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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SYSTEMS ENGINEERING RESEARCH CENTER

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Research Sponsor Domain

Organization
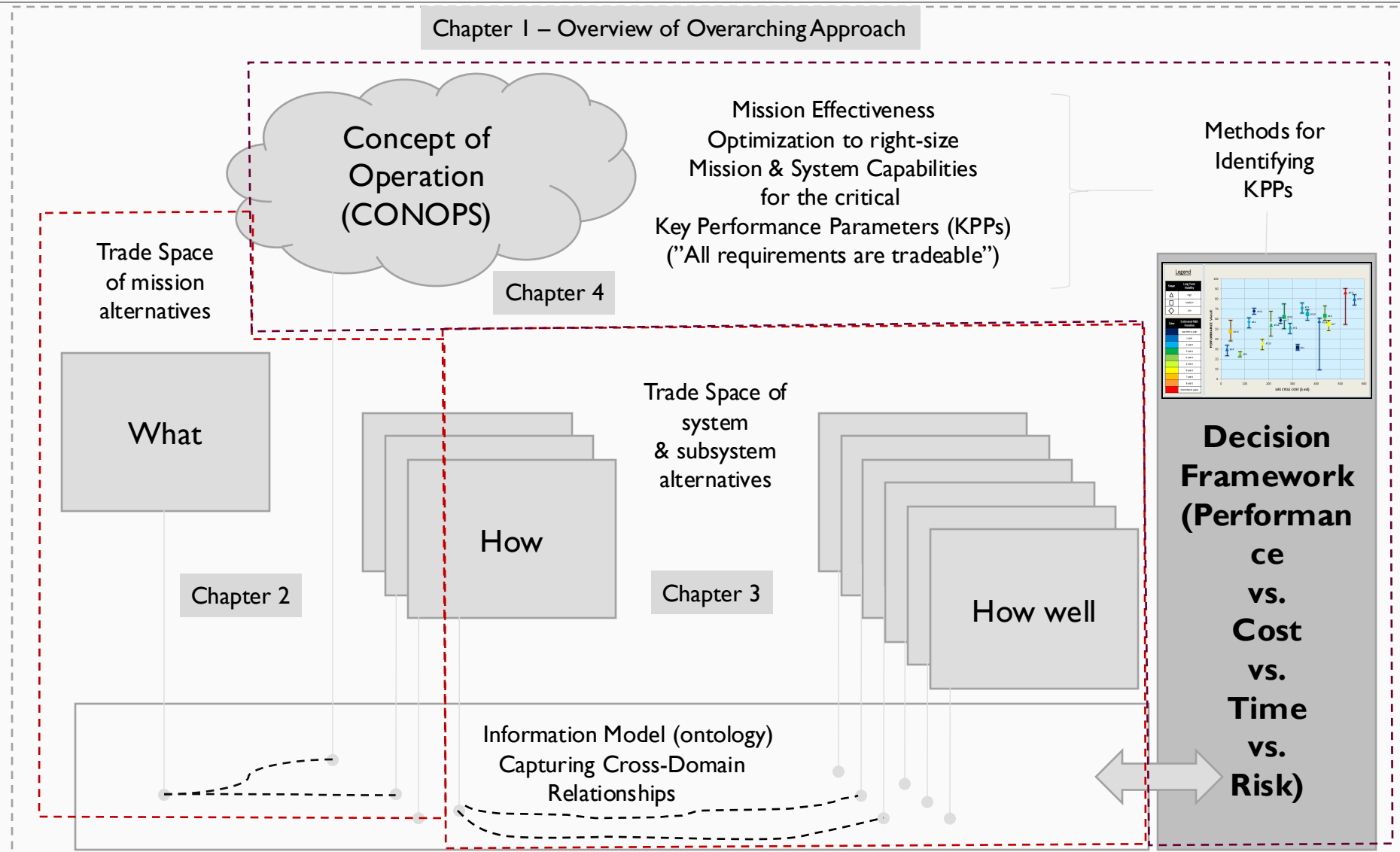
- INTRO (WHY): Context/Motivation – How did we get here?
- WHAT: Digital Engineering Enabling Technologies and Methods to Computationally Leverage Ontologies and Semantic Technologies
- HOW: "Full Stack" of Models with Integrated Workflows Coordinated using Armaments Interoperability and Integration 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

Concept of Operation (CONOPS)

Mission Effectiveness Optimization to right-size Mission & System Capabilities for the critical Key Performance Parameters (KPPs) ("All requirements are tradeable")

Chapter 4

Methods for Identifying KPPs

Trade Space of mission alternatives

What

Chapter 2

Trade Space of system & subsystem alternatives

How

Chapter 3

How well

Decision Framework (Performance vs. Cost vs. Time vs. Risk)

Information Model (ontology) Capturing Cross-Domain Relationships

Systems Engineering in the Digital Age: Practitioner Perspectives

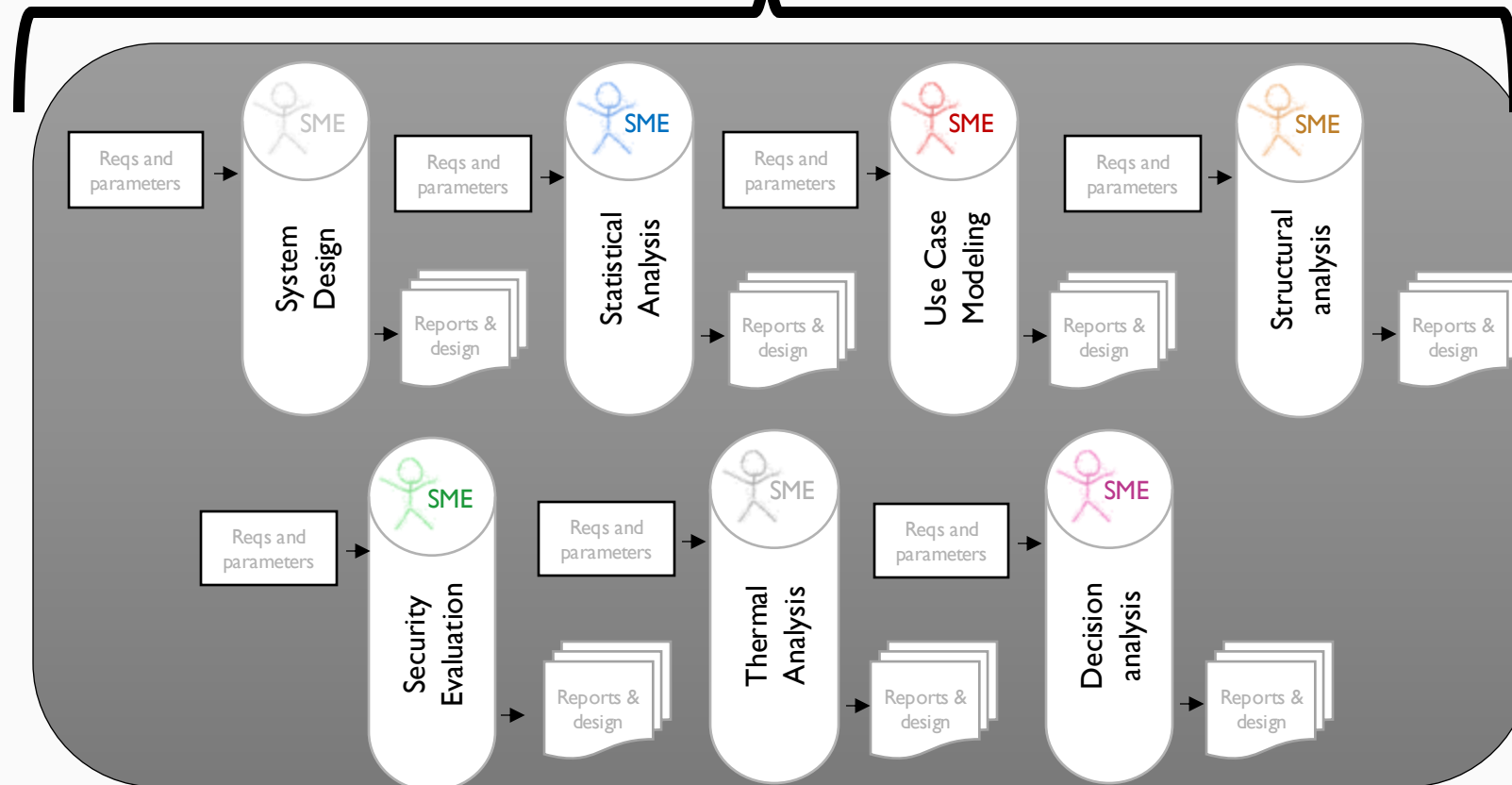# Visualize Mission & System Level Trades Across Cost, Schedule, Performance
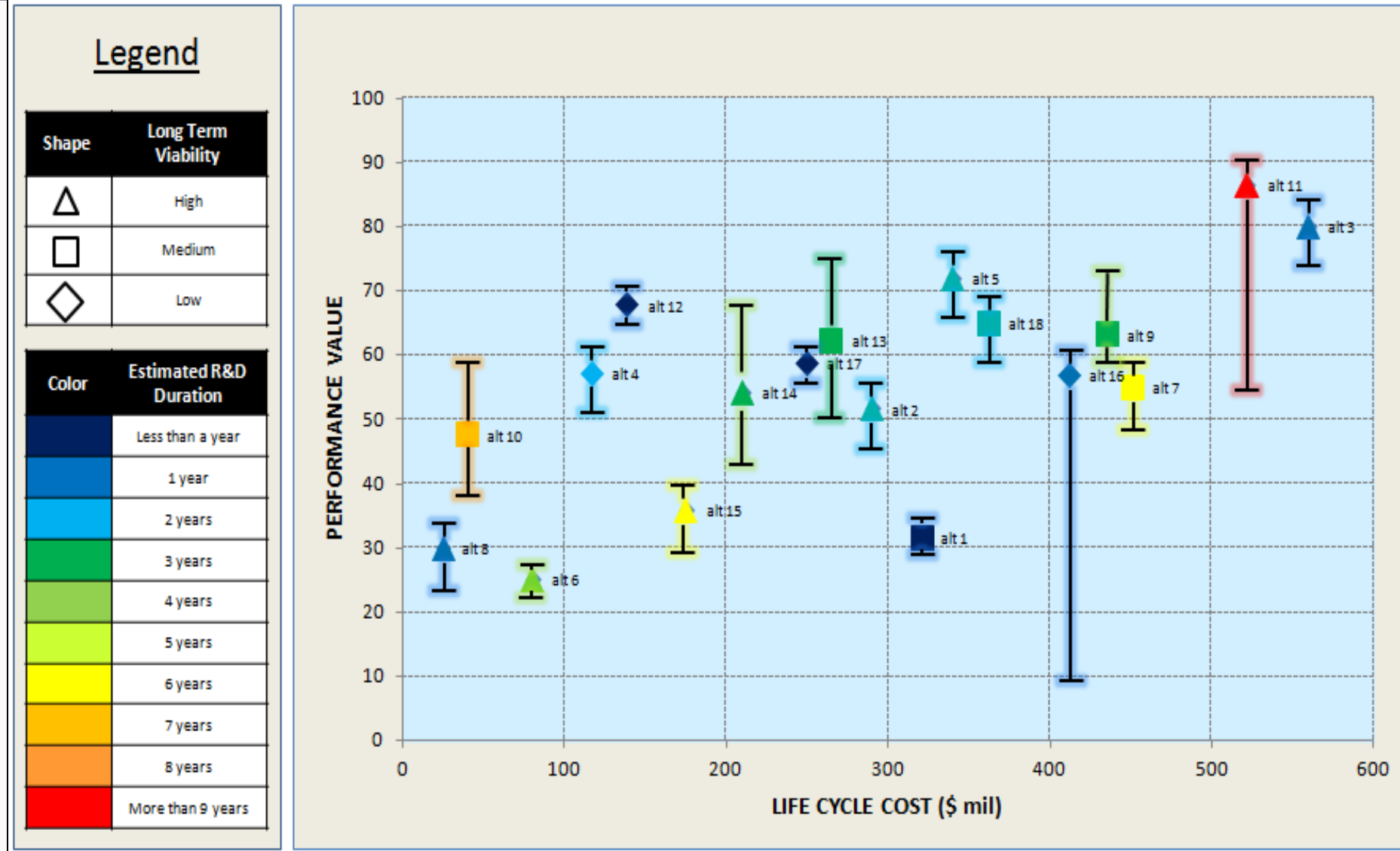
Cilli, M. Seeking Improved Defense Product Development Success Rates Through Innovations to Trade-Off Analysis Methods, Dissertation, Stevens Institute of Technology, Nov. 2015.

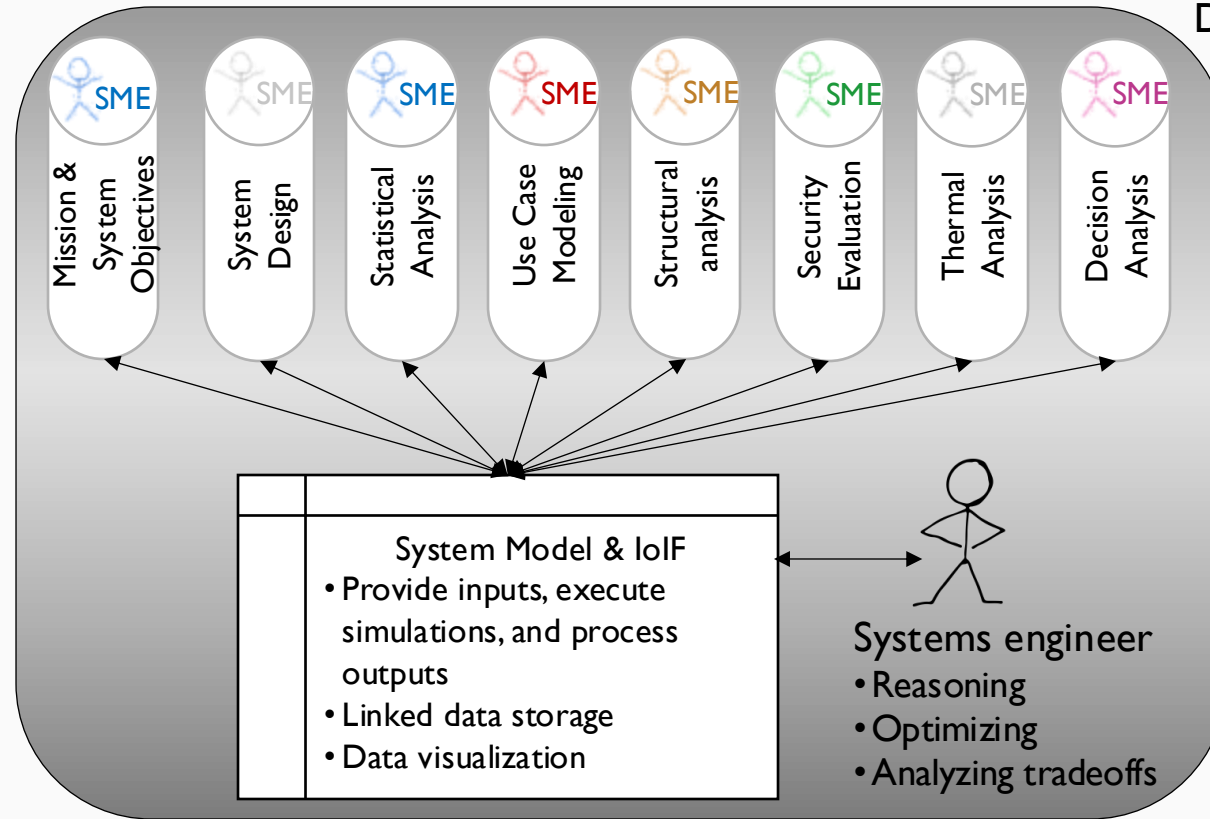# Challenges: Needed to Transform Beyond Stove Piped Analysis

Example: Cross Domain Relationships Needed for System Trades, Analysis and Design
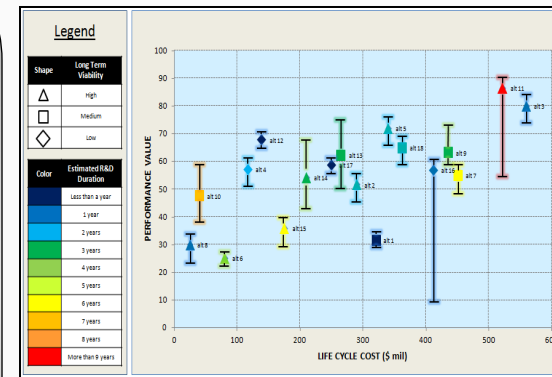
- Mission objective: continuous surveillance

- 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

Valve

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

Scatter Plot Dashboard for Decision Making related to Objectives

Systems engineer
- Reasoning
- Optimizing
- Analyzing tradeoffs

System Model & IoIF
- Provide inputs, execute simulations, and process outputs
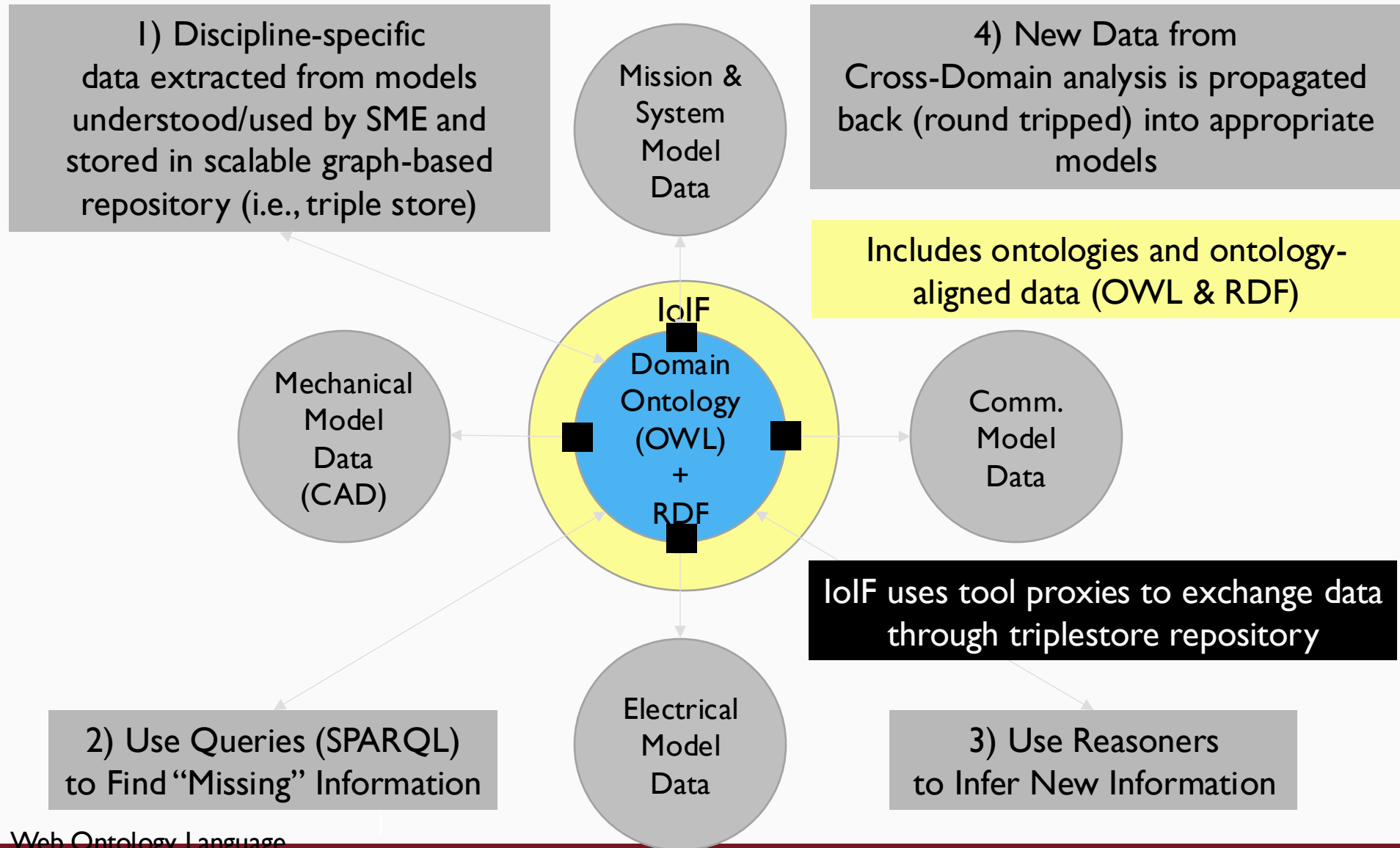- Linked data storage
- Data visualization

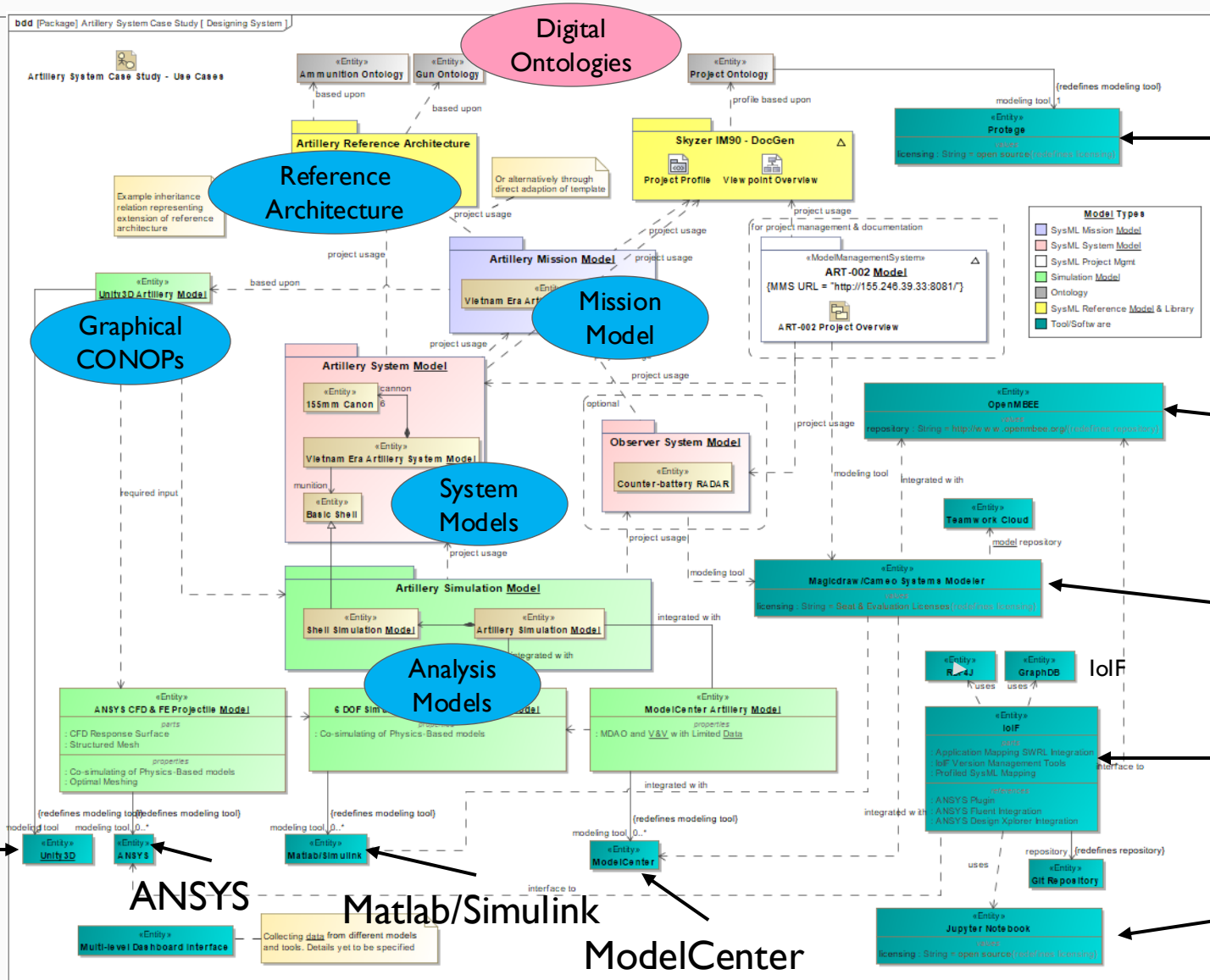Strategic/mission-level decision-maker
- Setting requirements & objectives
- Exploring tradeoffs
- Adjusting requirements & objectives based on capability information

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

1) Discipline-specific data extracted from models understood/used by SME and stored in scalable graph-based repository (i.e., triple store)

4) New Data from Cross-Domain analysis is propagated back (round tripped) into appropriate models

Includes ontologies and ontology-aligned data (OWL & RDF)

Mission & System Model Data

IoIF Domain Ontology (OWL) + RDF

Mechanical Model Data (CAD)

Comm. Model Data

IoIF uses tool proxies to exchange data through triplestore repository

2) Use Queries (SPARQL) to Find "Missing" Information

Electrical Model Data

3) Use Reasoners to Infer New Information

OWL: Web Ontology Language
RDF: Resource Description Framework

Example "Full Stack" Models and Related Tools

Tools:

- Protegé
- OpenMBEE
- Magicdraw/ Cameo
- IoIF
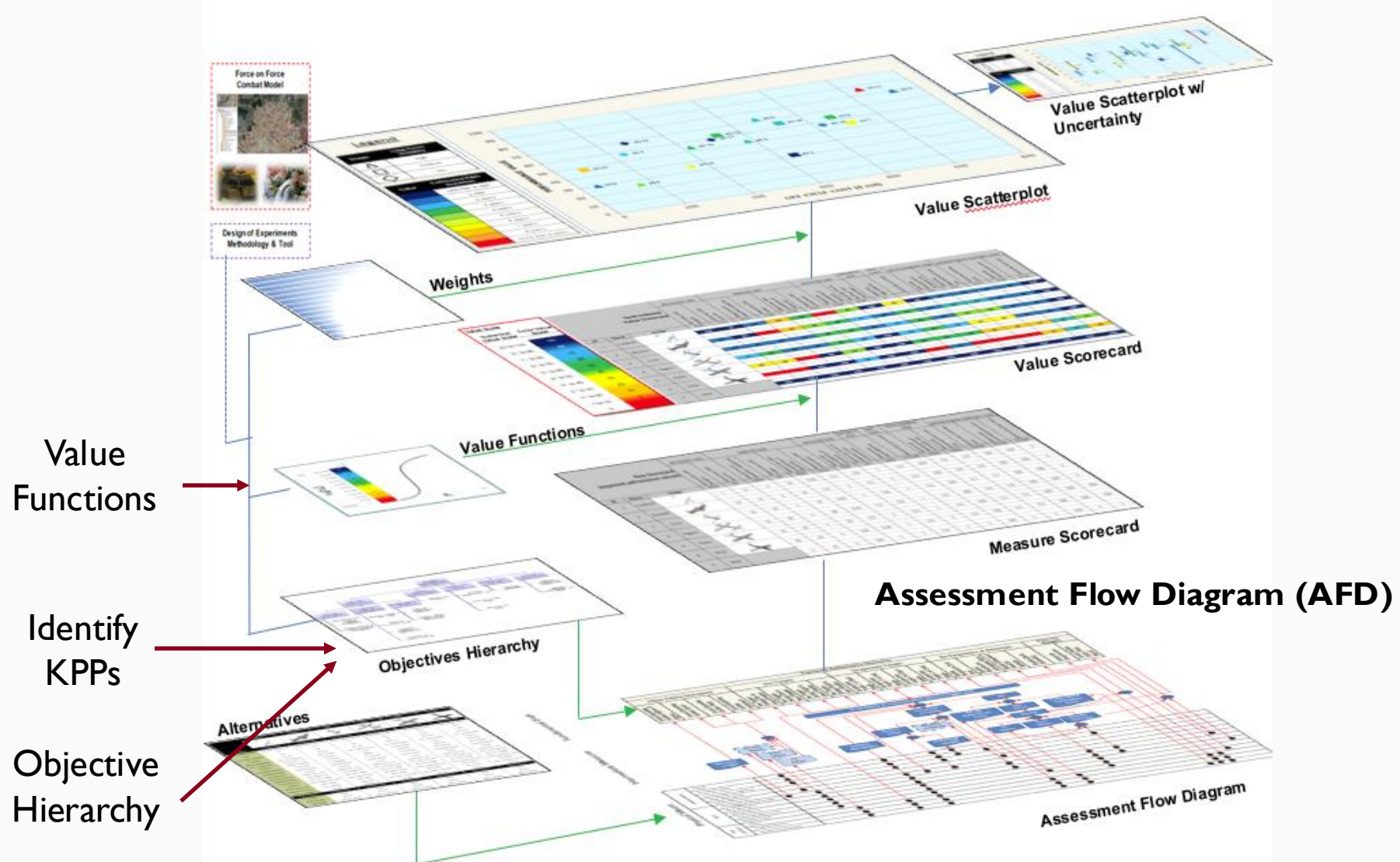- Gaming Engine Unity 3D
- ANSYS
- Matlab/Simulink
- ModelCenter
- Jupyter Notebook

Distribution Statement A: Approved for public release. Distribution is unlimited.

Decision Support Model Construct

Value Scatterplot w/ Uncertainty

Value Scatterplot

Weights

Value Scorecard

Value Functions

Value Functions

Measure Scorecard

Assessment Flow Diagram (AFD)

Identify KPPs

Objectives Hierarchy

Objective Hierarchy

Alternatives

Assessment Flow Diagram

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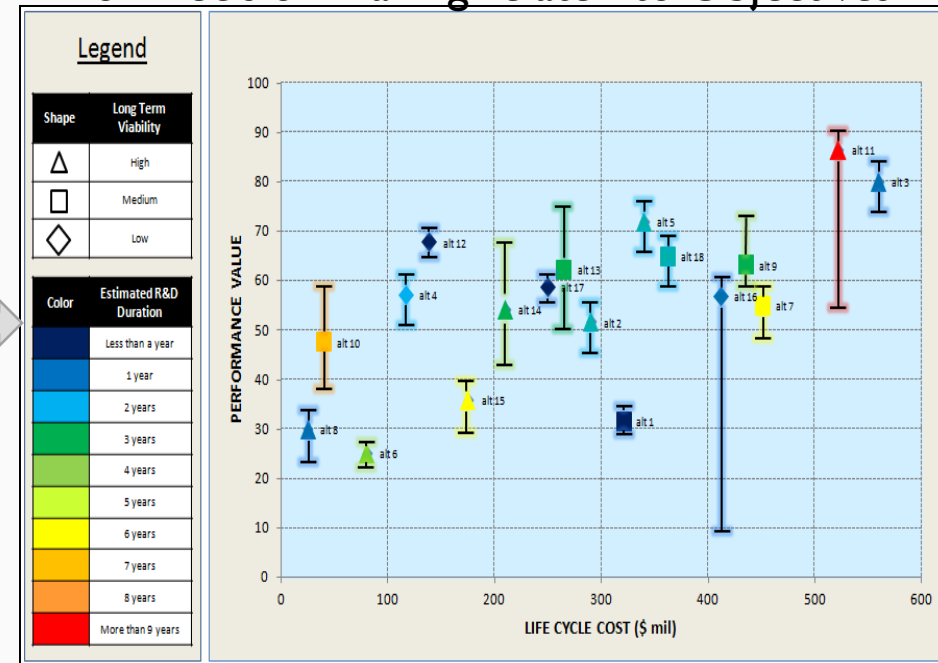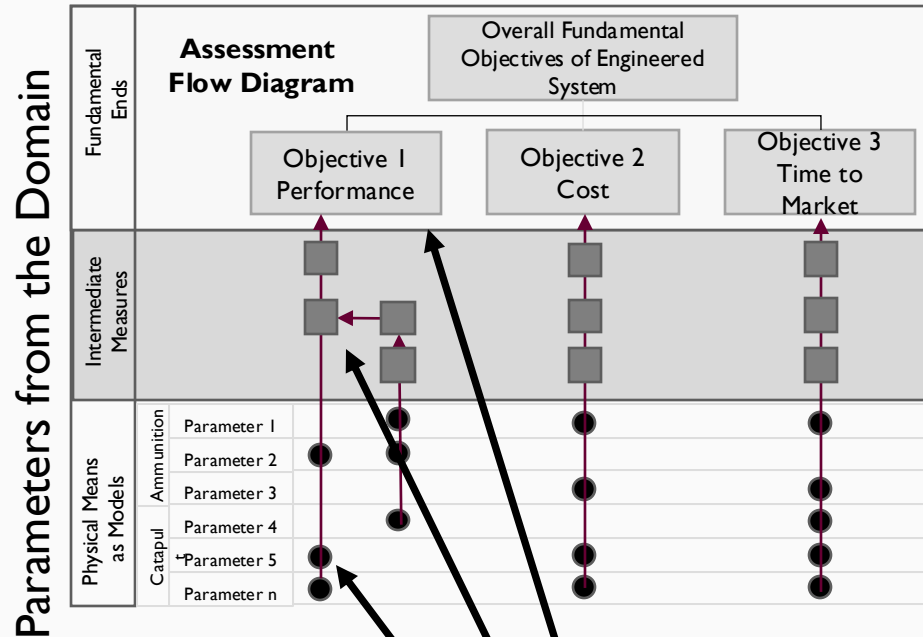
1. Objectives formalized in MBSE/Descriptive Model using SysML
2. Workflows characterized in MBSE/Descriptive Model using SysML to define interfaces to simulations and visualizations
3. Interfaces use defined parameters for every model in workflow using tool proxies to workflows defined in standards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

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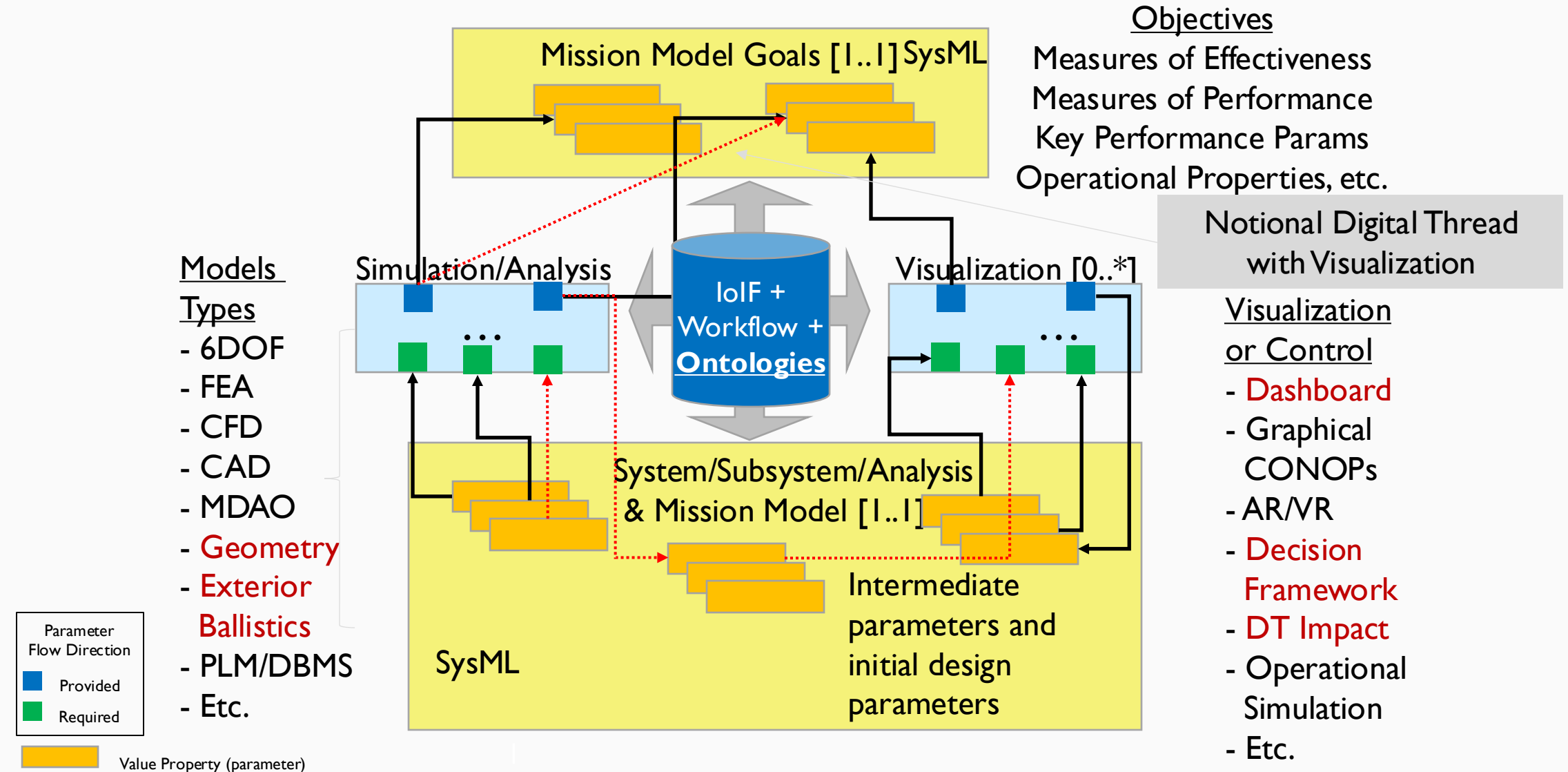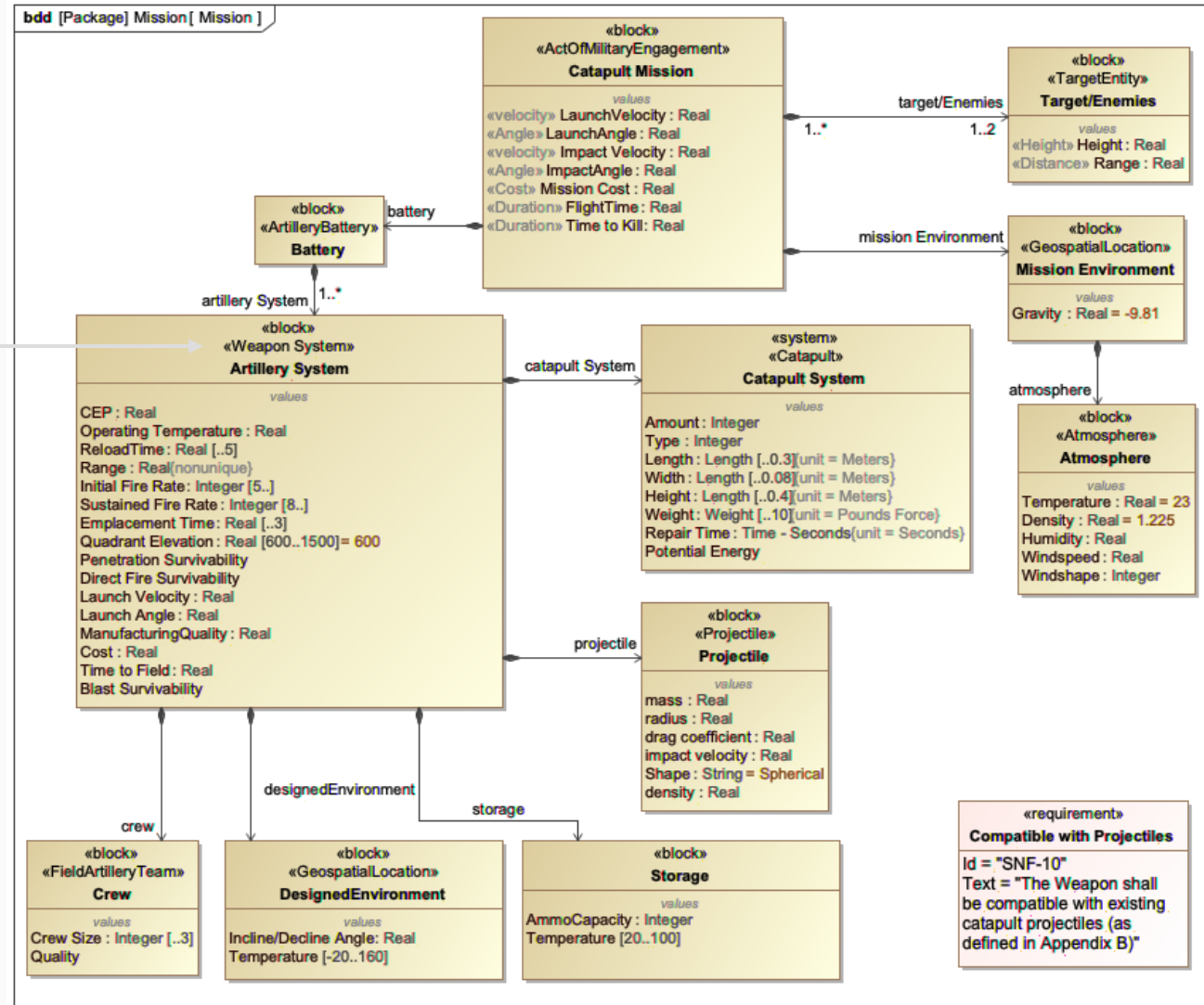
Catapult Structural Model

- Sponsor provided baseline Distribution A case study models that were incorporated into a Mission and System of Analysis for IoIF
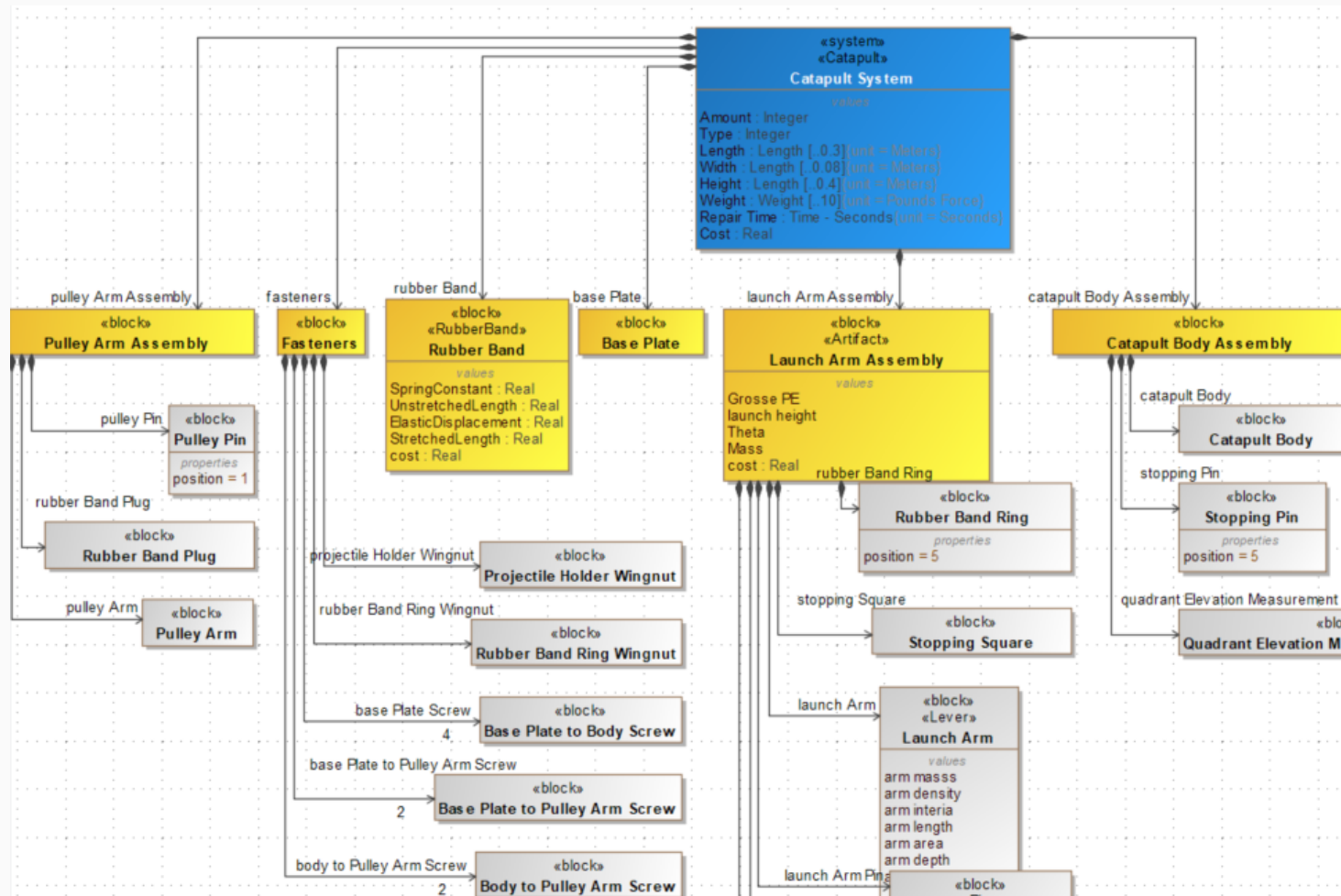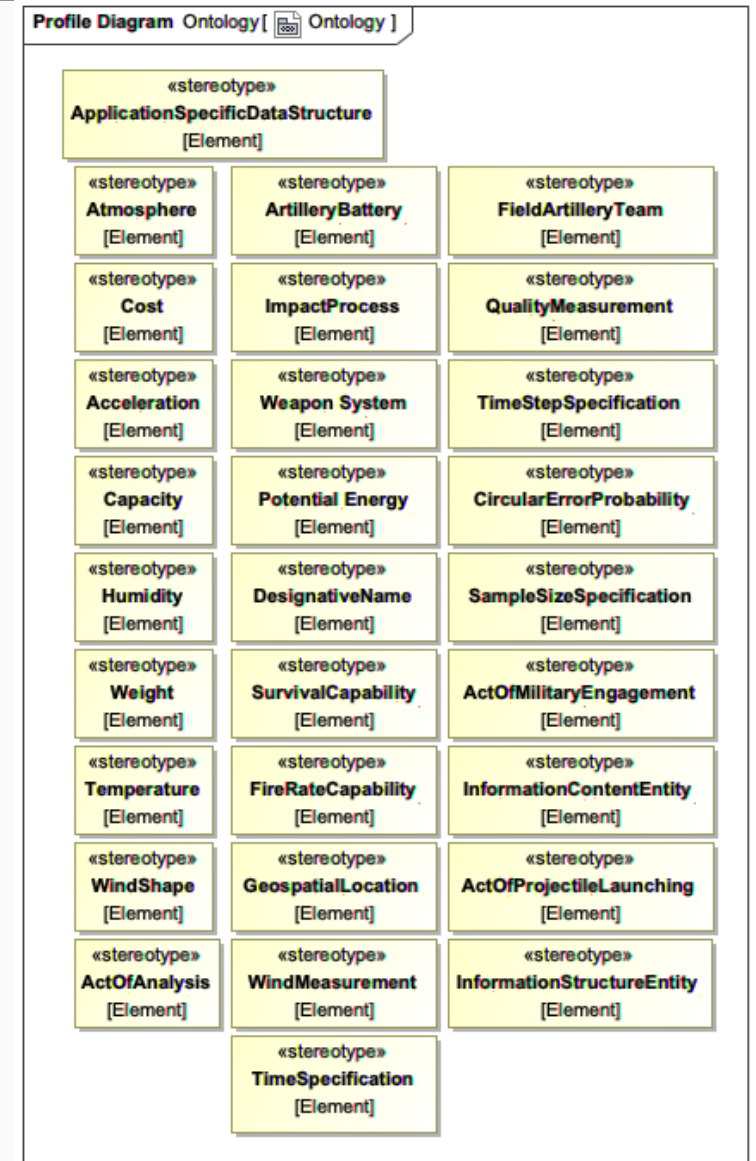
Catapult Mission/System Models Tagged with Stereotypes that Map to Ontology Classes

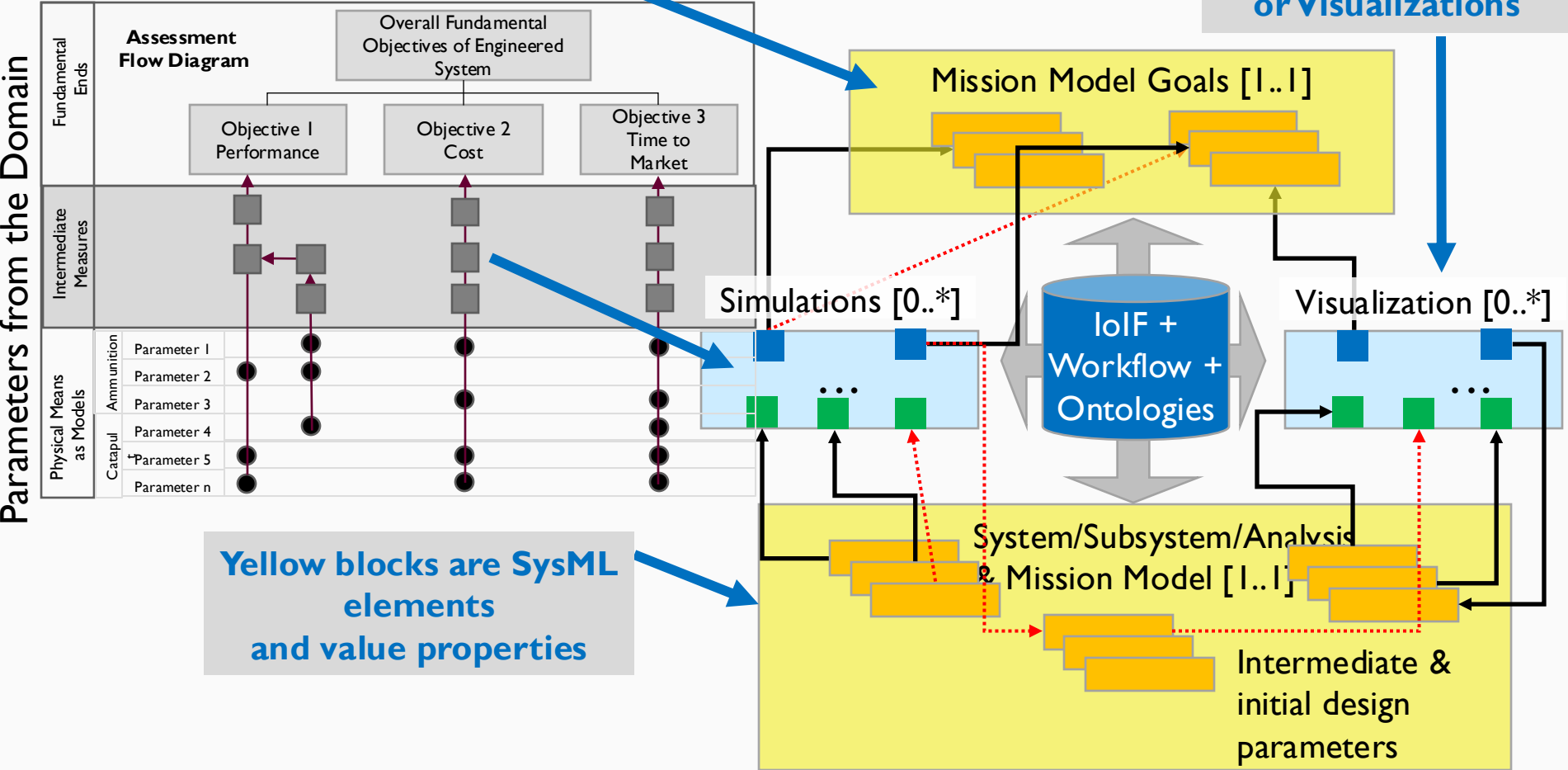Stereotype "Tag" map to Ontology Classes

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

Profile Diagram Ontology [Ontology]

«stereotype»
ApplicationSpecificDataStructure
[Element]

«stereotype» **Atmosphere** [Element]	«stereotype» **ArtilleryBattery** [Element]	«stereotype» **FieldArtilleryTeam** [Element]
«stereotype» **Cost** [Element]	«stereotype» **ImpactProcess** [Element]	«stereotype» **QualityMeasurement** [Element]
«stereotype» **Acceleration** [Element]	«stereotype» **Weapon System** [Element]	«stereotype» **TimeStepSpecification** [Element]
«stereotype» **Capacity** [Element]	«stereotype» **Potential Energy** [Element]	«stereotype» **CircularErrorProbability** [Element]
«stereotype» **Humidity** [Element]	«stereotype» **DesignativeName** [Element]	«stereotype» **SampleSizeSpecification** [Element]
«stereotype» **Weight** [Element]	«stereotype» **SurvivalCapability** [Element]	«stereotype» **ActOfMilitaryEngagement** [Element]
«stereotype» **Temperature** [Element]	«stereotype» **FireRateCapability** [Element]	«stereotype» **InformationContentEntity** [Element]
«stereotype» **WindShape** [Element]	«stereotype» **GeospatialLocation** [Element]	«stereotype» **ActOfProjectileLaunching** [Element]
«stereotype» **ActOfAnalysis** [Element]	«stereotype» **WindMeasurement** [Element]	«stereotype» **InformationStructureEntity** [Element]
	«stereotype» **TimeSpecification** [Element]	

How AFD Concept Maps to Generalization of AFD

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

Blue blocks are External Simulations or Visualizations

Mission Model Goals [1..1]

Simulations [0..*]

IoIF + Workflow + Ontologies

Visualization [0..*]

Yellow blocks are SysML elements and value properties

System/Subsystem/Analysis & Mission Model [1..1]

Intermediate & initial design parameters

Assessment Flow Diagram

Overall Fundamental Objectives of Engineered System

Objective 1 Performance

Objective 2 Cost

Objective 3 Time to Market

Fundamental Ends

Intermediate Measures

Physical Means as Models

Ammunition

Catapul

Parameter 1
Parameter 2
Parameter 3
Parameter 4
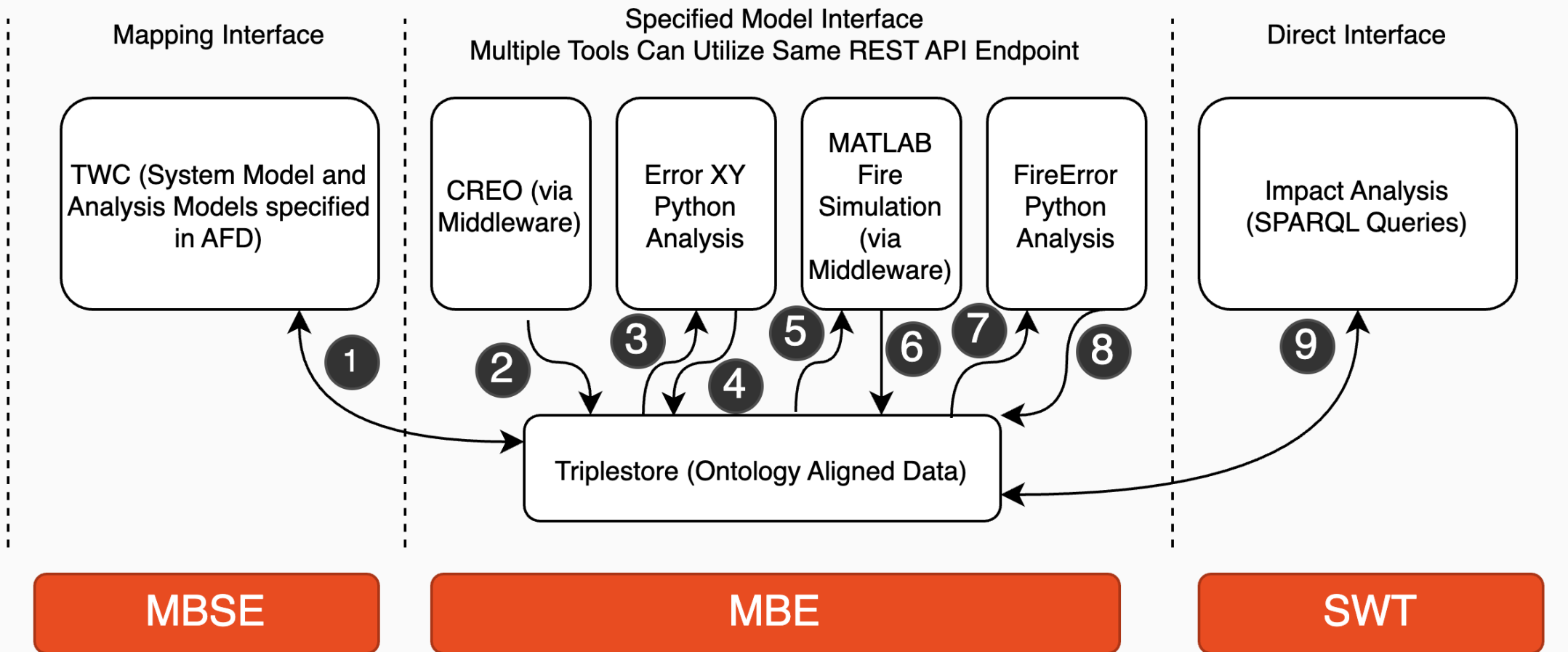Parameter 5
Parameter n

Parameters from the Domain

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

Fire Simulation (MATLAB)

Error XY Model

CREO Geometry Model

Mission, System & environment related parameters

Digital Thread Associated with Interfaces and Disciplines

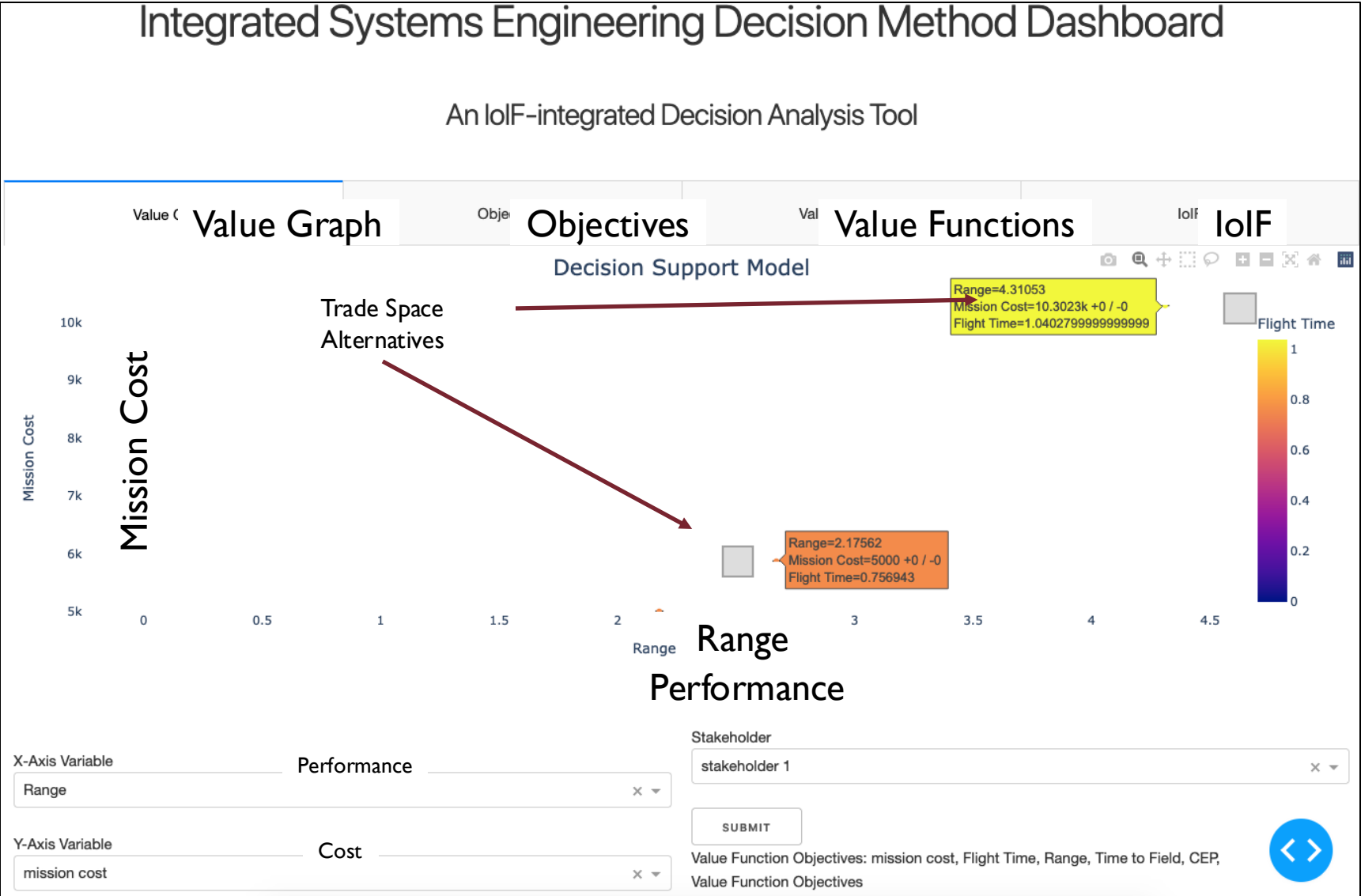# IoIF Workflow Coordinates Simulations and Visualizations

- 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
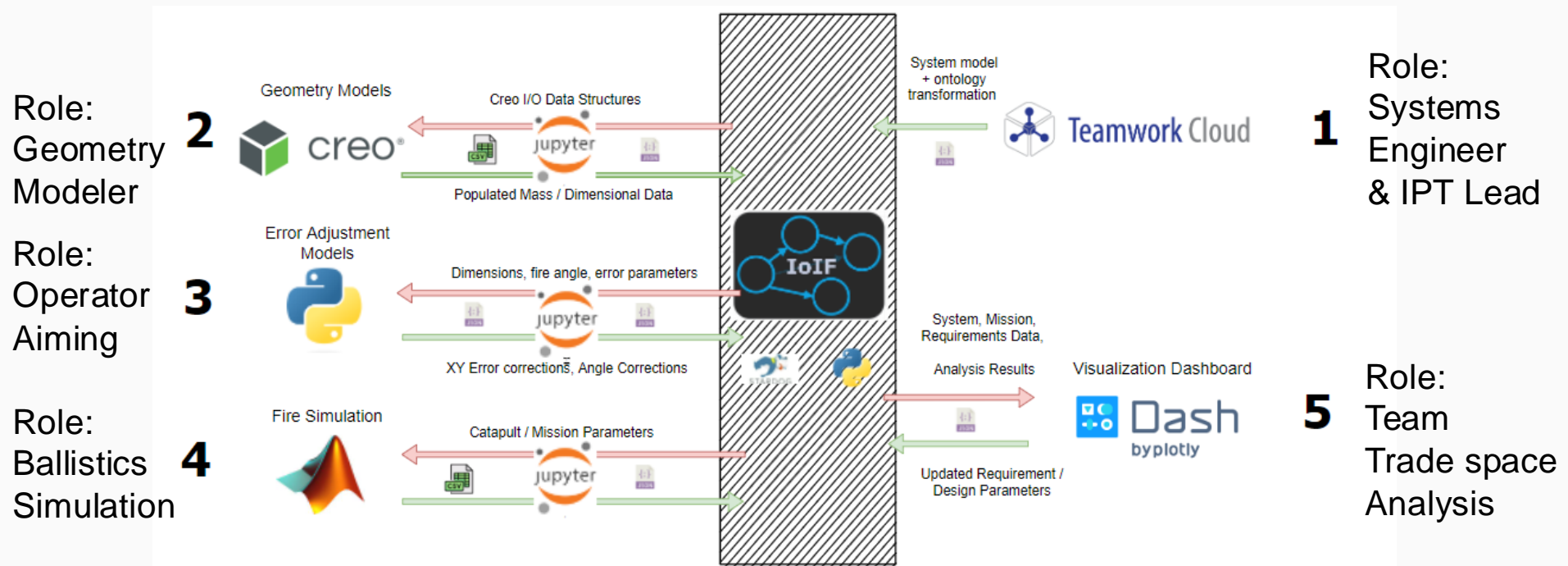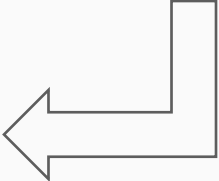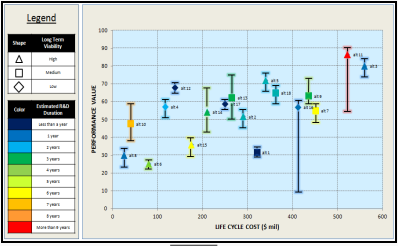

#	Name	P catapult Mission : Catapult Mission
1	Analysis as Designed	Mission as Designed : Catapult Mission
2	Analysis as Manufactured	Mission as Manufactured : Catapult Mission
3	Analysis Configuration Changed	Mission Configuration Changed : Catapult Mission
4	Analysis Requirement Changed	mission as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

IoIF Decision Dashboard

Integrated Systems Engineering Decision Method Dashboard

An IoIF-integrated Decision Analysis Tool

Value Graph | Objectives | Value Functions | IoIF

Decision Support Model

Trade Space Alternatives

Range=4.31053
Mission Cost=10.3023k +0 / -0
Flight Time=1.0402799999999999

Flight Time

Range=2.17562
Mission Cost=5000 +0 / -0
Flight Time=0.756943

Mission Cost

Range Performance

Performance

X-Axis Variable
Range

Cost

Y-Axis Variable
mission cost

Stakeholder
stakeholder 1

SUBMIT

Value Function Objectives: mission cost, Flight Time, Range, Time to Field, CEP,
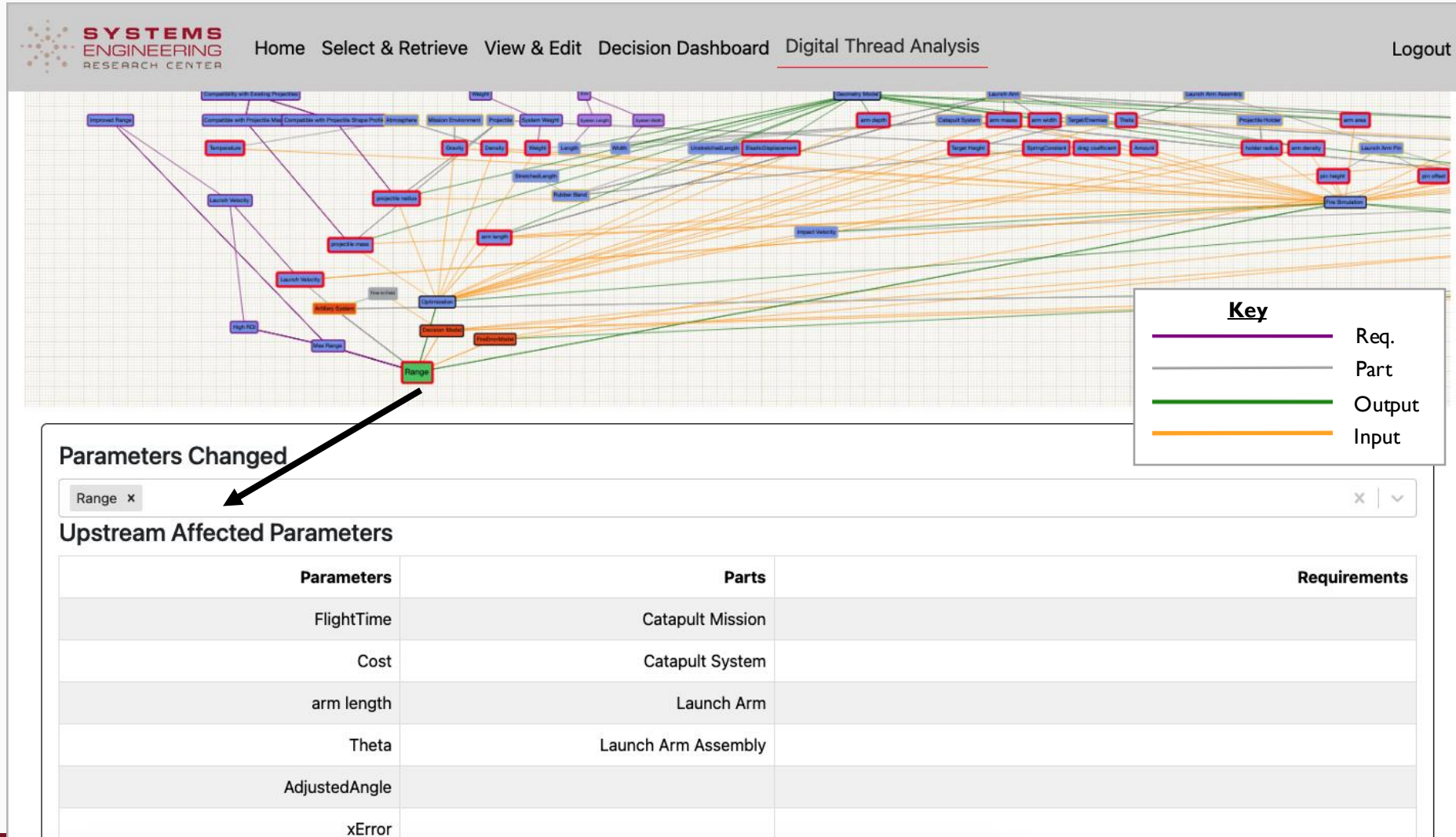Value Function Objectives

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

- First four chapters reflect on research over the past 10 years

- Provide guidelines related to topics covered in course modules
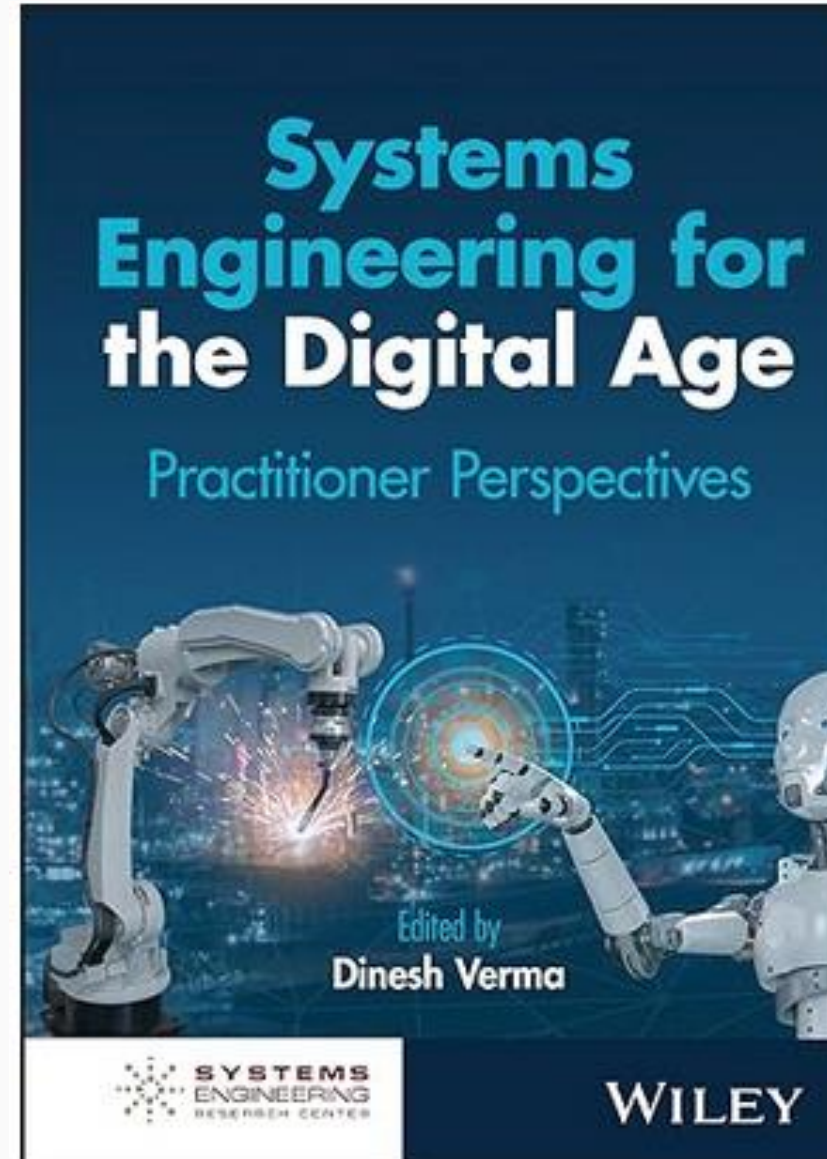
Conclusions – How Well

- 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

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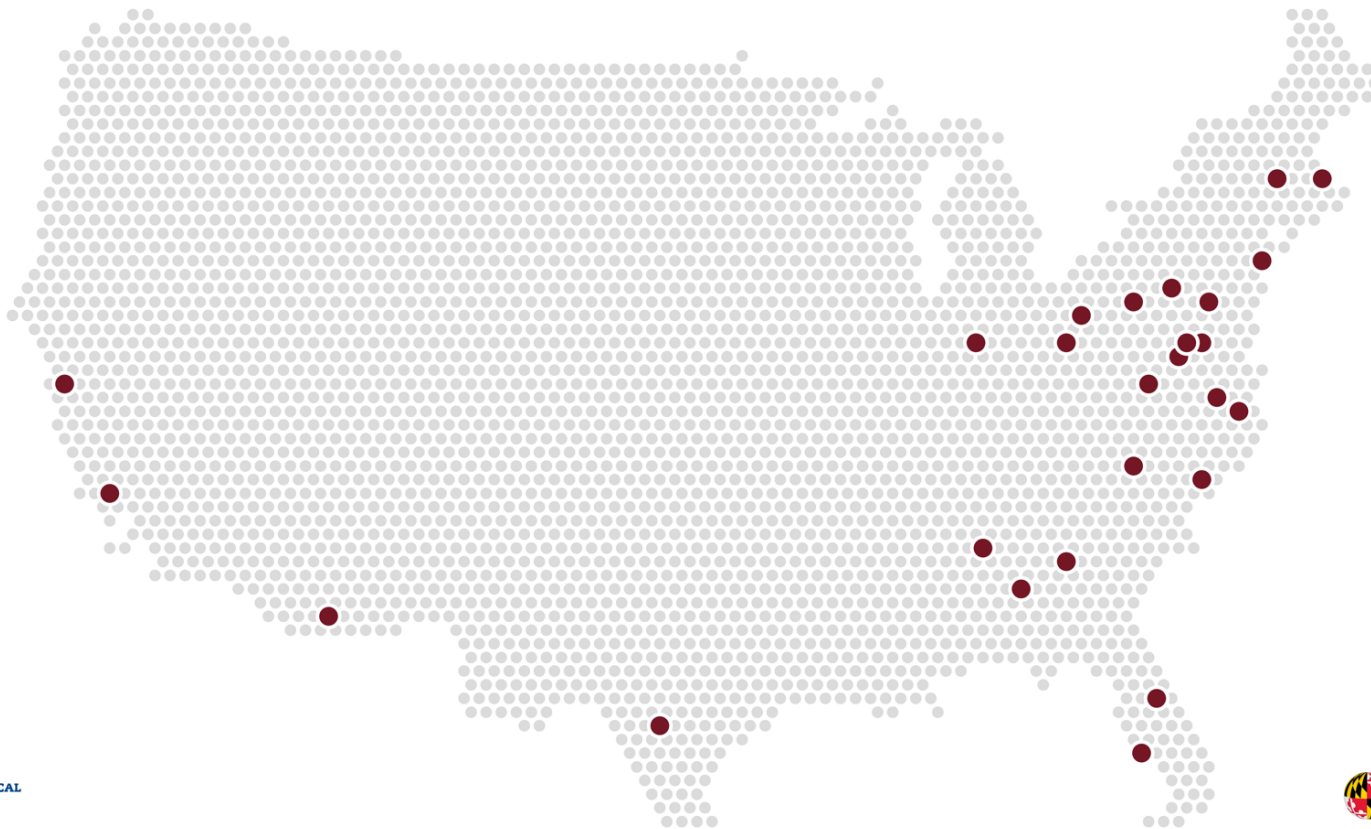
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