SoSECIE Webinar

Welcome to the
2018 System of Systems Engineering Collaborators Information Exchange (SoSECIE)

We will start at 11AM Eastern Time

Skype Meeting +1 (703) 983-2020, 46013573#

You can download today's presentation from the OUSD(R&E) Website:

https://www.acq.osd.mil/se/outreach/sosecollab.html

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NDIA System of Systems SE Committee

- **Mission**
  - To provide a forum where government, industry, and academia can share lessons learned, promote best practices, address issues, and advocate systems engineering for Systems of Systems (SoS)
  - To identify successful strategies for applying systems engineering principles to systems engineering of SoS
- **Operating Practices**
  - Face to face and virtual SoS Committee meetings are held in conjunction with NDIA SE Division meetings that occur in February, April, June, and August
  - SoS Track at NDIA 21th Annual Systems Engineering Conference, Grand Hyatt Tampa Bay, Tampa, FL, October 22-25, 2018
    - Conference Info: http://www.ndia.org/events/2018/10/22/9870---21st-systems-engineering-conference
    - Call For Papers Extended to July 3, 2018: http://www.ndia.org/events/2018/10/22/9870---21st-systems-engineering-conference/call-for-papers

NDIA SE Division SoS Committee Industry Chairs:
Mr. Rick Poel, Boeing
Ms. Jennie Horne, Raytheon
OSD Liaison:
Dr. Judith Dahmann, MITRE

Simple Rules of Engagement

- **I have muted all participant lines for this introduction and the briefing.**
- **If you need to contact me during the briefing, send me an e-mail at knharrington@mitre.org.**
- **Download the presentation so you can follow along on your own**
- **We will hold all questions until the end:**
  - I will start with questions submitted online via the CHAT window in Skype.
  - I will then take questions via telephone; State your name, organization, and question clearly.
- **If a question requires more discussion, the speaker(s) contact info is in the brief.**

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2018 System of Systems Engineering Collaborators Information Exchange Webinars

Sponsored by OUSD(R&E) and NDIA SE Division

October 30, 2018

Scaling Model-Based System Engineering Practices for System of Systems Applications

Dr. Aleksandra Markina-Khusid and Ms. Janna Kamenetsky, The MITRE Corporation

November 6, 2018

Model Based Systems of Systems Engineering

Mr. Francis McCafferty, Vitech Corporation

November 27, 2018

Emergence as a Subject of Research, Research Methods, and Engineering Knowledge and Practice

Dr. Timothy L.J. Ferris, Centre for Systems Engineering, Cranfield University, Defence Academy of the United Kingdom

Scaling Model-Based System Engineering Practices for System of Systems Applications

October 2017

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Motivation

Most DoD programs operate in a context of a large complex SoS

Want to take advantage of cutting edge MBE techniques, but it is not clear how well MBE scales to address SoS problems

- **Approach:**
  - Assess and improve return on investment (ROI) from MBE for SoS problems
    - Software techniques
    - Analysis methods
- **Key Findings:**
  - **Base model -** Kill-chain architecture that can be used as a template for modeling SoS in MBE environments
  - **Robustness analysis -** Results validated using multiple notional alternative architectures by EIMS
  - **Software Solutions -** Qualitative and quantitative data collection ongoing

Increase benefit by developing analysis techniques to answer crucial SoS-level questions

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Software Methods

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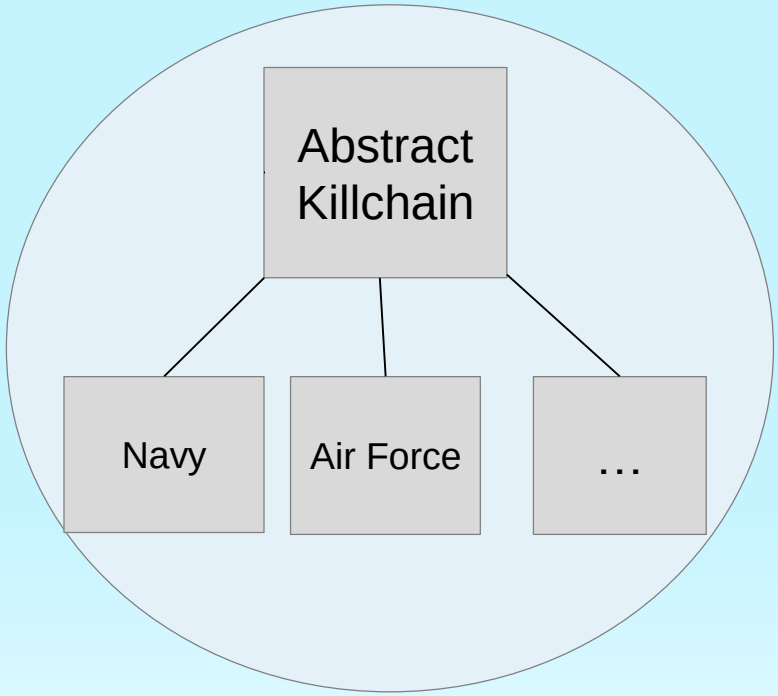
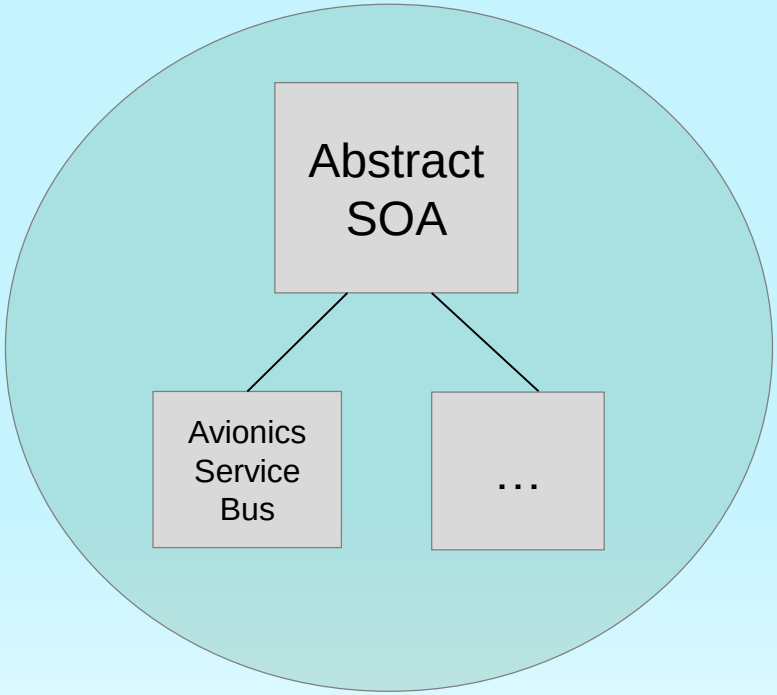
Technical Approach: Inheritable Architectures



Kill Chain Architecture



Service Oriented Architecture (SOA)

Enables Model Re-use corresponding to different architecture patterns

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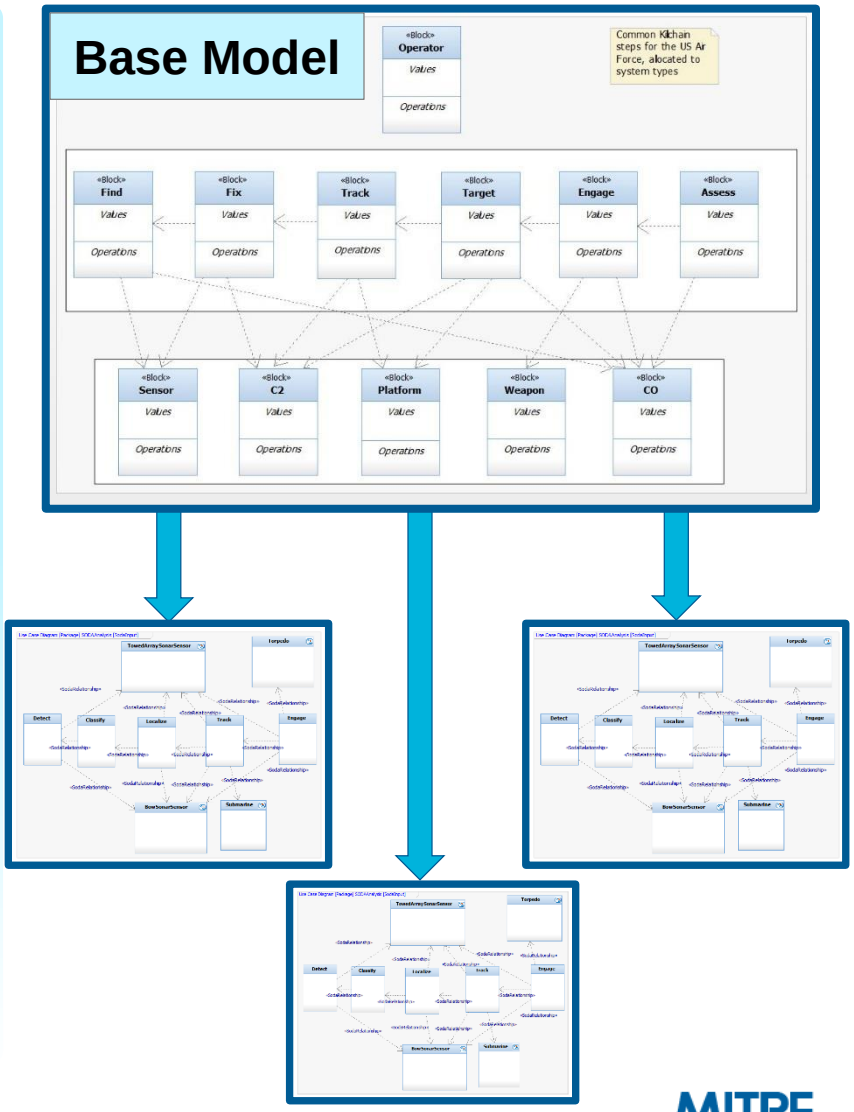
Base Model Architecture

- **Base/Derivative Model Framework**
  - Base Model captures key functional SoS architecture
  - Derivative model represent domain-specific behavior
- **This approach helps:**
  - Accelerate domain model development via Base Model reuse
  - Rapidly evaluate different options utilizing predefined stereotypes and analysis engines
  - Iterative design to continuously refine common SoS functions



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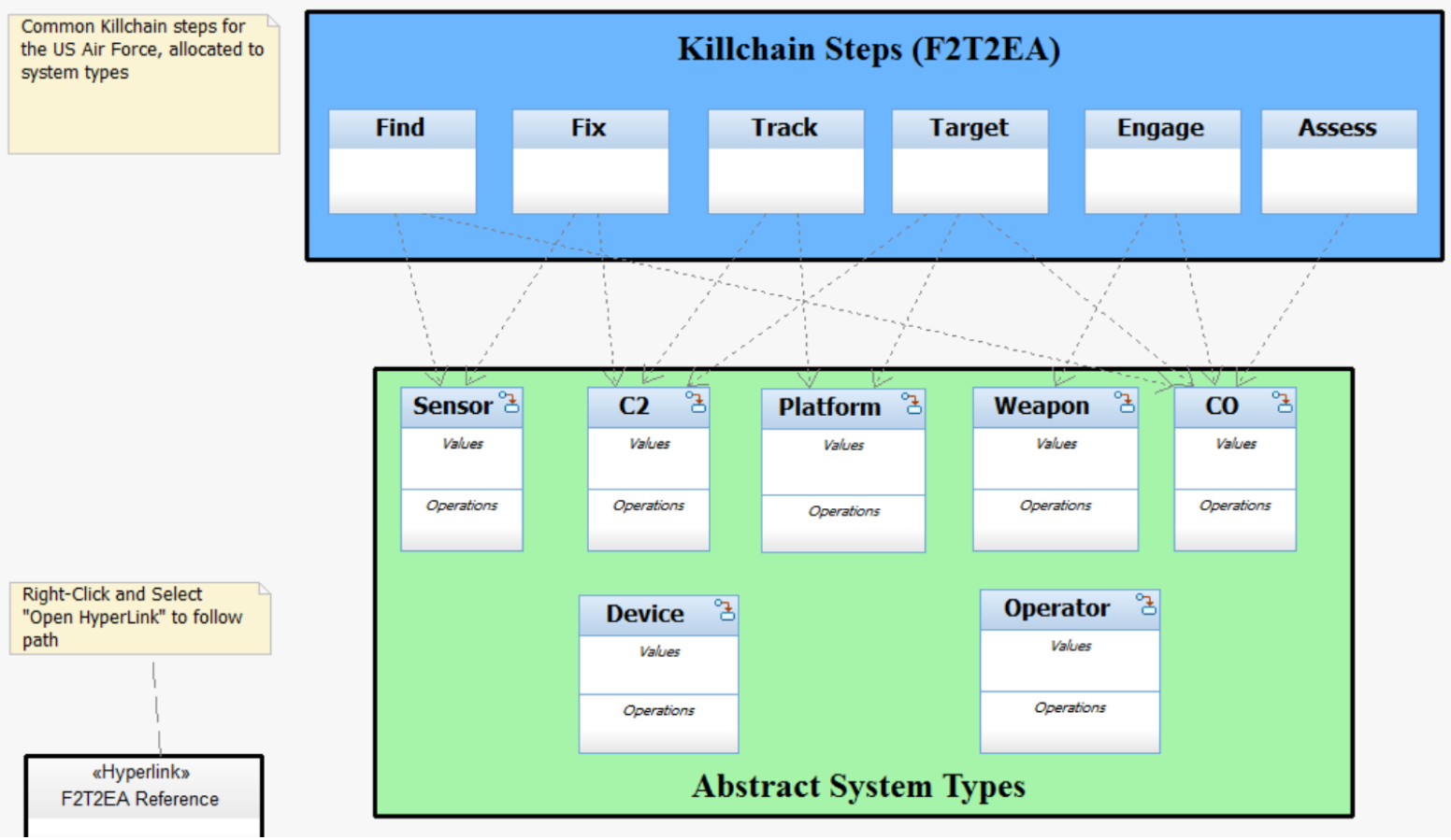
Base Model: High Level Structure



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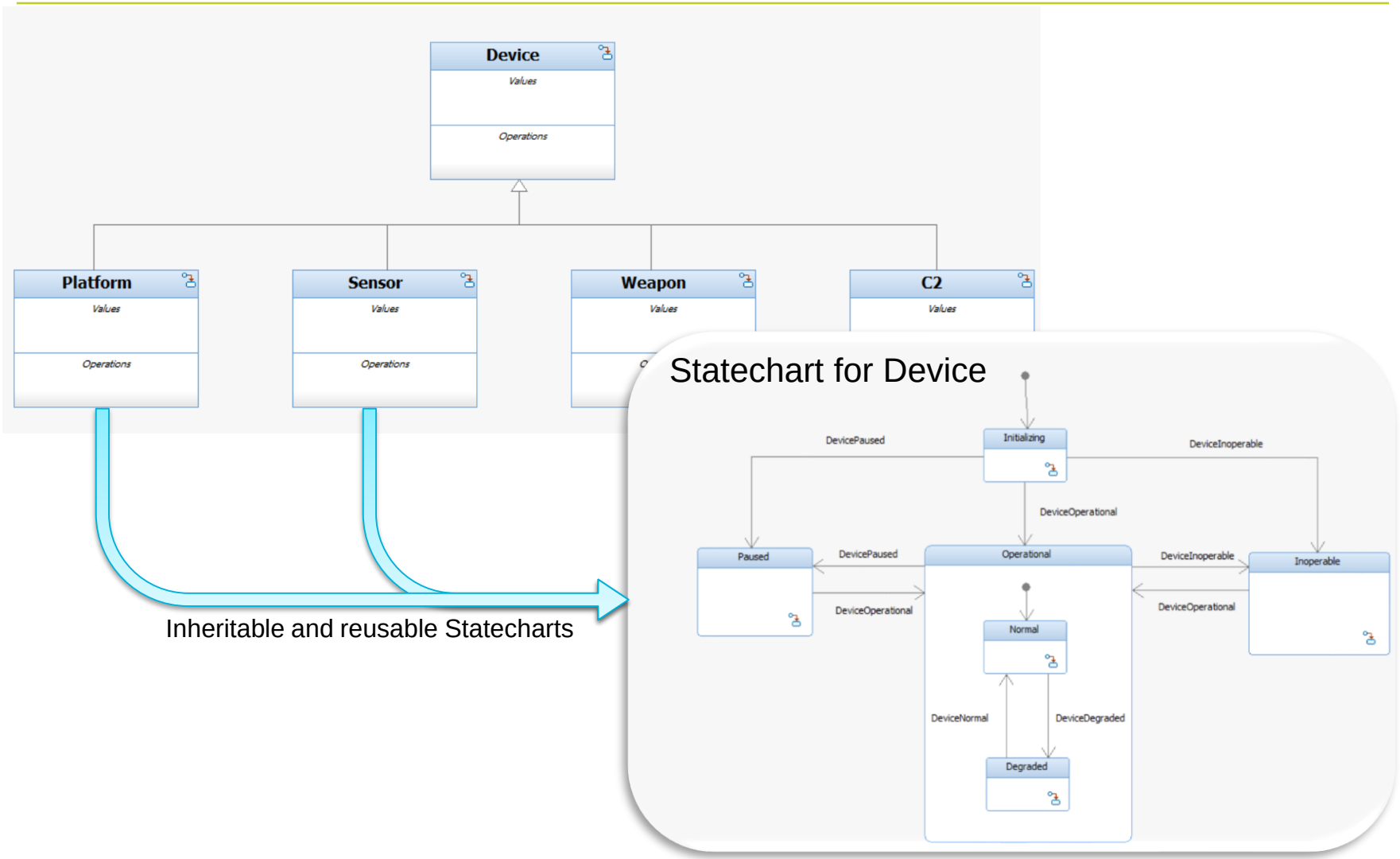
Base Model: Inheritance Structure



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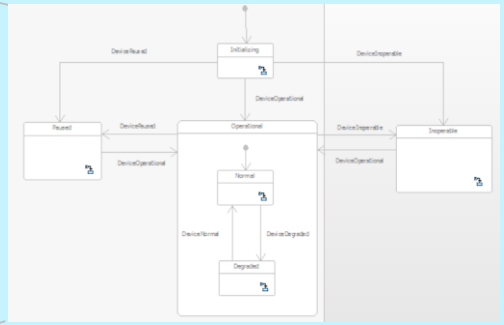
BASE Model: Inheritable Types

BASE

- Operations (i.e. functions)
  - processSignals()
- Attributes (i.e. metrics)
  - MaxRange

Sensor Type



Statechart

DERIVATIVE

(e.g. CDMaST)

- Towed Array Sonar Sensor
- Bow Sonar Sensor
- ISAR

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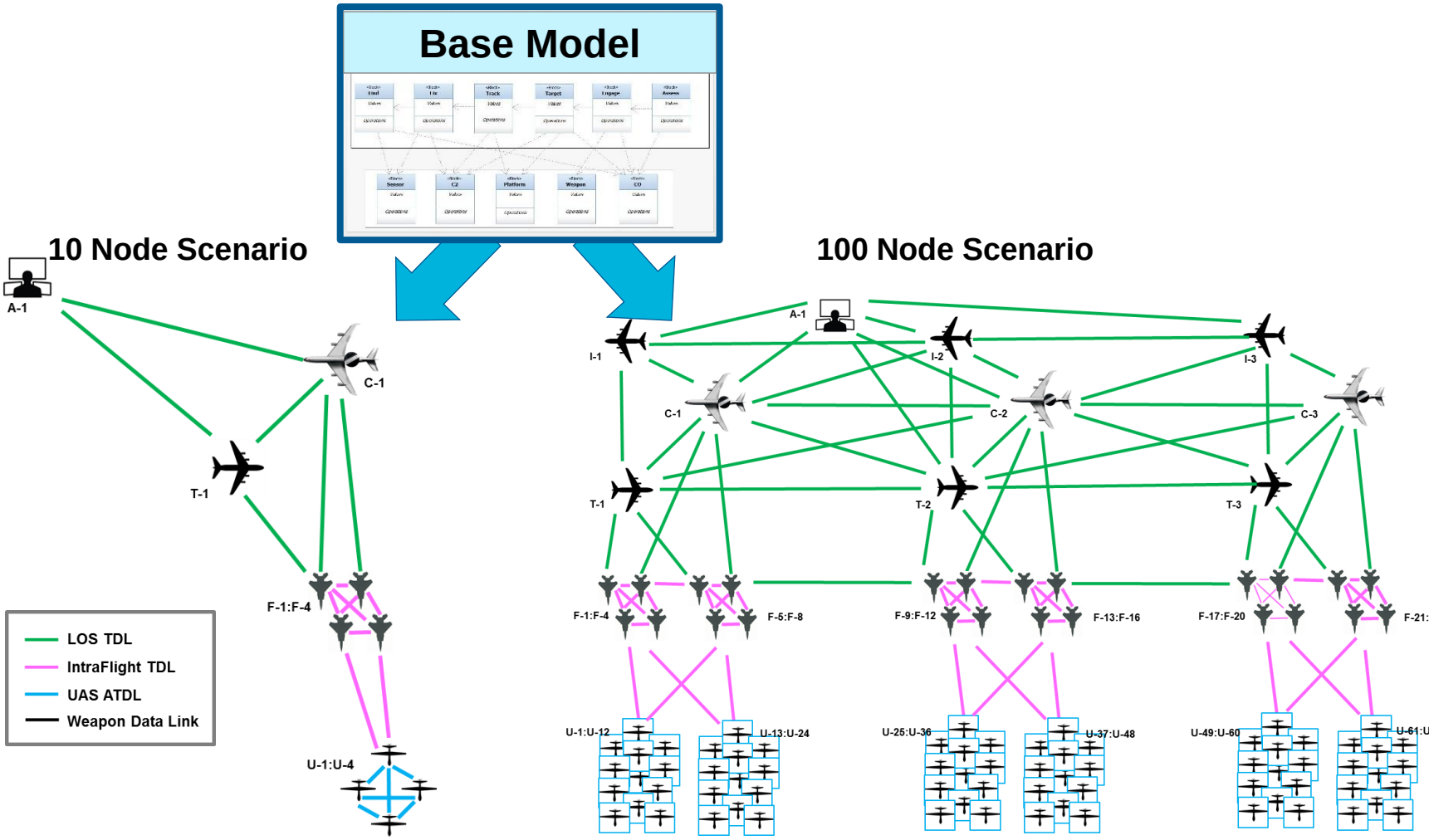
Base Model CSV Importer



MBE Utility to reduce development effort associated with modeling large SoS complex networks

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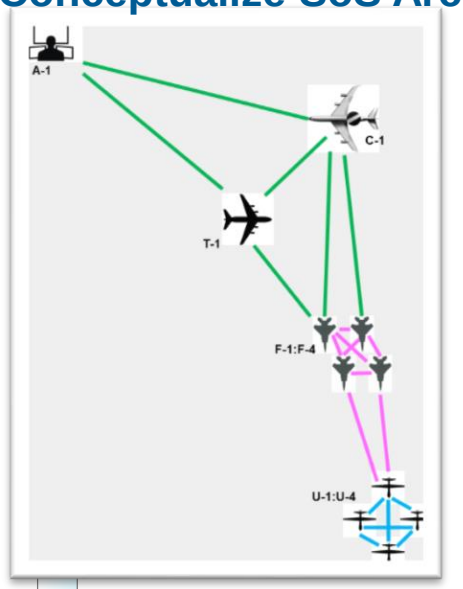
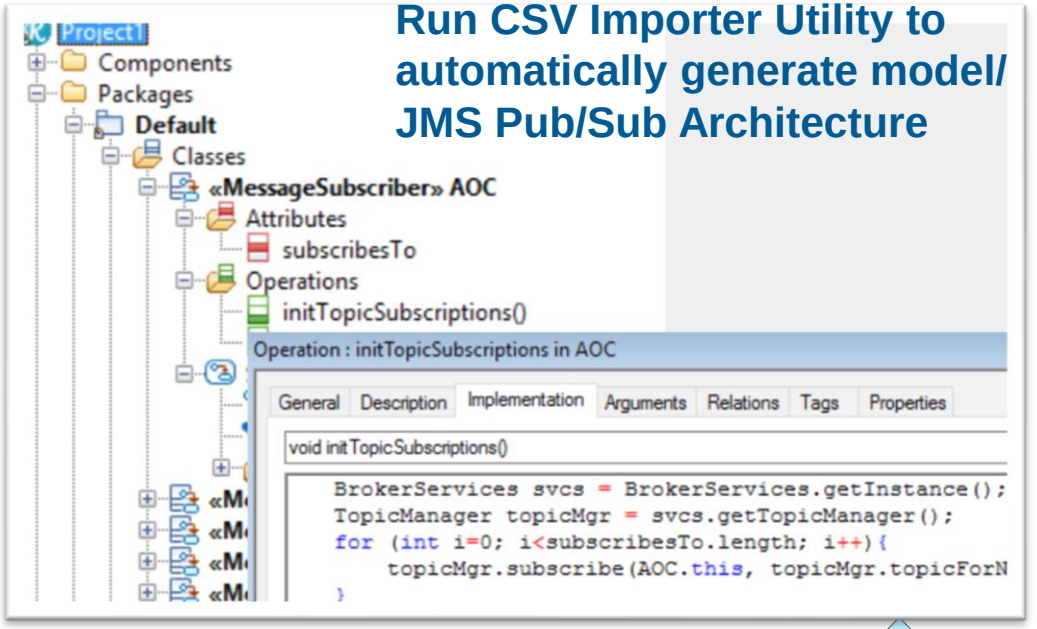
CSV Importer Utility

Conceptualize SoS Architecture



Run CSV Importer Utility to automatically generate model/ JMS Pub/Sub Architecture



Add Connectivity Framework

PUBLISHERS

SUBSCRIBERS	AOC	C2	Tanker	Fighter	UAS
AOC		threats, missionOutcome			
C2	aocDecisions			fightersToC2	
Tanker		beginMission, missionOutcome		lowFuel	lowFuel
Fighter		beginMission		intraFlightTDL	UASsToFighters
UAS				fightersToUASs	uasATDL

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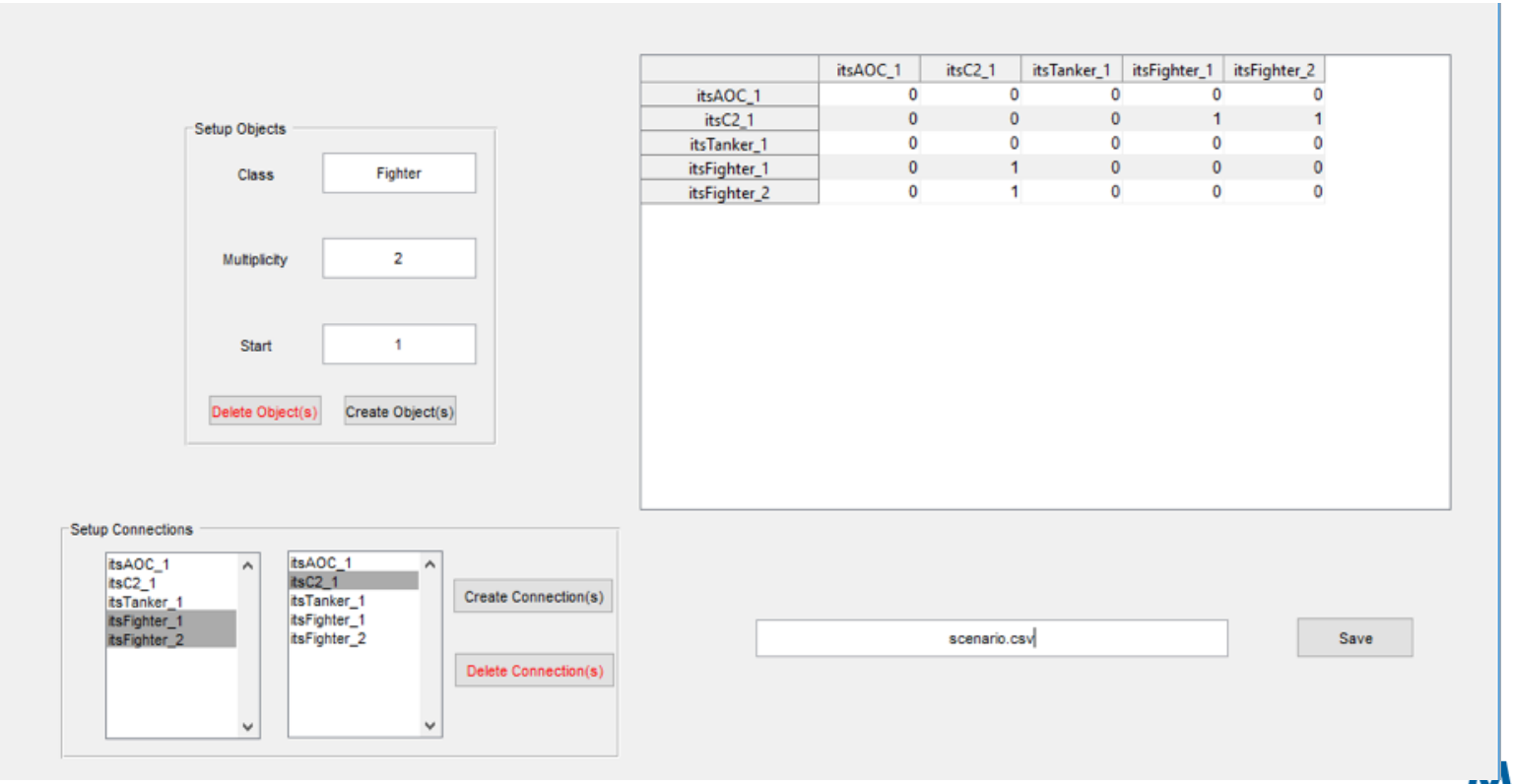
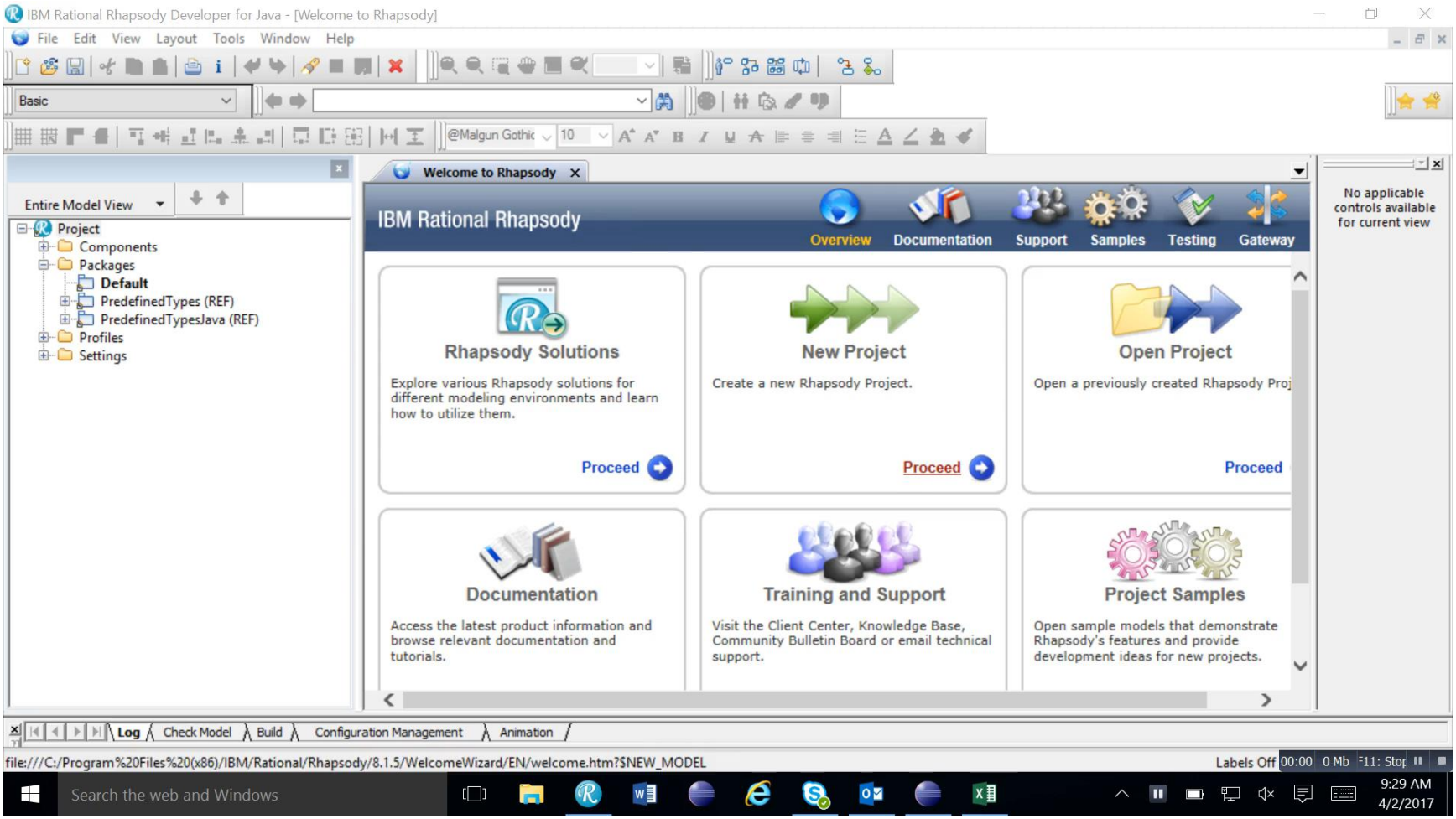
Base Model GUI

- **A MATLAB GUI has been built to simplify the process of populating a connectivity matrix**
- **The tool outputs a CSV file that can then be imported into the architecture model**



	itsAOC_1	itsC2_1	itsTanker_1	itsFighter_1	itsFighter_2
itsAOC_1	0	0	0	0	0
itsC2_1	0	0	0	1	1
itsTanker_1	0	0	0	0	0
itsFighter_1	0	1	0	0	0
itsFighter_2	0	1	0	0	0

Demonstration



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Metrics – Experiments

- **Qualitative**
  - Experiment 1: Give the base model to MITRE employees to use on their projects as they see fit. Collect feedback.
    - Likes, dislikes, pain points, time savings estimates, description of use case, experience level
    - Time Cost: 30 min interview
- **Quantitative**
  - Experiment 2: Give MITRE employees a sample coms network and have them create it by hand and by using the CSV importer
    - Networks of different sizes
    - Measure time to complete exercise
    - Time Cost: Approx. 45 min per data point
  - Experiment 3: Randomized control trial with ~20 new interns
    - Group A: Create reference model from scratch
    - Group B: Create reference model using base model

Metrics – Experiment 1 Results

- **Project 1:**
  - 3 reviewers
  - Not adopted

- **Feedback:**
  - "…This base model would be a great reference, e.g., utilizing the package structure framework used, with the inheritable architectures and the focus on reuse."
  - "…We expect to draw ideas from it as we build our own model."
  - "We intend to focus more on activity diagrams than state charts."
  - "Our project is not in the context of the Air Force, so we would have to change the block and activity names."
  - "Overall it is not a good fit for [our project]."

- **Project 2:**
  - 1 reviewer
  - Adopted

- **Feedback:**
  - Qualitative

    Base Model state charts look too "in-depth", "specific", need to take a closer look to see if they will work for my use case. But if they work, "that would be awesome", it will save tons of time.
  - Pseudo - Quantitative

    Estimated time savings of 40 hours on work completed so far.
  - Update

    Base Model has proven a good fit for project and has been used extensively.

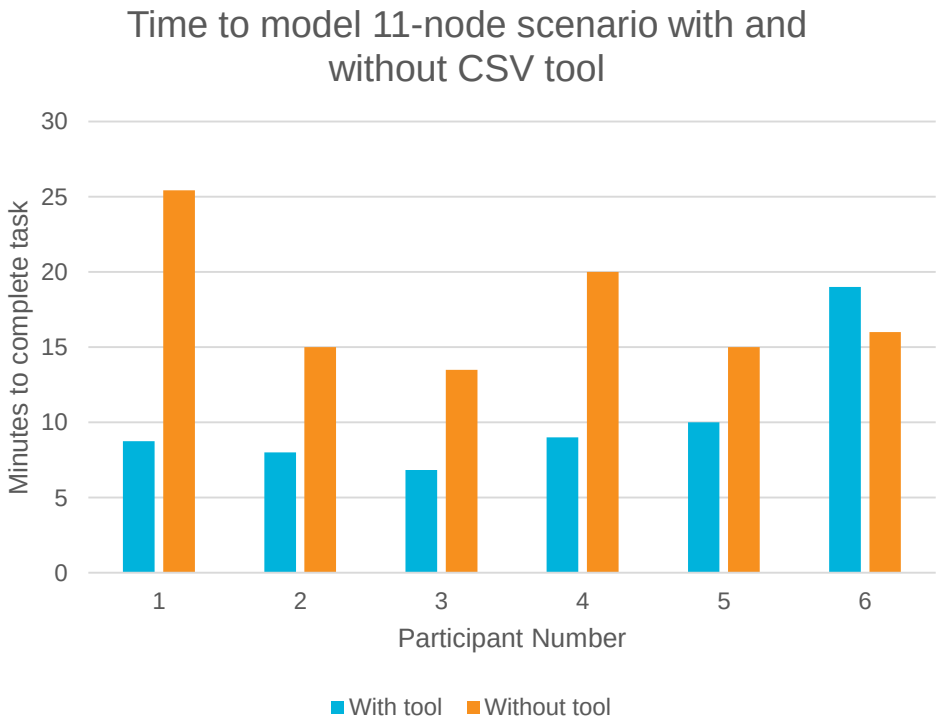
Metrics – Experiment 2 Results

The Scenario

This is a hypothetical Air Force kill-chain scenario consisting of 1 ground control station (AOC), 1 air command and control (C2), 4 Fighter Jets, 4 Unmanned Aircraft Systems (UASs), and 1 Tanker.

- AOC needs to be able to communicate with C2, since C2 alerts AOC when there is a threat and then gets its orders from the ground.
- C2 also needs to be able to communicate with all fighters and the Tanker during the mission.
- Also, all fighters and UASs need to be able to communicate with the Tanker, since they'll occasionally need to refuel during flight.
- Every fighter needs to be able to communicate with every other fighter, and
- every UAS needs to be able to communicate with every other UAS.
- Moreover, every fighter should be able to communicate with every UAS, and vice versa.

You may assume all communication channels are bi-directional (any communication matrix you set up should be symmetric with respect to rows and columns).



Time savings

Mean: 39%

Standard Dev: 12%

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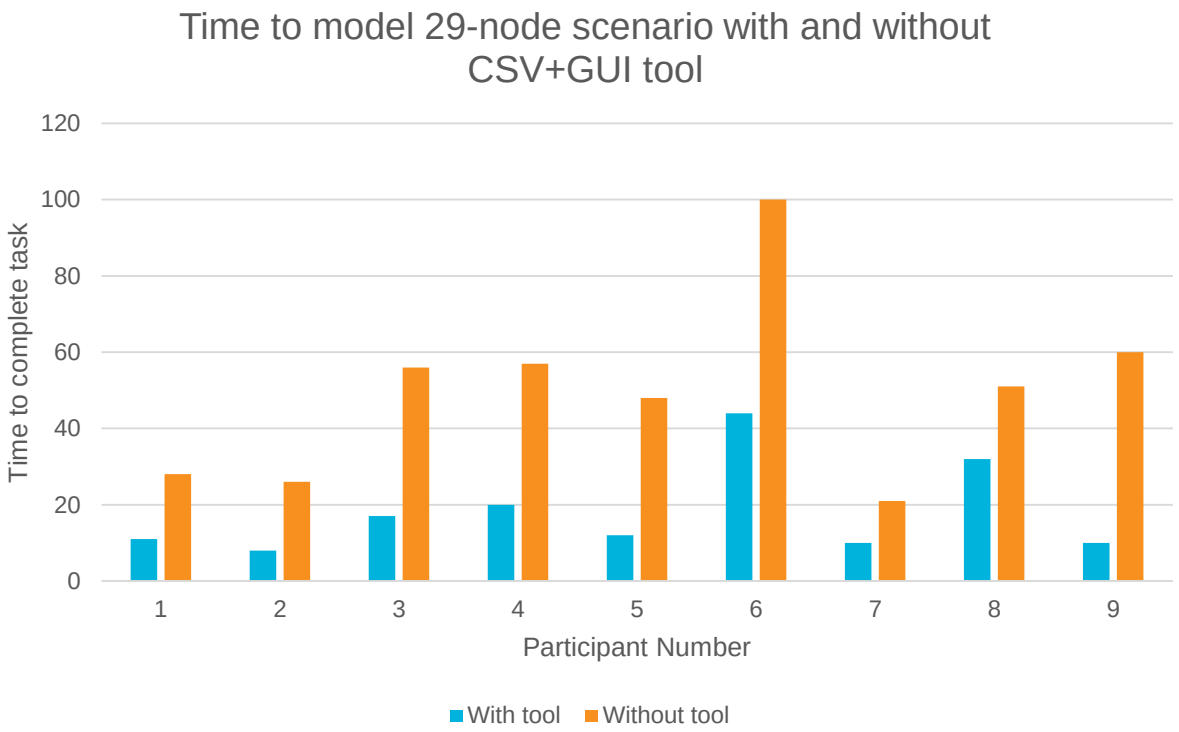
Metrics – Experiment 2 Results



Time savings
Mean: 63%
Standard Dev: 14%

Average mistakes
Without tool: 9.2
With tool: 0.8

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Analytic Methods

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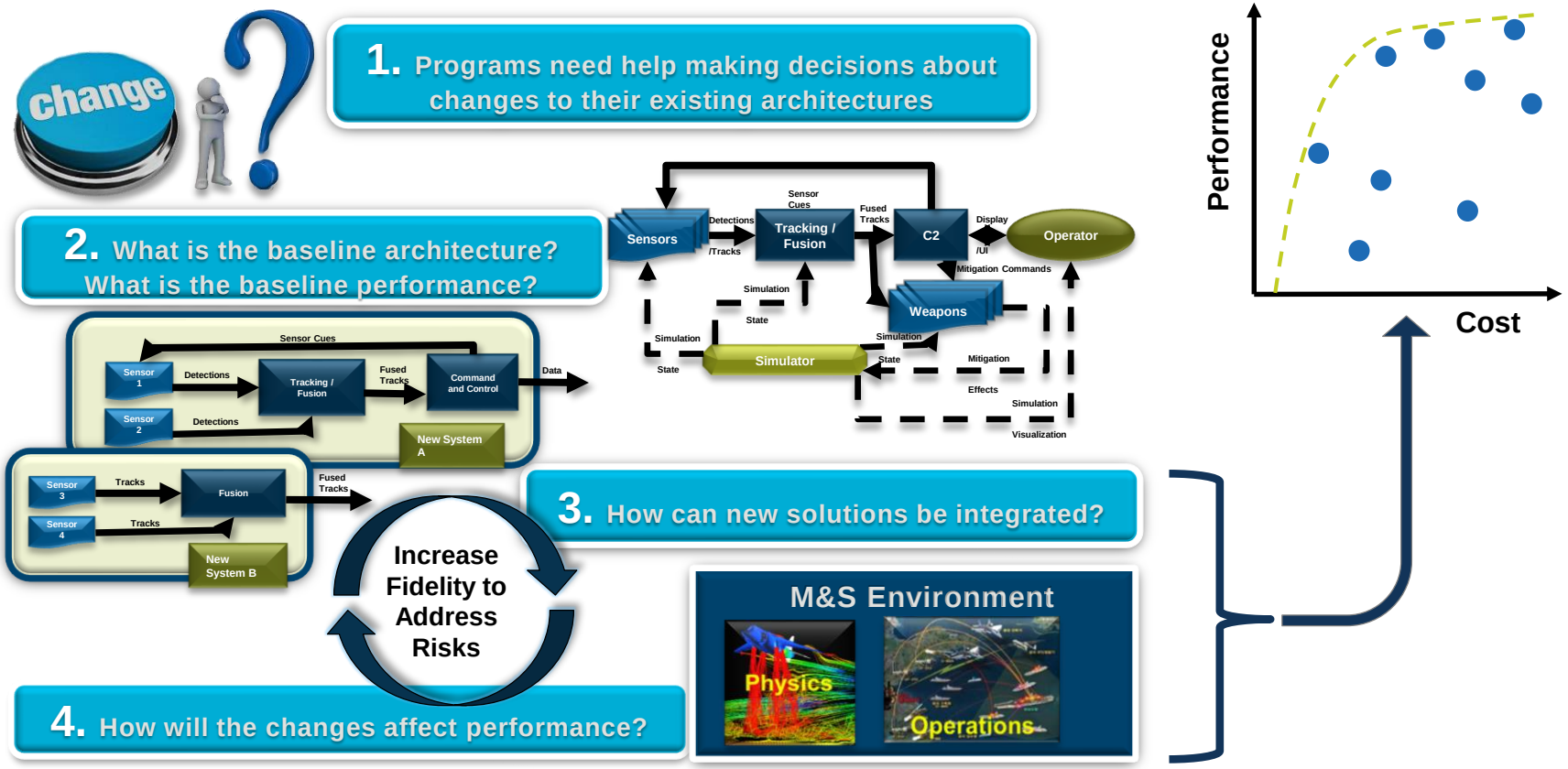
Motivation



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As-is for Evaluating Architectures

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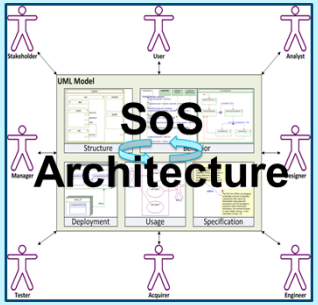
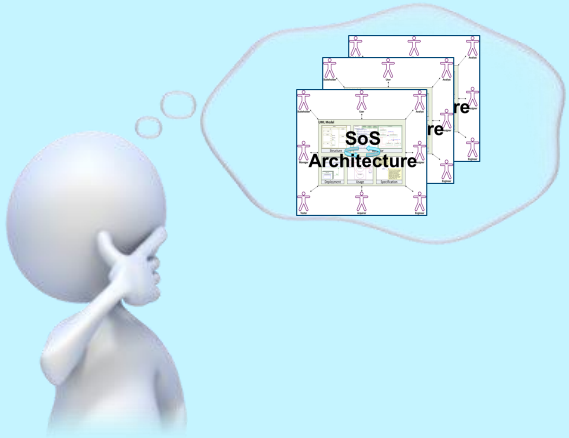
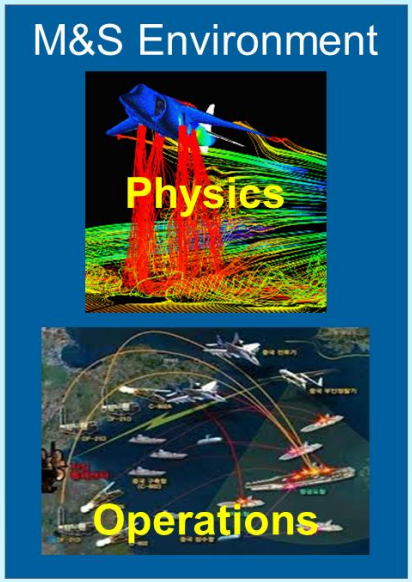
SoS Analysis of Alternatives



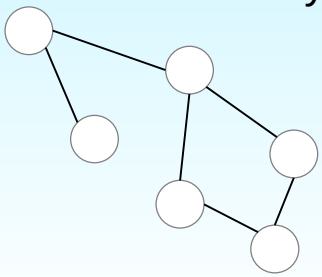




Establish baseline SoS architecture

Generate SoS architecture alternatives

SoS graph abstraction and network analysis



MIP contribution: inform prioritization of alternatives using lightweight analytics

Detailed evaluation with M&S environment

Informed architecture selection

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Robustness Metric (Algebraic Connectivity Value)

- **Represents average difficulty of isolating a node**
  - Second smallest eigenvalue of a Laplacian Matrix
- **Inputs:**
  - Degree Matrix
    - Diagonal matrix that contains the number of nodes adjacent to a given node

$$D_{ij} = \begin{cases} d_i & \text{degree of component } i \text{ when } i = j \\ 0 & \text{otherwise} \end{cases}$$

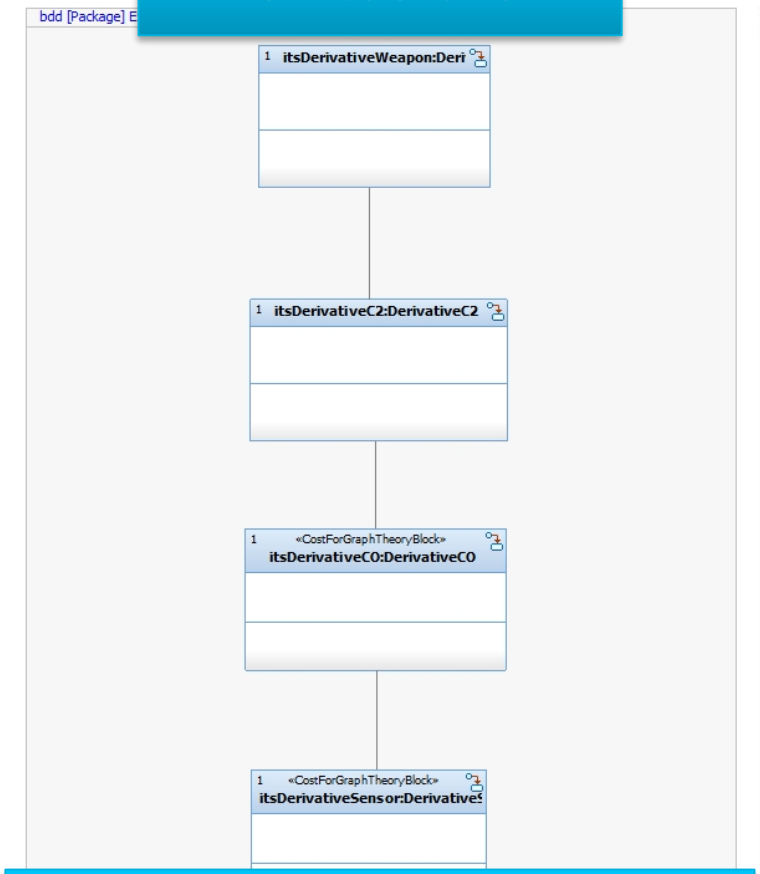
  - Adjacency Matrix
    - Symmetric matrix that contains a 1 if two given nodes are adjacent and 0 otherwise

$$A_{ij} = \begin{cases} 1 & \forall[(i,j)|(i \neq j) \quad \text{and} \quad (i,j) \in \Delta] \\ 0 & \text{otherwise} \end{cases}$$

Reference: H. Mehrpouyan, B. Haley, A. Dong, I. Y. Tumer, and C. Hoyle, "Resiliency analysis for complex engineered system design," *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, vol. 29, no. 01, pp. 93–108, Jan. 2015.

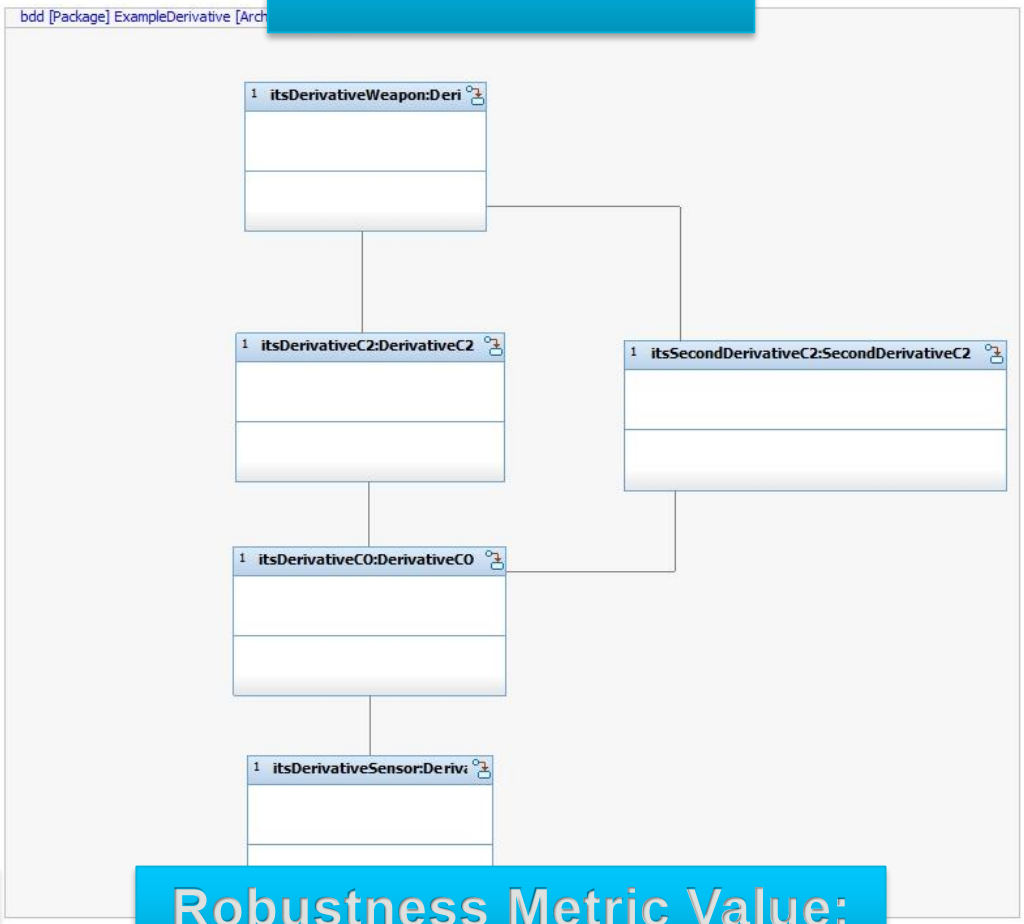
Identifying Robust SoS Architectures

Architecture 1



Robustness Metric Value: 0.5858

Architecture 2



Robustness Metric Value: 0.8299

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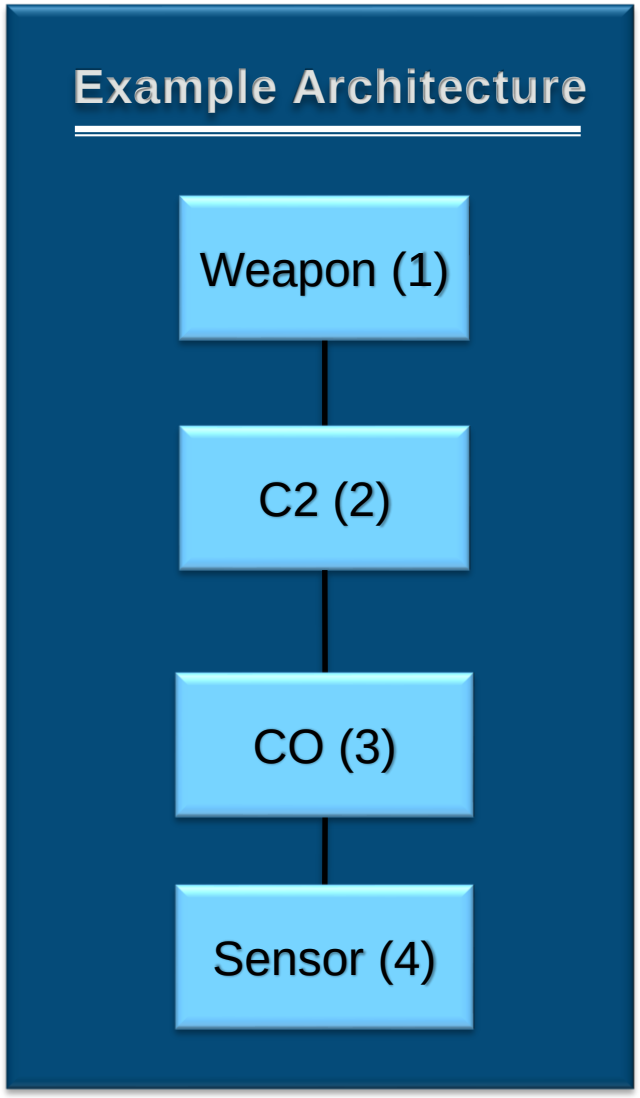
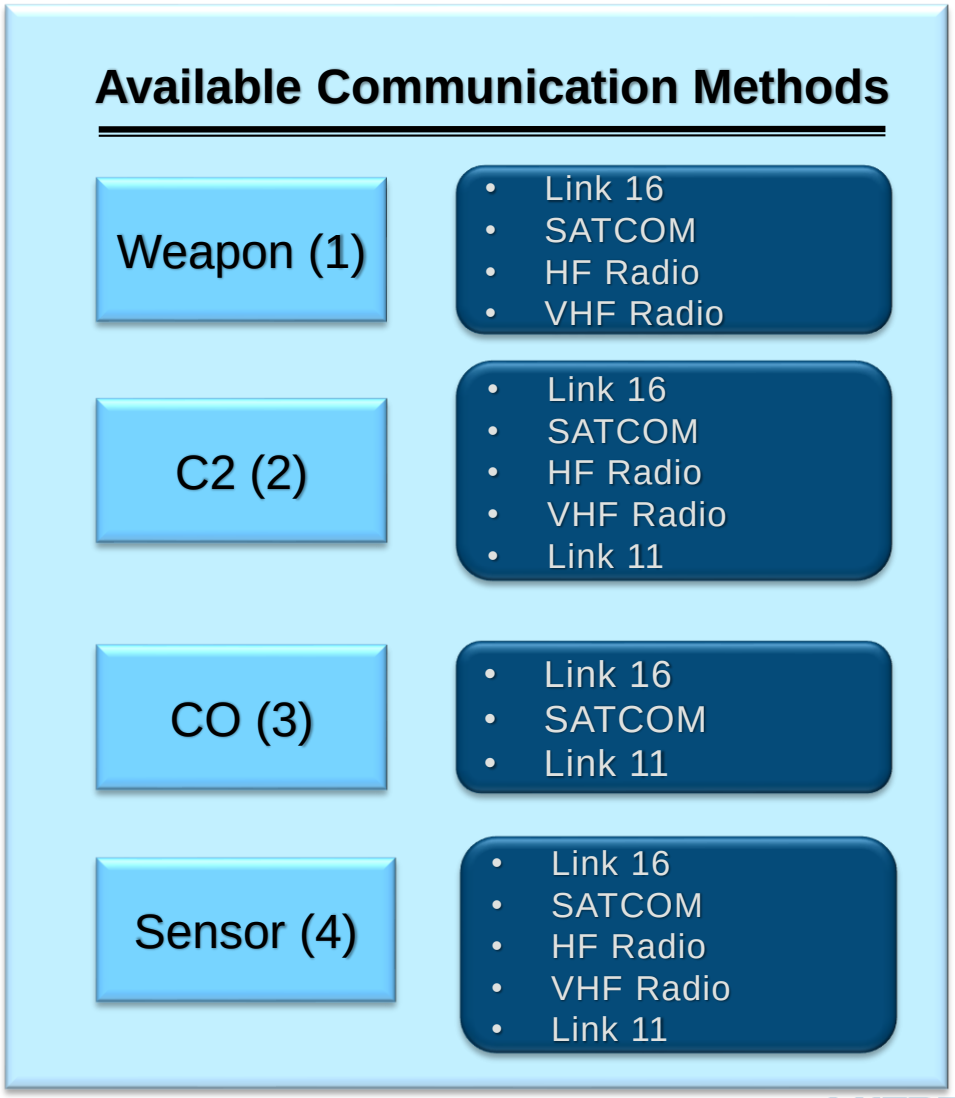
Multi-layer Architecture Analysis

Example Architecture





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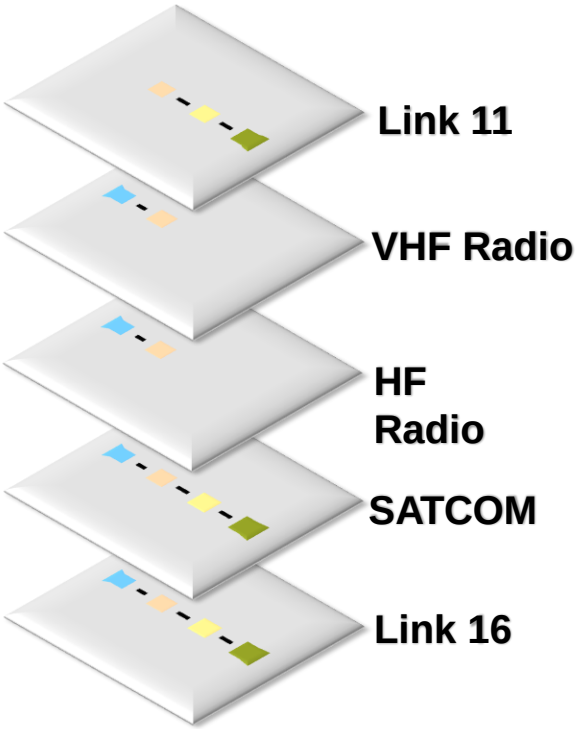
Mapping Architecture to Multilayer Graph – Intralayer Graph Representation



Available Communication Methods

Weapon (1)	• Link 16 • SATCOM • HF Radio • VHF Radio
C2 (2)	• Link 16 • SATCOM • HF Radio • VHF Radio • Link 11
CO (3)	• Link 16 • SATCOM • Link 11
Sensor (4)	• Link 16 • SATCOM • HF Radio • VHF Radio • Link 11

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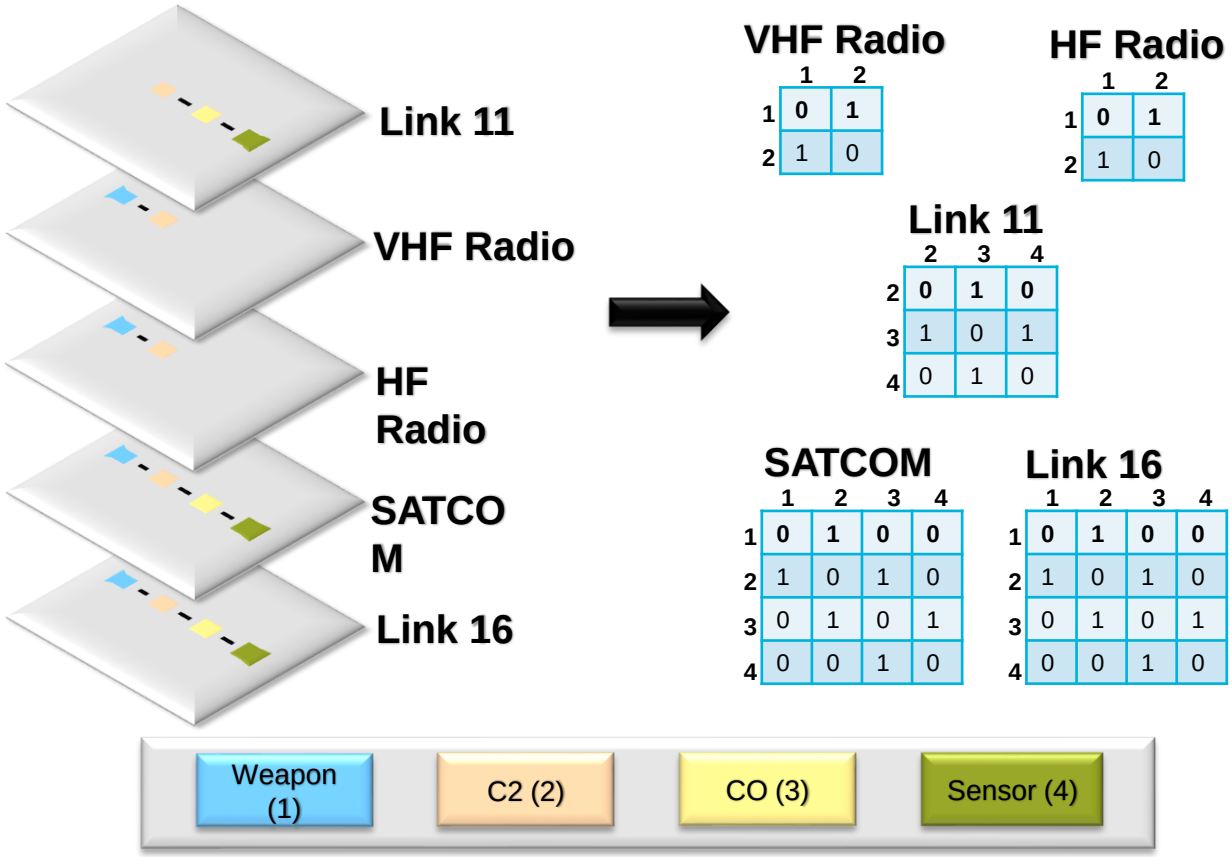
Mapping Architecture to Multilayer Graph – Intralayer Adjacency Representation



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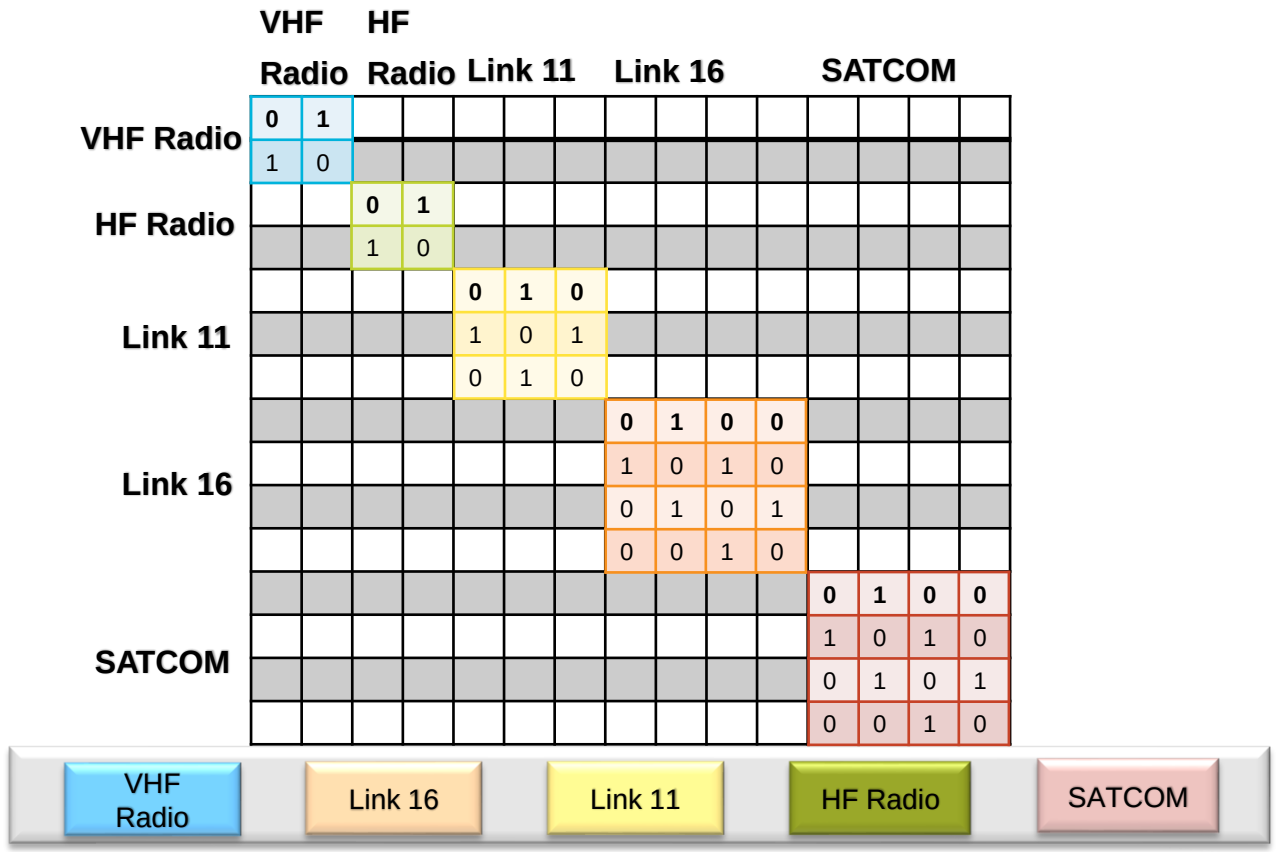
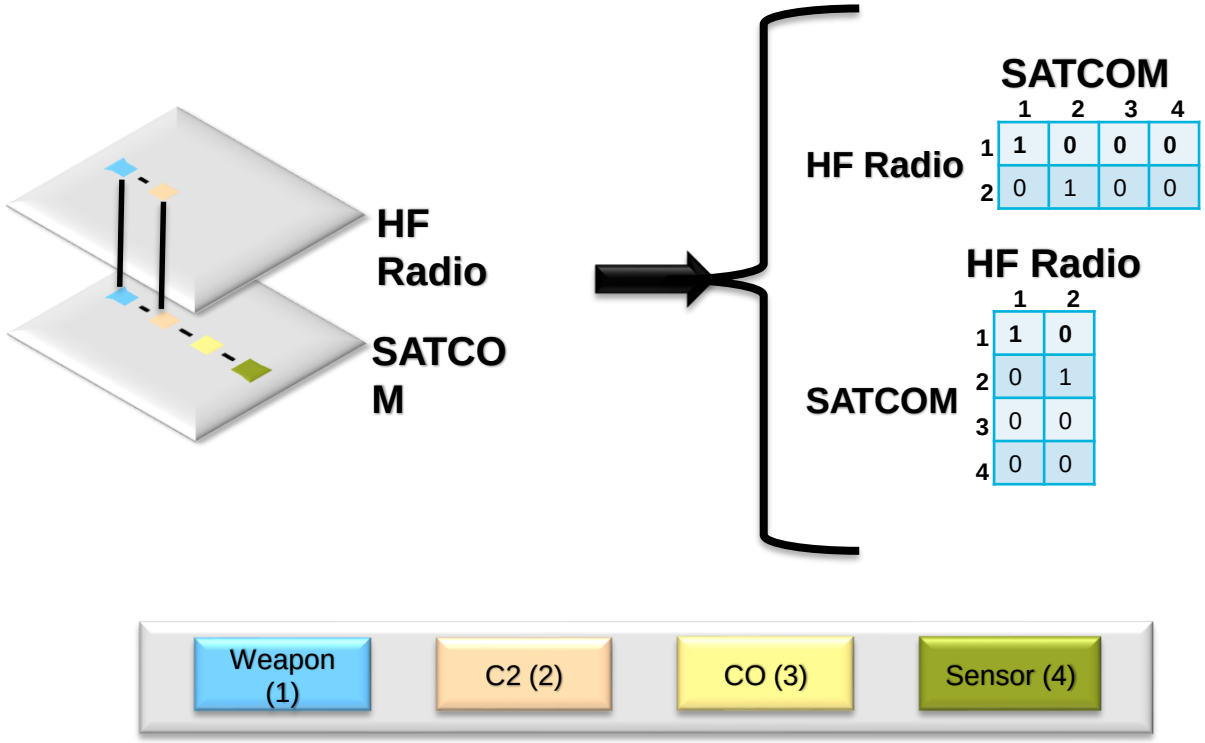
Mapping Architecture to Multilayer Graph – Intralayer Adjacency Representation

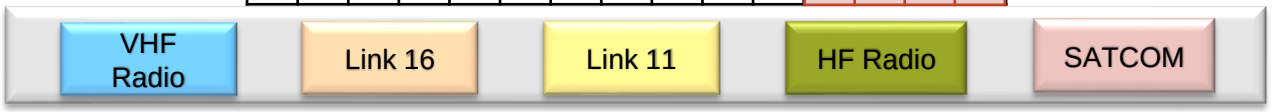


Mapping Architecture to Multilayer Graph – Interlayer Matrix Representation



Mapping Architecture to Multilayer Graph – Adding Interlayer to Intralayer in Matrix

	VHF Radio		HF Radio		Link 11			Link 16				SATCOM			
VHF Radio	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**
	1	0	0	1	0	0	0	0	1	0	0	0	1	0	0
HF Radio	1	0	**0**	**1**	0	0	0	1	0	0	0	1	0	0	0
	0	1	1	0	0	0	0	0	1	0	0	0	1	0	0
	0	0	0	0	**0**	**1**	**0**	0	1	0	0	0	1	0	0
Link 11	0	0	0	0	1	0	1	0	0	1	0	0	0	1	0
	0	0	0	0	0	1	0	0	0	0	1	0	0	0	1
	1	0	1	0	0	0	0	**0**	**1**	**0**	**0**	1	0	0	0
	0	1	0	1	1	0	0	1	0	1	0	0	1	0	0
Link 16	0	0	0	0	0	1	0	0	1	0	1	0	0	1	0
	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1
	1	0	1	0	0	0	0	1	0	0	0	**0**	**1**	**0**	**0**
	0	1	0	1	1	0	0	0	1	0	0	1	0	1	0
SATCOM	0	0	0	0	0	1	0	0	0	1	0	0	1	0	1
	0	0	0	0	0	0	1	0	0	0	1	0	0	1	0



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Summary

- **Results**
  - Developed a scalable rapid analysis capability for MBSE software tools
  - Identified a proxy for resilience that can be measured using lightweight analysis techniques
  - Tested the analysis method on notional architectures and compared the results with a low fidelity operational modeling and simulation tool
- **Lessons Learned**
  - Detailed analysis will have to accompany the graph theoretic analysis to account for operationally critical architectural components
  - Based on the domain the optimal graph theoretic value may vary

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