SERC RESEARCH REVIEW 2023 | NOVEMBER 15, 2023

Transforming Systems Engineering to Model-Based Systems Engineering

Transforming Systems Engineering Through Model-Based Systems Engineering/ART-022

US Army Armaments Center/DEVCOM

Dr. Mark Blackburn

STEVENS
INSTITUTE of TECHNOLOGY
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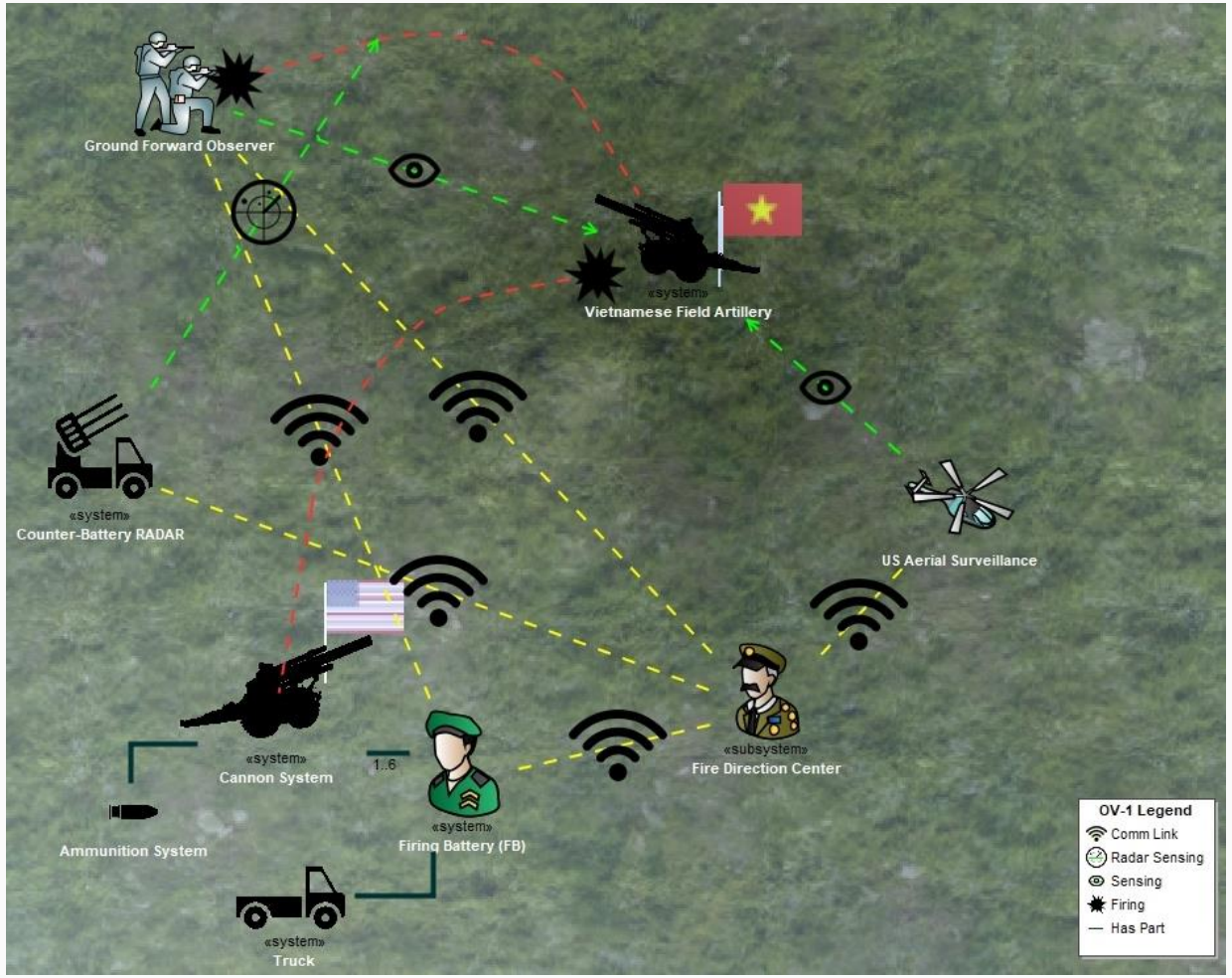
Armaments Missions



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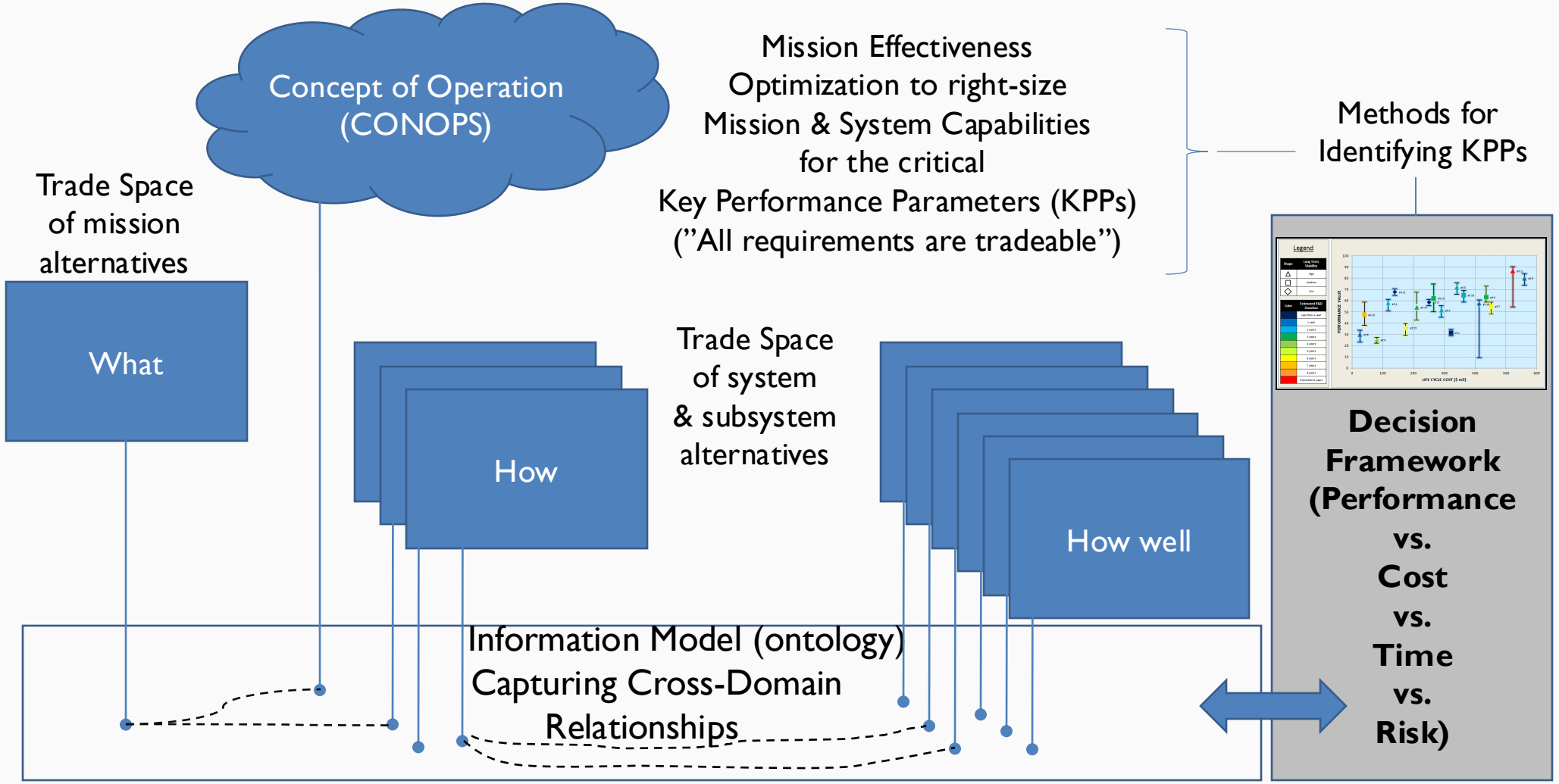
Organization

- **INTRO (WHY):** Context/Motivation – How did we get here?
- **WHAT:** Digital Engineering Enabling Technologies and Methods to Computational 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

Overview on Topics

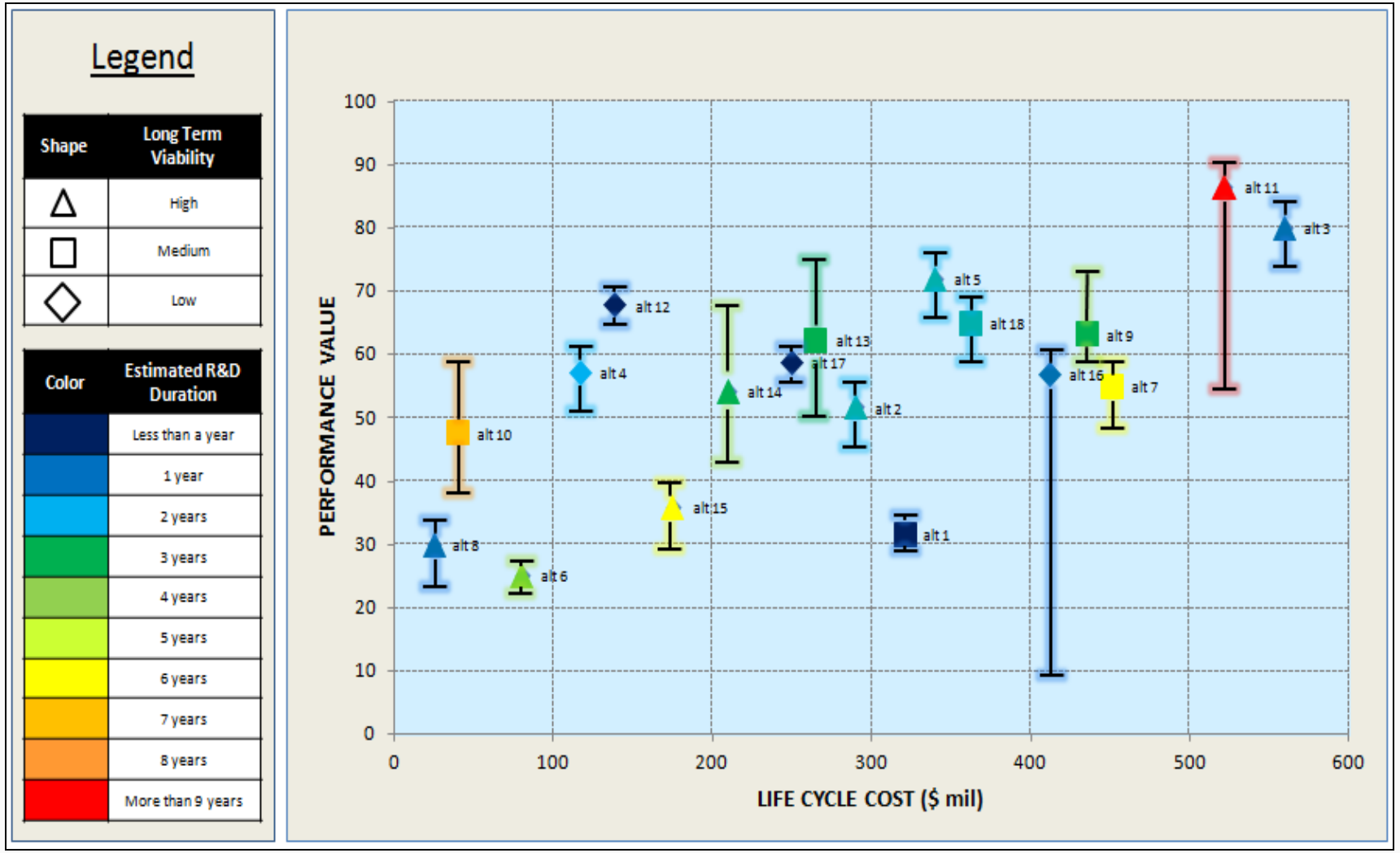
- Tool-to-tool integration challenges for cross-domain & physics-based analyses needed at multiple levels of abstraction (mission, system, subsystems)
- Integrated Systems Engineering Decision Management (ISEDM) Process (Cilli 2015)
- How we formalized the ISEDM process using SysML models, ontologies and semantic technologies with Interoperability and Integration Framework (IoIF) and workflows
  - Initial concept of formalized Assessment Flow Diagram (AFD)
  - AFD used to characterize the parametric relationships between 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
- Demonstration of workflow and digital thread & decision framework dashboards

DE Ecosystem Needs Cross-Domain "Integration" at Different Abstraction Levels for Decision Making



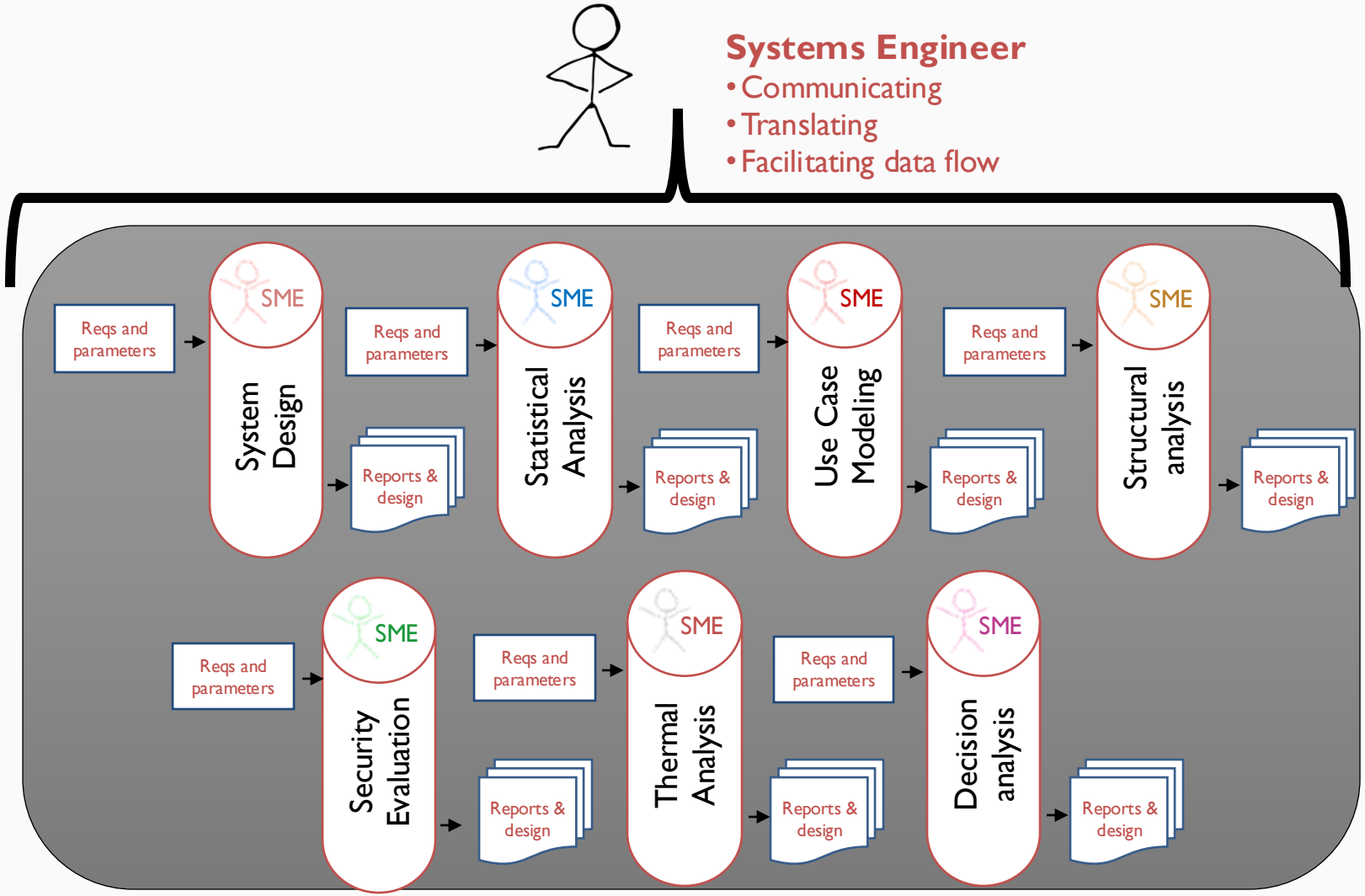
Reasoning about completeness and consistency of information across domains

We Want to Visualize Mission & System Level Trades Across Cost, Schedule, Performance, and Long-Term Viability Dimensions & Account for Uncertainty



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

Early Challenges: Lack of "Integrated" Models/Tools -> Stove Piped Analysis

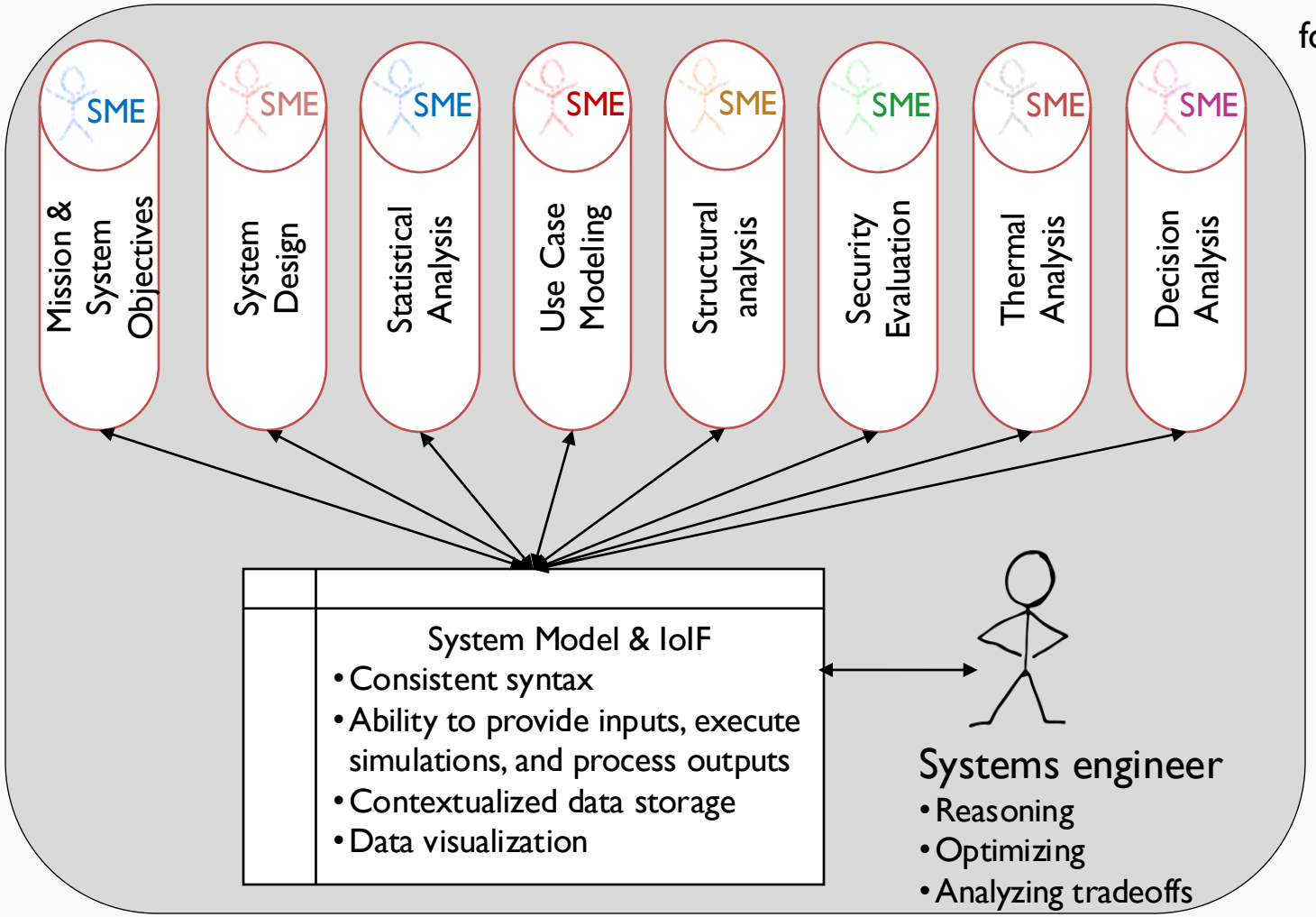


Cross Domain "Integration" Needed for Mission/System Trade Analyses

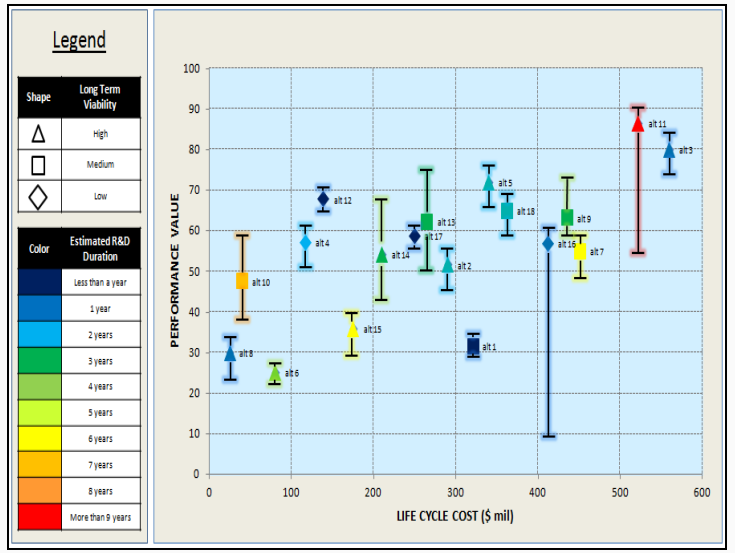
- Mission objective: continuous surveillance
- Capability Refueling UAV
- Systems: UAV and Refueler
- Valve – Cross-domain Object
- Mechanical Domain
  - Valve connects to Pipe
- Electrical Domain
  - Switch opens/closes Value
  - Maybe software

- 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 & Semantic Technologies Support Cross-Domain Model "Integration" through Interoperability



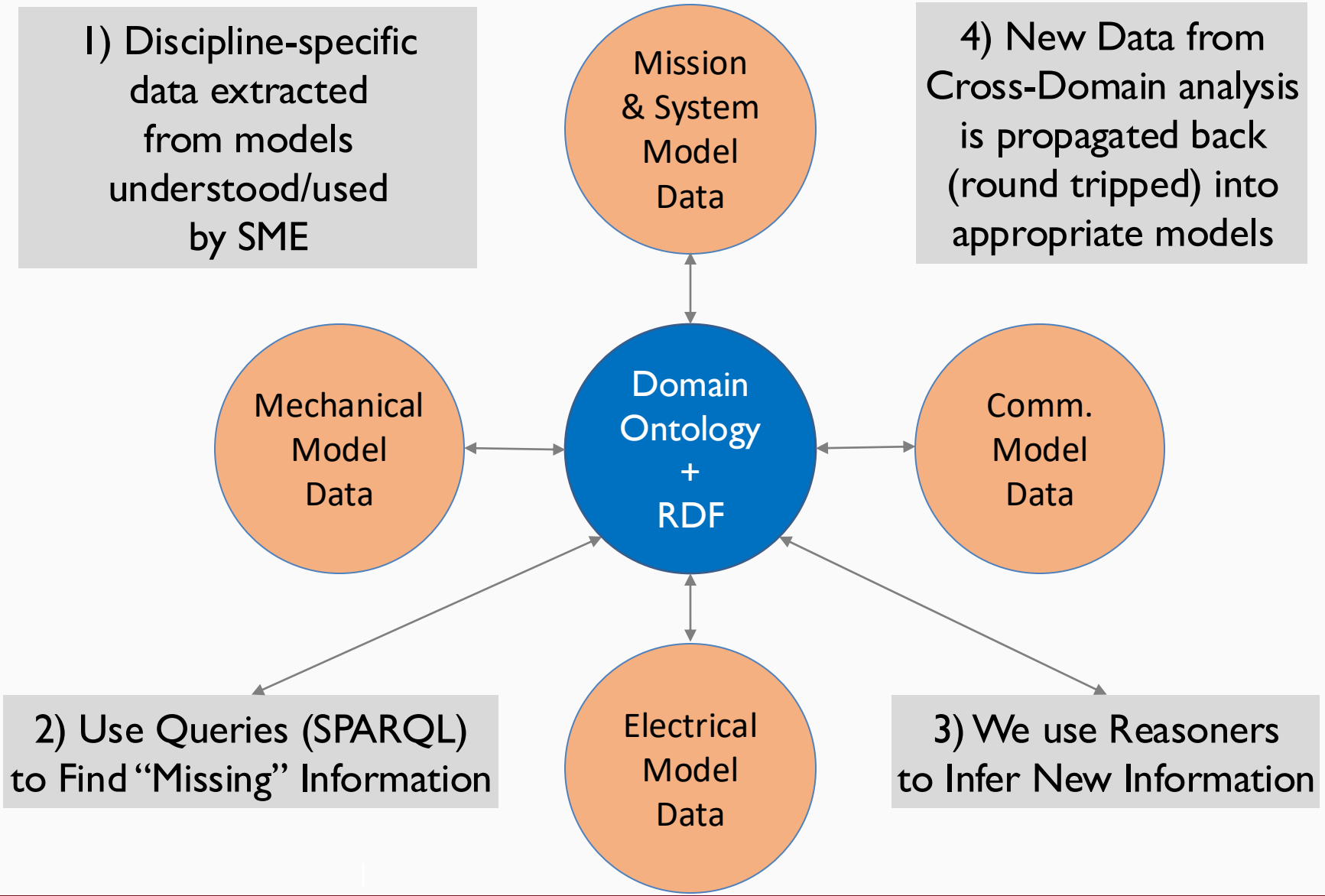
Scatter Plot Dashboard
for Decision Making related to Objectives



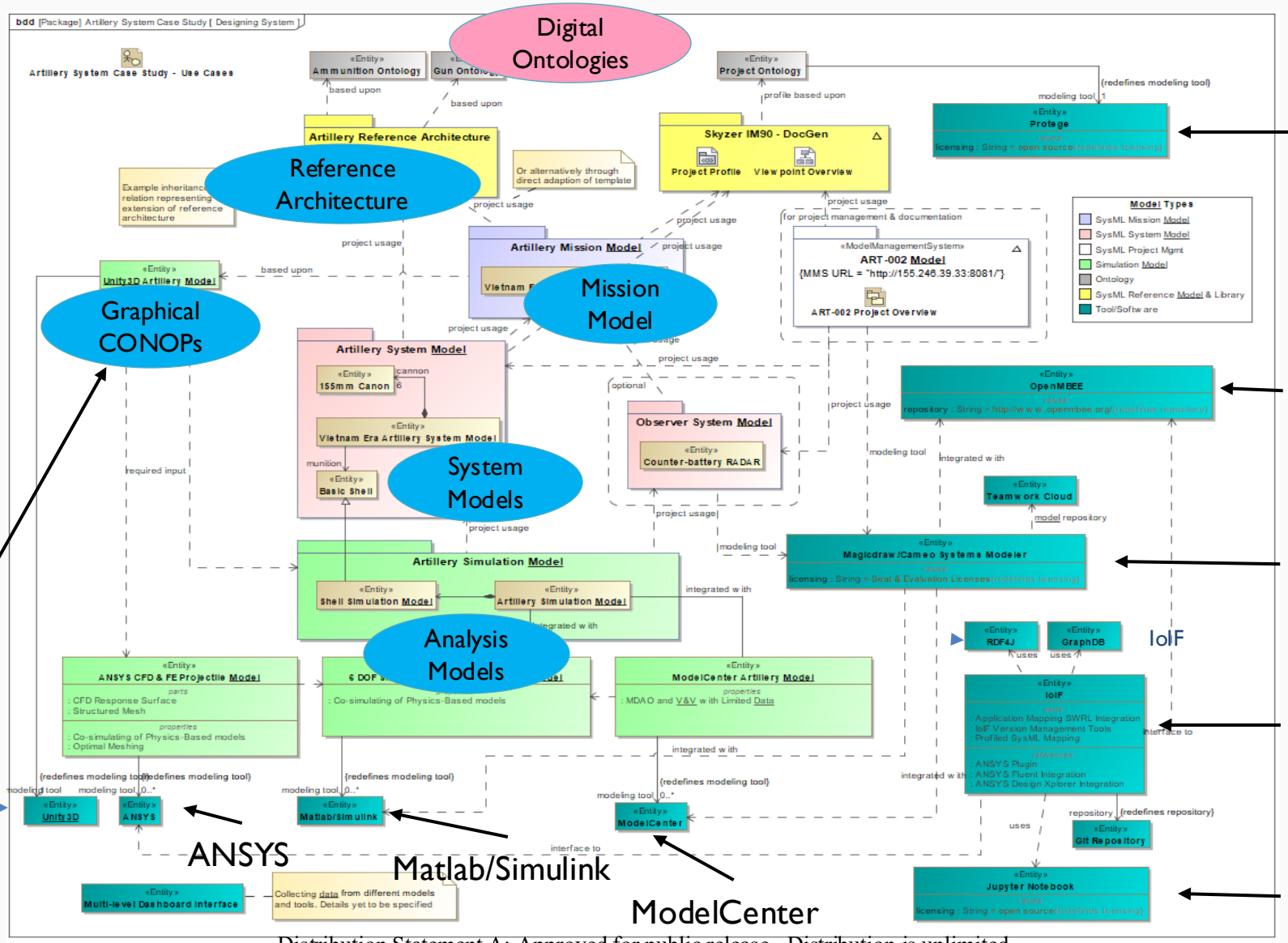
Strategic/mission-level decision-maker

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

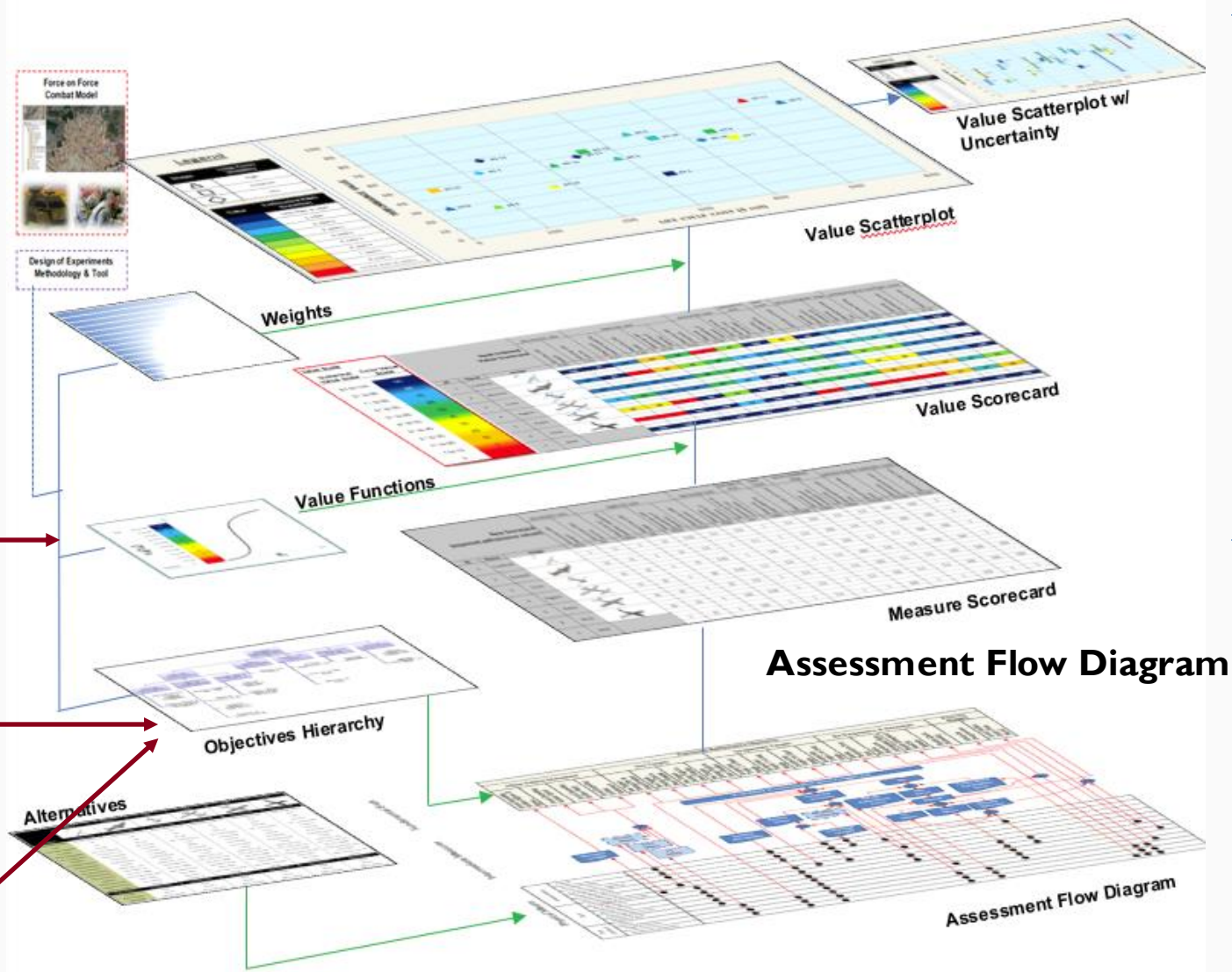
Data Across Disciplines Linked & Mapped to Computationally-Enabled Domain Ontologies



“Full Stack” linking Mission and Systems to Physics-based Models



Decision Support Model Construct



Renderings in New Decision Framework Dashboard

Value Functions

Identify KPPs

Objective Hierarchy

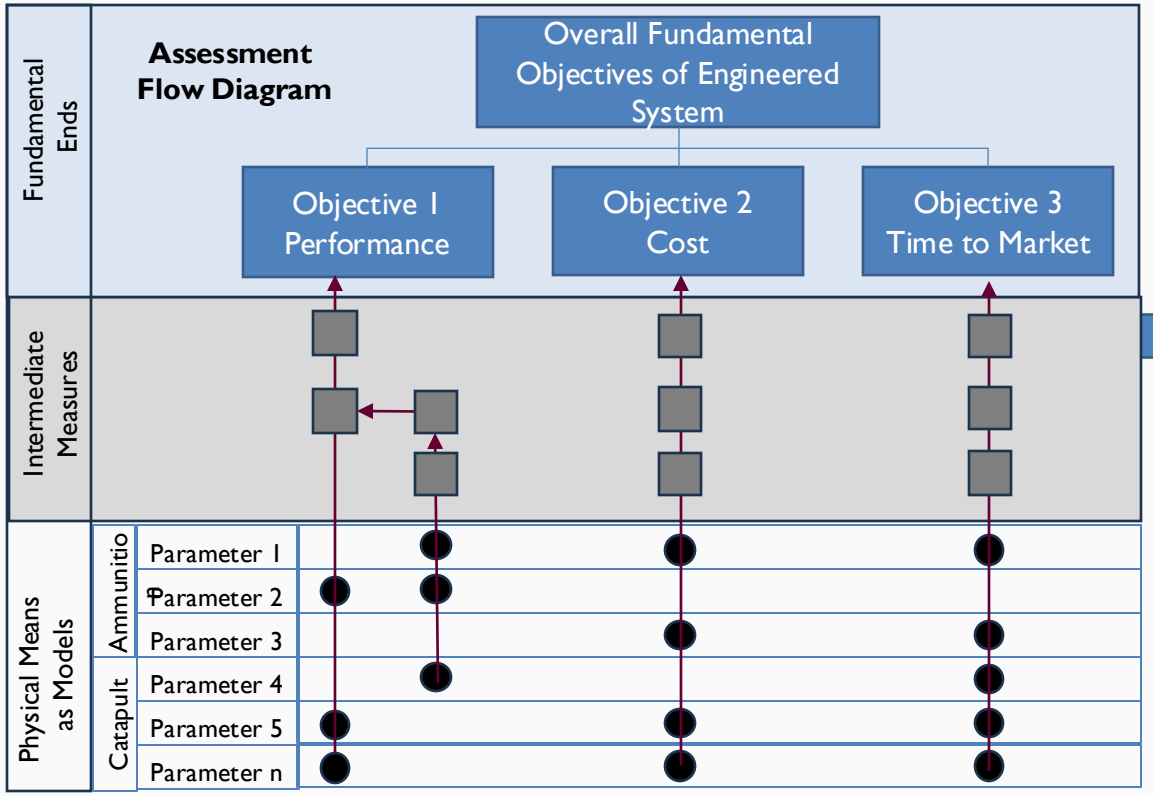
Assessment Flow Diagram (AFD)

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

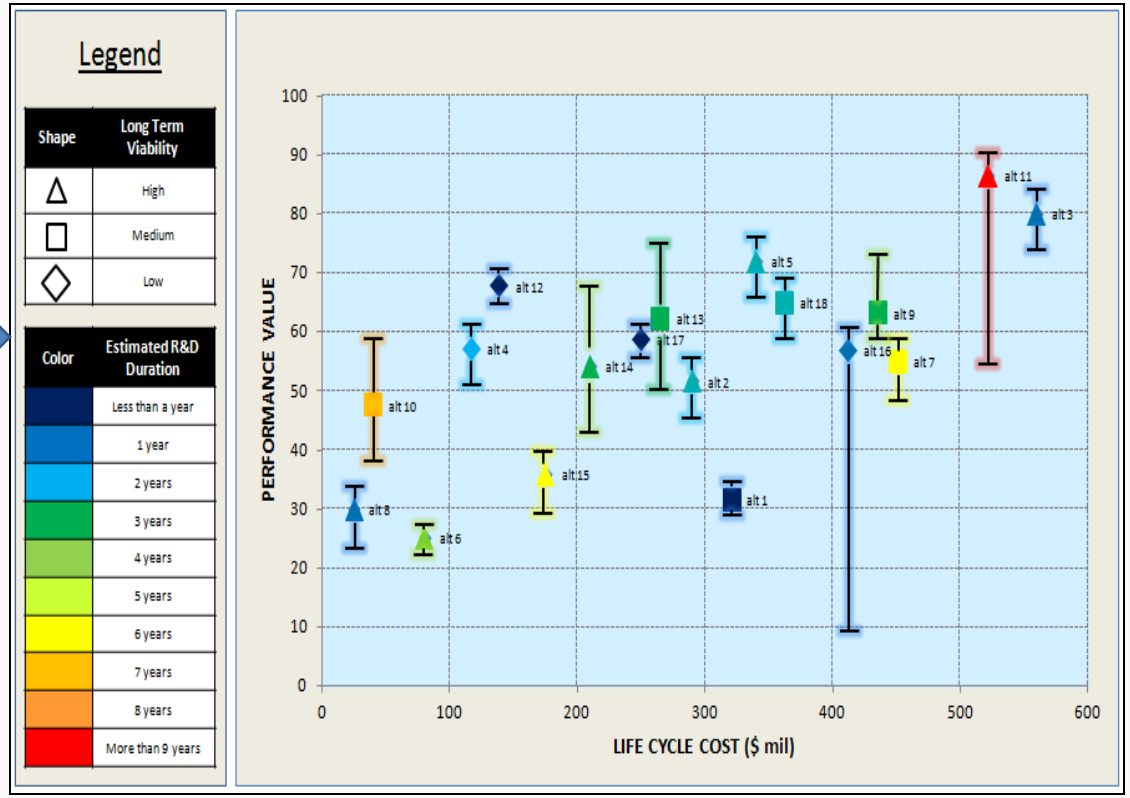
Notional Elements of AFD Concept

Parameters from the Domain

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



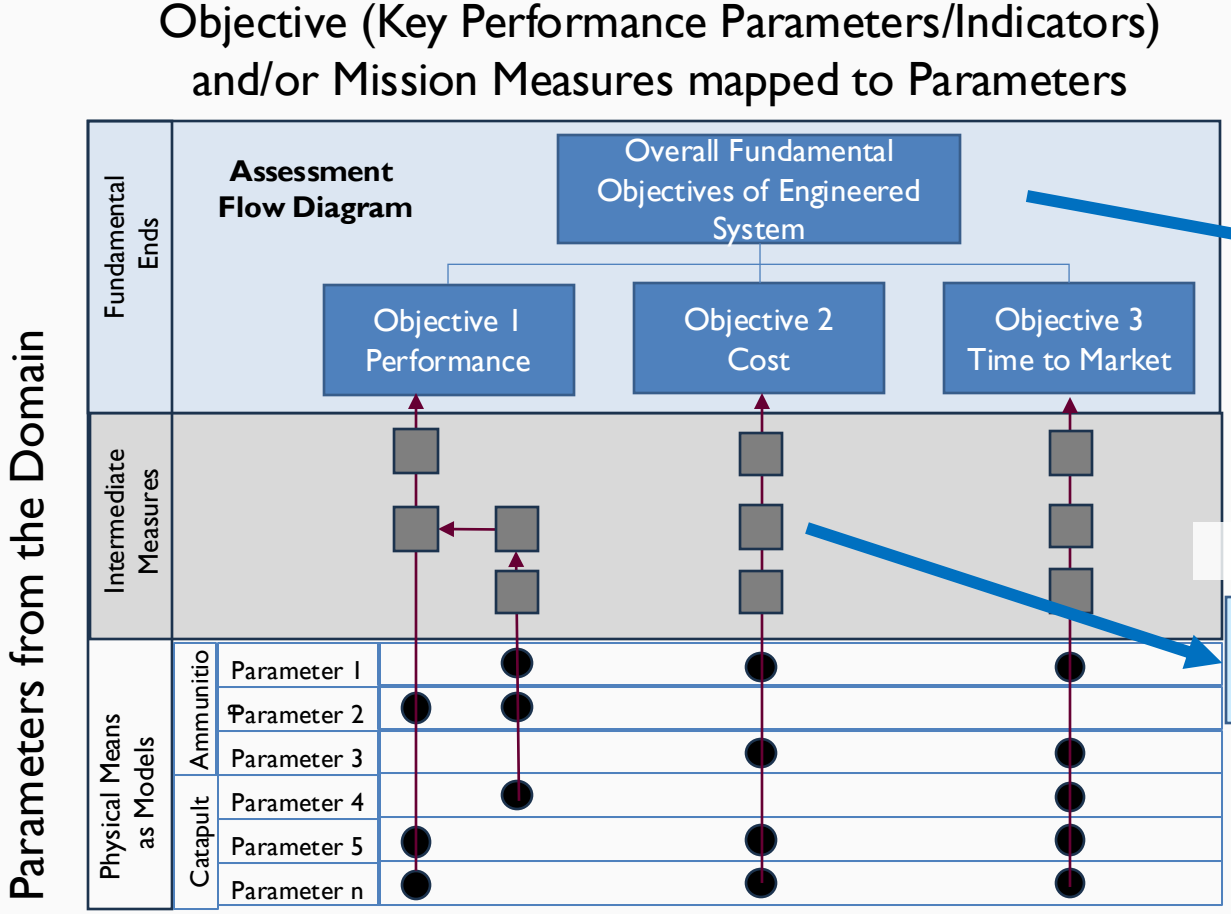
Scatter Plot Dashboard for Decision Making related to Objectives

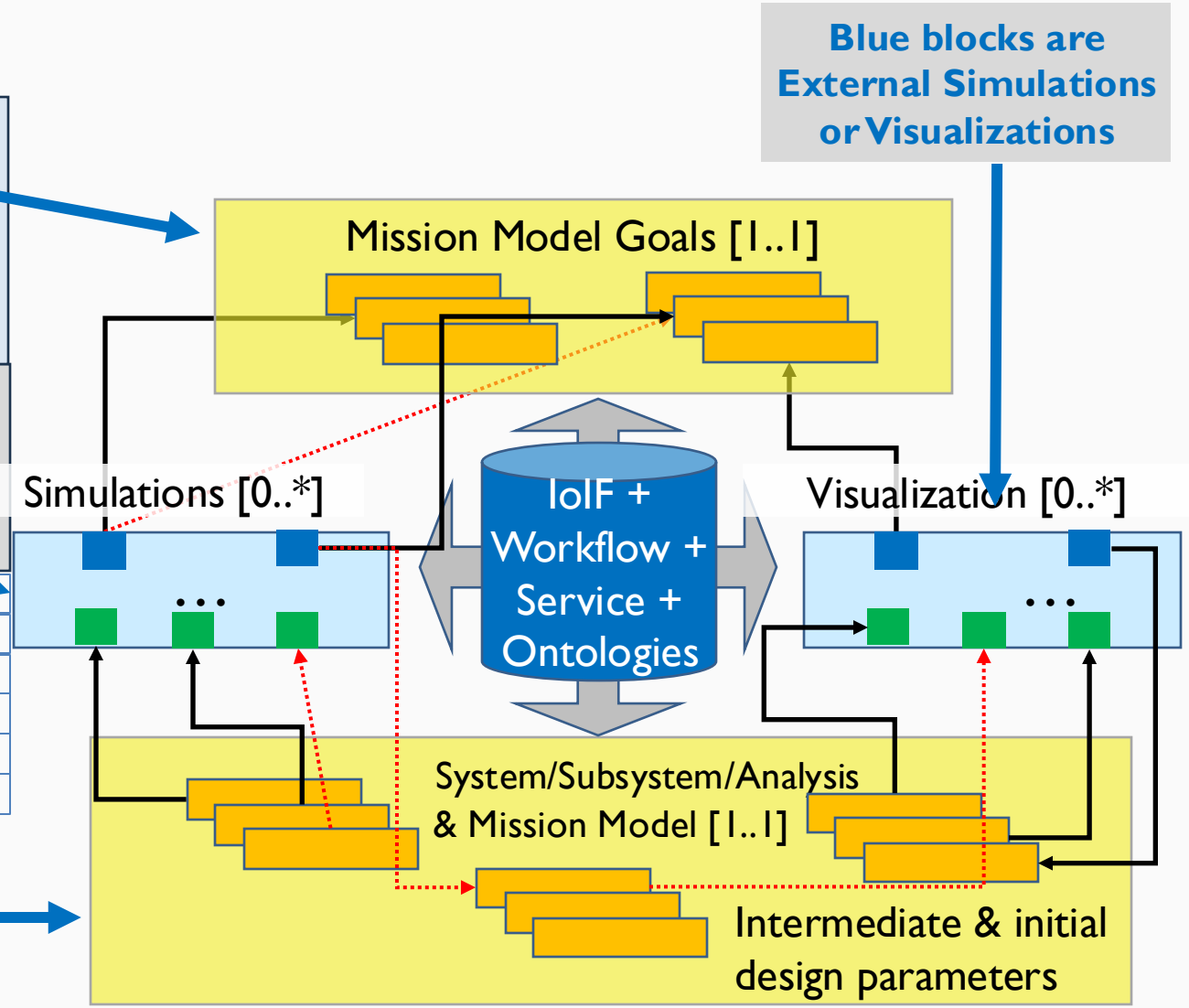


*Integrated Systems Engineering Decision Method (Cilli 2015): additional details in backup.

Mapping AFD Concept to Generalization of AFD Modeled in SysML

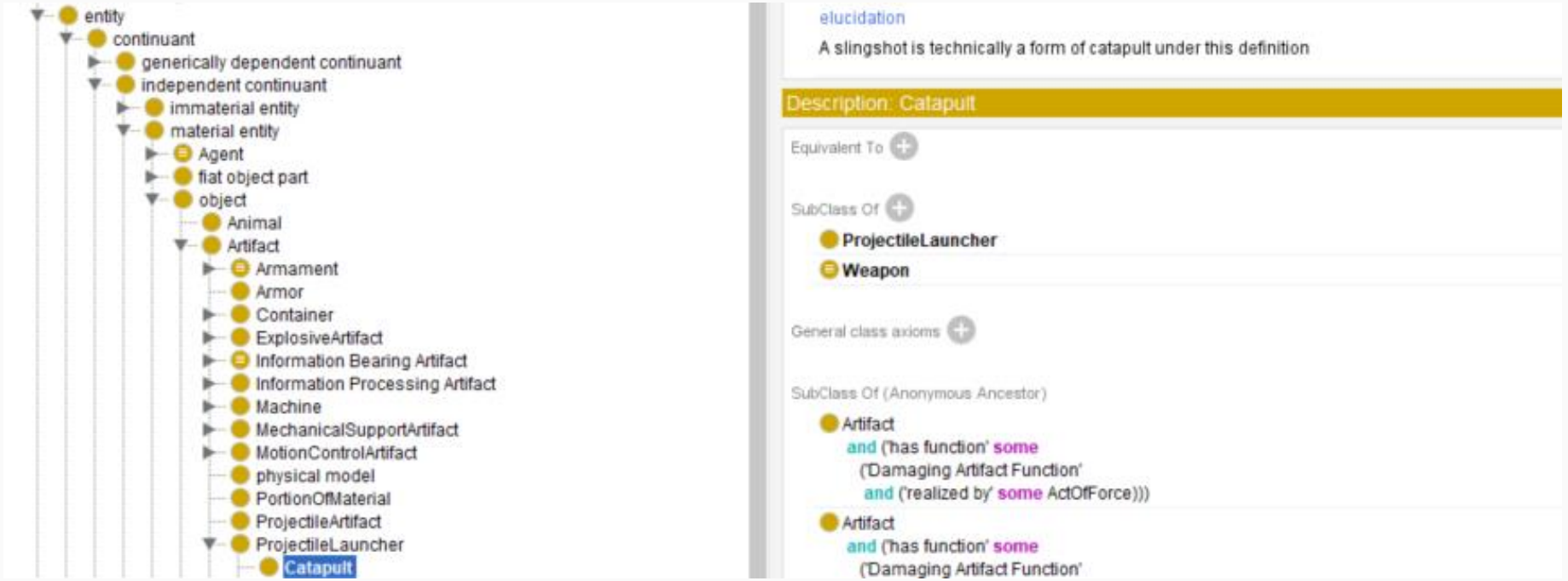
Objective (Key Performance Parameters/Indicators) and/or Mission Measures mapped to Parameters





What is the Ontology

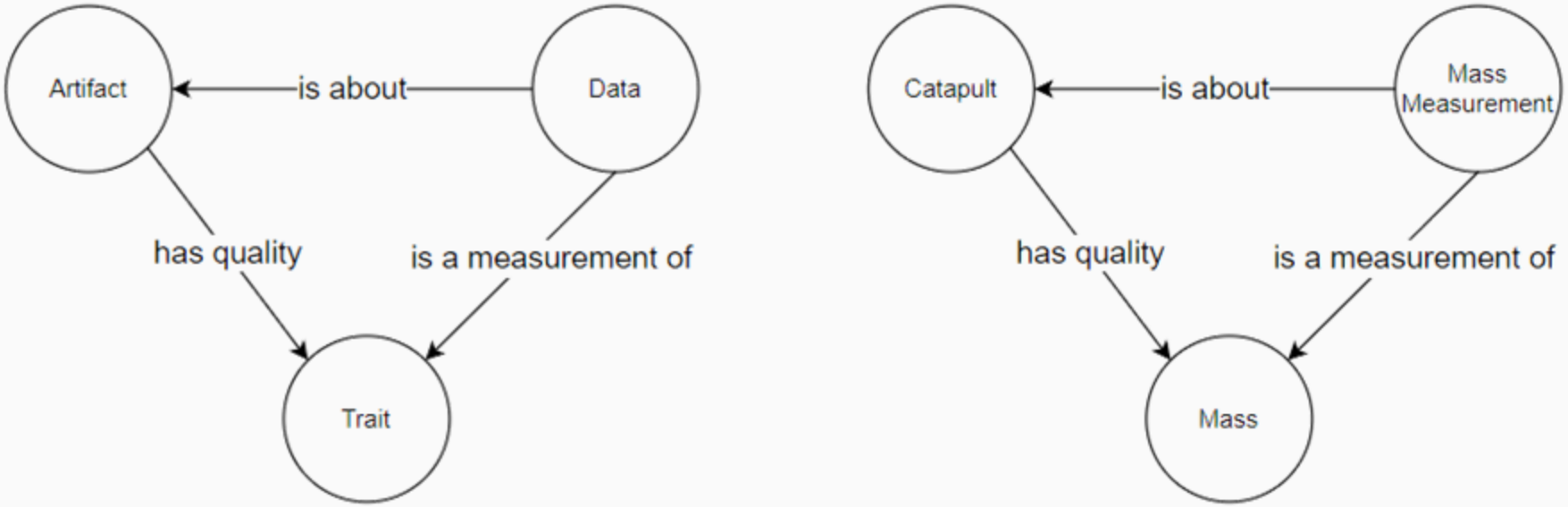
- Types of thing, relations between them, used to mark up graphs of triples



- Practically, the ontology is a language for very precise markup
  - Taxonomical relationships, logical expressions and rules, and careful classification of terms form the “grammar” of the ontology aligned data
- Permit automated reasoning, semantic query

IoIF Core Concept

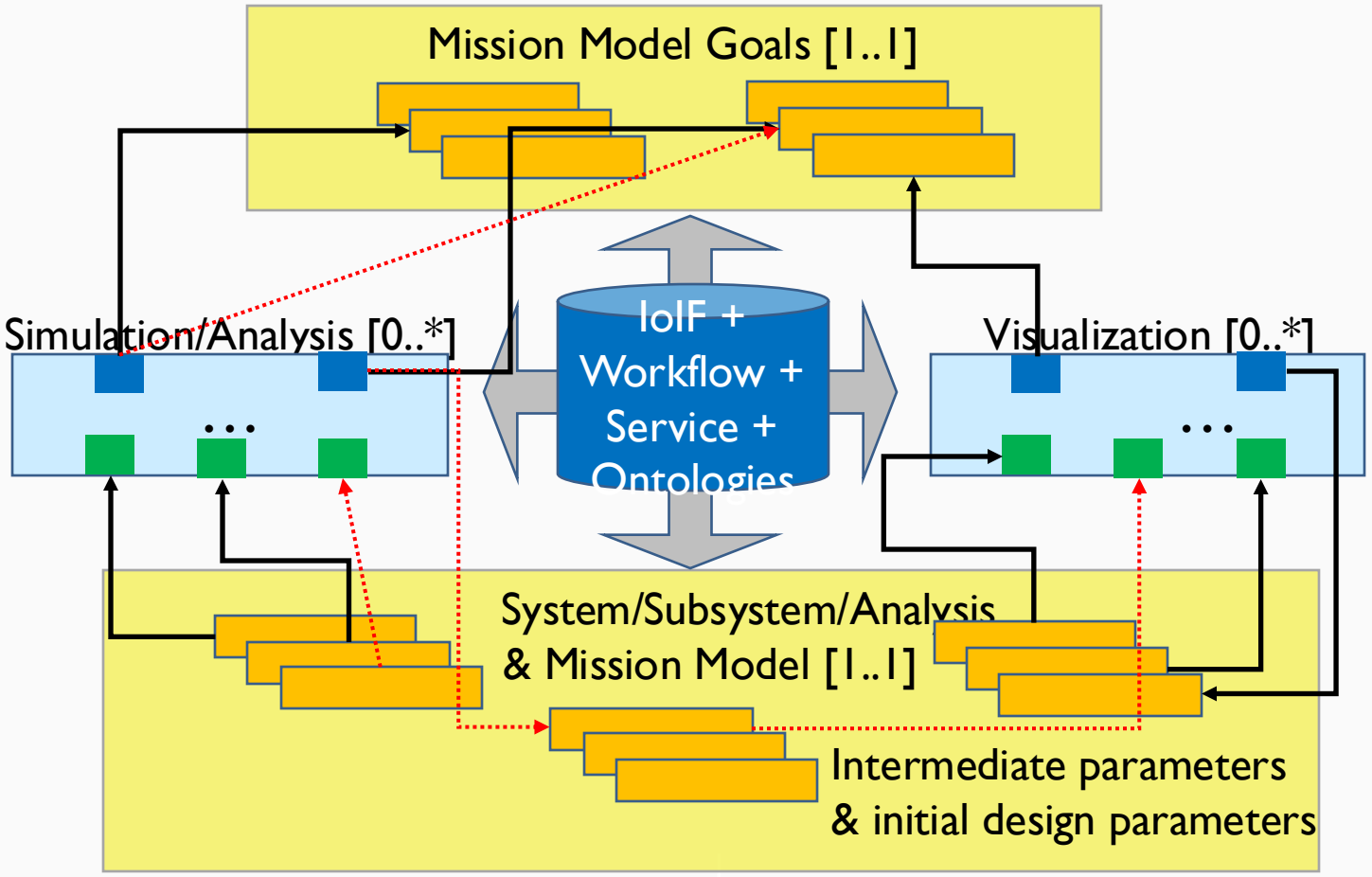
- Ontology enforces patterns within data irrespective of source
  - (Patterns are sets of things and relations and with like labels)
- Reasoning means queries can be written at higher levels of abstraction and still retrieve specific data



  - Ontology provides the information such that a query for the left-hand side can return the right-hand side

AFD Generalization

- Instantiated AFDs expressed in an ontology tagged pattern irrespective of how it was created
  - SysML or some other descriptive model is a means to obtain the pattern

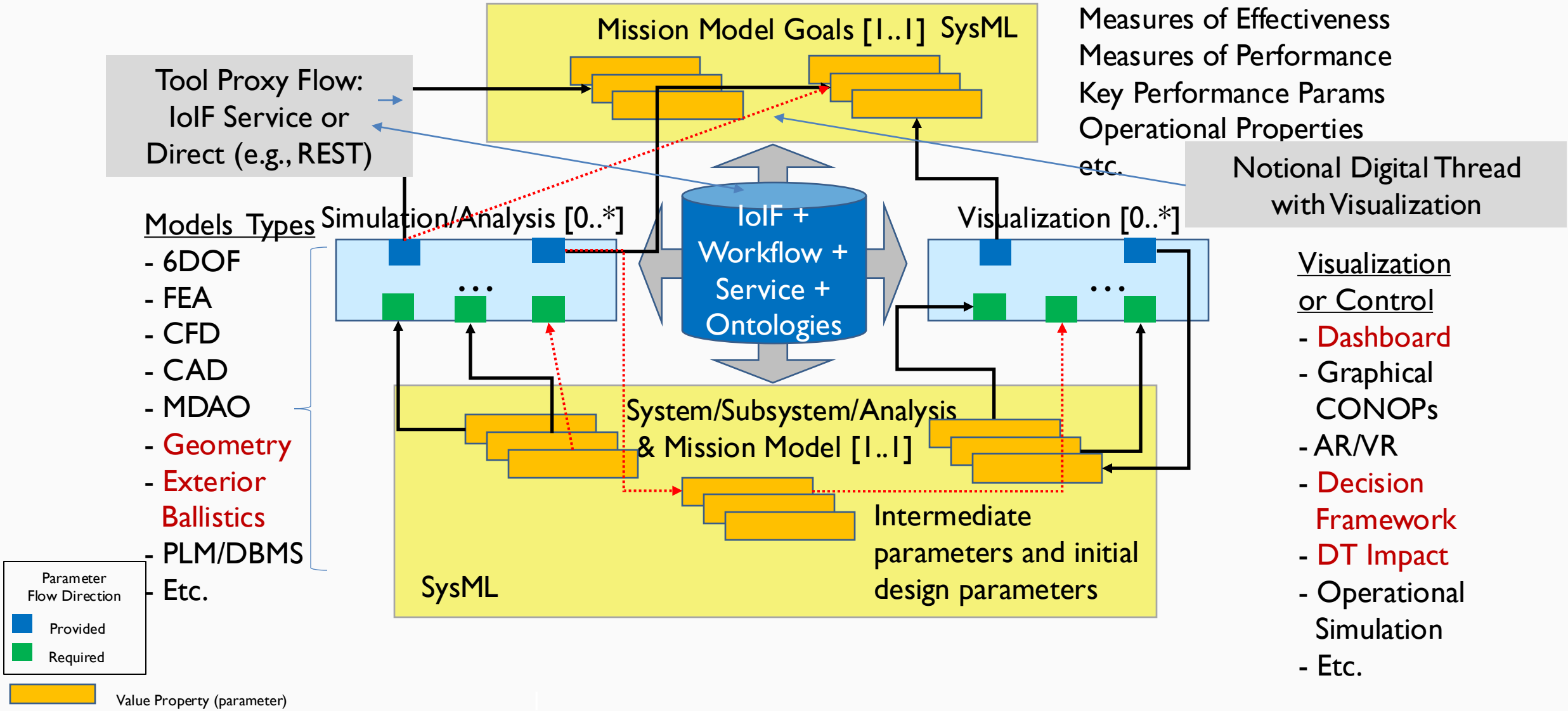


What we want to know

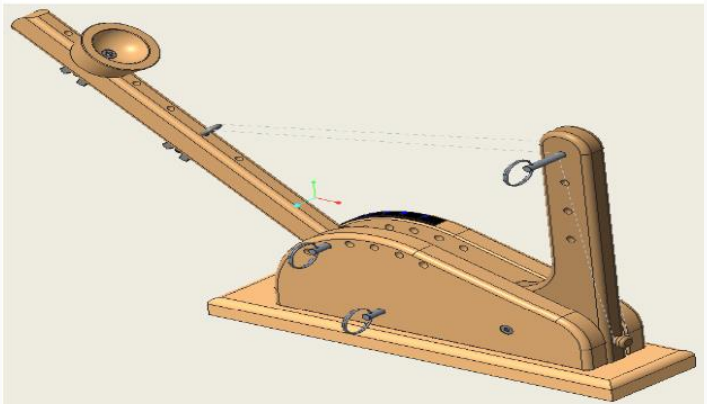
What data to send where, and how it needs to be marked up

What that data is about

Generalized AFD can be Configured for Various Types of Analyses with Digital Thread

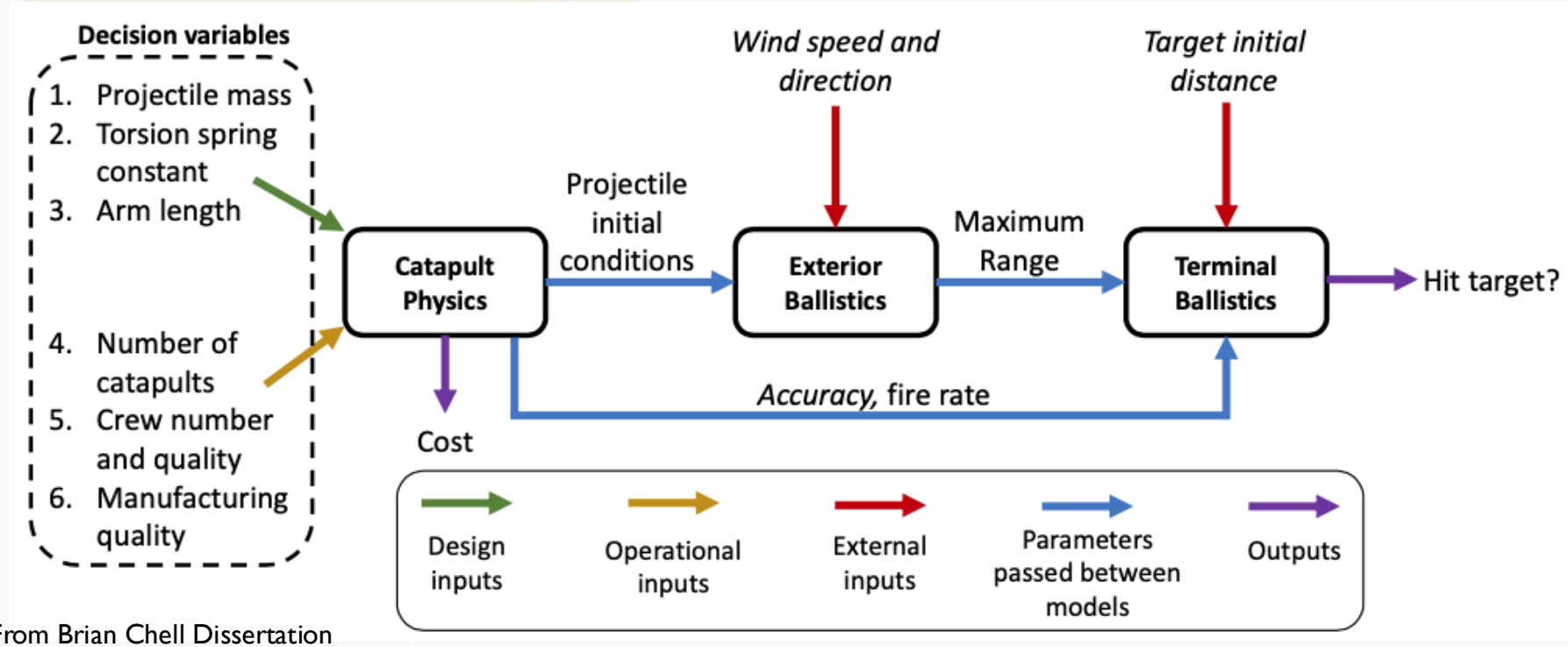


Example Case Study for Catapult



Three Scenarios

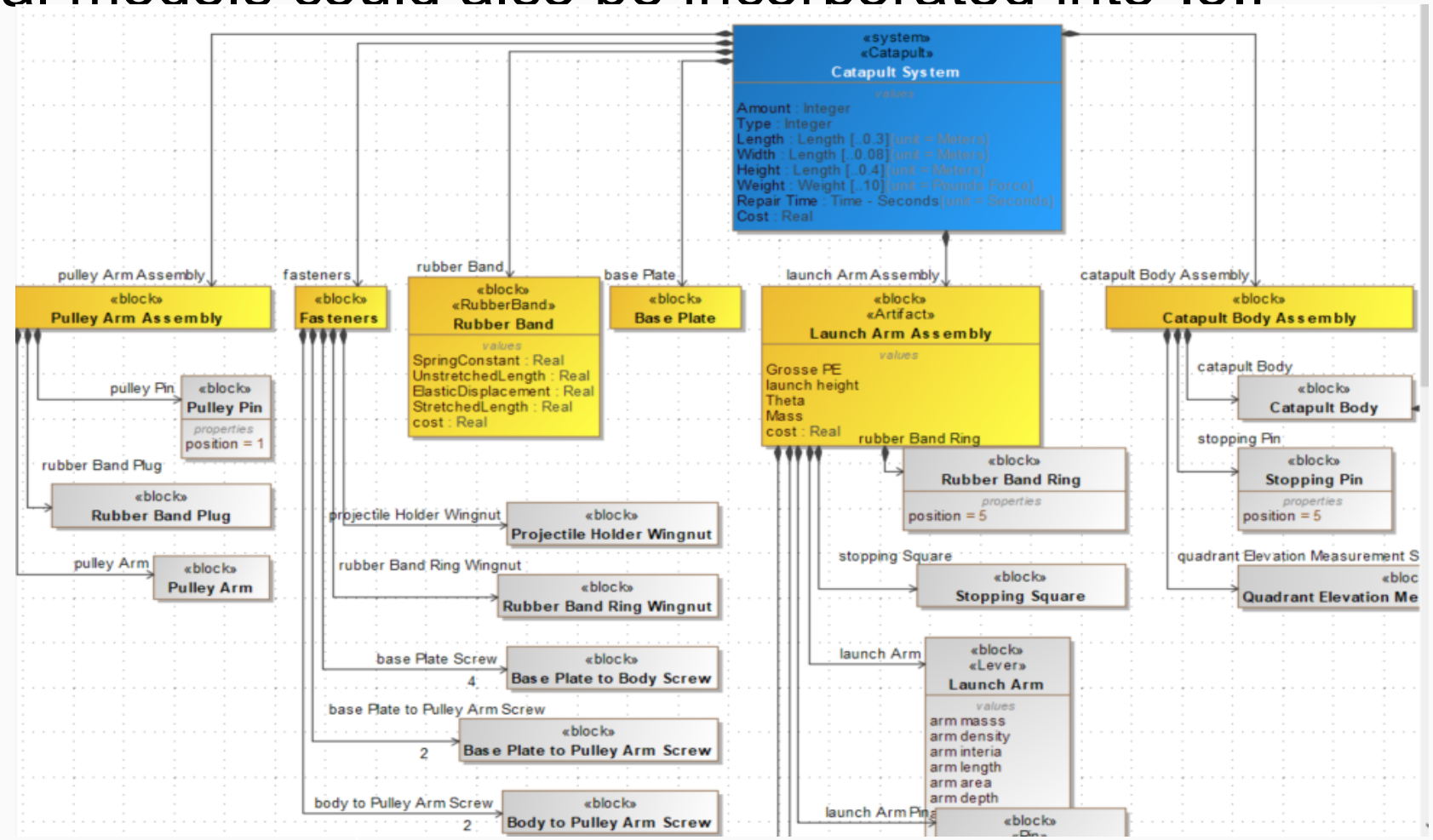
1. Baseline set of requirements
2. Requirement change
3. Mechanical part change



From Brian Chell Dissertation

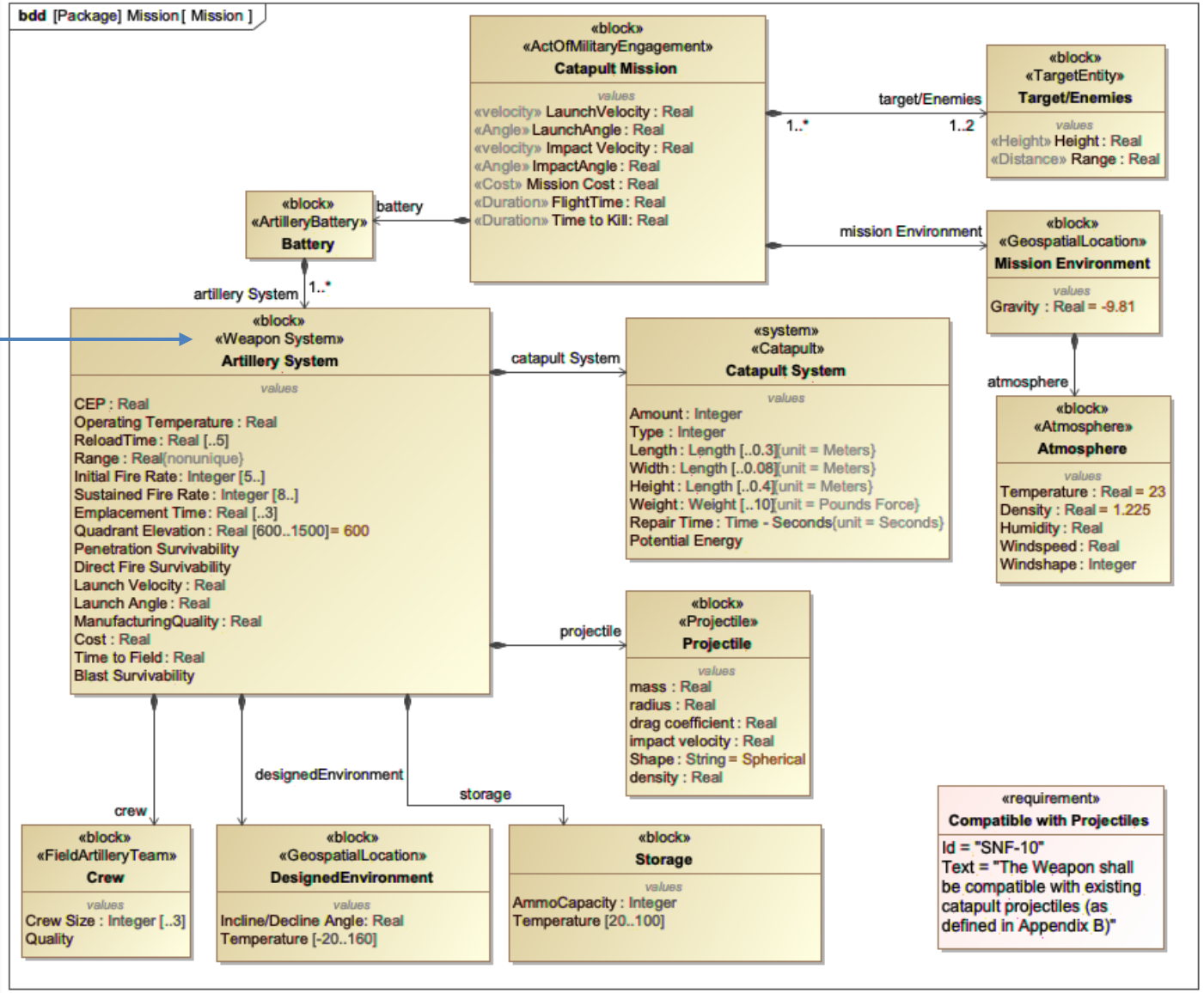
Catapult Structural Model

- Case study and exercises focus on structural model, but logical and functional models could also be incorporated into IoIF



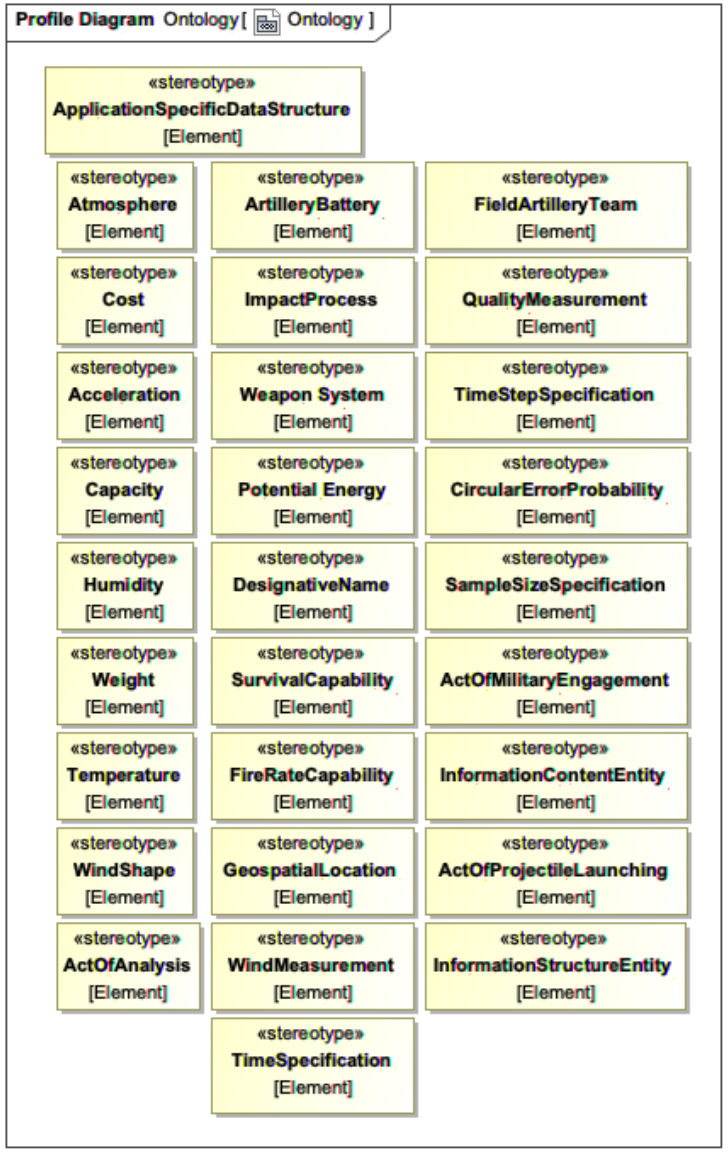
Mission/System Models Tagged with Stereotypes that Map to Ontology Classes

Stereotype "Tag" map to Ontology Classes



IoIF Catapult Demo: SysML Profile

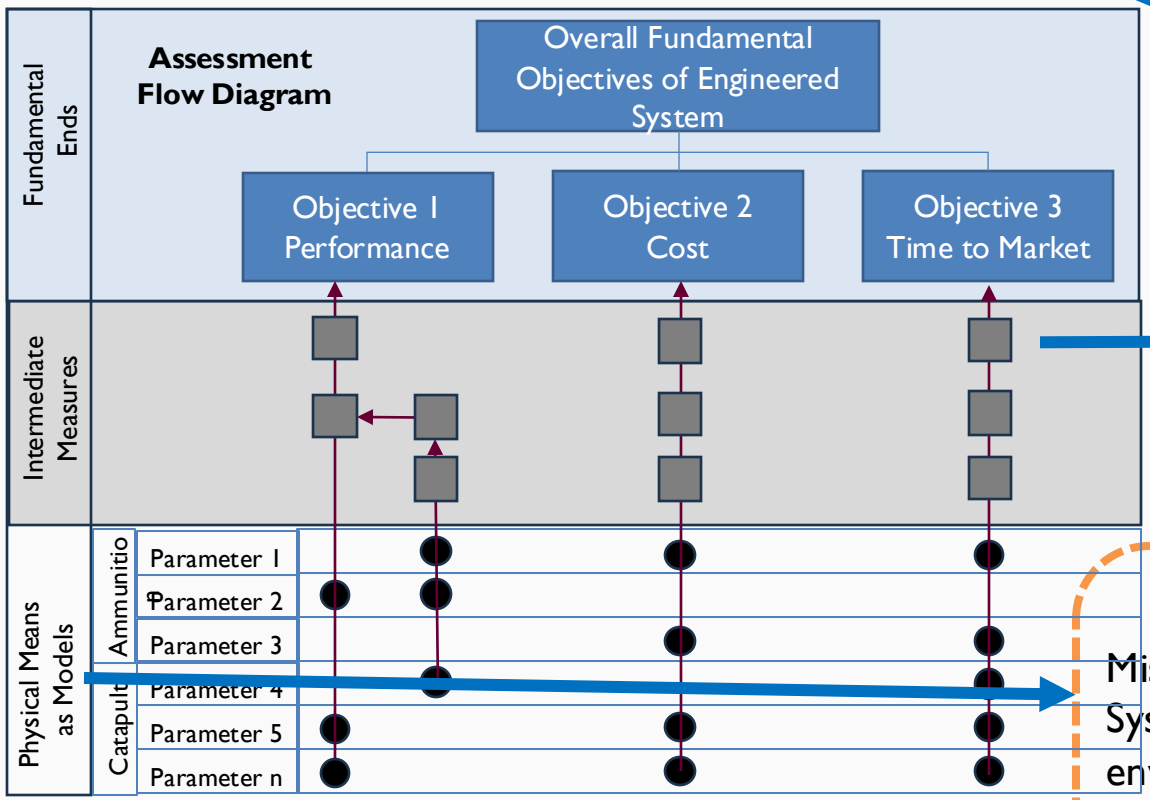
- Extend the model with stereotypes
  - This is not the only way, but it is a very convenient one and good for teaching concepts
- Three (3) Purposes:
  - Unambiguously and repeatably tie SysML elements to an ontology term
  - Provide a means to “retrofit” a model to IoIF
  - Indicate elements in the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



AFD is Blueprint for Facilitating IoIF Data Exchanges between Analysis Tools

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

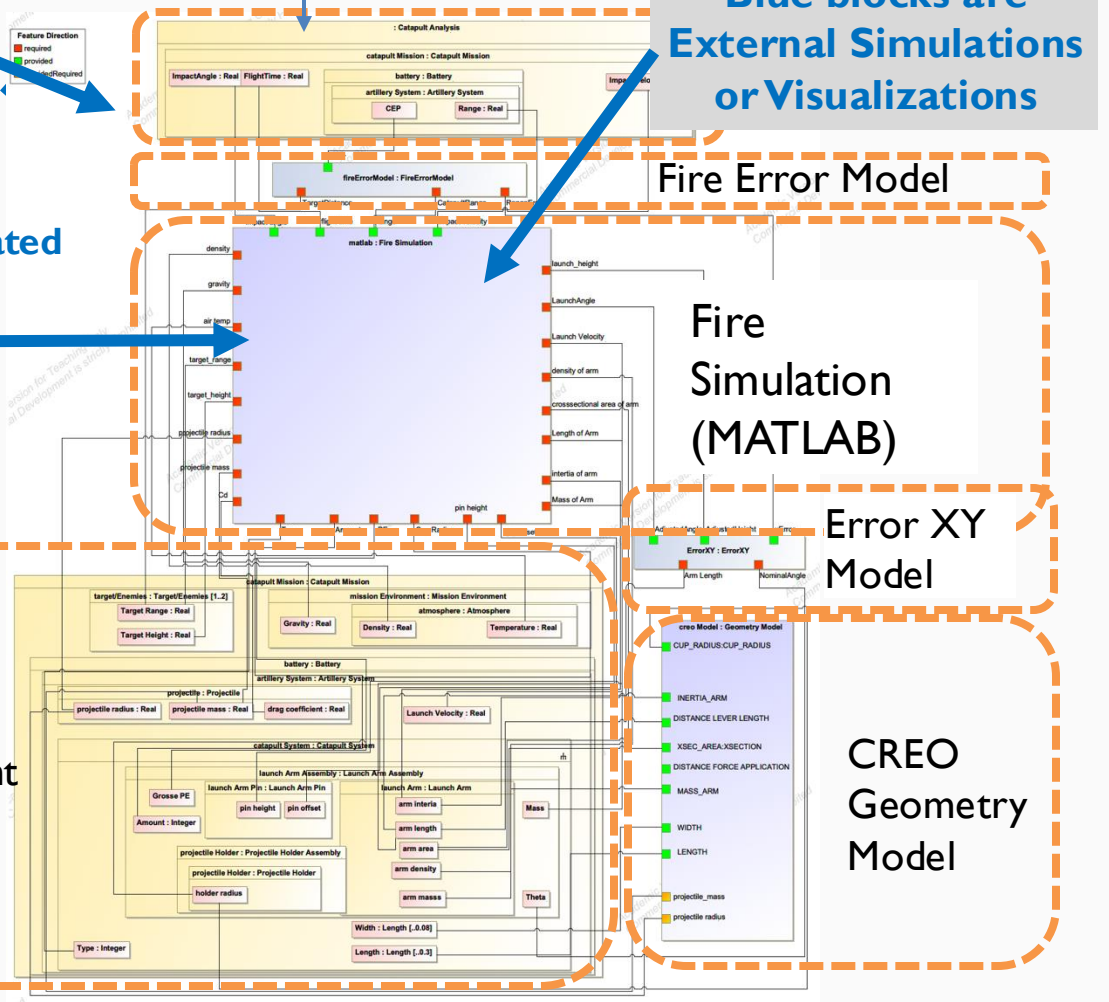
Parameters from the Domain



Yellow blocks are SysML elements and value properties

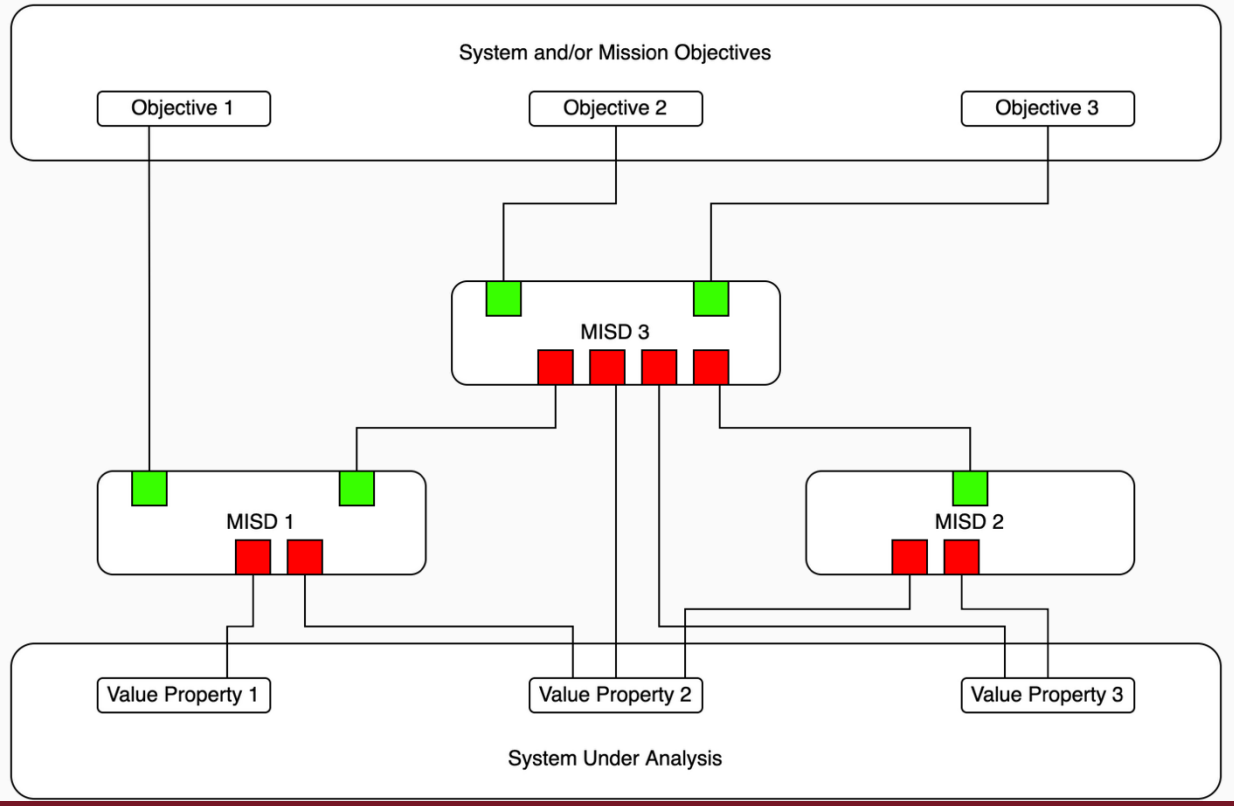
Blue blocks are External Simulations or Visualizations

Associated Models

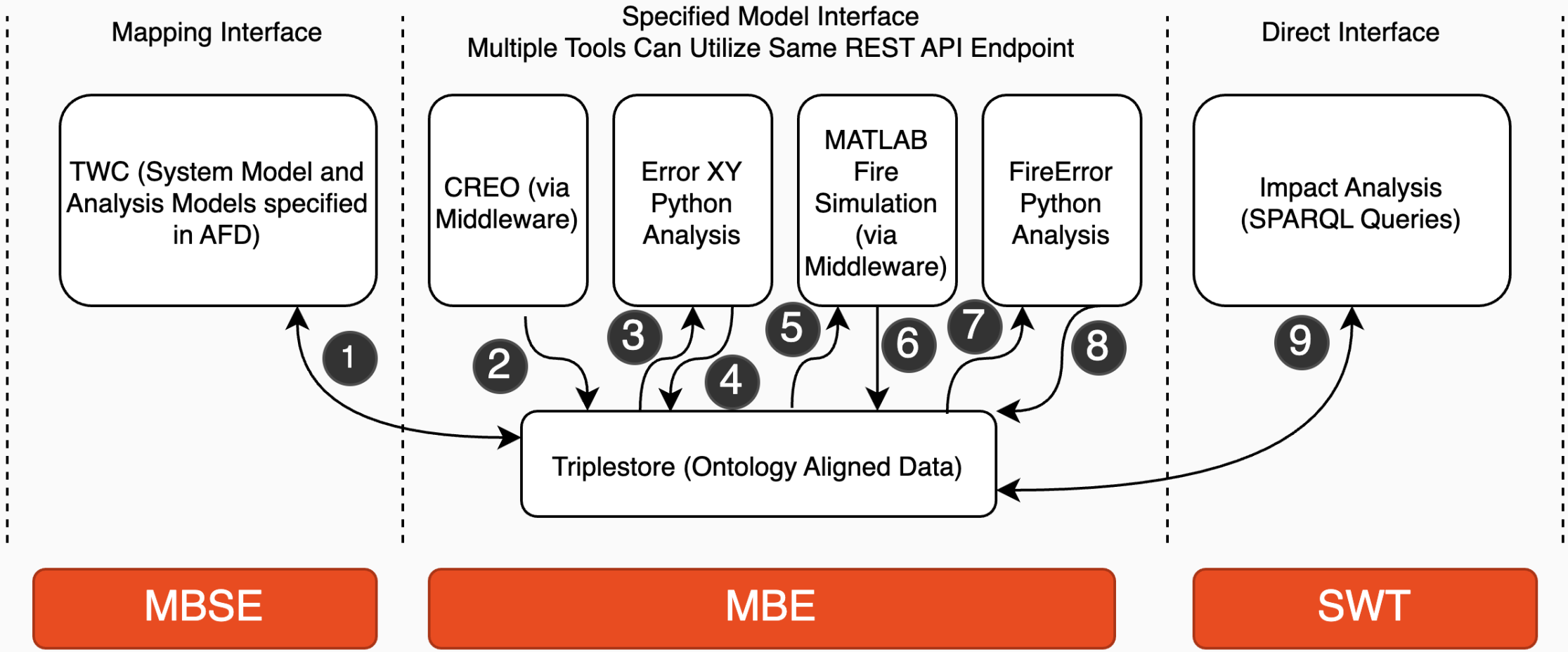


Generalized Abstraction of Assessment Flow Diagram (AFD)

- Aggregates multiple models (MISDs) into a larger analysis
- Makes explicit connections between analysis models, system model, and system and/or mission objectives
- Provides notion of sequence and flow through port directions



Digital Thread Associated with Interfaces and Disciplines



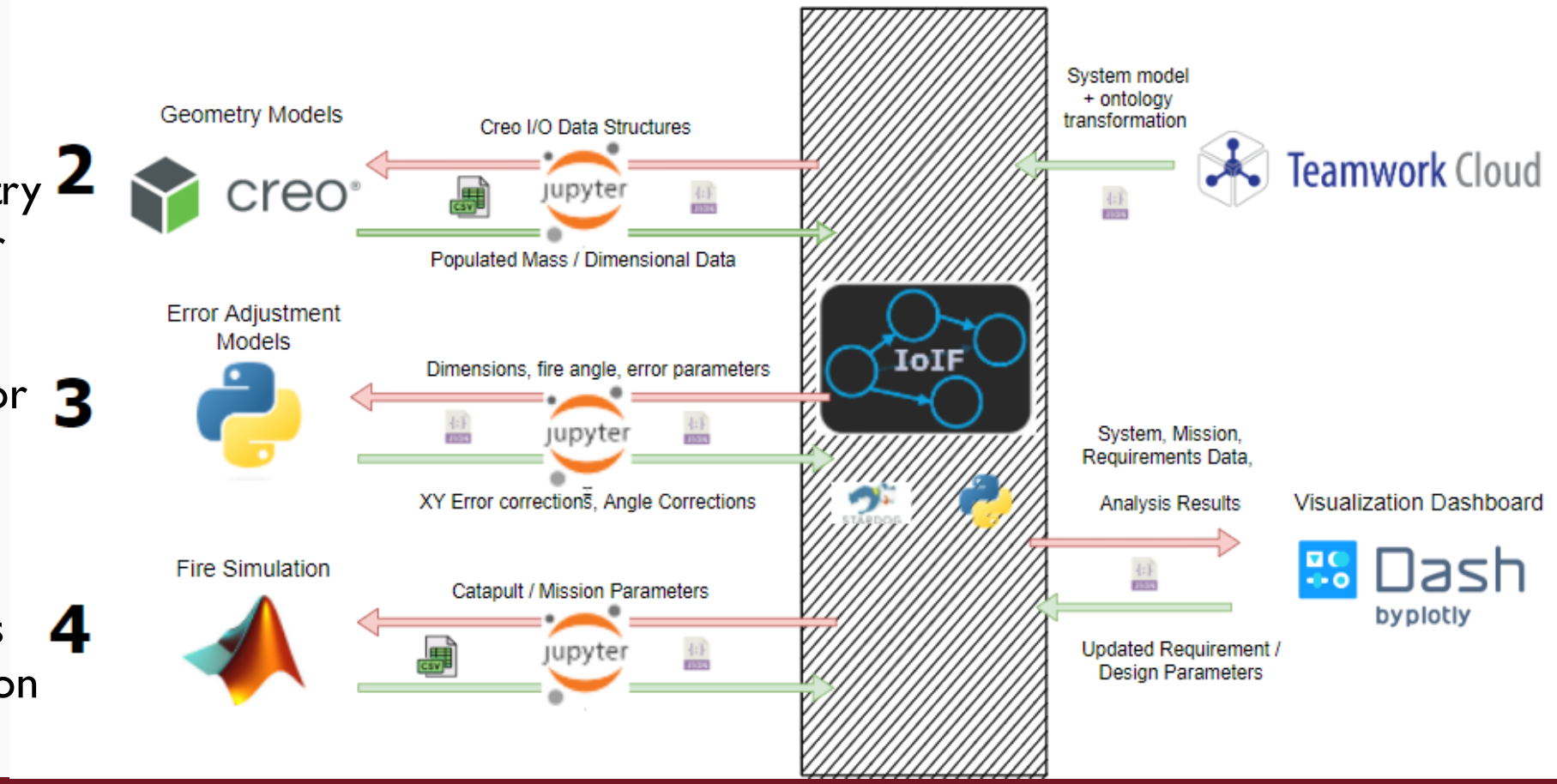
DEVCOM Team Executed IoIF on Army Network for Catapult Use Cases

- An objective of SERC is to enable sponsors to Execute and Transition research results
- DEVCOM successfully demonstrated to other Army Sponsors an Armaments Case Study and Workflow on Army computers and networks

Role: Geometry Modeler **2**

Role: Operator Aiming **3**

Role: Ballistics Simulation **4**

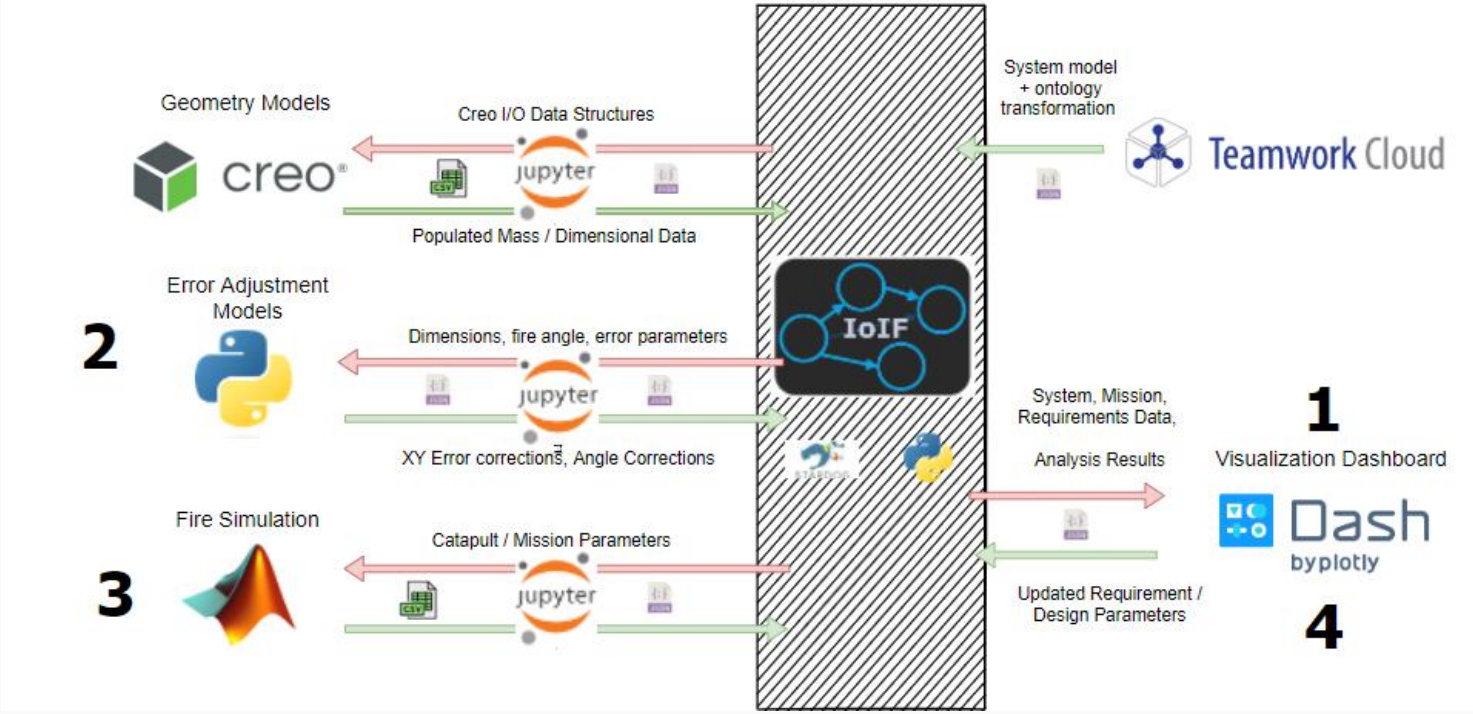


1 Role: Systems Engineer & IPT Lead

5 Role: Team Trade space Analysis

Scenario 1: Requirement Change

- Update value properties (parameters) in Dashboard (next slide) and change type of analysis in workflow and re-execute necessary workflow cells

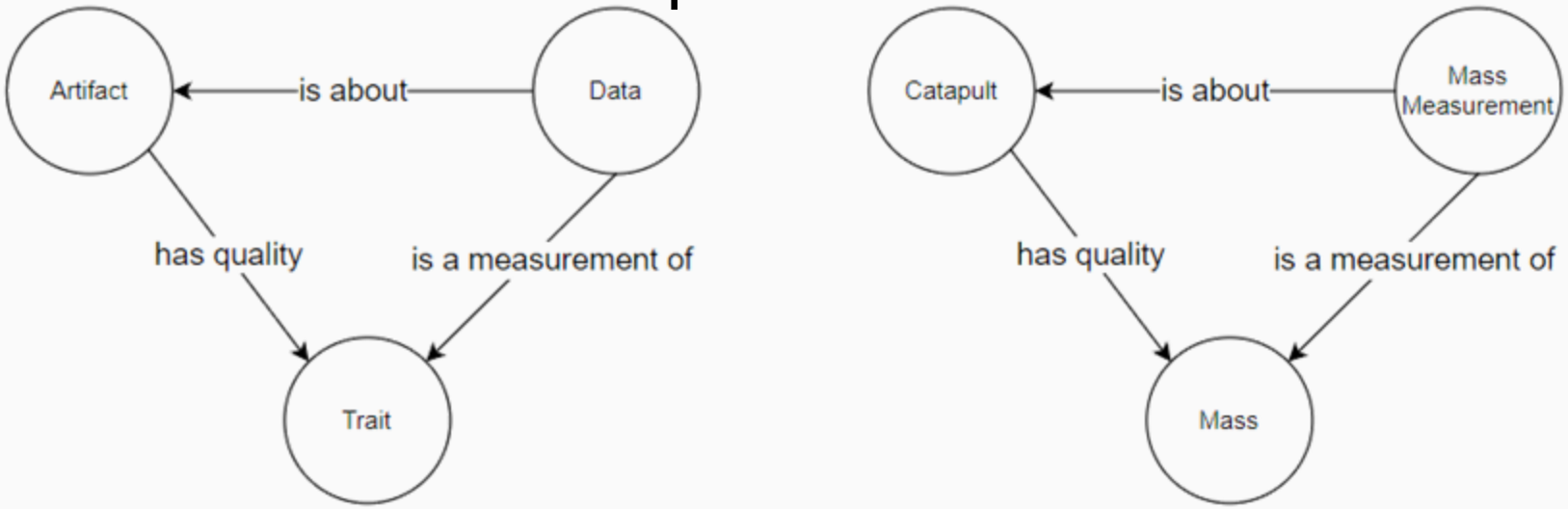


#	Name	catapult Mission : Catapult Mission
1	Analysis as Designed	Mission as Designed : Catapult Mission
2	Analysis as Manufactured	Mission as Manufactured : Catapult Mission
3	Analysis Configuration Changed	Mission Configuration Changed : Catapult Mission
4	Analysis Requirement Changed	mission as required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

Analysis Type

Dashboards

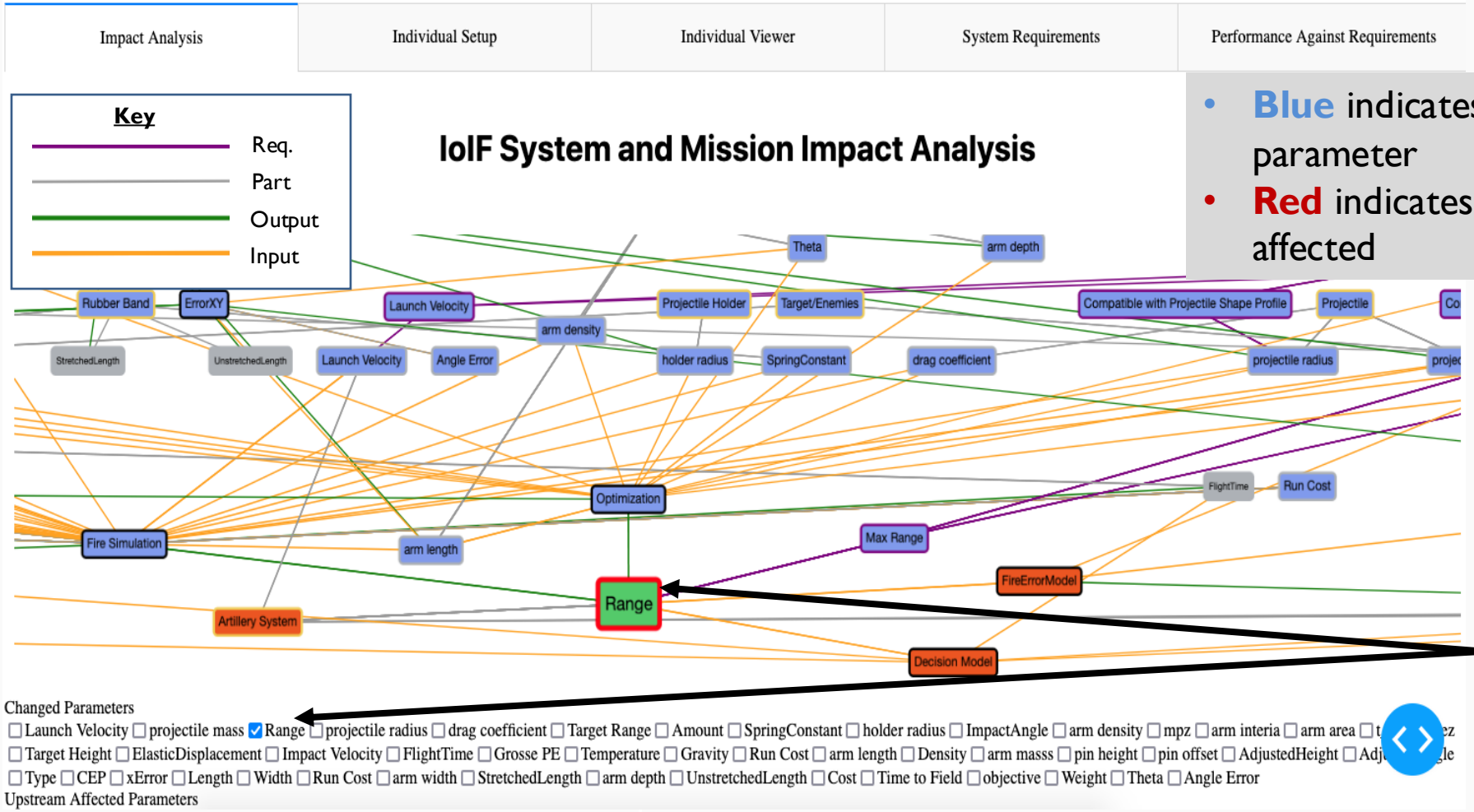
- Reasoning means queries can be written at higher levels of abstraction and still retrieve specific data



  - Anything captured in our digital thread can be accessed for visualization by query, which need not be project specific
- Create visualizations and interactive tools
  - Perspectives on the data, a simplified means to do useful data operations

Digital Thread Impact Analysis Visualization

- Data rendered in dashboard is live data coming from IoIF

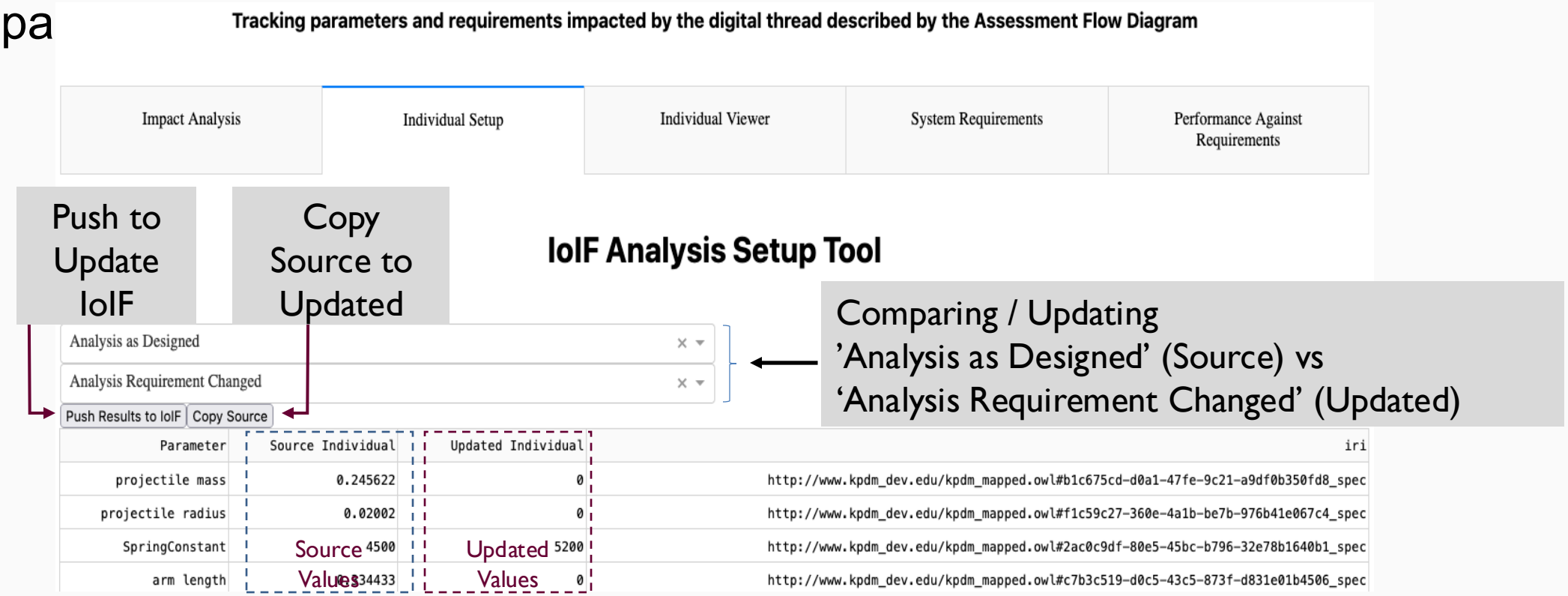


- **Blue** indicates entities upstream of a changed parameter
- **Red** indicates entities downstream that may be affected

Range is modified parameter

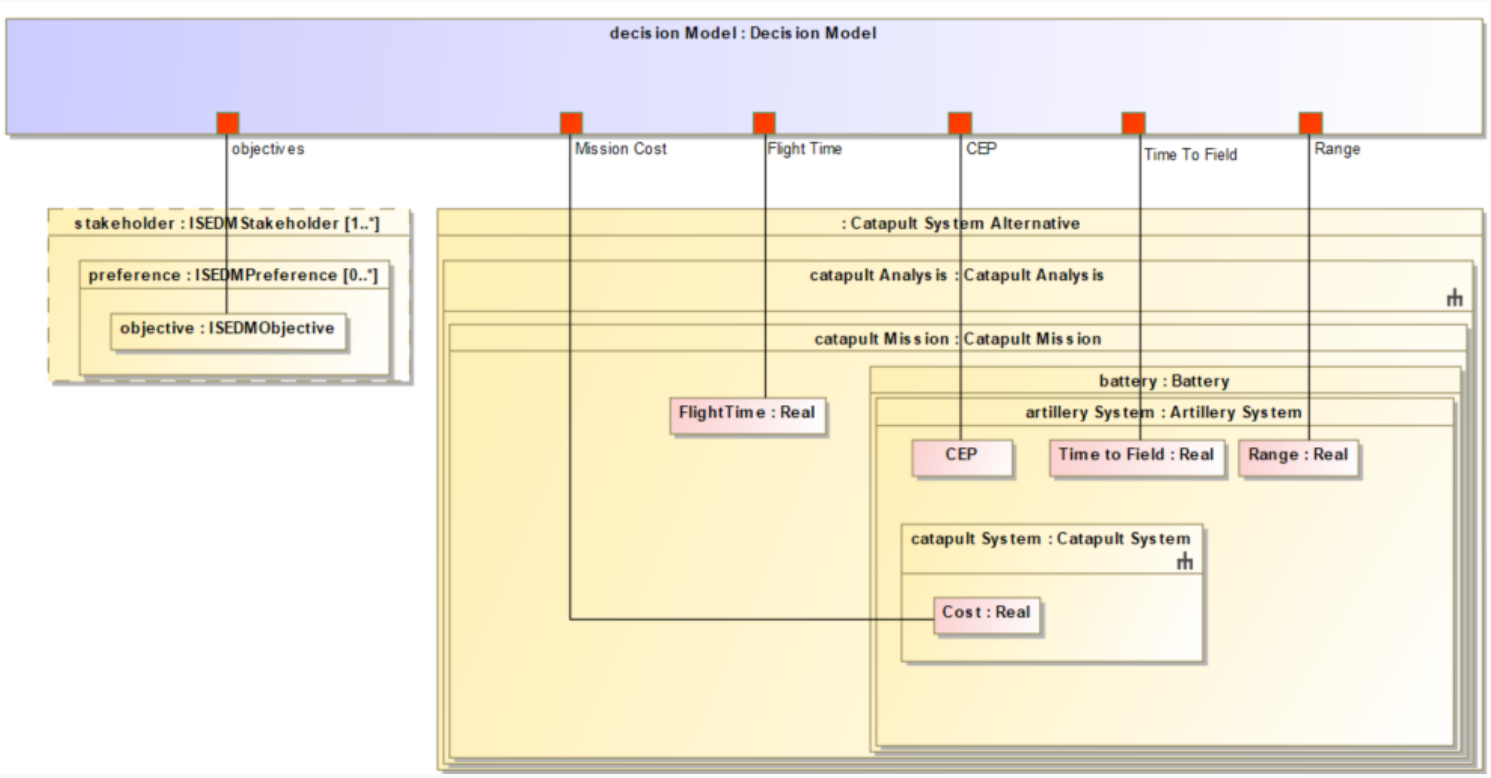
Setup Tab for Dashboard

- Used to setup analyses based on impact analysis
  - Interactive table allows values to be changed in an instance, push button lets those values be pushed to IoIF
  - Internal logic figures out how to populate unchanged variables based on impa



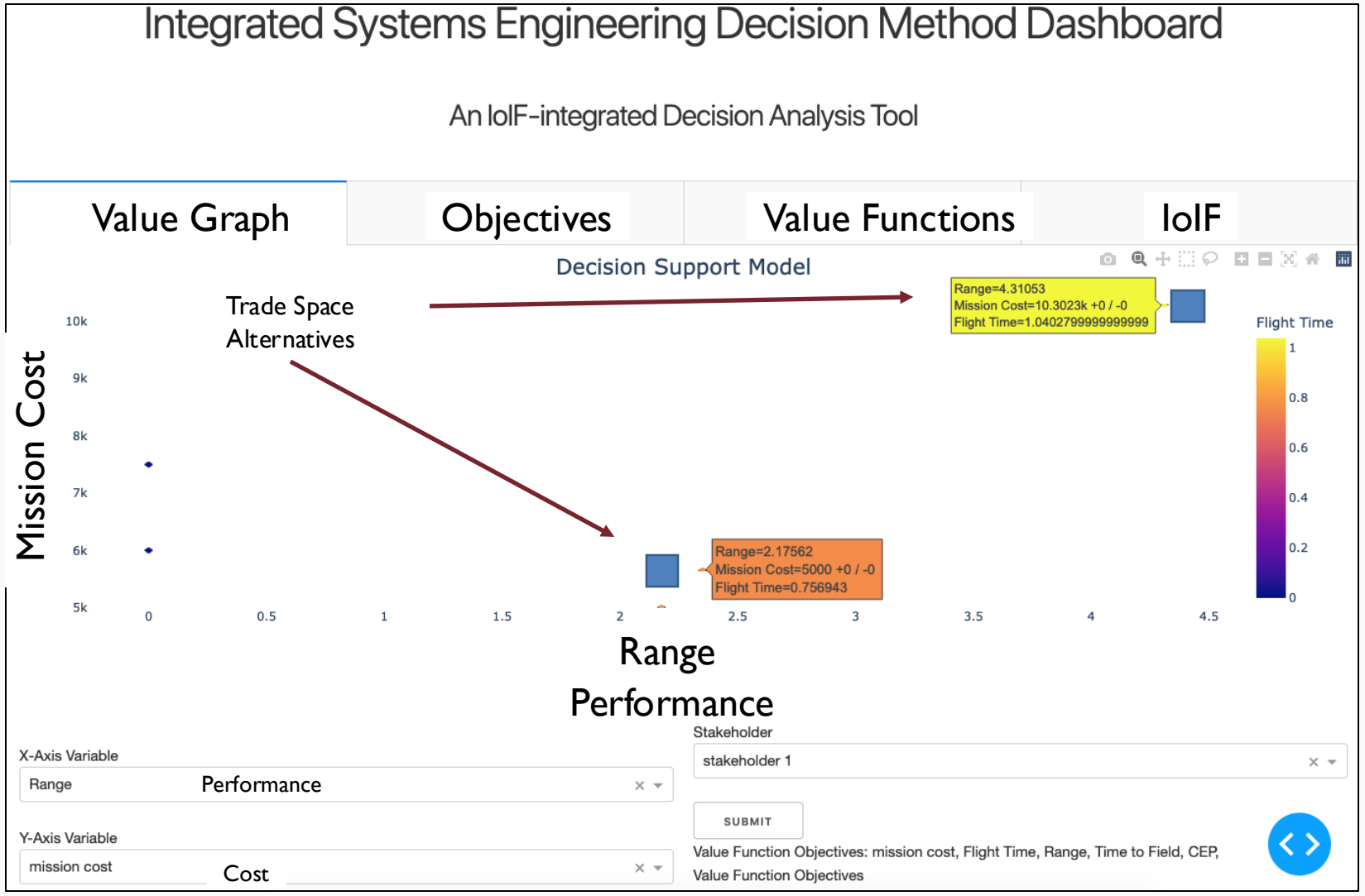
Decision Making

- Create parametric that describes the specific variables that will be passed to the decision tool, variable names, etc.

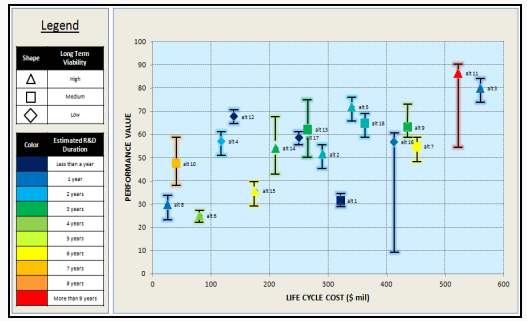


- Instantiating the decision analysis and linking the system instances will allow output of information to run decision tool

IoIF Decision Dashboard Renders using Live Data from IoIF



Dashboard Implementation is Python-based Notional Rendering of Scatter Plot



Conclusions – How Well

- Developed seven (7) case studies with different ontologies using an evolving IoIF Methodology, including two (2) new 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
- Developed and delivered two IoIF training course to transition research
- IoIF Training is part of the Digital Engineering Research Transition workshop

Discussion

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

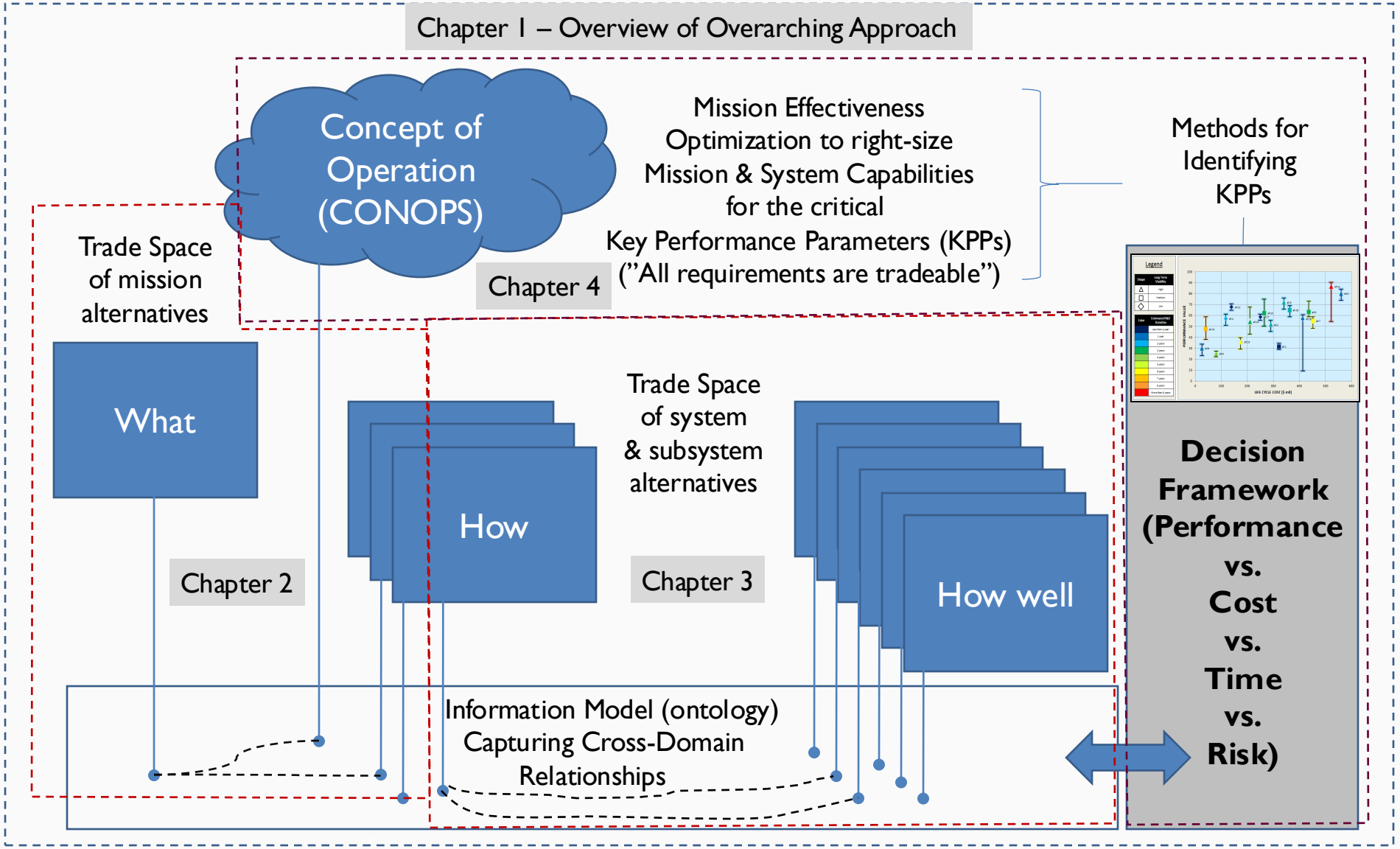
WRT-1025 (2020)
- Mark Blackburn (PI), Stevens
- Mark Austin (Co-PI) – Univ. Maryland
- Maria Coelho (Grad) – Univ. Maryland

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)
- Mark Blackburn (PI), Stevens
- John Dzielski- Stevens
- 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)
- Mark Blackburn (PI), Stevens
- John Dzielski- Stevens
- Tom Hagedorn – Stevens
- 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.

New Book: *Systems Engineering in the Digital Age: Practitioner Perspectives*



Thank you

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