SYSTEMS ENGINEERING RESEARCH CENTER

SERC RESEARCH REVIEW 2024 | NOVEMBER 12, 2024

A Digital Engineering Methodology and Framework for Interoperability Using Ontologies

ART-022 & WRT-1084

US Army Armaments Center & Office of Undersecretary of Defense (R&E)

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STEVENS INSTITUTE of TECHNOLOGY
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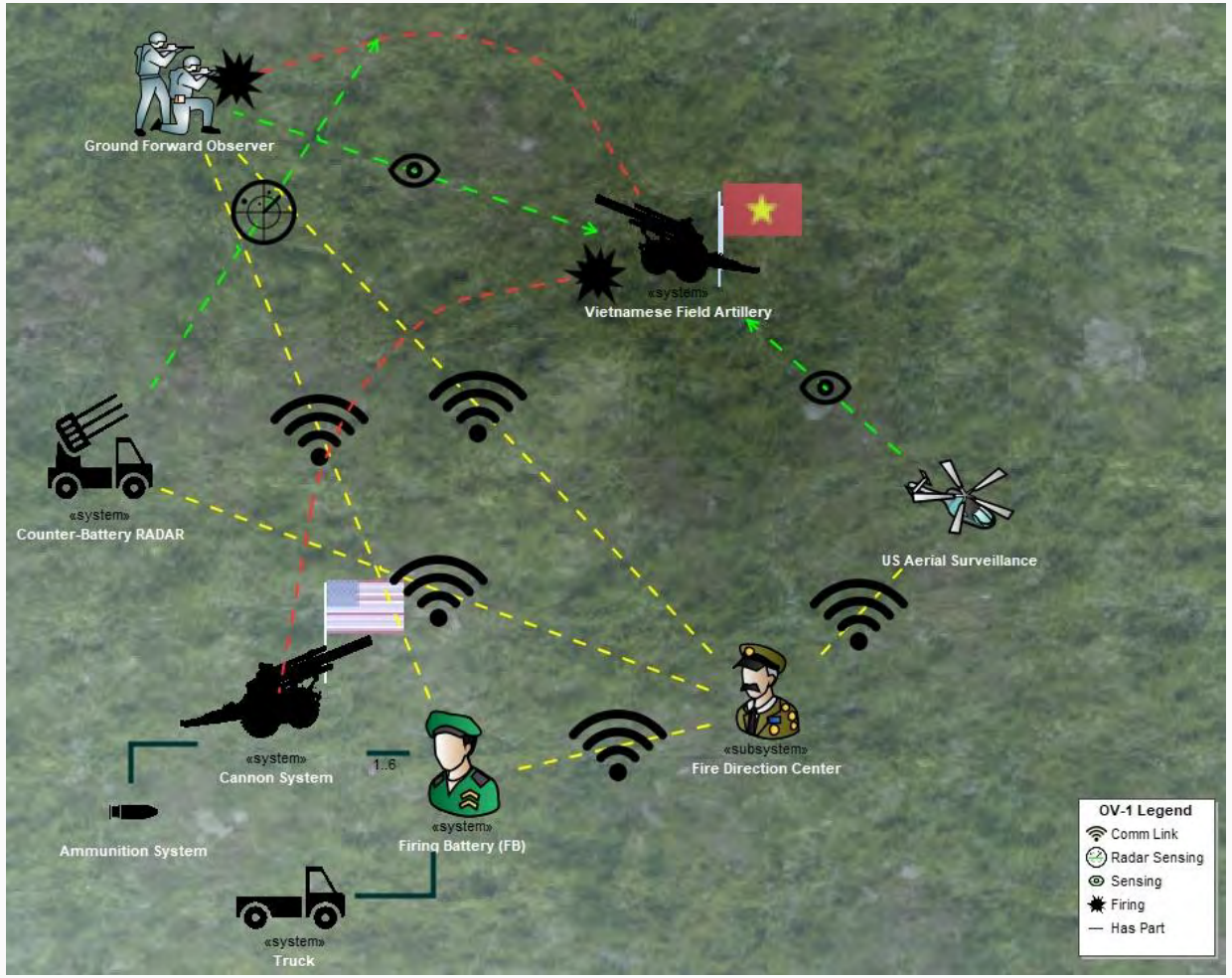
Research Sponsor Domain

Armaments Missions



Organization

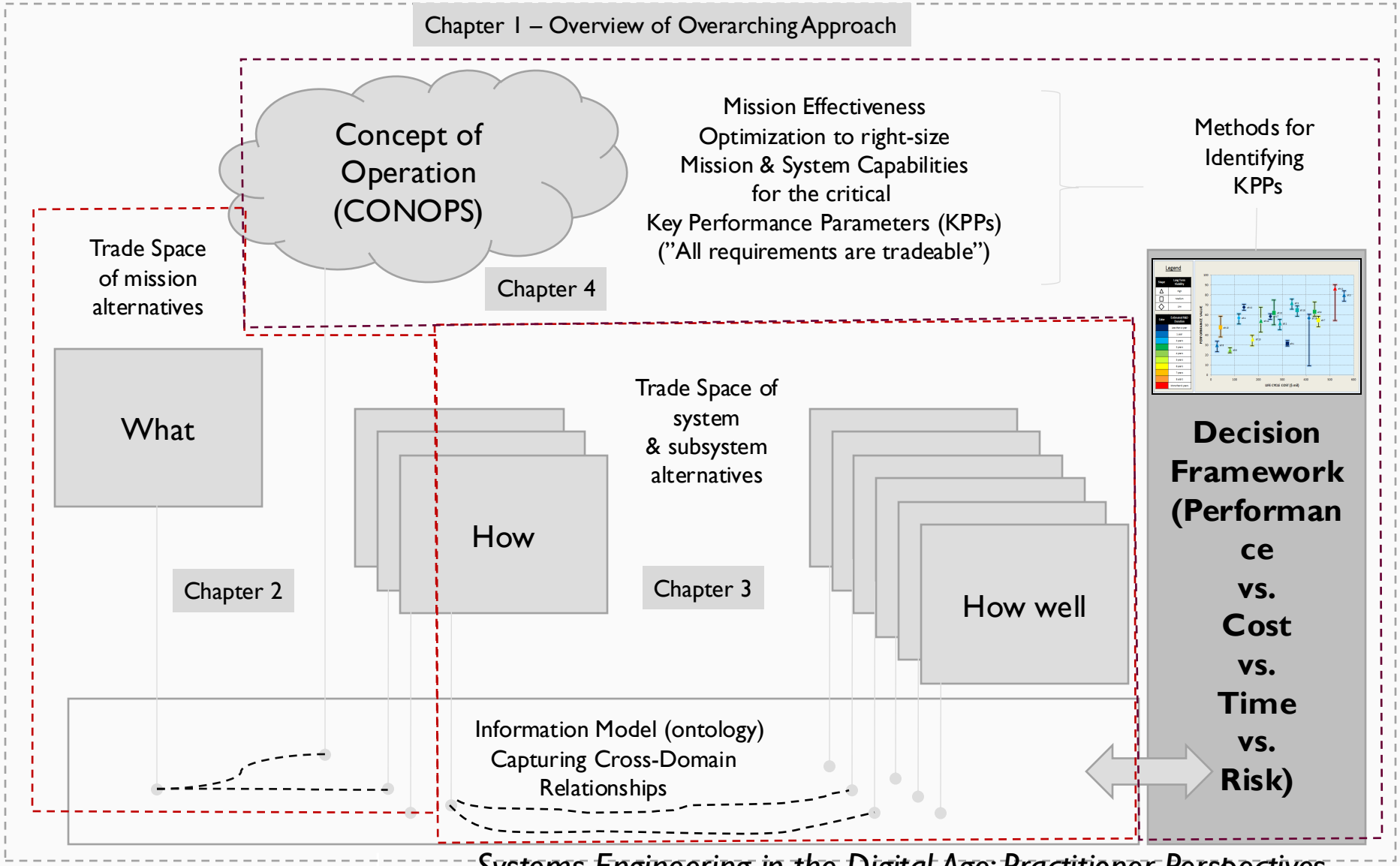
- INTRO (WHY): Context/Motivation – How did we get here?
- WHAT: Digital Engineering Enabling Technologies and Methods to Computationally Leverage Ontologies and Semantic Technologies
- HOW: "Full Stack" of Models with Integrated Workflows Coordinated using Armaments Interoperability and Integration Framework (IoIF)
- HOW WELL: Transitioning research using two different training courses for two different use cases – one which is discussed herein
  - Ontology Workshop and also modules in Digital Engineering/MBSE Bootcamp

Overview on Topics

- Tool-to-tool integration challenges for cross-domain & physics-based analyses needed at multiple levels of abstraction (mission, system, subsystems)
- Integrated Systems Engineering Decision Management (ISEDM) Process (Cilli 2015) for tradespace alternative analysis
- Formalized ISEDM process using SysML models, ontologies and semantic technologies (SWT) with Armaments Interoperability and Integration Framework (IoIF) and workflows
  - Formalized Assessment Flow Diagram (AFD) to characterize parametric relationships between Mission and System objectives represented as value properties associated with Catapult case study
  - IoIF links mission, system, and discipline-specific modeled parameters in analysis to determine mission & system measures for objectives

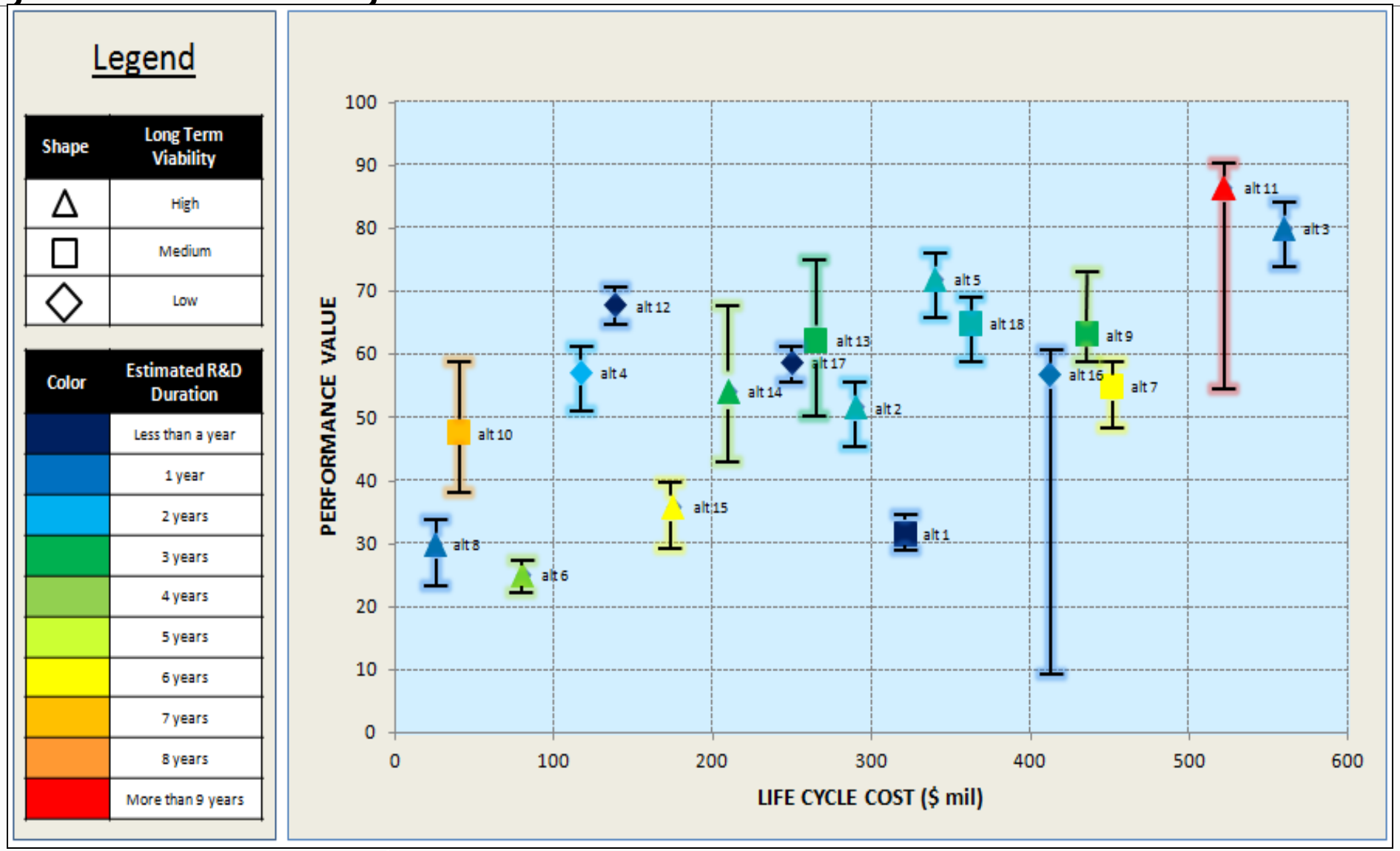
Operational Use Case from a Traditional Systems Engineering Perspective

Circa ~2015



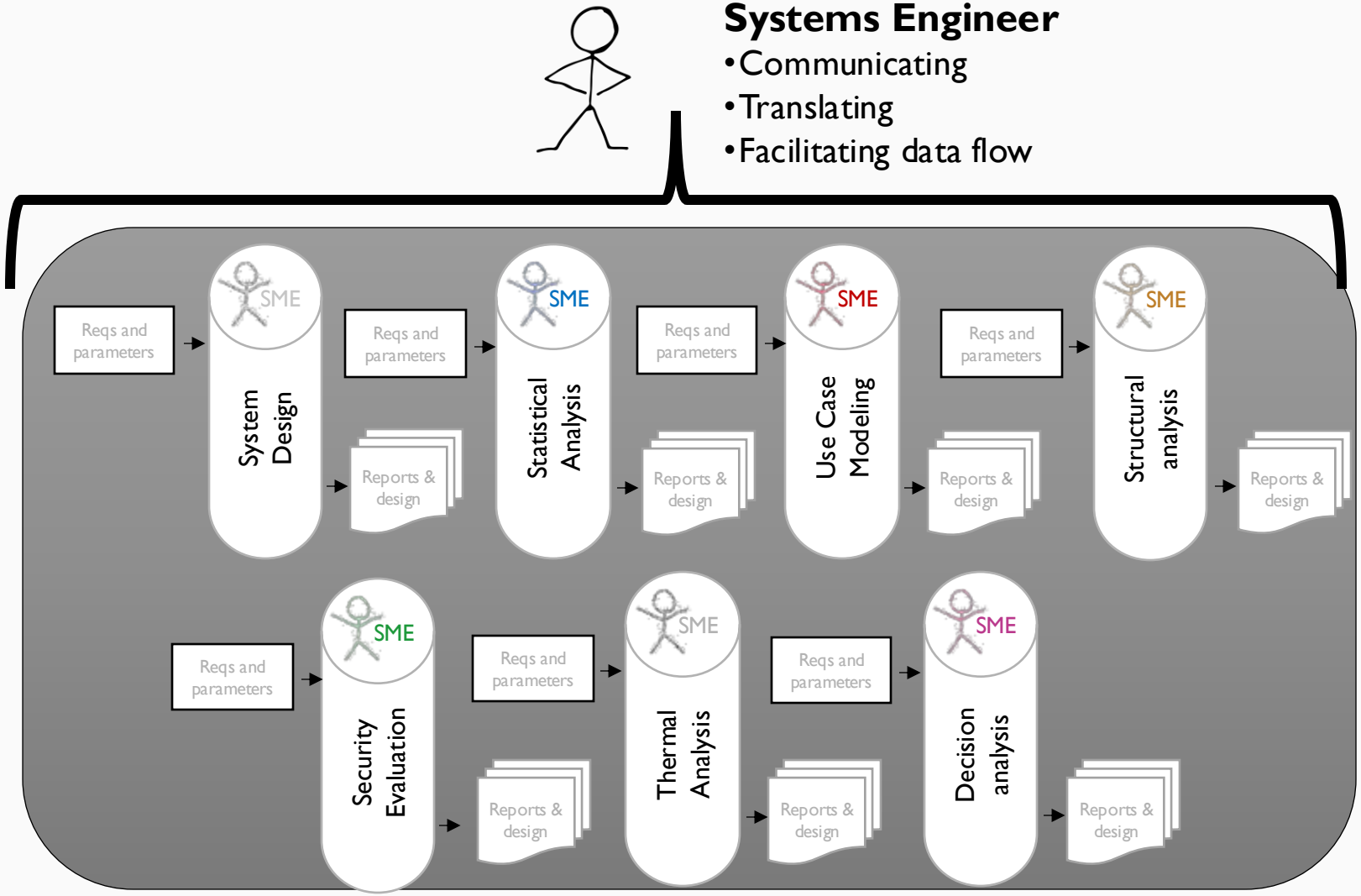
Systems Engineering in the Digital Age: Practitioner Perspectives

Visualize Mission & System Level Trades Across Cost, Schedule, Performance



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

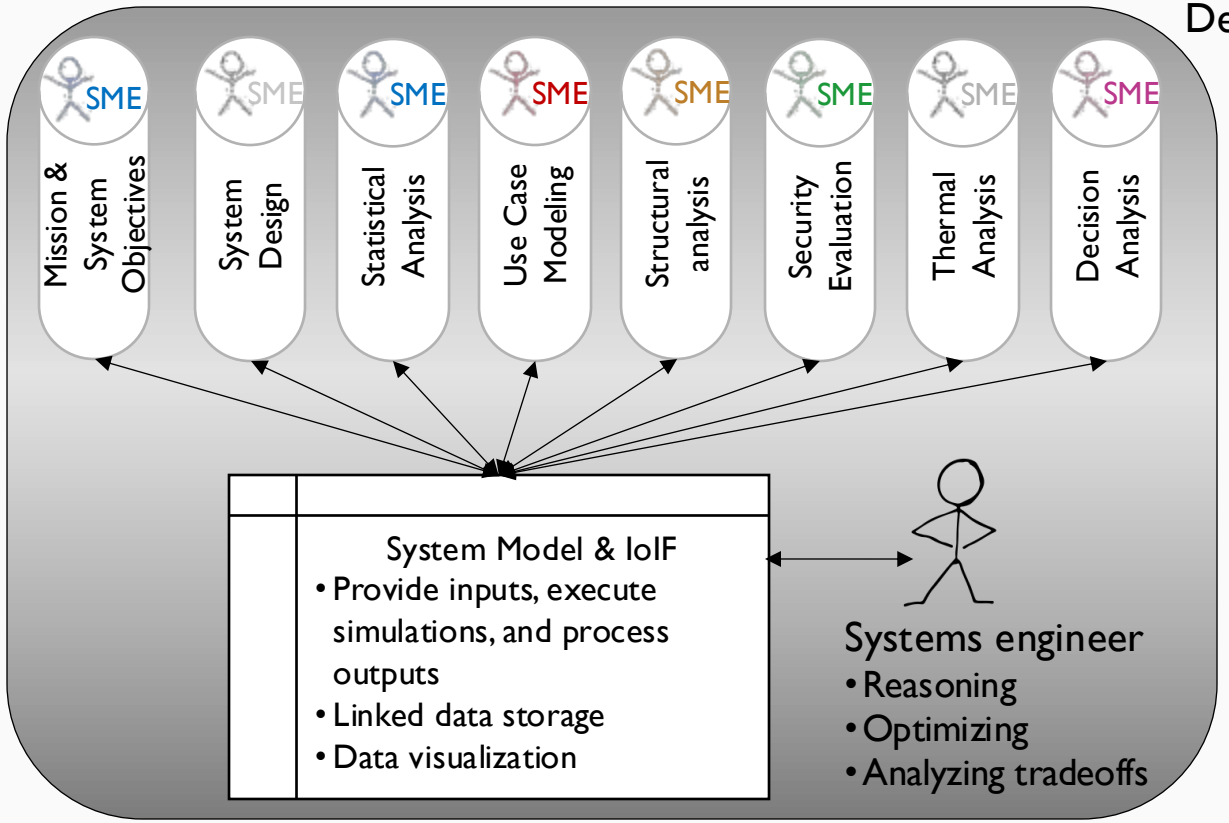
Challenges: Needed to Transform Beyond Stove Piped Analysis



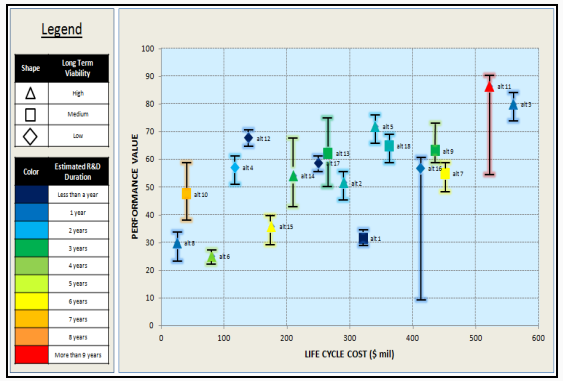
Example: Cross Domain Relationships Needed for System Trades, Analysis and Design

- Mission objective: continuous surveillance
- Capability Refueling UAV
- Systems: UAV and Refueler
- Valve – Cross-domain Object
- Mechanical Domain
  - Valve connects to Pipe
- Electrical Domain
  - Switch opens/closes Value
  - Maybe software
- Operator Domain
  - Pilot remotely sends message to control value
- Communication Domain
  - Message sent through network
- Fire control Domain
  - Independent detection to shut off valve
- Safety Domain

Ontologies and Semantic Technologies Support Cross-Domain Model "Integration" through Interoperability



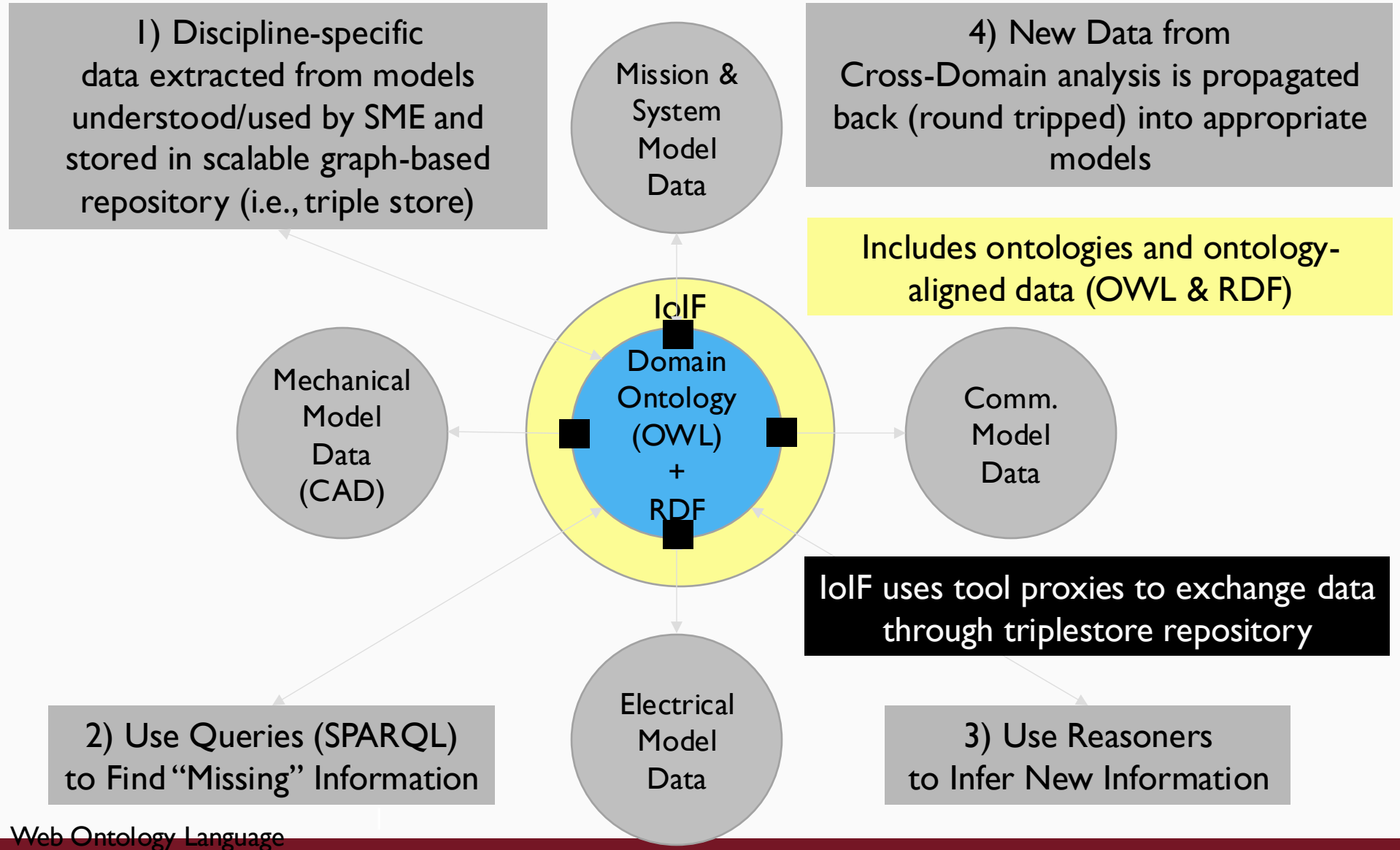
Scatter Plot Dashboard for Decision Making related to Objectives



Strategic/mission-level decision-maker

- Setting requirements & objectives
- Exploring tradeoffs
- Adjusting requirements & objectives based on capability information

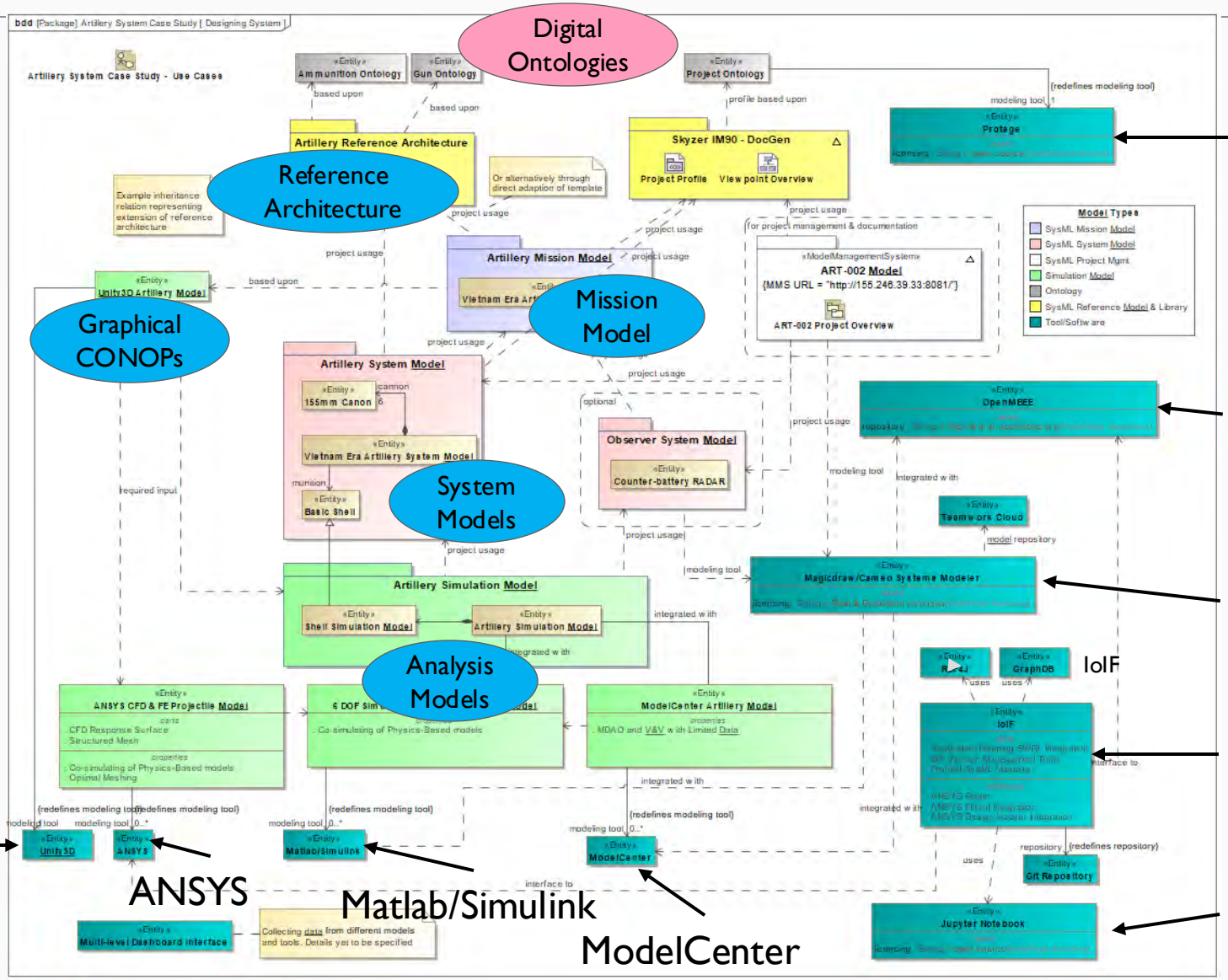
Bring Data Across Disciplines into Linked Data that Complies with Evolving Domain Ontology



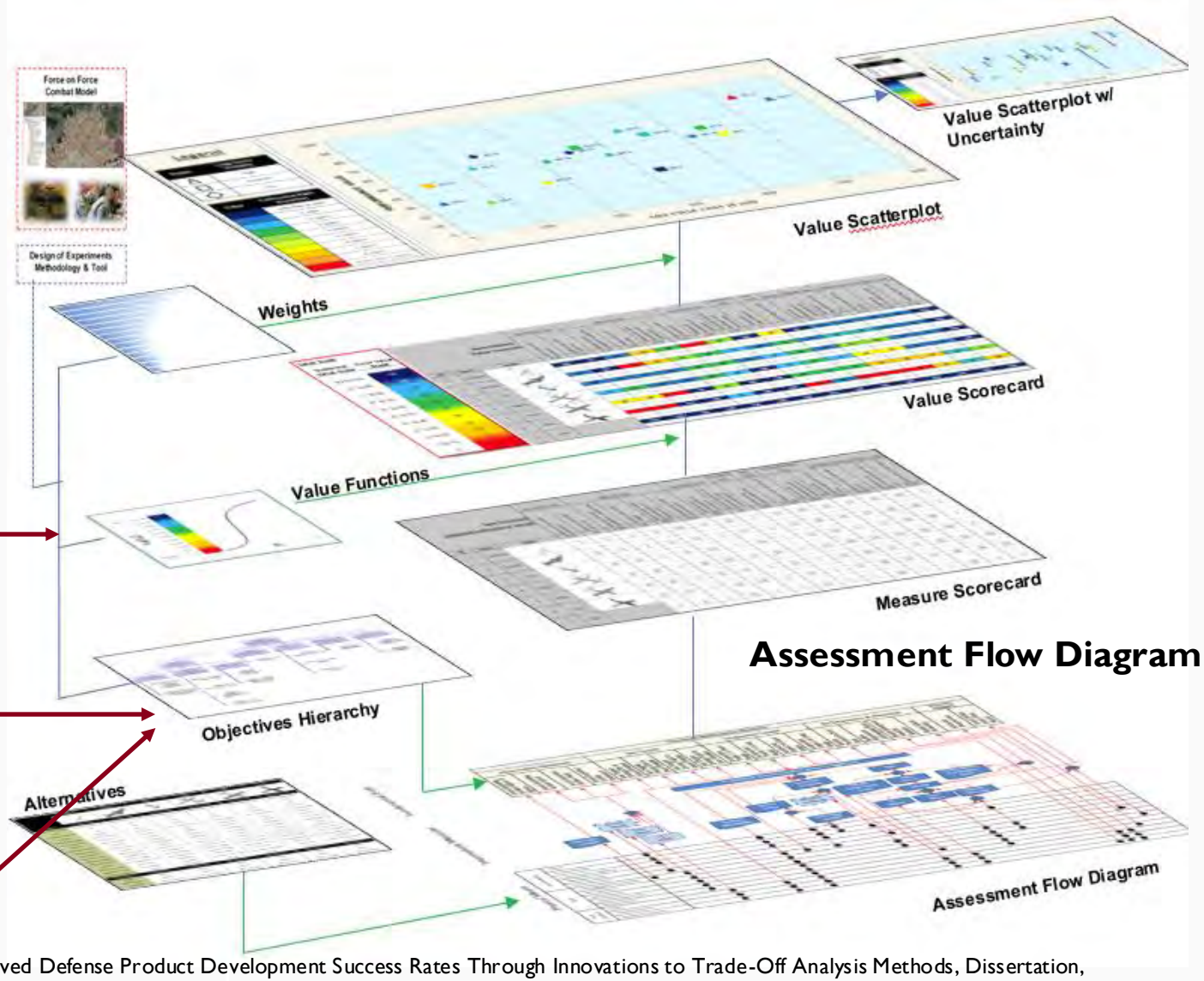
OWL: Web Ontology Language

RDF: Resource Description Framework

Example “Full Stack” Models and Related Tools



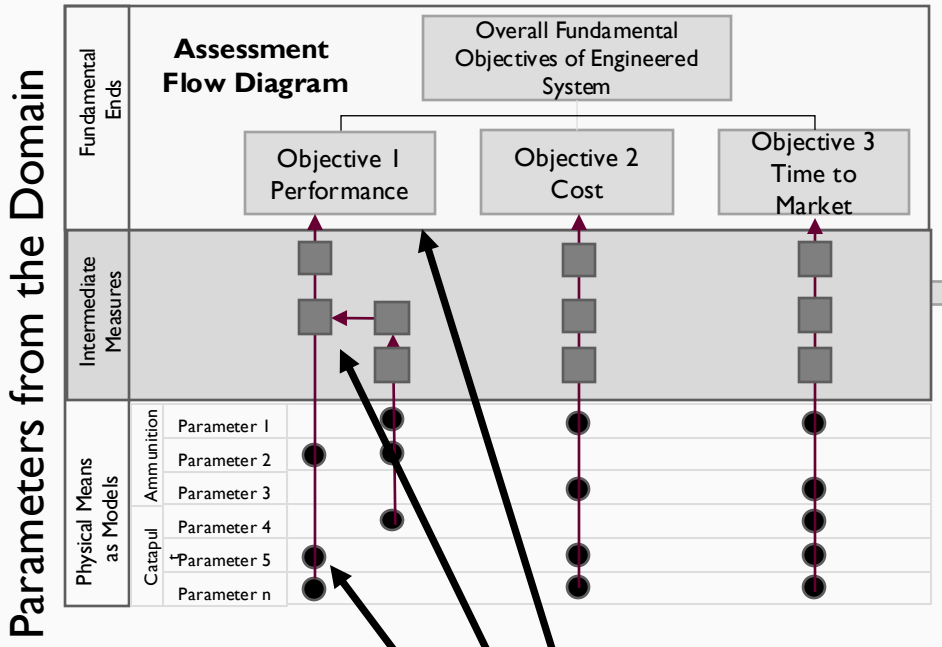
Decision Support Model Construct



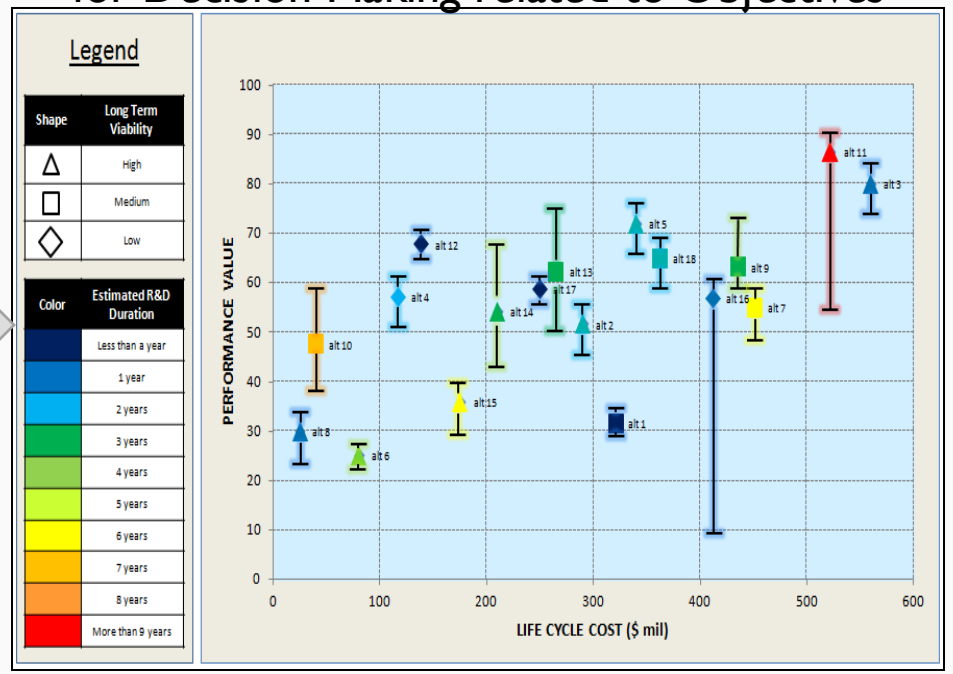
Cilli, M. Seeking Improved Defense Product Development Success Rates Through Innovations to Trade-Off Analysis Methods, Dissertation, Stevens Institute of Technology, Nov. 2015.

Methodology Formalizes using DE/SysML Workflows Executed by IoIF for Trade Space Decision Making

Objective (Key Performance Parameters/Indicators) and/or Mission Measures



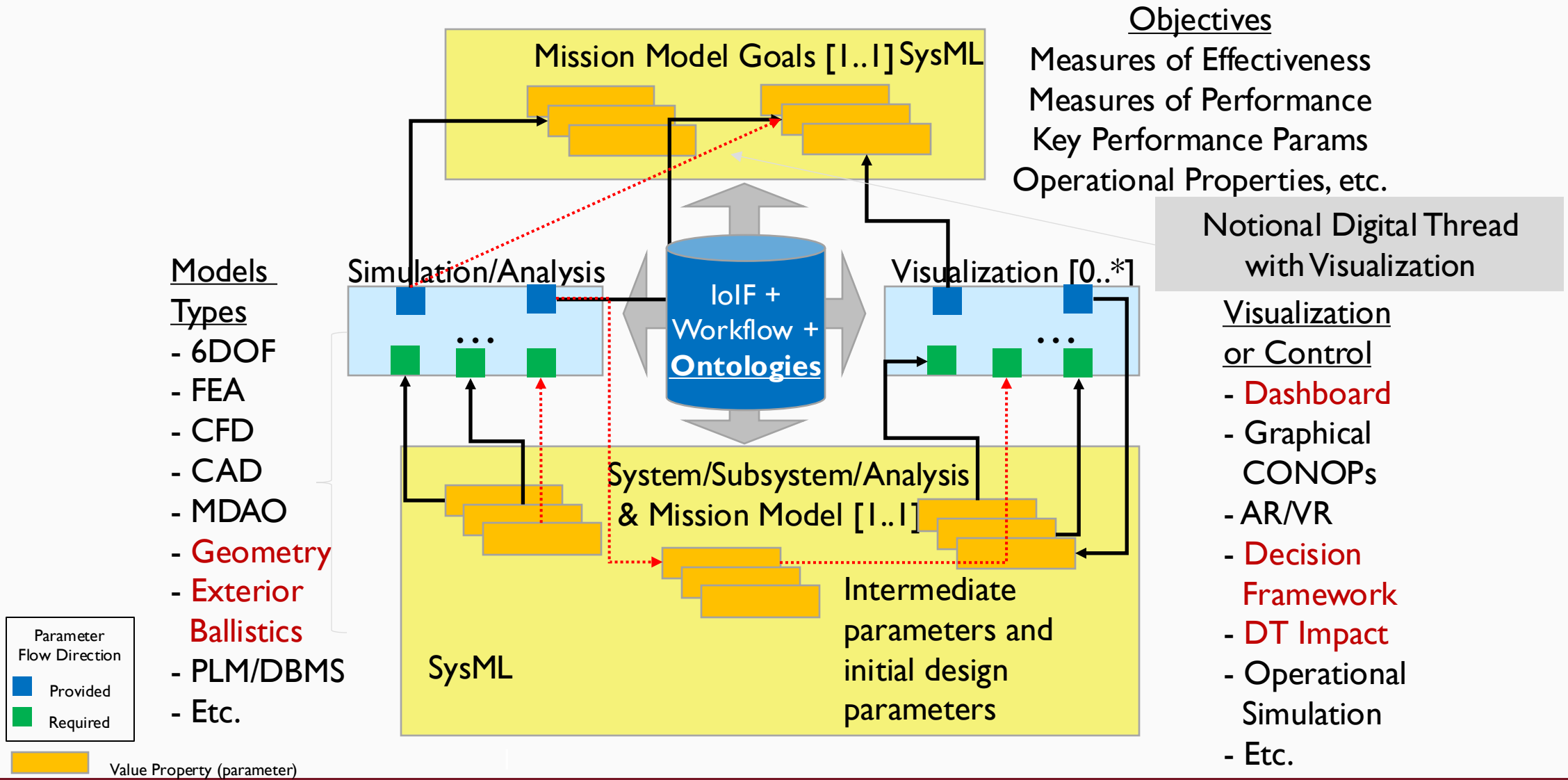
Scatter Plot Dashboard for Decision Making related to Objectives



1. Objectives formalized in MBSE/Descriptive Model using SysML
2. Workflows characterized in MBSE/Descriptive Model using SysML to define interfaces to simulations and visualizations
3. Interfaces use defined parameters for every model in workflow using tool proxies to workflows defined in standards such as JSON, XML, CSV, etc.

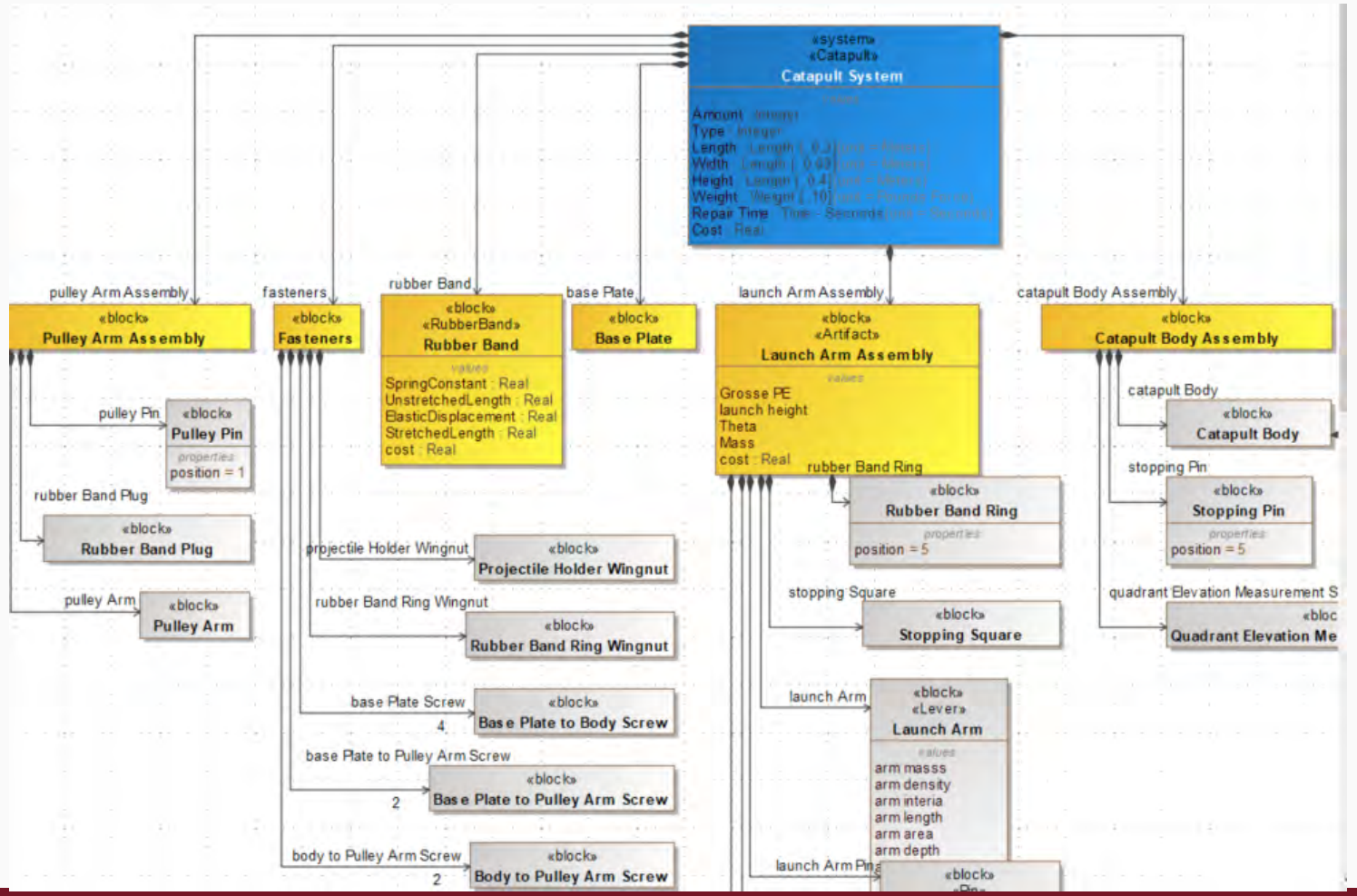
*Integrated Systems Engineering Decision Method (Cilli 2015): additional details in backup.

AFD Generalization that can be Configured for Various Types of Analyses with Digital Threads



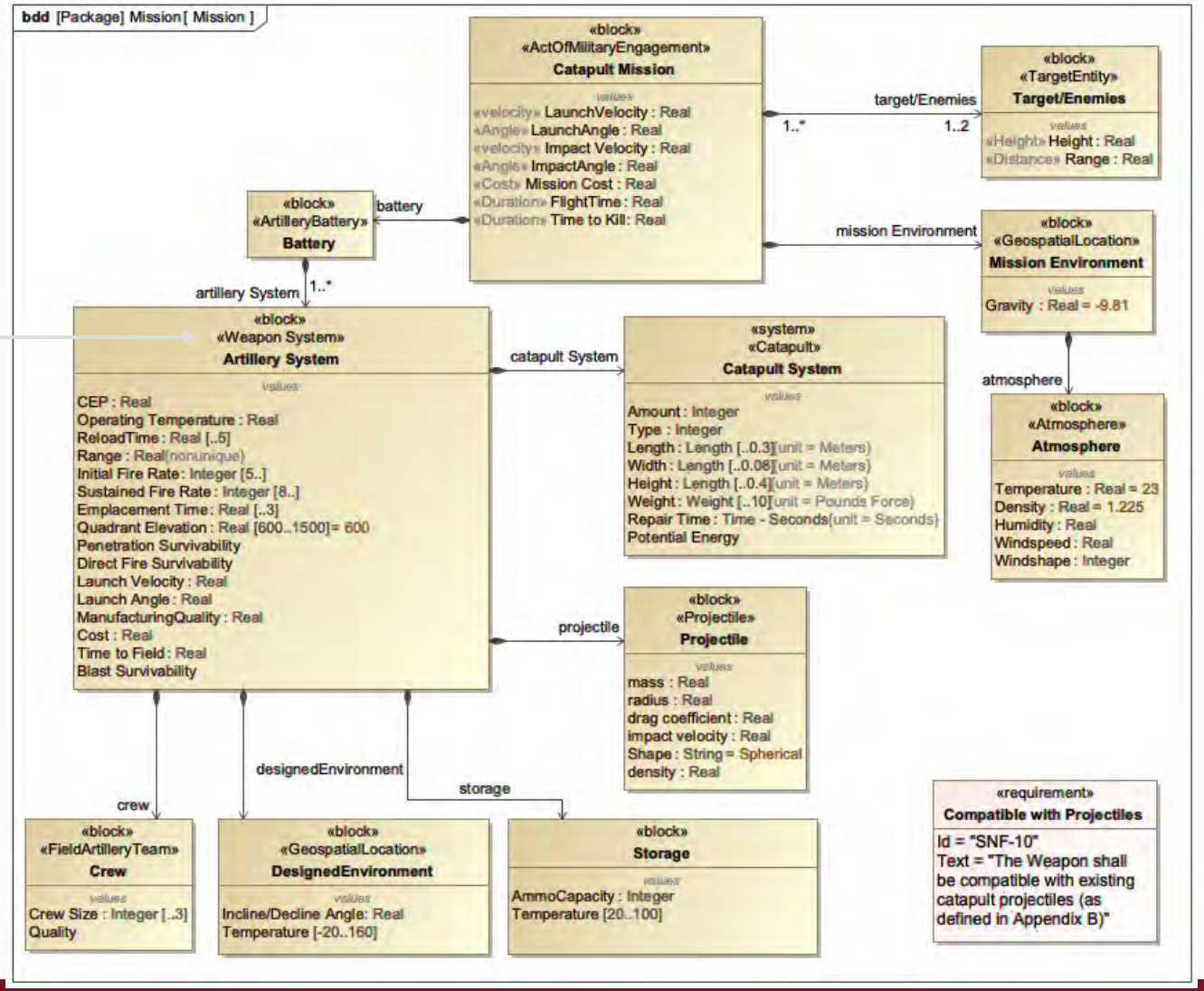
Catapult Structural Model

- Sponsor provided baseline Distribution A case study models that were incorporated into a Mission and System of Analysis for IoIF



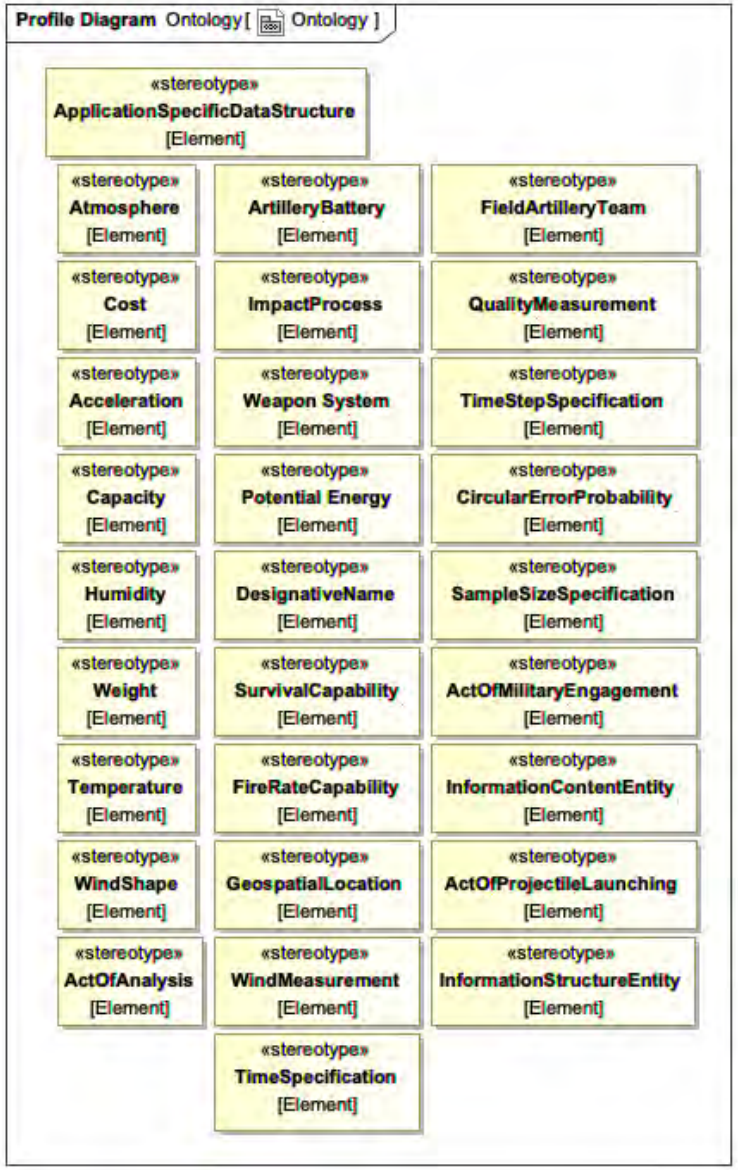
Catapult Mission/System Models Tagged with Stereotypes that Map to Ontology Classes

Stereotype "Tag" map to Ontology Classes

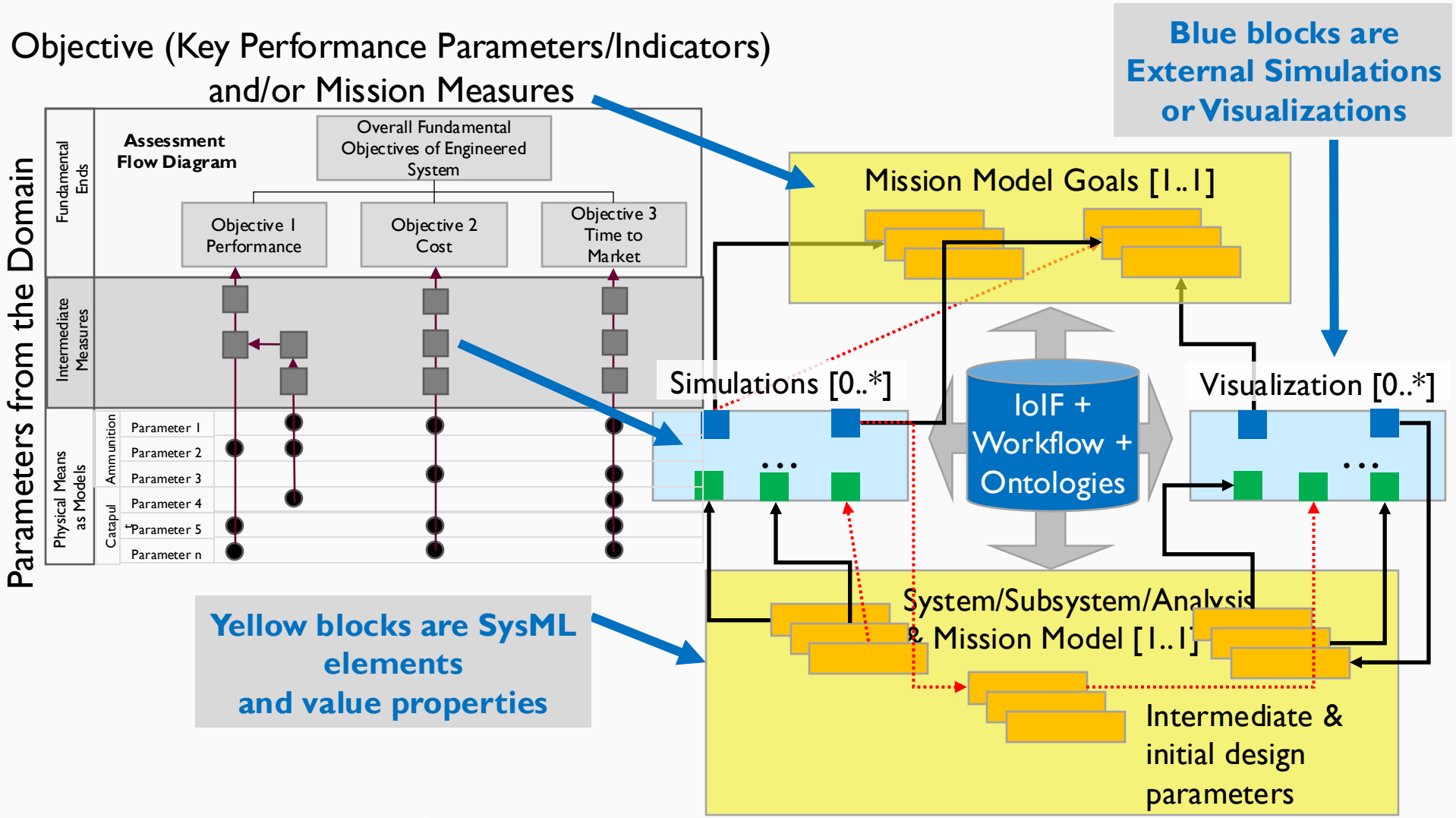


IoIF Catapult SysML Profile of "Tags"

- Extend the model with stereotypes
  - This is not the only way, but it is a very convenient one and good for teaching concepts
- Three (3) Purposes:
  - Unambiguously and repeatably tie SysML elements to an ontology term
  - Provide a means to "retrofit" a model to IoIF
  - Indicate elements in the model that are of interest to IoIF
- Allows IoIF to interpret an arbitrary SysML model



How AFD Concept Maps to Generalization of AFD

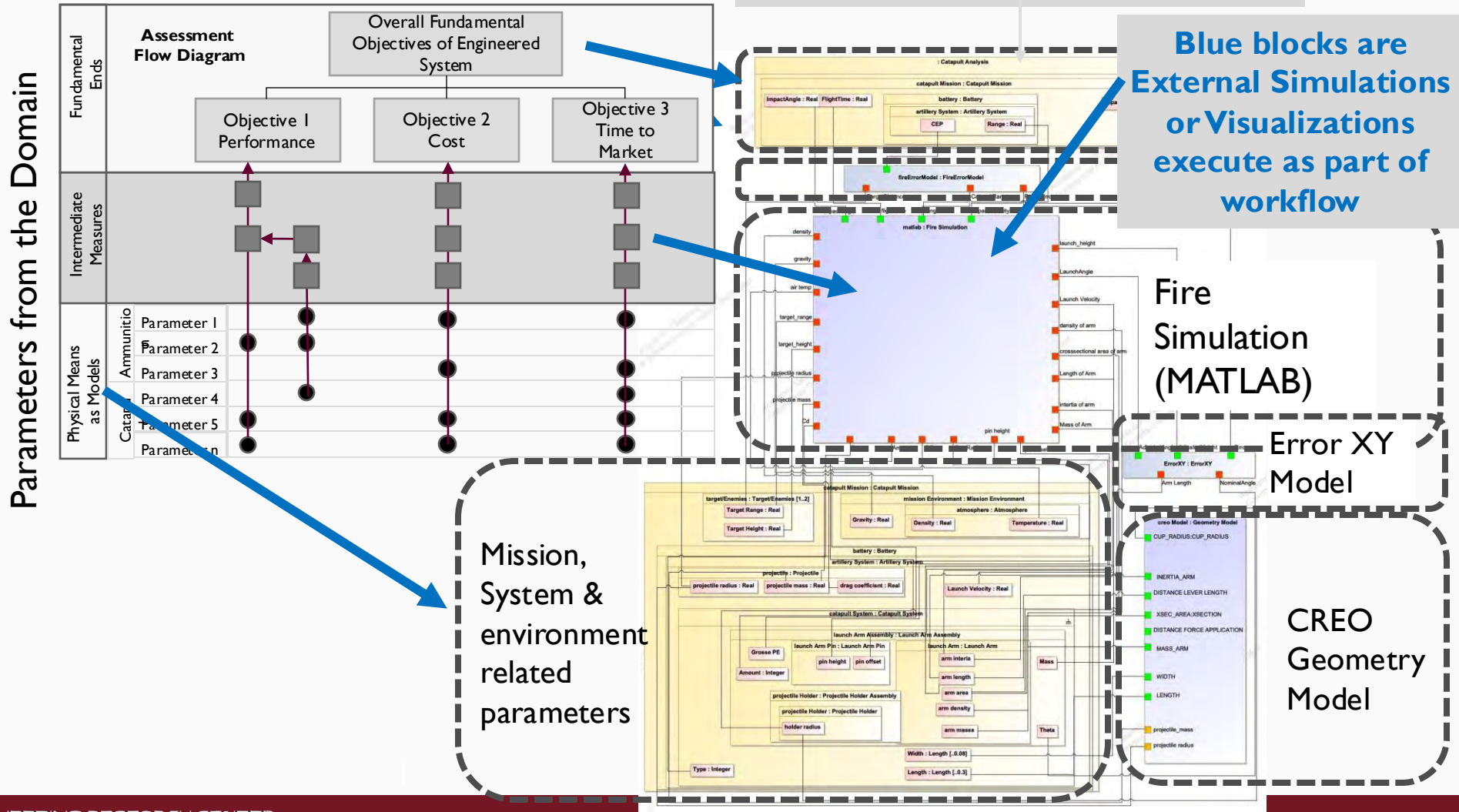


How: AFD in SysML is Blueprint for Facilitating IoIF Data Exchanges between Analysis Tools

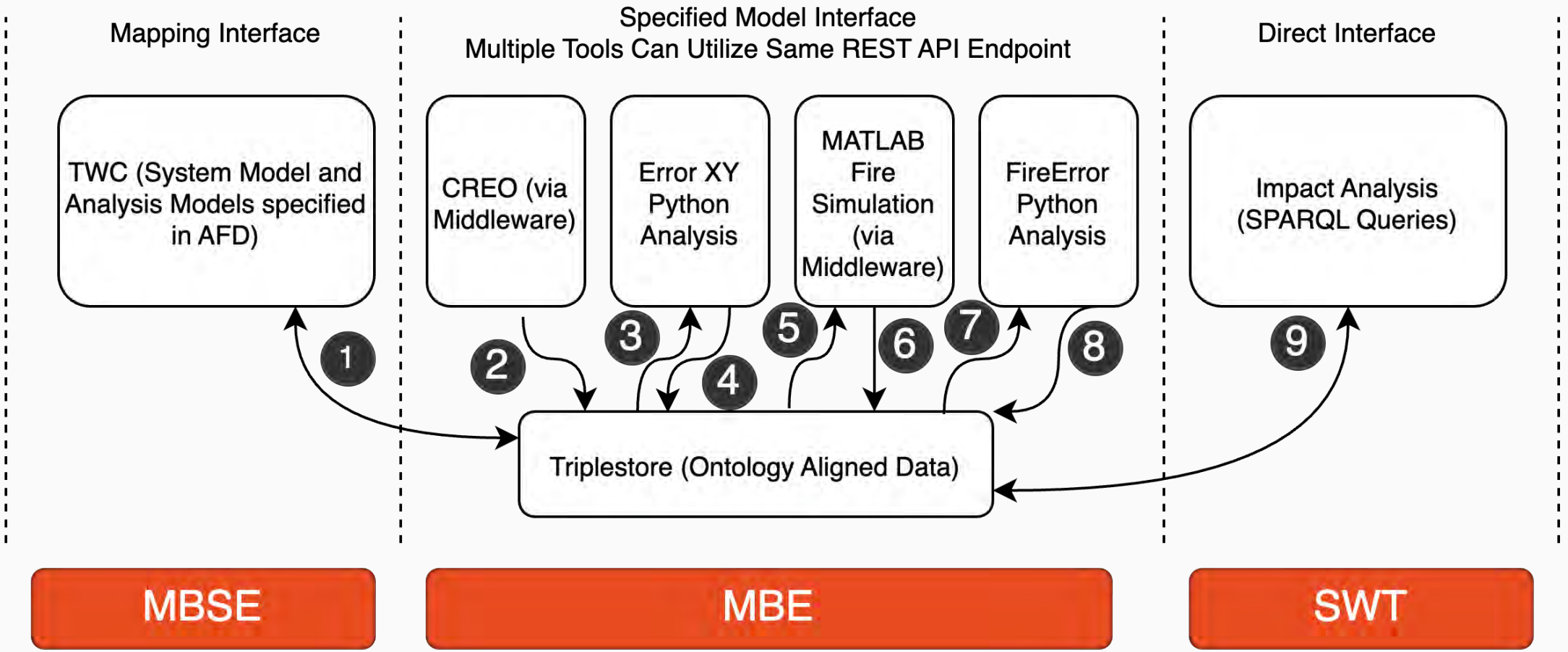
Objective (Key Performance Parameters/Indicators) and/or Mission Measures mapped to Parameters

Yellow blocks are SysML elements and value properties

Blue blocks are External Simulations or Visualizations execute as part of workflow

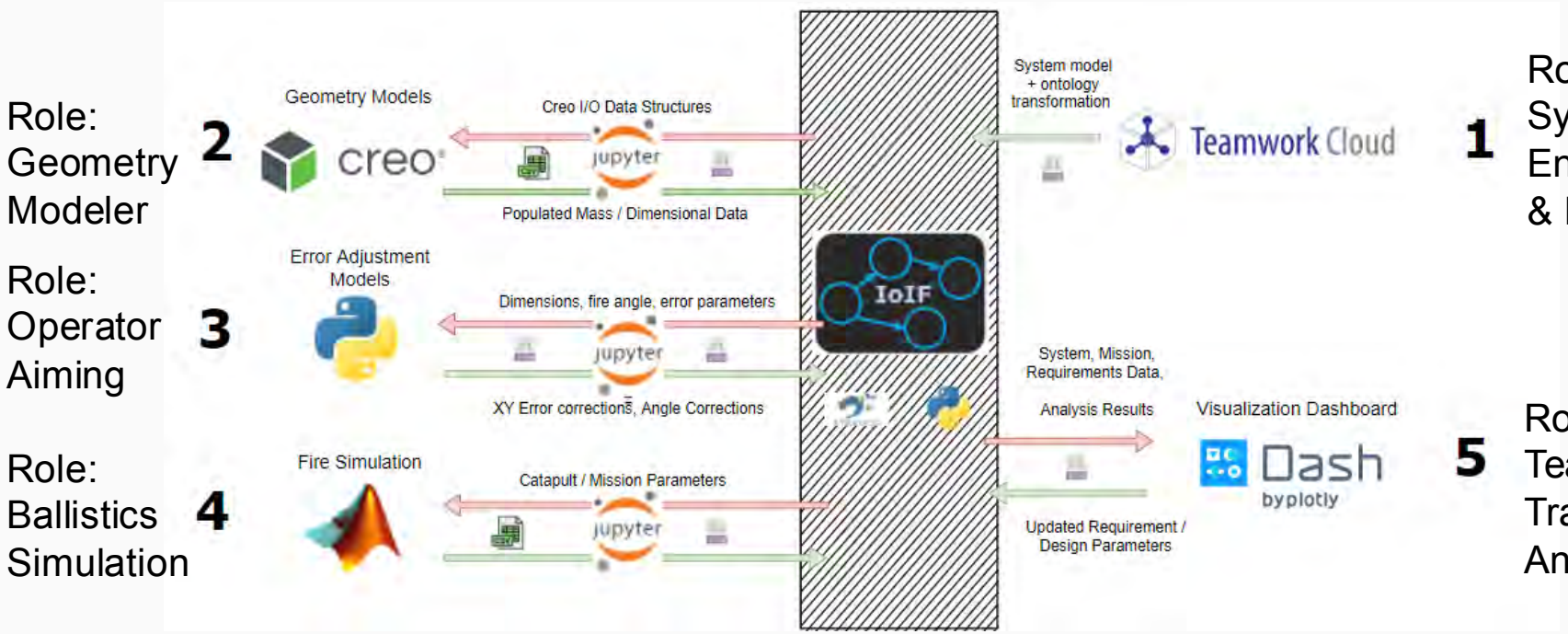


Digital Thread Associated with Interfaces and Disciplines



IoIF Workflow Coordinates Simulations and Visualizations

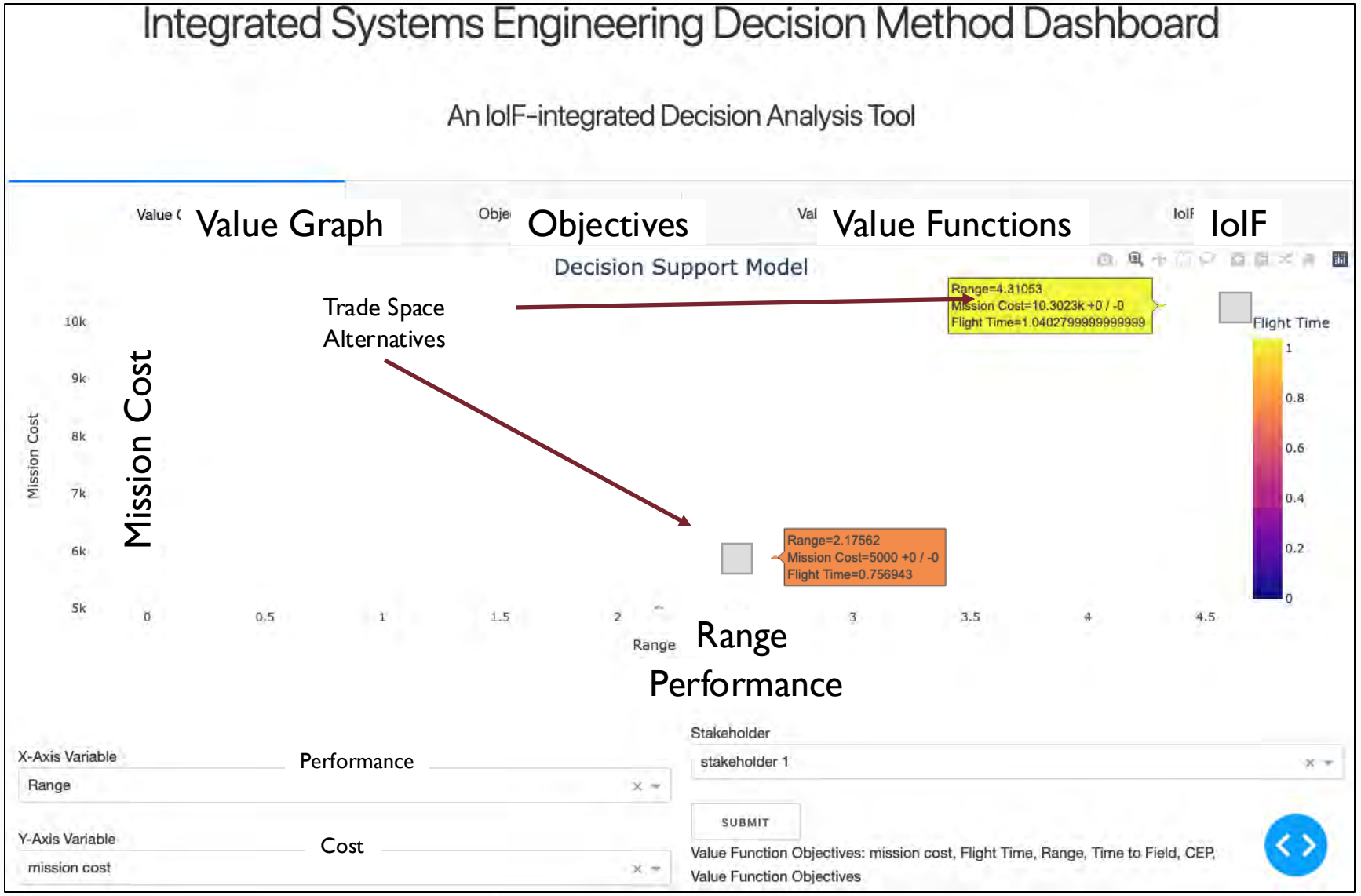
- IoIF Workflows coordinate simulations for different roles for different subject matter experts and for different Analysis Types (called instances)
- DEVCOM successfully demonstrated to other Army Sponsors an Armaments Case Study and Workflow on Army computers and networks



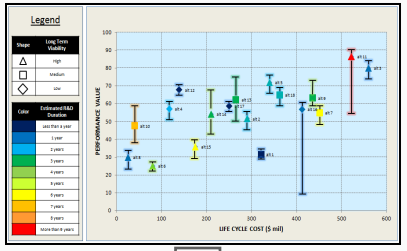
Analysis Type

#	Name	catapult Mission : Catapult Mission
1	Analysis as Designed	Mission as Designed : Catapult Mission
2	Analysis as Manufactured	Mission as Manufactured : Catapult Mission
3	Analysis Configuration Changed	Mission Configuration Changed : Catapult Mission
4	Analysis Requirement Changed	mission as required : Catapult Mission

IoIF Decision Dashboard

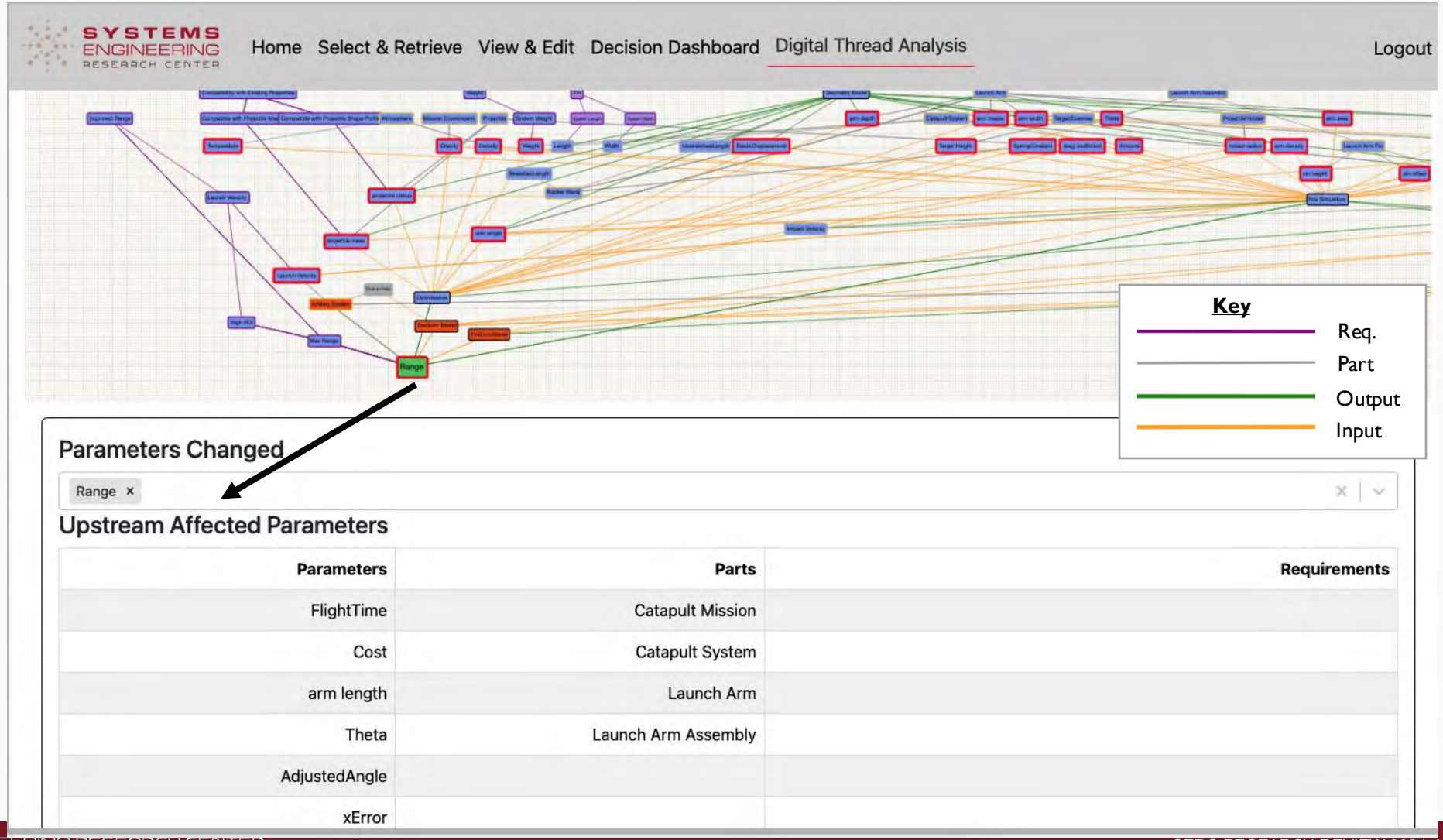


Dashboard Implementation is Python-based Notional Rendering of Scatter Plot



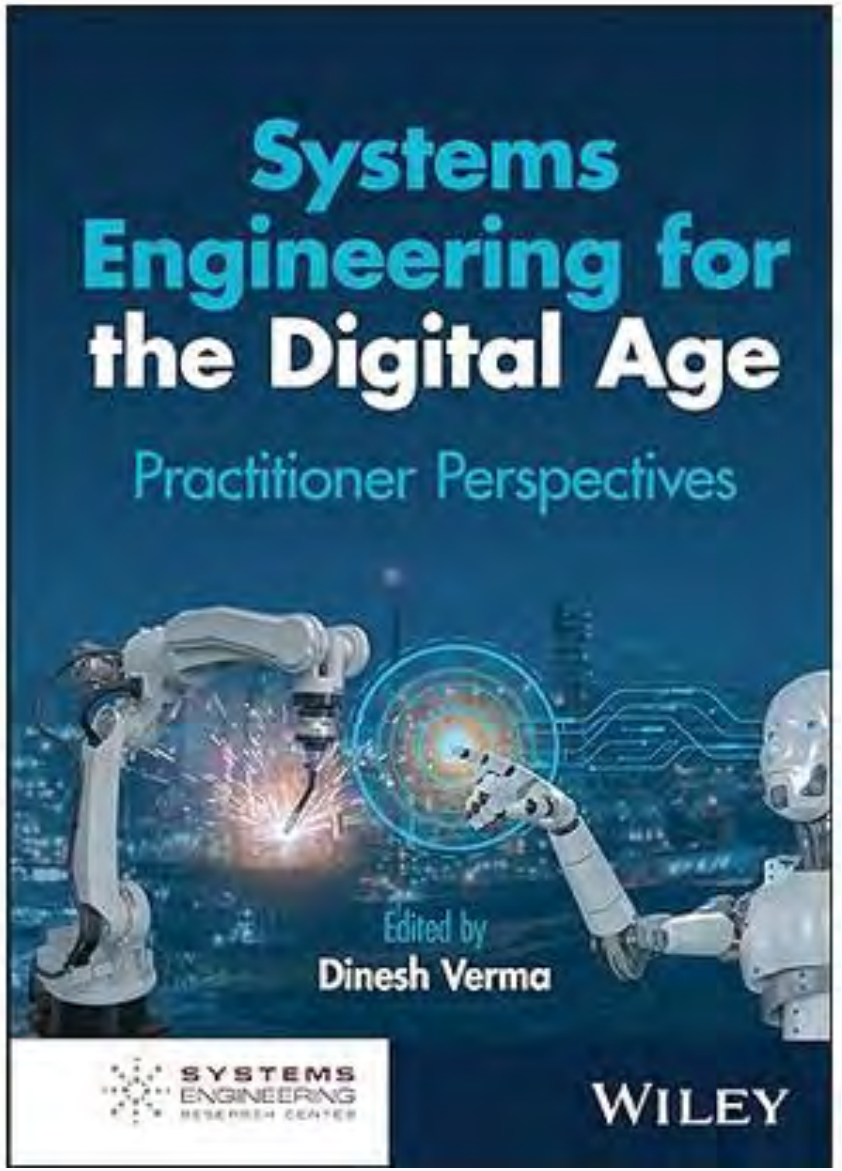
Digital Thread Impact Analysis Visualization

- Blue indicates entities upstream of a changed parameter;
- Red indicates entities downstream that may be affected



Book Chapters Summarize Research

- First four chapters reflect on research over the past 10 years
- Provide guidelines related to topics covered in course modules



Conclusions – How Well

- Transitioning research to our sponsors
- Developed seven (8) case studies with different ontologies using an evolving IoIF Methodology, and two (2) manufacturing use cases
  - Methodology formalizes mission & system objectives and parameters using an Assessment Flow Diagram (AFD) based on Integrated System Engineering Decision Method
  - Mission and System models are tagged with stereotypes that are aligned with the Ontologies used by IoIF
  - IoIF use AFD to represent interconnection of models, simulations & visualizations used in the analyses
  - IoIF coordinates workflow of the simulations and visualization of Digital Thread and Decision Framework dashboards
- IoIF Training is part of the Ontology Workshop and DE/MBSE Bootcamp course

RESEARCH TASKS AND COLLABORATOR NETWORK

RT-48 (2013)
- Mark Blackburn (PI), Stevens
- Rob Cloutier (Co-PI) - Stevens
- Eirik Hole - Stevens
- Gary Witus – Wayne State

RT-118 (2014)
- Mark Blackburn (PI), Stevens
- Rob Cloutier - Stevens
- Eirik Hole - Stevens
- Gary Witus – Wayne State

RT-141 (2015)
- Mark Blackburn (PI), Stevens
- Mary Bone - Stevens
- Gary Witus – Wayne State

RT-157 (2016)
- Mark Blackburn (PI), Stevens
- Mary Bone - Stevens
- Roger Blake - Stevens
- Mark Austin – Univ. Maryland
- Leonard Petnga – Univ. of Maryland

RT-170 (2016)
- 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) – UMD
- Russell Peak – Georgia Tech.
- Stephen Edwards – Georgia Tech.
- Adam Baker (Grad) – Georgia Tech.
- Marlin Ballard (Grad) – Georgia Tech.

RT-168 – Phase I & II (2016)
- 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
- Ian Grosse – UMass
- Tom Hagedorn – UMass
- Todd Richmond – USC
- Edgar Evangelista – USC

RT-195 (2018)
- Mark Blackburn (PI), Stevens
- Mary Bone - Stevens
- Ralph Giffin - 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

WRT-1008 (2019)
- Mark Blackburn (PI), Stevens
- Mary Bone - Stevens
- John Dzielski- Stevens
- Benjamin Kruse - Stevens
- Bill Rouse – Stevens/Georgetown
- Russell Peak – Georgia Tech.
- Selcuk Cimtalay – Georgia Tech.
- Adam Baker (Grad) – Georgia Tech.
- Marlin Ballard (Grad) – Georgia Tech.
- Alanna Carnevale (Grad) – Georgia Tech.
- William Stock (Grad) – Georgia Tech.
- Michael Szostak (Grad) – Georgia Tech.
- Donna Rhodes - MIT
- Mark Austin – Univ. Maryland
- Maria Coelho (Grad) – Univ. Maryland

WRT-1025 (2020)
- Mark Blackburn (PI), Stevens
- Mark Austin (Co-PI) – Univ. Maryland
- Maria Coelho (Grad) – Univ. Maryland

ART-002 (2018) – ART-022 (2021/23)
- Mark Blackburn (PI), Stevens
- Dinesh Verma (Co-PI) – Stevens
- Kunal Batra – Stevens
- Mary Bone - Stevens
- John Dzielski, Stevens
- Steven Hoffenson - Stevens
- Steve Hespelt – Stevens
- Tom Hagedorn – Stevens
- Roger Jones – Stevens
- Philip Odonkor – Stevens
- Annie Yu – Stevens
- Benjamin Kruse – Stevens/VT
- Chris Snyder - Stevens
- Brian Chell – Stevens
- Chuck Colllard– Stevens
- Daniel Dunbar (PhD) – Stevens
- Josh Maccoby (PhD) – Stevens
- Renee Blatchley (PhD) – Stevens
- Maximillian Vierlboeck (PhD) - Stevens
- Andrew Underwood (Ungrad) – Stevens
- Benjamin Steinwurtzel (Ungrad)
- Ariela Litvin (Ungrad)
- Aughdon Breslin (Ungrad)
- Joshua Bernstein (Ungrad)
- Cory Phillipe (Grad) - Stevens
- Ian Grosse – Univ. of Massachucetts
- Doug Eddy – Univ. of Massachucetts
- Joe Gabbard – Virginia Tech
- Kyle Tanous– Virginia Tech
- Jared Van Dam (PhD) – Virginia Tech
- Kelsey Quinn (PhD) – Virginia Tech

WRT-1036 (2020)
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- Russell Peak – Georgia Tech.
- Selcuk Cimtalay – Georgia Tech.
- Taylor Fields – Georgia Tech.
- William Stock (Grad) – Georgia Tech.
- Sahil Panchal – Georgia Tech
- Jake Sisavath – Georgia Tech
- Gabriel Rizzo – Georgia Tech

WRT-1054 (2022)
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- Steve Hespelt – Stevens
- Chuck Collard– Stevens
- Daniel Dunbar (PhD) – Stevens
- Kevin Morrill)– Stevens
- Russell Peak – Georgia Tech.
- Selcuk Cimtalay – Georgia Tech.
- Taylor Fields – Georgia Tech.
- Adam Baker – Georgia Tech.
- Avik Banerjee – Georgia Tech.
- Vanessa J. Nuhn – Georgia Tech.
- Cole A. Sherling – Georgia Tech.

WRT-1084 (2023)
- Mark Blackburn (PI), Stevens
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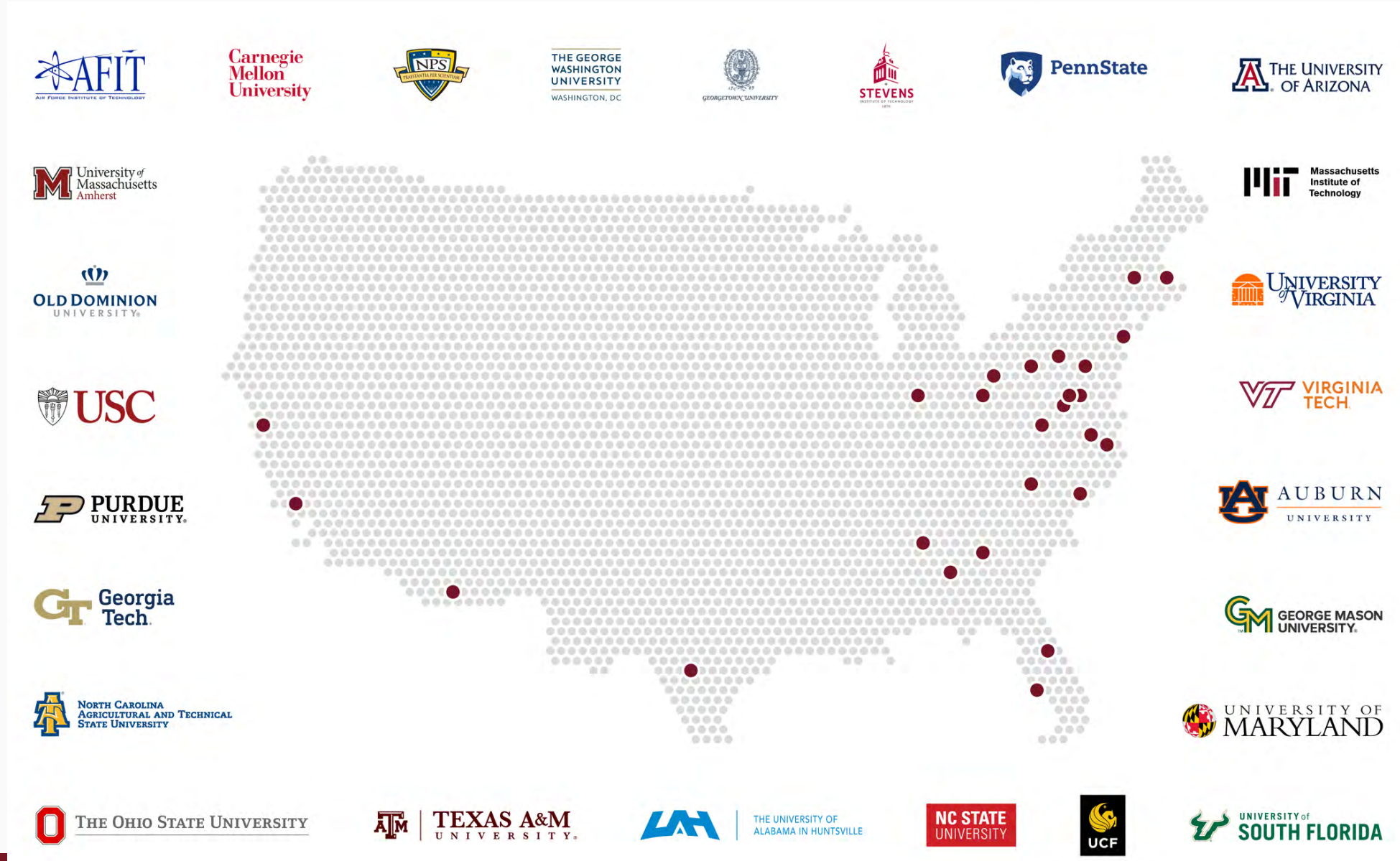
- Steve Hespelt – Stevens
- Chuck Collard– Stevens
- Daniel Dunbar – Stevens
- Steve Jenkins – Stevens

SERC/AIRC University Network



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Thank you!

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