INTEGRATED MODELING AND SIMULATION TO SUPPORT THE DIGITAL MISSION ENGINEERING ENVIRONMENT

2021 PHOENIX INTEGRATION WEBINAR SERIES

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CONTENTS

THE DIGITAL ENGINEERING ECOSYSTEM

- Definition:
  - “A digital engineering ecosystem includes enterprises' interconnected digital environments, stakeholder-networks, and semantic data that allows the exchange of digital artifacts from an authoritative source of truth to serve the stakeholder communities' interests”*
- Description
  - Collaborative system of systems that uses digital environments to enable pre-agreed rules for transacting the exchange of digital artifacts from authoritative sources of truth within a stakeholder-network
  - Collaborative system that enforces the protection of intellectual property, cybersecurity, and security classification of participants’ digital artifacts
  - Enables an agile, rapid, and flexible development cycle to field complex systems and Systems of Systems (SoS)
  - Encompasses the entire Product Lifecycle
  - Allows multi-disciplinary stakeholders to operate on interconnected and domain-specific data

*Source: www.omgwiki.org

DIGITAL ENGINEERING ECOSYSTEM COMPONENTS

- **The Value Exchange - Promote Innovation**
  - The interchange of digital artifacts provide data for alternative views to visualize, communicate, and deliver data, information, and knowledge to stakeholders
  - The digital environment serves as the means to exchange digital artifacts and ensures the authoritative sources of truth
- **Digital Environment – Collaboration and Integration**
  - Integrated data sharing environments – database systems and Data Lakes, Portals, etc.
  - Integrated Modeling and Simulation (M&S) environments – Parsons Digital Engineering Framework (PDEF)
  - Integrated development environments – Software development, analytics, trade studies
  - Immersive collaboration environments – SharePoint, JIRA, Confluence
- **Stakeholder-Network – Data Sharing in a Protected Environment**
  - Entities that have an interest in exchanging digital artifacts related to specific project, program, technical platform, knowledge domain, or industry in order to manage the development

DIGITAL ENGINEERING ECOSYSTEM COMPONENTS

- Rule-Based Transactions
  - A rules-based technology that defines, initializes, constrains, and instructs the transactions and interchanges of digital artifacts between all of the stakeholders
  - It may use fixed rules established by the system developer, interactions with decision makers, dynamic analytics leveraging Artificial Intelligence (AI), Machine Learning, Data Science, and High Performance Computing (HPC) or combinations of these rules
- Model-Based Engineering (MBE) Methods
  - Includes any type of engineering digital artifacts used to conceive, design, develop, and build an engineered system or product
  - Model Based Systems Engineering (MBSE), Digital Mission Engineering (DME), Model Based Design, Digital Twining, Agile Development
- Digital thread
  - Bridges the gap by creating a closed loop between digital and physical worlds to optimize products, people, processes, and places
  - Includes the process of Requirements Trace to ensure the artifacts map to Key Performance Parameters and Key System Attributes contained in the authoritative Requirements Repository

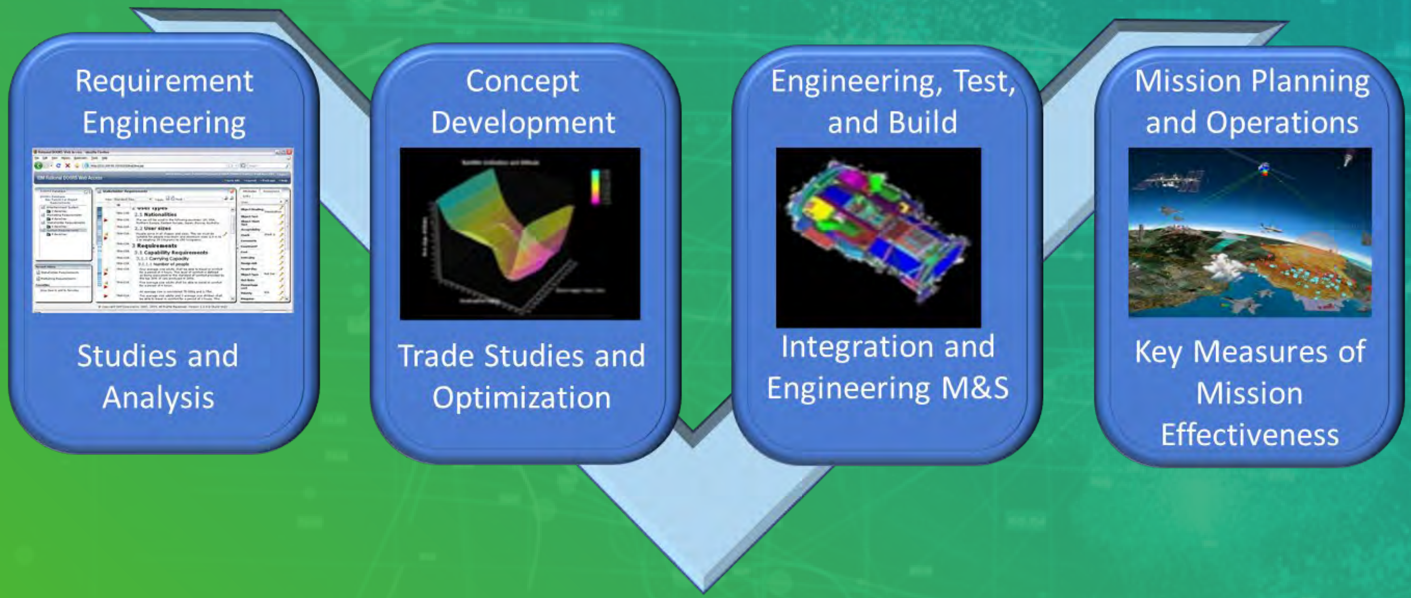
The Department of Defense (DoD) is shifting to digital engineering and needs authoritative sources of digital artifacts for systems. These digital artifacts must span both a network of disciplines and the continuum across lifecycle activities from concept through disposal.

Office of the Deputy Assistant Secretary of Defense (Systems Engineering) [ODASD (SE),, “Digital Engineering,,” Defense Acquisition University (DAU), 2017

PARSONS

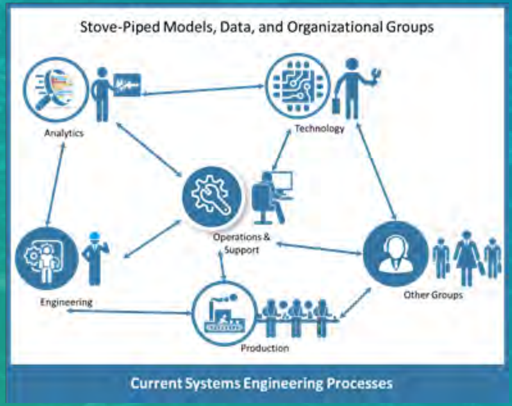
MODEL BASED SYSTEMS ENGINEERING

- An Extension of Digital Engineering that utilizes computer-based modeling simulation and analytical tools to evaluate mission objectives and outcomes during design, test planning, and execution.
- Connects Requirements to digital representations of components, systems, and system of systems to the mission objectives
- Provides and environment for collaboration and configuration management of all engineering, simulation, and test data



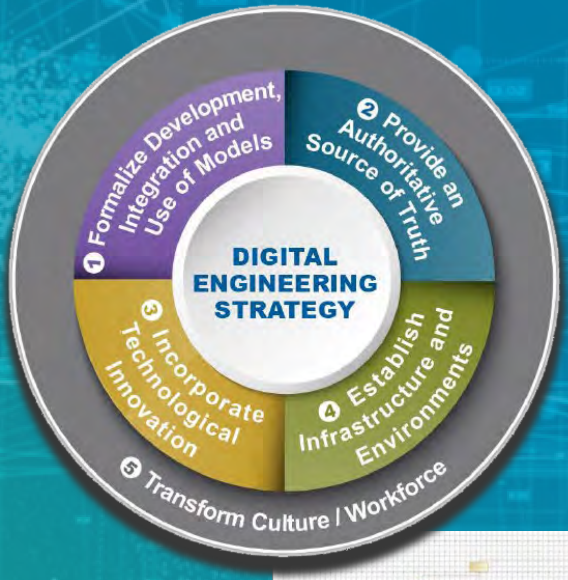
MBSE Digital Engineering Environment

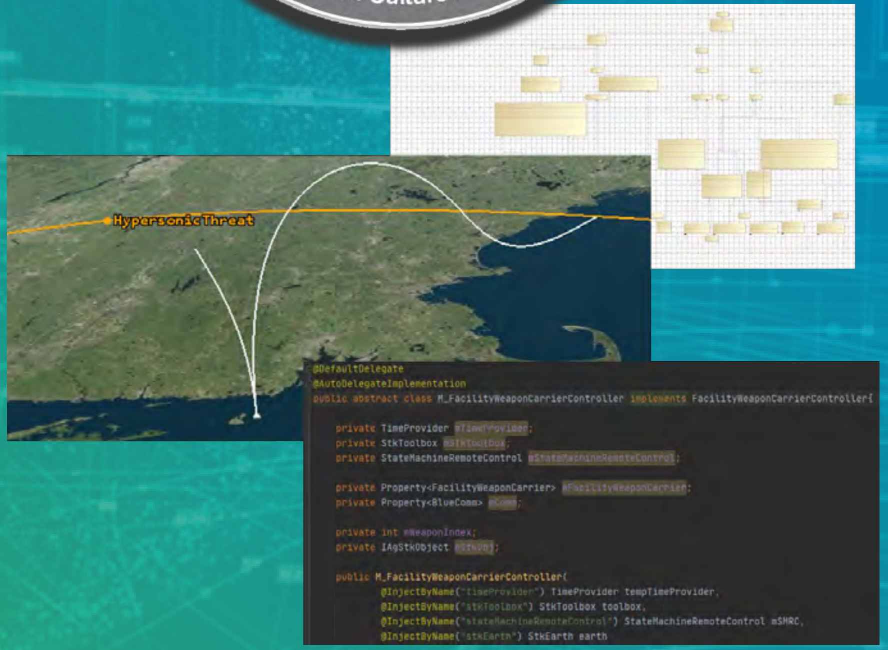
Current Systems Engineering Practice



DIGITAL MISSION ENGINEERING

- An Extension of MBSE that utilizes computer-based modeling simulation and analytical tools to evaluate mission objectives and outcomes during design, test planning, and execution
    - The end-to-end mission is the system
    - Individual systems are components of the larger mission system
    - Systems engineering is applied to the SoS supporting operational mission outcomes
    - Mission engineering addresses cross cutting functions, end-to-end control and trades across systems
    - Technical trades exist at multiple levels across the SoS
    - Model Based Systems Engineering (MBSE) architectures promote resilience, adaptability, and rapid insertion of new technologies

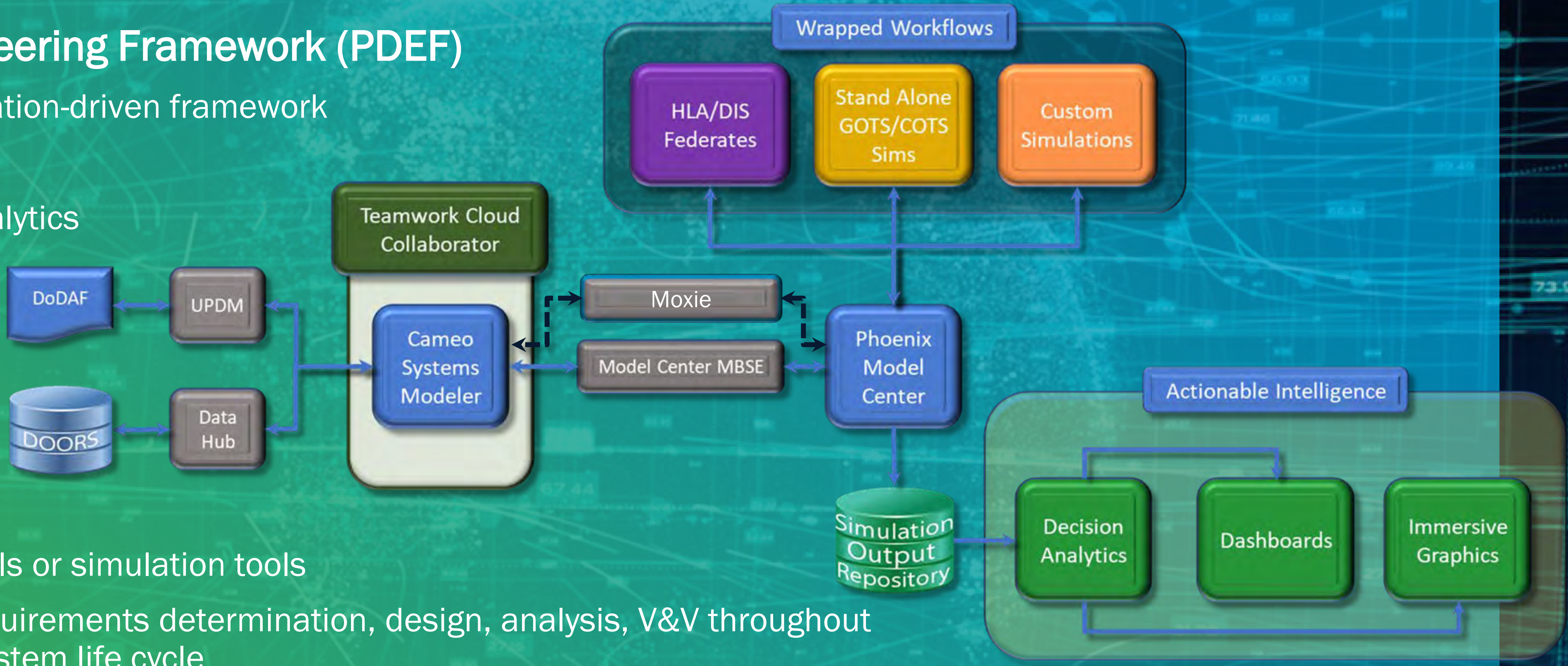




INTEGRATED MODELING AND SIMULATION

Parsons Digital Engineering Framework (PDEF)

- Model-based, simulation-driven framework
- Supports MBSE
- Complex System Analytics

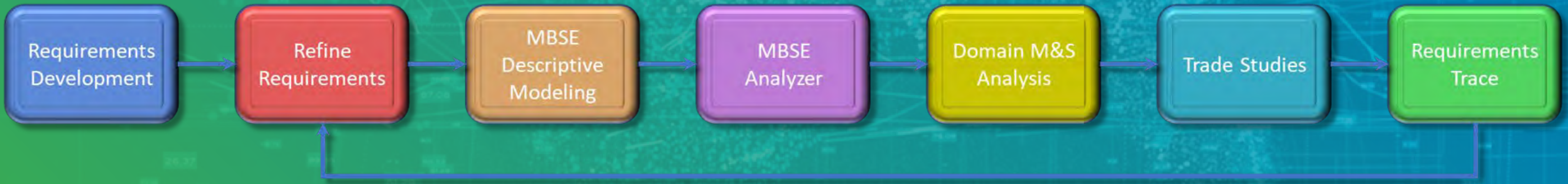


- Model Agnostic
- Federates any models or simulation tools
- Supports system requirements determination, design, analysis, V&V throughout development and system life cycle
- Inherent analytic capability supporting:
- Enterprise-level system engineering integrating framework and processes
- leverages simulations, tools and data residing in the Enterprise Web Services (EWS) or Azure cloud
- Multi-variate optimization and discrete event simulation techniques
- Handles a Seamless flow of requirements modifications

*Source: www.omgwiki.org

PDEF BENEFITS

- Connect systems architecture models with engineering analyses to calculate system performance, validate requirements, and perform Analysis of Alternatives and other trade studies



Benefits:

- Execute SysML Parametrics to Evaluate Designs
- Perform Requirements Trace to VV&A
- Trade studies and Analytics
- Update SysML Models with Analytic Results
- Import Engineering Analysis into SysML
- Ability to archive, manage and share Data
- Sensitivity Analysis and AoAs
- Utilizes M&S throughout Product Lifecycle
- Establishes a Library/repository of Analysis Models and Engineering Workflows
- Automatic Execution of Workflows across different computers and operating systems
- Multivariate Optimization, Trades and Design of Experiments
- Visualization of design space

Decision Analytics-as-a-Service with Workflows and Use Cases Unified Across the BMDS Elements

SAMPLE SCENARIO:
DEFENSE OF RIYADH AIRBASE KINGDOM OF SAUDI ARABIA (KSA)

ALL DATA DERIVED FROM UNCLASSIFIED SOURCES

AND

FOR DEMONSTRATION PURPOSES ONLY

INTRODUCTION

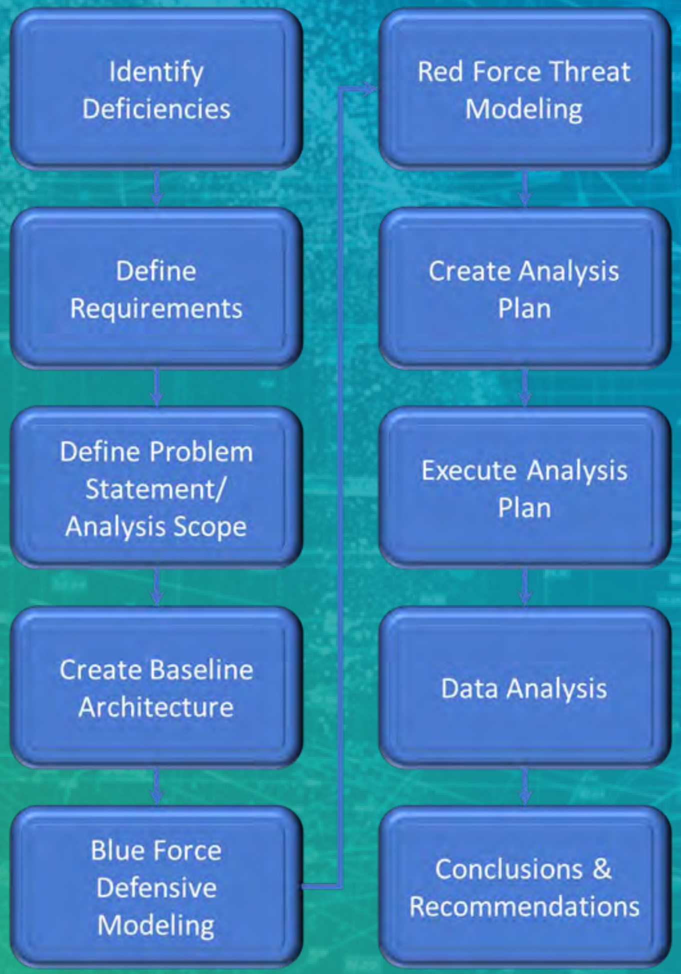
- Background
  - KSA has a need for a 360 degree, multi-layered defensive architecture
  - THAAD (long to intermediate threats)
  - PATRIOT (short range air breathers and tactical ballistic missiles)
  - Point defense gun systems (UAS and cruise missiles)
  - Early warning systems
  - Air Operations Center
- **Objective: Demonstrate ability of Parson's Universal Modeling and Analysis (PUMA) Lab to guide the enhancement of this defensive architecture**
  - Assess Current Defensive Architecture
  - Identify deficiencies
  - Simulate multiple laydowns and architectures to identify improvements
    - PUMA allows us to "Plug and Play" any candidate system into the architecture
    - Force-on-force simulations can be run in any simulation environment (STK, EADSIM, AFSIM, Moxie, etc.)
    - Optimize which systems to add and where to place them

SAMPLE SCENARIO OBJECTIVES

- Optimization of RIYADH airbase Defense
  - Multi-Layered Defense against Unmanned Aerial Systems (UAS) and Cruise Missiles (CM)
  - Sample Requirement to defend the airbase against these threats up to 5 simultaneous incoming threats
  - Three defensive locations
- Scenario Objective
  - Demonstrate using Moxie, MBSE, and STK to perform a simulation of an engagement scenario
  - Scenario Order of Battle
  - Defenders – Catalogue of 3 air defense systems
  - Asset – Airfield at Riyadh airbase, Kingdom of Saudi Arabia
  - MBSE architecture
  - Moxie – Digital Mission Engineering Toolset
  - Simulation performed in STK using Aviator and war gaming using Advanced Framework for Simulation Integration and Modeling (AFSIM)
  - No classified data – Derived From Open Sources
  - Weather effects are ignored
  - Using simplified sensor models and opensource data for aircraft characteristics and basic access models
  - Results were planned to exercise rulesets, not intended to represent actual performance

WORKFLOW

- Develop Baseline Architecture in Cameo
- Create Equivalent System and Threat Models in:
  - STK
  - AFSIM
- Define Scenarios for Analysis and Excursion
- Execute Analysis Plan
- Identify Alternatives
- Summary and Recommendations



SAMPLE SCENARIO OBJECTIVES AND ASSUMPTIONS

- Optimization of RIYADH airbase Defense
  - Multi-Layered Defense against Unmanned Aerial Systems (UAS) and Cruise Missiles (CM)
  - Sample Requirement to defend the airbase against these threats up to 17 simultaneous incoming threats
  - Three defensive locations
- Scenario Objectives and Assumptions
  - Demonstrate using Moxie, MBSE, and STK to perform a simulation of an engagement scenario
  - Scenario Order of Battle
  - Defenders – Catalogue of 3 air defense systems
  - Asset – Airfield at Riyadh airbase, Kingdom of Saudi Arabia
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CAMEO SYSTEMS MODELER

- Cameo Systems Modeler is an industry leading cross-platform collaborative Model-Based Systems Engineering (MBSE) environment, which provides smart, robust, and intuitive tools to define, track, and visualize all aspects of systems in the most standard-compliant SysML models and diagrams. The environment enables systems engineers to:

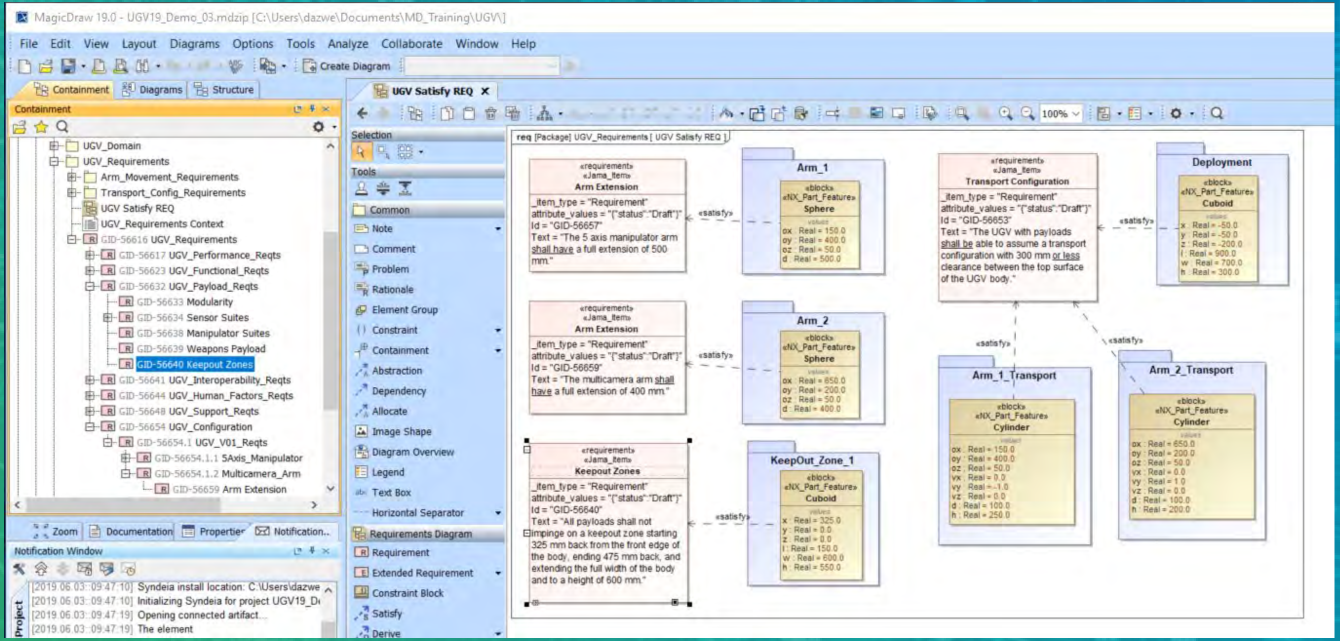
- Run engineering analysis for design decisions evaluation and requirements verification

- Continuously check model consistency

- Track design progress with metrics

- System models can be managed in remote repositories, stored as standard XMI files, or published to documents, images, and web views to address different stakeholder concerns.

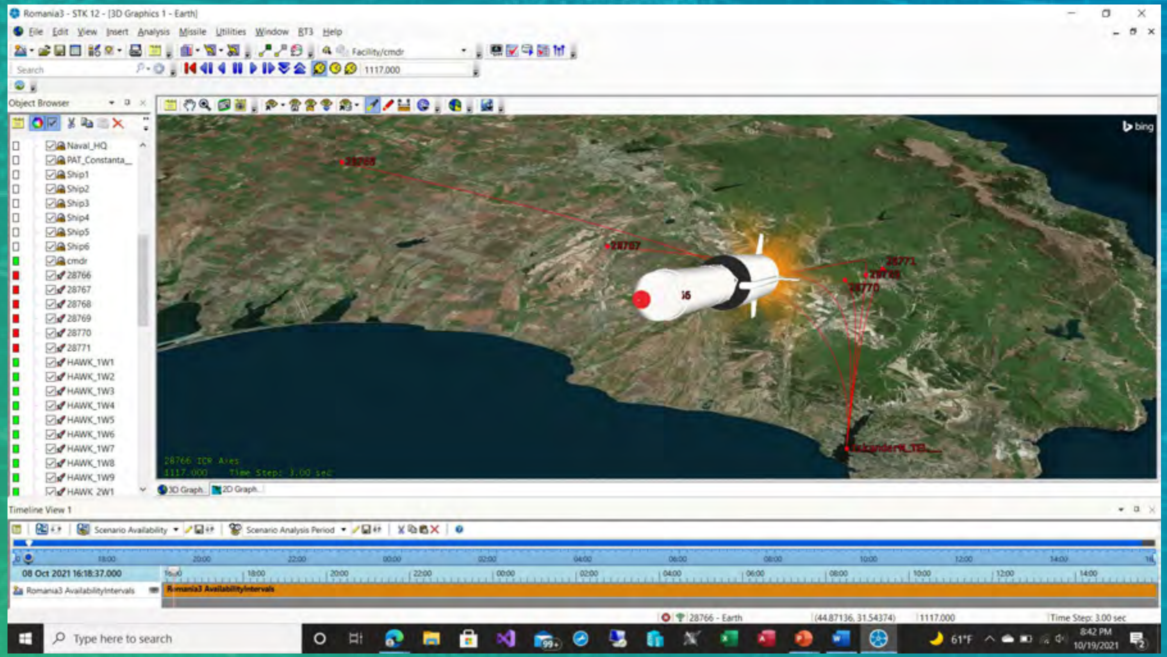
- Plugin to connect to Phoenix Model Center to expose value properties in the MBSE model



SYSTEMS TOOL KIT (STK)

ANSYS AGI STK

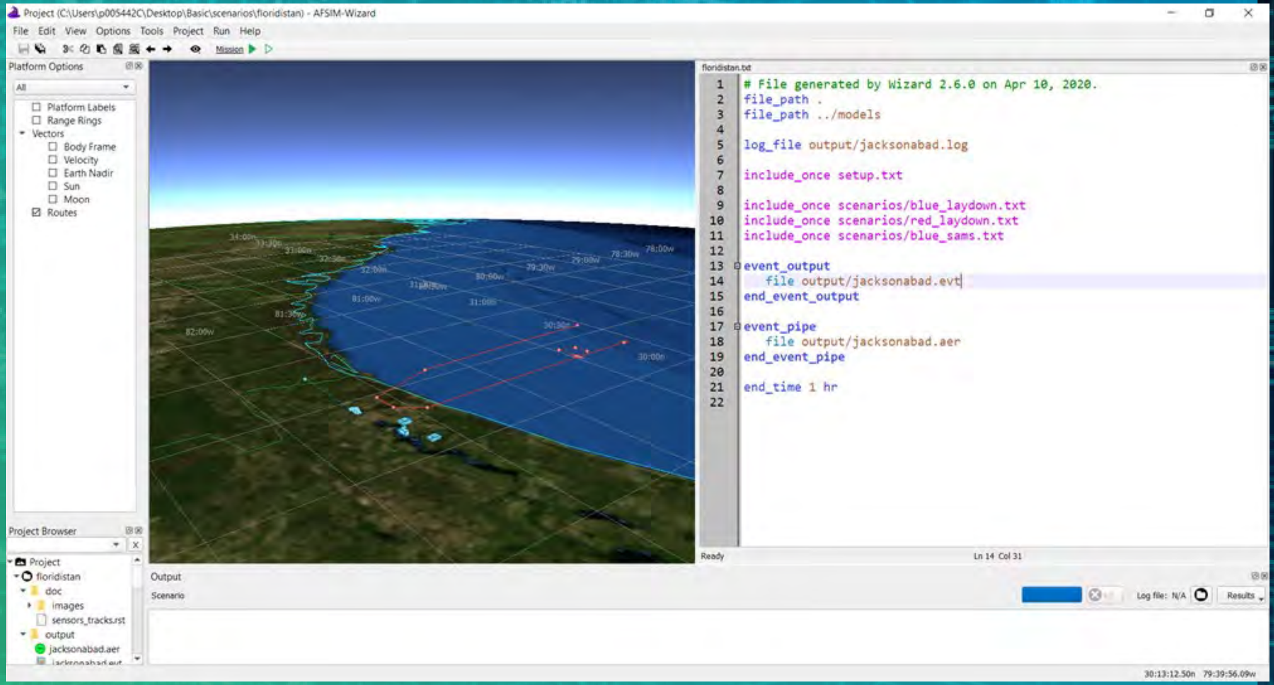
Systems Tool is a multi-physics software application from Analytical Graphics, Inc. (an Ansys company) that enables engineers and scientists to perform complex analyses of ground, sea, air, and space platforms, and to share results in one integrated environment. At the core of STK is a geometry engine for determining the time-dynamic position and attitude of objects ("assets"), and the spatial relationships among the objects under consideration including their relationships or accesses given a number of complex, simultaneous constraining conditions. STK has been developed since 1989 as a commercial off the shelf software tool. Originally created[2] to solve problems involving Earth-orbiting satellites, it is now used in the aerospace and defense communities and for many other applications.



ADVANCED FRAMEWORK FOR SIMULATION INTEGRATION AND SIMULATION (AFSIM)

WEAPONS

- All weapon behaviors are developed in-house using a modeling and simulation framework
- All parameters derived from Open Source specifications
- Interceptor parameters are varied after firing to simulate environmental effects
- Custom code used to calculate interceptor launch times and trajectories in real-time based on enemy aircraft position and speed



COUNTER-UAS CYBER SYSTEMS

- AIRCRAFT ARE FORCED TO CRASH LAND UPON SUCCESSFUL ENGAGEMENT
- AIRCRAFT CAN BE FITTED WITH DIFFERENT DEFENSES AND PROBABILITIES AGAINST CYBER ENGAGEMENTS
- BEHAVIORS ARE MEANT TO SERVE AS PROOF OF CONCEPT AND DO NOT REFLECT REAL-WORLD PERFORMANCE

PARSONS

PHOENIX MODEL CENTER WITH MBSE PLUGIN

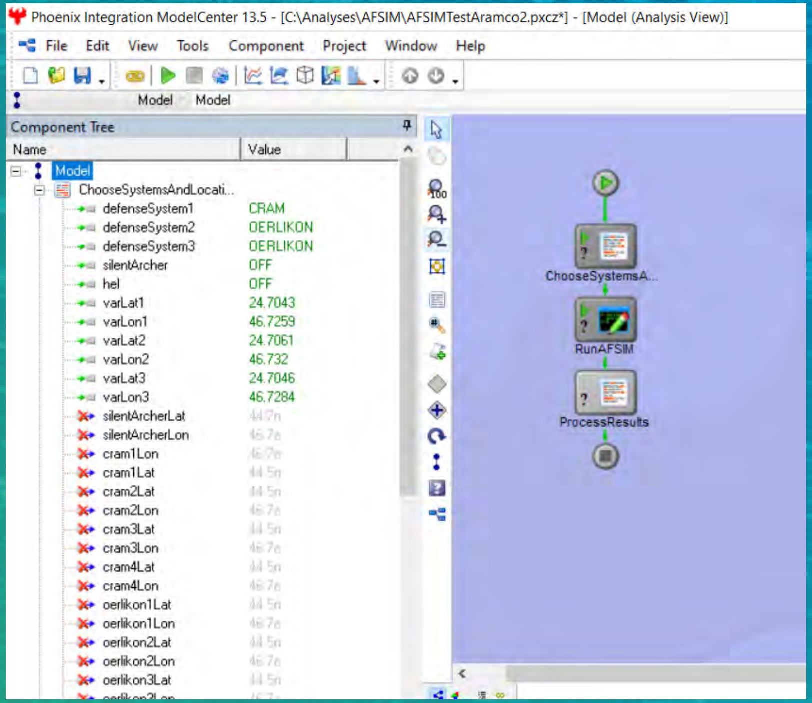
ANSYS

ModelCenter
The Framework for Model Based Engineering
PHOENIX INTEGRATION

ModelCenter Integrate provides users with tools and methods that allow them to automate the execution of almost any modeling and simulation tool.

ModelCenter Explore allows users to create fast-running approximations for long-running analysis tools. In essence, Response Surface Models are general-purpose multi-dimensional “curve fits”. Given a set of data points (a set of inputs and outputs), ModelCenter can generate a quickly executing mathematical model (the response surface) that approximates this data.

ModelCenter MBSE provides an integrated modeling and analysis capability that bridges the gap between systems engineering and domain/disciplinary engineering. This integrated capability aims to streamline the system development process by enabling collaboration among design teams for defining, designing, optimizing, and validating complex engineering systems.

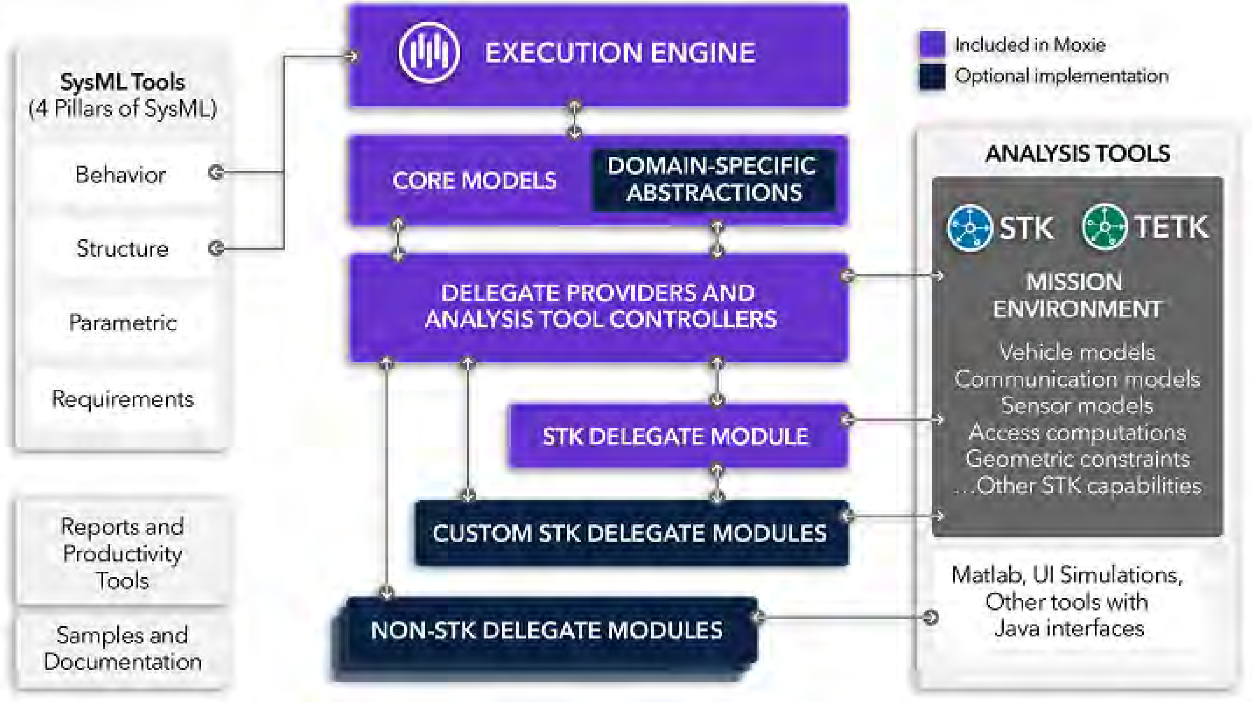


MOXIE

Moxie is a model execution and integration engine for executable architectures.

- Implemented as a No Magic Cameo plugin to run state machine simulations that uses analysis tools such as STK, MATLAB, and others that have Java interfaces.

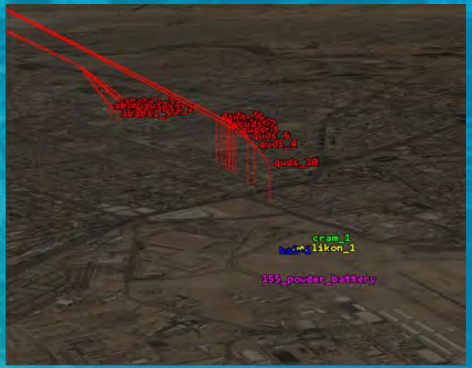
- Delegate Module: enables execution of custom Java code to drive the analysis tools and perform custom logic during runtime.

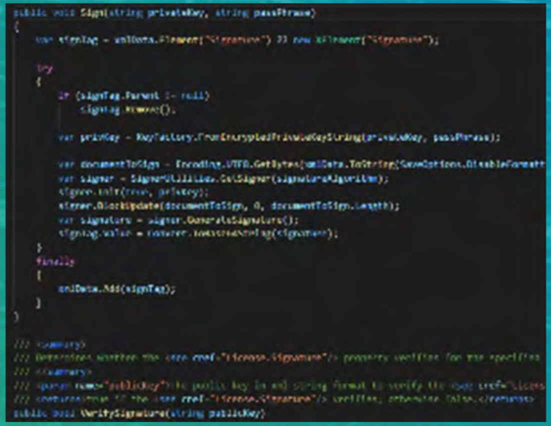


DEVELOP PLUGINS FOR CROSS PLATFORM ANALYSIS

AFSIM

STK





Plugin design

- Custom plugins that allow modelers to easily transition between different toolsets
- Created with custom code that was developed in-house
- Plugins allow modelers to easily transition between toolsets to perform analysis or visualize engagements
- Plugins are developed so transitions are bi-directional to allow greater freedom in analysis
- Plugin development is tool agnostic and can be created for most frameworks and simulation tools

THREATS

Threat Overview

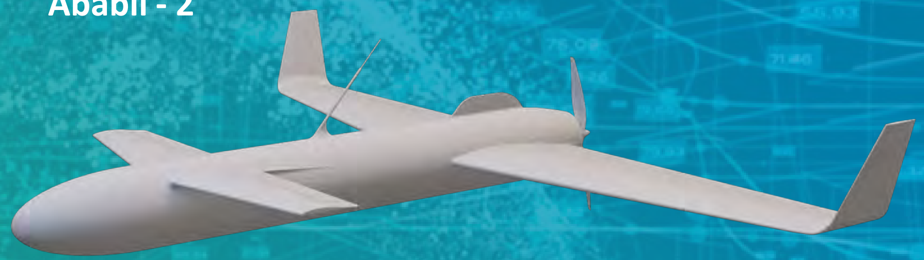
Ababil-2 Tech Specs

- Disposable Strike Munition Version
- 30 – 50 Kg Warhead
- Camera and Data Link – Unknown
- GPS/INS Capable
- Length 2.8 m, Wingspan 3.25 m
- Weight 30 kg Empty, Payload 40 kg
- MTOW: 83kg
- Speed, Cruise: 250 – 305 km/h; Ceiling 3 km; Endurance up to 2 hrs
- Max Range based on Specs 500 – 610 km

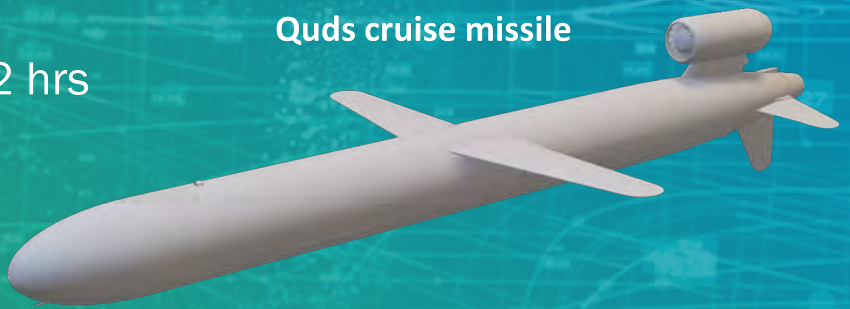
Quds (Iranian Soumar) Tech Specs

- Long-Range Cruise Missile based on Russian Kh-55
- 400 kg Warhead
- 1200 km range

Ababil - 2



Quds cruise missile



PEACE SHIELD

- Royal Saudi Air Force (RSAF) C3I system
- Links the networks of the Royal Saudi Land Forces (RSLF)
- Royal Saudi Naval Forces (RSNF) and
- Royal Saudi Air Defense Force [RSADF]
- Key elements:
    - 17 radars
    - Central command operations center
    - Five sector command and operations centers
    - Nation wide communications links
    - Interfaces with all agencies having a role in national defense, and communications centers to contact and control civil and military aircraft
    - Long-range radar and remote-controlled air/ground radio communications sites
    - Associated telecommunications network
    - 17 AN/ FPS-117 long-range 3-D radars
    - 6 AN/TPS-43 tactical radars
    - System Integrated with 10 AWACS ground entry stations
    - AN/TPS-43 radars, the Improved HAWK and the radars of the RSNF are also integrated into the system

PEACE SHIELD AIR SURVEILLANCE NETWORK COVERAGE

PEACE SHIELD Network

- Optimal Coverage for Air Surveillance of Aircraft at Normal Altitudes
- Little to no Coverage for Aircraft Flying at Low Altitudes
- Limited Detection Range for Low Radar Cross Section (RCS) Aircraft

CANDIDATE WEAPON SYSTEMS

Oerlikon Skyguard III

- 35 mm artillery round
- Max range: 3500 m
- Tracking: External Fire Control Radar
- Elevation: -5 – 92 deg
- 1100 Rounds per minute (550 x 2 barrels)

Counter Rocket, Mortar, and Artillery system (C-RAM)

- 20 mm artillery round
- Max range: 1500 m
- Tracking: Ku Radar and FLIR
- 4500 Rounds per minute (High Explosive Incendiary Tracer, Self Destruct)

Oerlikon Skyguard III

C-RAM

CANDIDATE WEAPON SYSTEMS

155 mm Powder Regiment

- 18 km range (standard HE projectiles)
- Elevation: -5 – 72 deg
- Rate of fire: 4 rounds per minute sustained

155mm Powder Regiment

High-energy laser (HEL)

- Power: 50 kW (est.)
- Range: 1000m (est.)
- 10 shots per minute before cooling cycle (est.)

Example HEL platform

CANDIDATE WEAPON SYSTEMS

Counter-UAS Cyber Defense
Notional counter-UAS system comprised of radar, cameras, and electronic warfare systems that can be used to detect, identify, and disrupt groups 1-5 UAS.

- Type of attack: Navigation disruption through GPS spoofing
- Maximum detection range: 93 km
- Maximum attack range: 93 km
- 1 second attack and detection intervals
- PK: 30%

Platform with comparable radar and EW assets

PARSONS

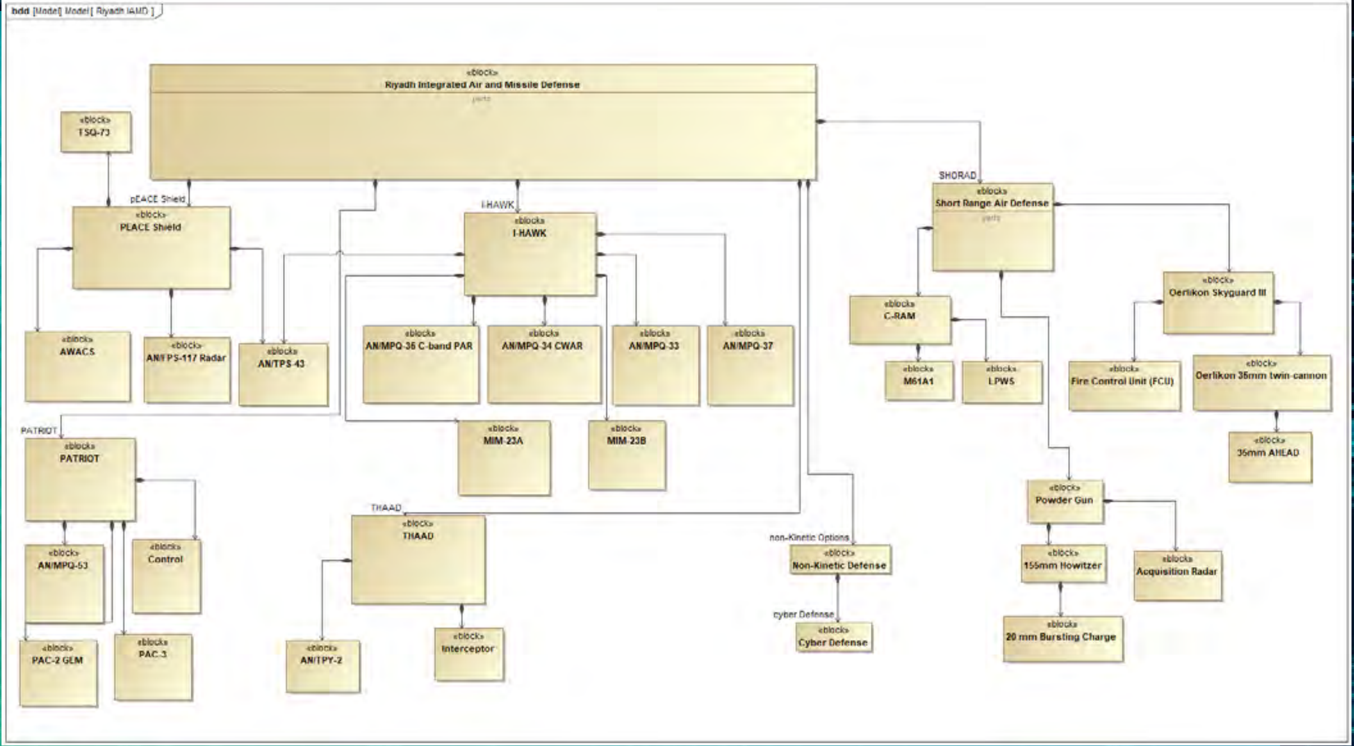
SCENARIO SUMMARY

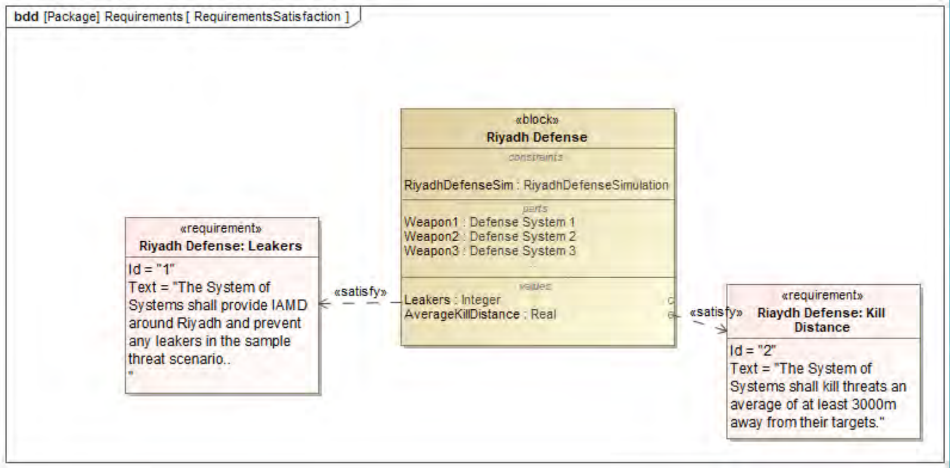
Defense of Riyadh Air Base

- Threats coming in from southern side of the airport (opposite main defensive posture)
- 7 Ababil UAS drones
- 10 Quds cruise missiles
- Available weapon systems
- Network of EWR sensors
- Counter Rocket, Mortar, and Artillery system (C-RAM)
- Oerlikon cannon
- 155mm Powder regiment and battery
- High-energy laser (HEL)
- Non-kinetic defense (cyber)

MBSE MODEL

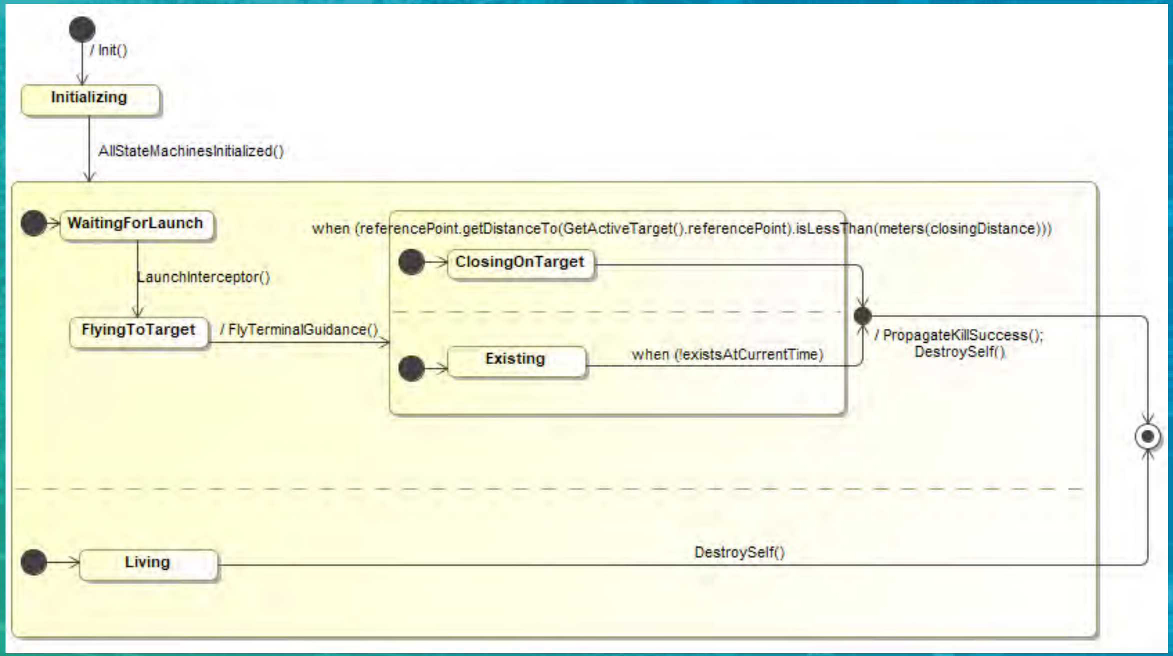
- Created an MBSE model with the Riyadh defensive architecture
- Defined Requirements and build a Requirements Satisfaction Diagram
    - The System of Systems Shall provide IAMD around the Riyadh and prevent any leakers in the sample threat scenario
    - The System of Systems Shall kill threats an average of at least 3000 m away from their targets
- MBSE model can be tied to analyses using Phoenix Integration's Model Center MBSE software
- Analysis results can be traced back to requirements





MOXIE

- Moxie is an execution engine that integrates SysML state machine simulations with the STK physics environment.
- Enables running custom Java code at various points in the simulation to perform C2 operations, estimate variable communications delays, and roll against the PK to determine if threats leak.
- Currently developing a similar Riyadh defense simulation using Moxie to validate approach.




```java
import ...

@DelegateFor("PlatformLibrary::BuiltBehaviors::AviatorPropAircraftInterceptorRMC")
public interface AviatorPropAircraftInterceptorRMC extends AviatorPropAircraftInterceptor {
    Property<String> initialPositionObjectPathProperty();

    Property<BooleanValue> isWithinTerminalGuidanceDistanceProperty();

    Property<EnvironmentRMC> environmentRMCProperty();
}
```

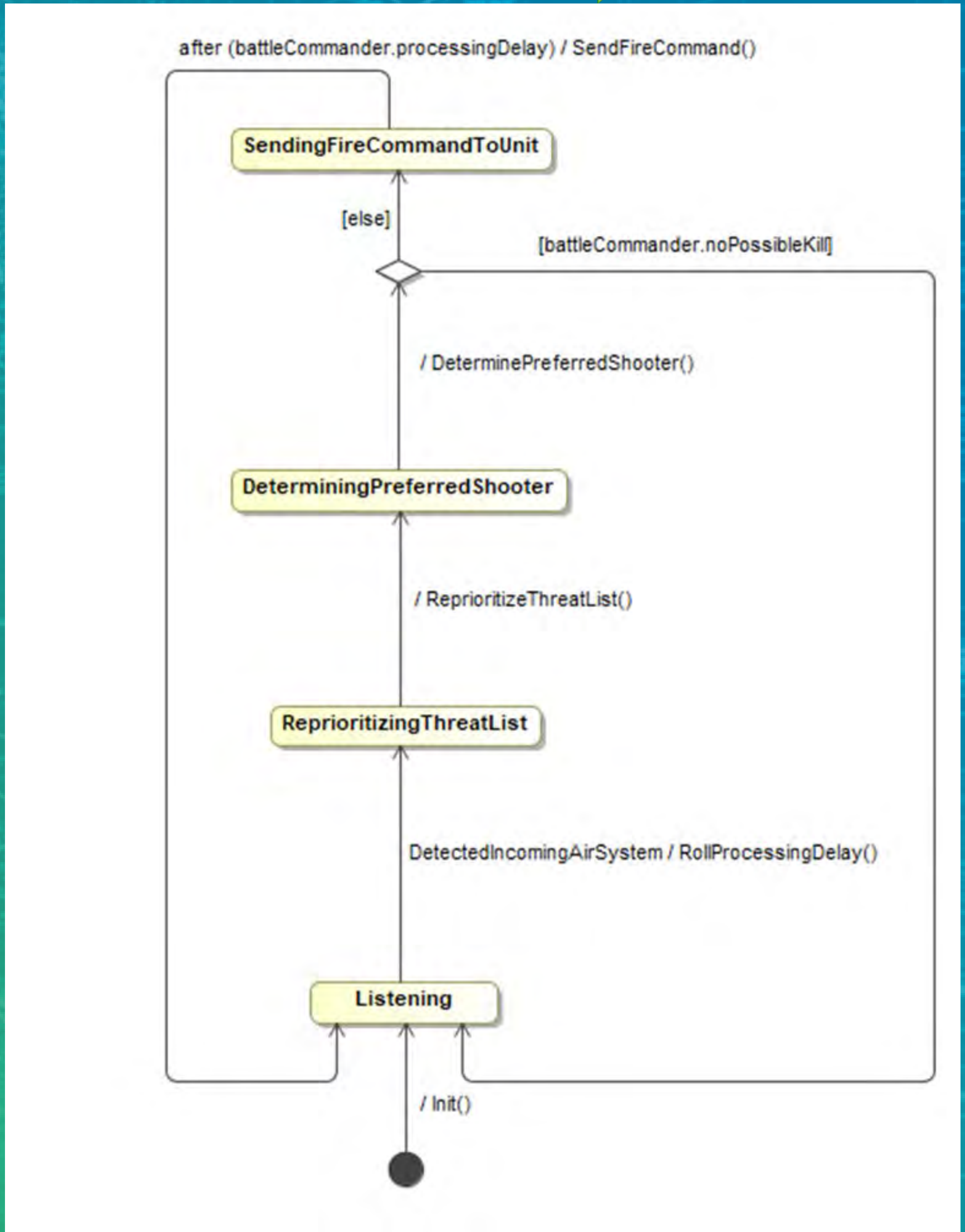
STATE MACHINES

State machines define system behavior

- Provides a graphical representation of rulesets
- Define triggers and behavior for transitions between states

Example: Battle Commander

- Models the behavior of the Battle Manager
- Prioritize the Threat
- De-confliction of Fires
- Lethality Assessment



MOXIE DELEGATES

- A delegate is a Java class or interface that represents a one-to-one relationship between itself and a block in the SysML model

- Contains all of the custom code to run the state machine opaque expressions

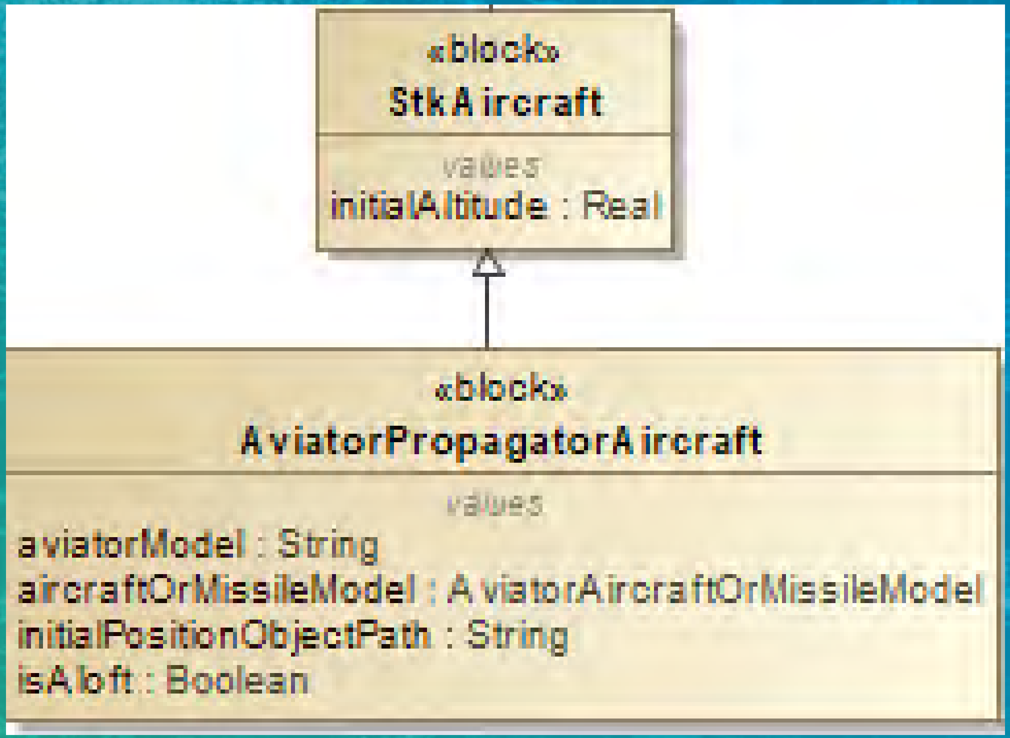
- Example: AviatorPropagatorAircraft

```
@DelegateFor("Structure::AviatorPropagatorAircraft")
public interface AviatorPropagatorAircraft extends StkAircraft {
  Property<String> aviatorModelProperty();

  Property<AviatorAircraftOrMissileModel> aircraftOrMissileModelProperty();

  Property<String> initialPositionObjectPathProperty();

  Property<Boolean> isAloftProperty();
}
```



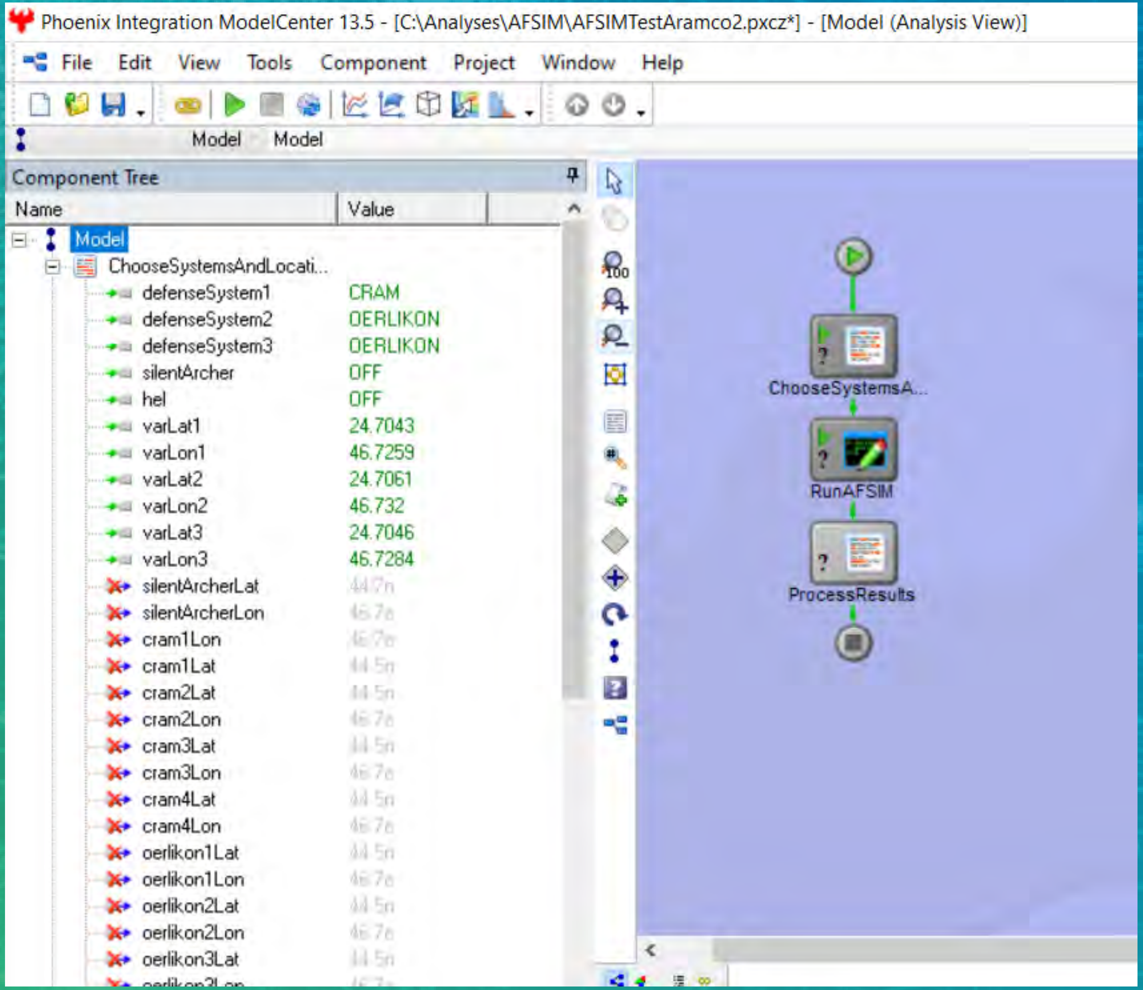
DEFENSE LAYDOWN FOR OPTIMIZATION

Optimization Methodology

- Defensive systems located in defined Operational Areas
- C-RAM, Oerlikon, or Powder Gun are available to be placed in each Operating Area
- A Simulation Execution Engine is used to vary the positions of the defenders
- Positions can be selected using a variety of methods (Genetic Algorithm, Monte Carlo, etc..)
- Each scenario evaluated on a set of Key Performance Parameters (KPPs)
- Optimize on threats killed and distance from targets

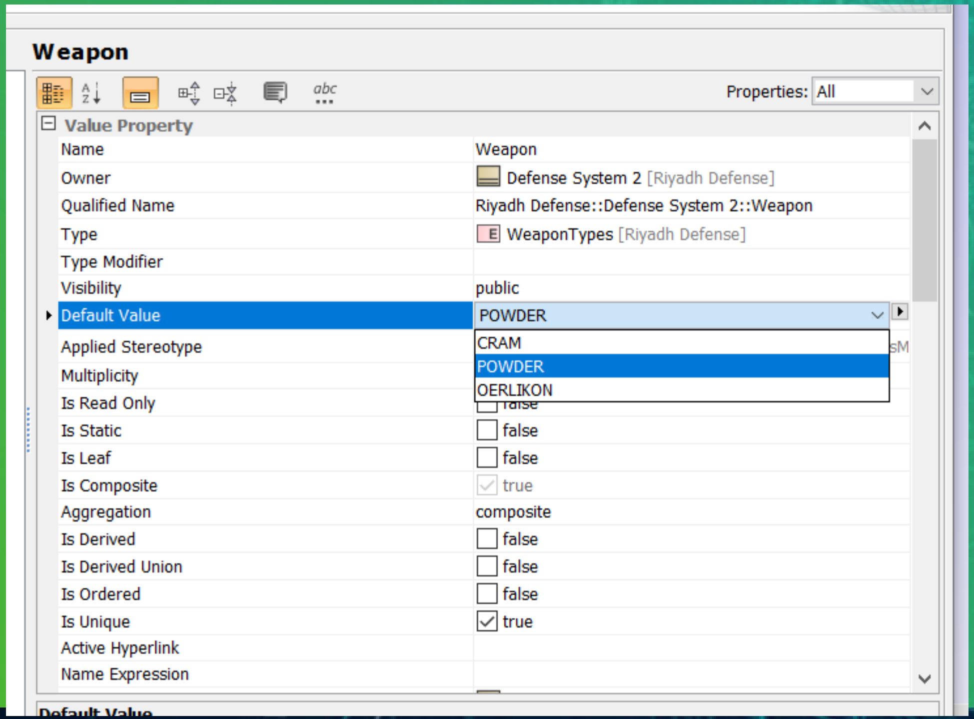
WORKFLOW IN PHOENIX INTEGRATION'S MODEL CENTER

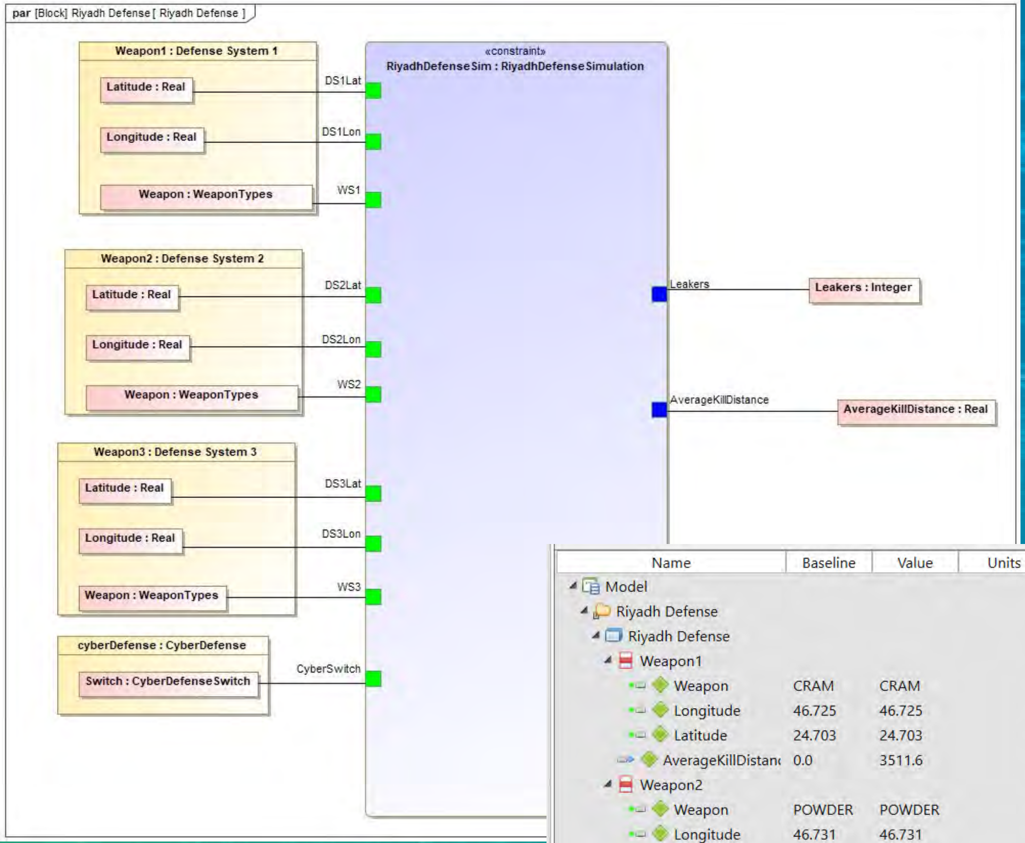
- Three parts to the workflow
- First, we have a script that allows us to select which defense systems we want to use and where to put them (linked to inputs from MBSE model)
- Next, we update the Blue laydown input file with the chosen configuration and run the simulation
- Finally, get the results from the simulation
- Trade studies/optimization
- The workflow allows us to run trade studies where we can swap out defense systems (using a "Parts Catalog" to select which system is active at each location
- Alternately, we can run a trade study or optimization where we use selected systems but vary the location of one or more of them
- Output metrics are number of threats killed, number of shots, average distance from target when killed, etc.

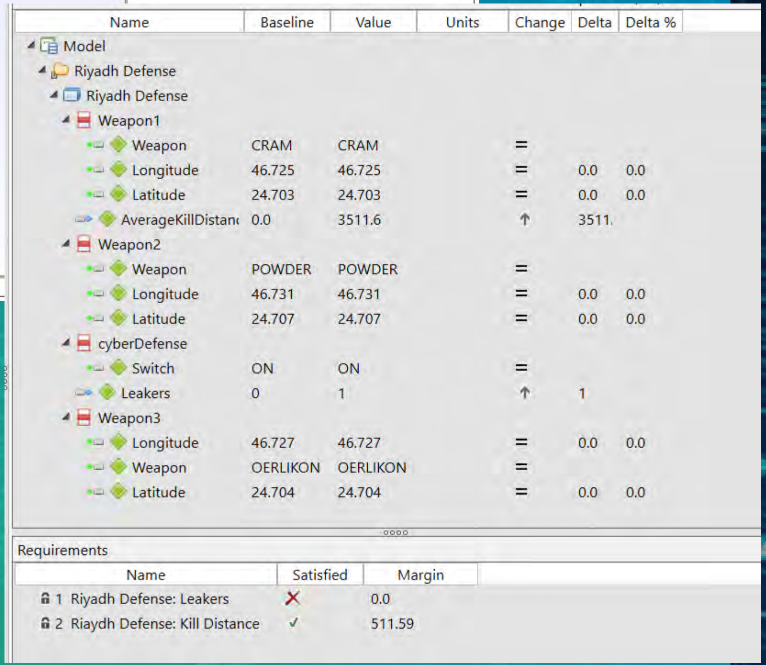


ENGINEERING ANALYSIS

- MBSE constraint block links to Model Center engineering analysis
- Dropdown menu represents a parts catalogue and allows the analyst to choose weapon type for each defense system
- Defense system locations can also be varied

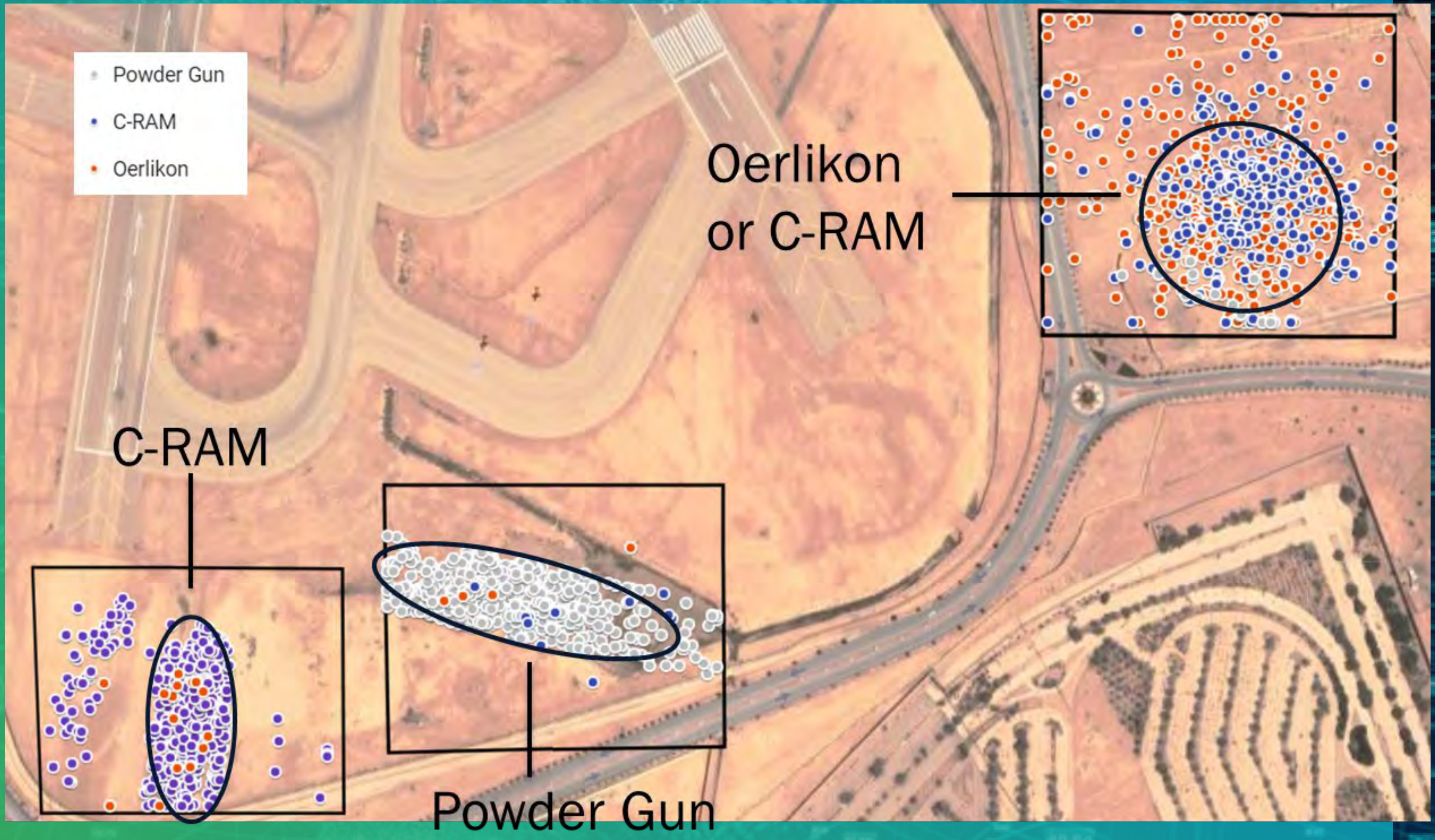






OPTIMIZATION RESULTS

- Out of over 20,000 cases run, 1537 met both requirements
- C-RAM favored as weapon system 1 (over 99% of the cases)
- Powder Gun favored as weapon system 2 (over 99% of cases)
- Only kills a few threats, but kills them further from their targets
- Oerlikon was most common as weapon system 3 (80% of successful cases), but a second C-RAM could alternatively be placed there



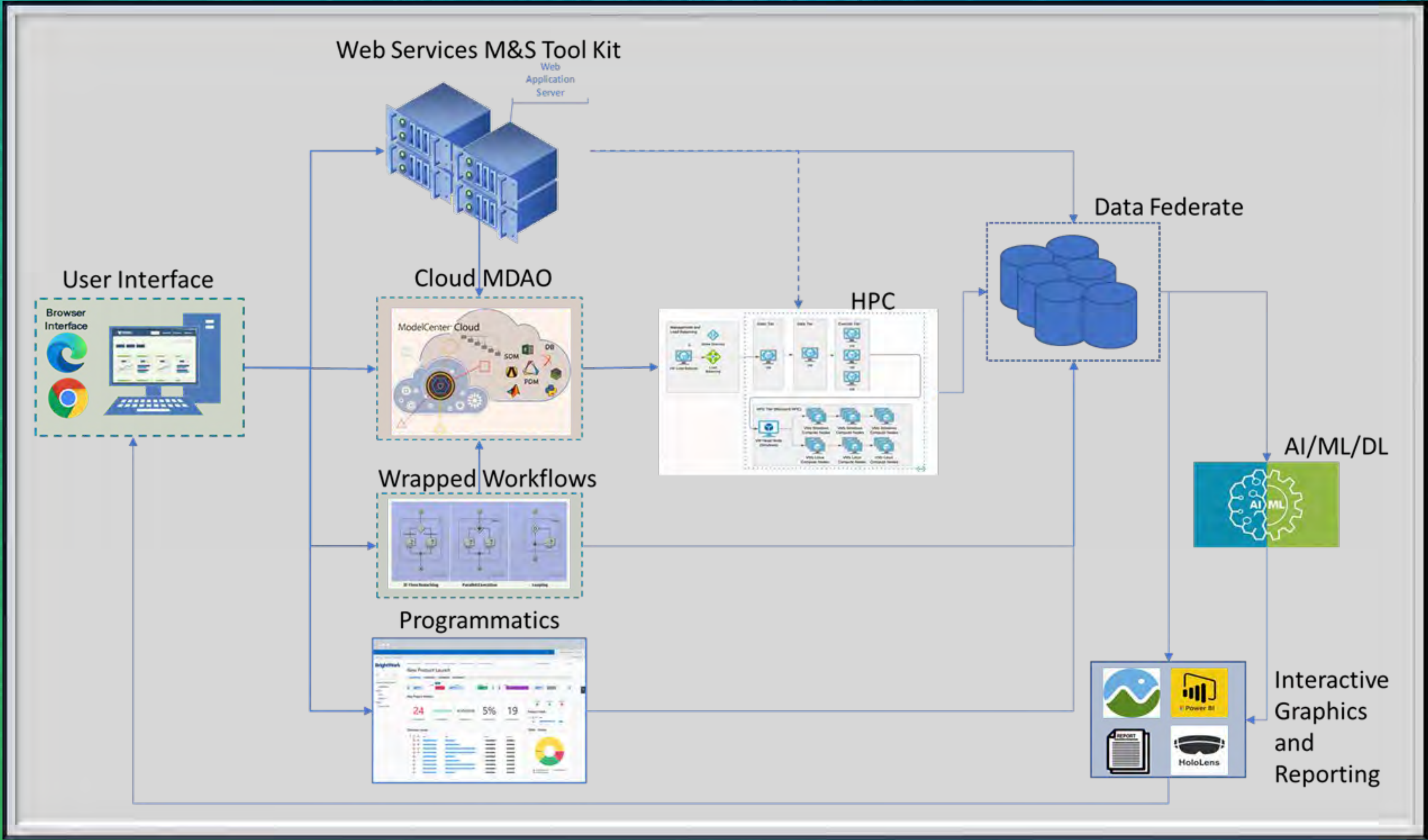
SUCCESSFUL SIMULATION EXAMPLE

DEMONSTRATION SUMMARY

- Parsons's PUMA Lab ideally suited to help guide the addition of weapon systems to fill in gaps in a 360 degree, multi-layered defensive architecture in the KSA
- Ability to model any weapon system and simulate its capabilities in a variety of high-fidelity tools
- Integration of simulations into our MBSE Architecture enables us to perform detailed trade studies and optimizations while tracing simulation results back to requirements
- Demonstrated the ability to optimize the selection and placement of assets in a scenario defending Riyadh Air Base
- Further studies could be performed to see how the weapon system configurations respond to additional threat scenarios, how capabilities improve with additional assets, or assigning assets to counter specific threat types

FUTURE ACTIVITIES – ANALYTICAL CAPABILITIES

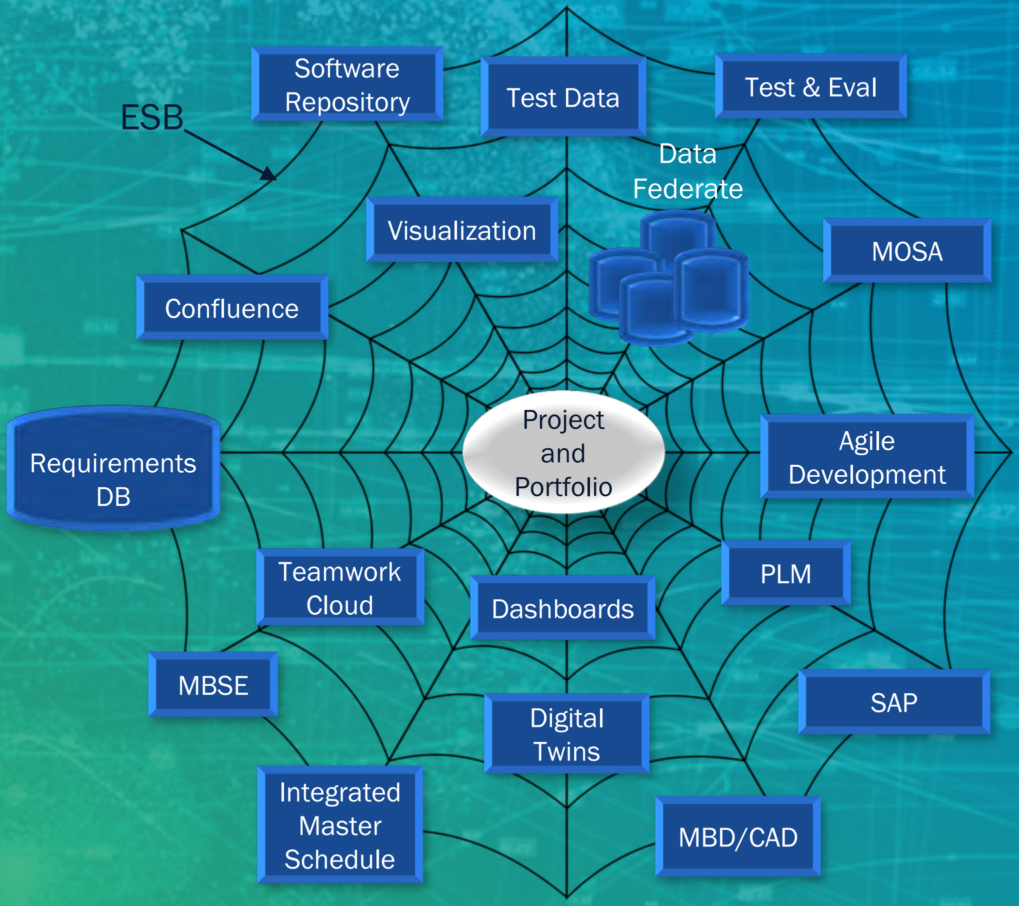
- Enhancing The Analytical Environment
  - Web based User Interface
  - Web Services M&S Tool Kit
  - Full Integration of Moxie into Model Center Workflows and Cameo
  - Cloud Multi Disciplinary Analysis and Optimization (MDAO) Capability
  - Head Node for HPC
  - Data Federate for Simulation Artifacts
  - AI/ML/DL for analysis at the Enterprise Level utilizing the Data Federate
  - Interactive Graphics and Digital Dashboards utilizing the Data Federate



FUTURE ACTIVITIES – DIGITAL ENGINEERING ECOSYSTEM

- Enterprise Level Digital Engineering Ecosystem
- Development of web/micro services for Integration
- Configuration Management of Multiple Sources of Truth
- Digital Backbone leveraging a Business Process Executable Language (BPEL) programmable Enterprise Service Bus (ESB)
- Incorporation of multiple information nodes
- Integration of Product Life Cycle Management (PLM)
- Integration of Software Development tools and repositories
- Integration of Project and Portfolio Management (PPM) tools
- Advanced Digital Dash Boards for Product Management

Ecosystem is the web and each tool is a node
When any node is modified all affected nodes are informed by the web, which is the ESB Digital Backbone



Enables the Stakeholders to have Informed Decisions backed up by all available data

SUMMARY

- **Digital Ecosystem: is a collaborative system of systems employing digital environments, enabling application of standards to support the exchange of digital artifacts from Multiple Authoritative Sources of Truth (ASoT)**
    - This is of paramount importance to implementing MBSE, Digital Mission Engineering and Integrated Modeling and Simulation
- **Multidisciplinary Engineering is Enabled: Digital Engineering, Analytics and program management are flexibly streamlined**
    - Knowledge is configuration controlled and stakeholders (All engineering disciplines) benefit from an informed, deliberative, collaborative decision making process
- **Implementation: The DE Ecosystem implementing the "Web of Knowledge" allows a multidisciplinary engineering team to address multiple domain requirements to interconnect and iterate use cases and workflows**
    - An enhanced digital way of doing the business of engineering
- **Value to the Client: manifest in the unified "Web of Knowledge" - a collaborative environment built upon a Digital Backbone with Business Process Executable Language and programmable Enterprise Service Bus**
    - The flow of engineering data is turned into knowledge…and knowledge becomes the basis for informed decision making