, Georgetown, Naval Postgraduate School, Univ. of Maryland, Univ. of Massachusetts, Univ. of Southern Cal., Wayne State
- Digital Engineering Working Group
- Airspace Industry Association: CONOPS for Industry/Government Collaborative Framework
- Semantic Technologies for Systems Engineering Foundation
- NDIA Working Group – Using Digital Engineering for Competitive Down Select
- NASA/JPL
- OpenMBEE Collaborator Group
  - https://groups.google.com/d/forum/openmbee/

Thank You

- For more information contact:
  - Mark R. Blackburn, Ph.D.
  - Mark.Blackburn@stevens.edu
  - Stevens Institute of Technology
  - Links to technical reports: http://www.sercuarc.org/researcher-profile/mark-blackburn/
  - Overview briefing of both projects from SERC Sponsor Review 2016: http://www.sercuarc.org/wp-content/uploads/2014/05/05B_SSRR-2016_RT157_Blackburn_v2.pdf
  - Historical perspective with a long briefing: http://www.sercuarc.org/publications-papers/presentation-systems-engineering-transformation-through-model-centric-engineering-past-why-present-what-and-future-how/

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Acronyms

CDD	Capability Description Document
CONOPS	Concept of Operations
CDR	Critical Design Review
CDRL	Contract Data Requirements List
CFD	Computational Fluid Dynamics
DARPA	Defense Advanced Research Project Agency
DASD	Deputy Assistant Secretary of Defense
DoD	Department of Defense
DoE	Design of Experiments
FEA	Finite Element Analysis
HPC	High Performance Computing
IMCE	Integrated Model-Centric Engineering
IMCSE	Interactive Model-centric Systems Engineering
IoT	Internet of Things
JCIDS	Joint Capabilities Integration and Development System
KPP	Key Performance Parameter
MBSE	Model-based System Engineering
MBE	Model-Based Engineering
MCE	Model-Centric Engineering
MCSE	Model-Centric System Engineering
MDAO	Multidisciplinary Design Analysis and Optimization
MDE	Model-Driven Engineering
NAVAIR	Naval Air Systems Command
OV	Operational View
P&FQ	Performance and Flight Quality
PDR	Preliminary Design Review
PLM	Product Lifecycle Management
RT	Research Task
SLOC	Software Lines Of Code
SE	Systems Engineering
SET	Systems Engineering Transformation
SERC	System Engineering Research Center
SETR	Systems Engineering Technical Review
SFR	System Functional Review
SRR	System Requirements Review
SoS	System of Systems
SOW	Statement of Work
SSTT	Single Source of Technical Truth
SV	System View
UAV	Unmanned Air Vehicle
V&V	Verification and Validation