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Model-Driven UAS ISR Tradespace Analysis

David Jacques, Air Force Institute of Technology
Ray Madachy, Naval Postgraduate School

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Agenda

- Introduction and Overview
- Case Study: TBM Identification and Elimination: 3-Tier UAS SoS
- System Cost Modeling and SysML Integration
- Conclusions and Future Work

2

Research Overview

- Joint approach to incorporate methods in case studies for assessing impacts of requirements changes and scenario variations in MBSE tools, Modeling and Simulation (M&S) environments.

- Focus on translations between models/tools in MBSE, specifically mapping architectural elements into behavior/performance analysis and cost model inputs.
  - SysML, DoDAF, Monterey Phoenix, parametric cost models, M&S environments

- Initial application to UAV Intelligence, Surveillance and Reconnaissance (UAS ISR) mission involving heterogeneous teams of autonomous and cooperative agents.

- AFIT develop mission CONOPS, Architectures and provide modeling support.

- NPS provide cost modeling expertise, tools and modeling support.

- Approach
  - Develop operational and system architectures to capture sets of military scenarios.
  - Develop the architectures in MBSE environments.
  - Design and demonstrate UAS ISR tradespace in MBSE and/or M&S environments .
  - Develop cost model interfaces for components of the architectures in order to evaluate cost effectiveness in an uncertain future environment.

Affordability

- Goal of Total Ownership Cost (TOC) modeling to enable affordability tradeoffs with other ilities
  - Integrated costing of systems, software, hardware and human factors across full lifecycle operations
  - Combine with other MBSE architecture-based behavior and performance analysis
- Current shortfalls for ilities tradespace analysis
  - Models/tools are incomplete wrt/ TOC phases, activities, disciplines, SoS aspects
  - No integration with physical design space analysis tools or system modeling
- Cost estimation can be improved by using the same architectural definitions for cost model inputs, without the need for independent cost modeling expertise and effort expenditure.
- Developing translation rules and constructs between MBSE methods, performance analysis and cost model inputs.
- Demonstrating tool interoperability and tailorability

UAS Mission Summaries

- Single UAS Search and Target Tracking (Simple Mission)
- UAS Pair Search and Target Tracking
- Find, Fix and Finish Terrorist Leadership (1)
- Find, Fix and Finish Terrorist Leadership (2)
- Mobile Missile Launcher Monitoring (1)
- Mobile Missile Launcher Monitoring (2)



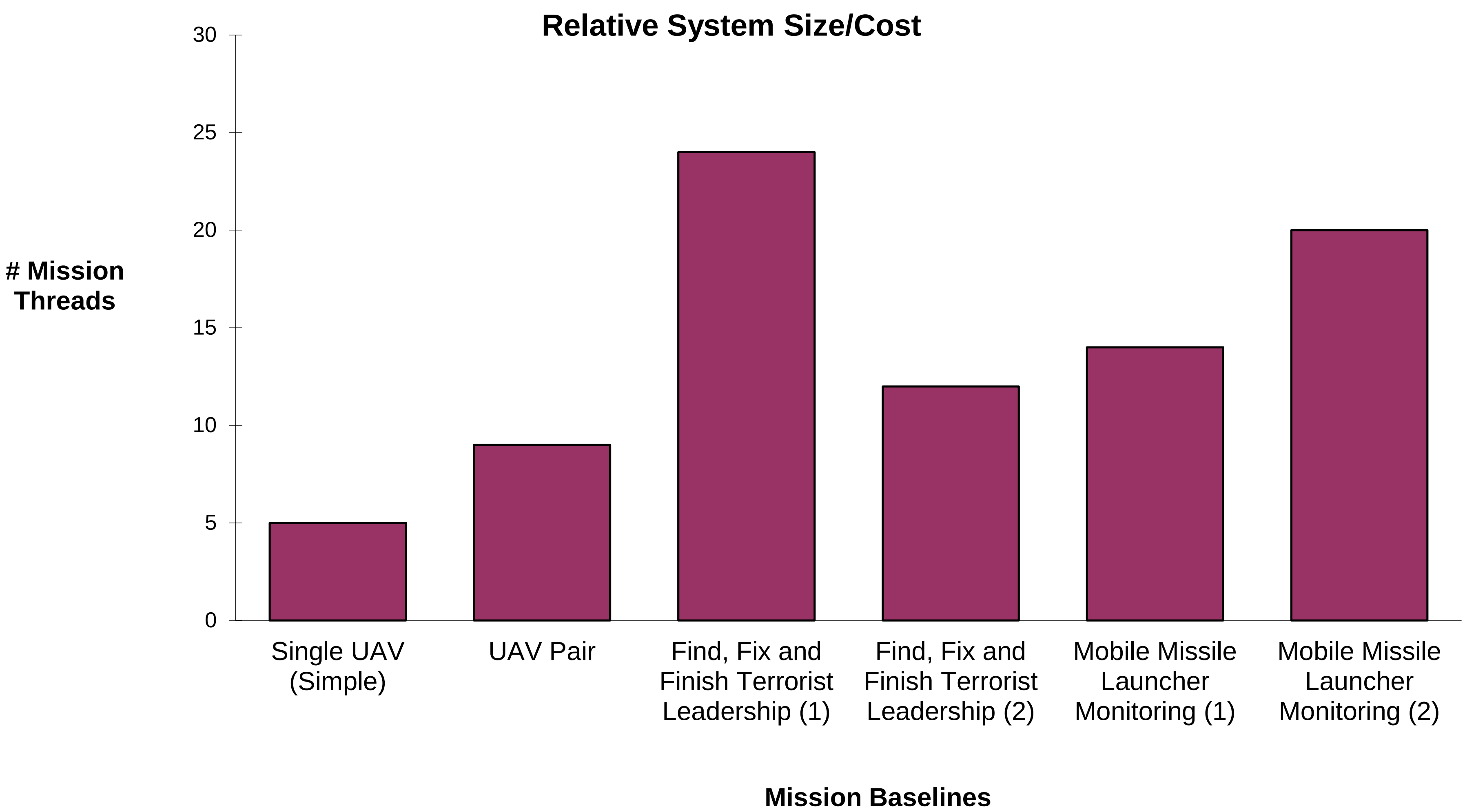


Single UAS Simple Mission Threads

- Launch
- Navigation and flight
- Search and target ID including evaluation
  - Probabilistic target detection allowing for false targets and missed detections
- Target tracking
- Return/recovery

- *Enumeration of these in MBSE models constitutes primary size input for Constructive Systems Engineering Cost Model (COSYSMO)*

UAS Mission
Nominal Cost Comparisons



Case Study Method

- Use various MBSE methods and tools to evaluate behavior and performance analysis in the face of requirements changes and System of System (SoS) architectural variations.
- Develop operational and system architectures to capture sets of UAS military scenarios for cooperative swarms with 3 UAS group sizes
- Develop the architectures in MBSE environments.
  - SysML diagrams and executable activity models using Innoslate
- Develop cost model interfaces for components of the architectures in order to evaluate cost effectiveness in an uncertain future environment.
  - XML model files parsed automatically to extract cost model inputs
- Design and demonstrate UAS ISR tradespace including cost in integrated MBSE environment with executable models of architectures

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Implementation of Methodology

Operational Need

1. Increase in Theater Ballistic Missile (TBM) threats.
2. TBM launchers employing shoot-and-scoot technique, increasing challenge to counter-TBM operations.
3. Capability to preemptively seek and destroy TBM launchers.

CONOPS overview

1. Multi-tier UAS System-of-Systems to
    i. Maintain persistent situational awareness over a designated area
    ii. Search and locate possible TBM Launchers
    iii. Target and strike the located launchers.
    iv. Perform BDA?
2. Leverage on capabilities of different groups of UAS and sensor systems.
3. Optimizing UAS employment for mission effectiveness while minimizing operational cost and risk
4. Cooperative control among various UAS groups to assign roles and plan safe routes for ingress and egress.

Implementation of Methodology

Measures of Performance

1. Target Acquisition Pct

$$Target\ Acquisition\ (Percentage) = \frac{Target\ Positively\ Acquired}{Total\ number\ of\ Targets\ encountered} \times 100\%$$

2. False Alarm Pct

$$False\ Alarm\ (Percentage) = \frac{False\ Target\ Acquired}{Total\ number\ of\ targets\ declared\ in\ area} \times 100\%$$

3. Time-to-Strike

$$Time\ to\ strike = Bomb\ launched\ Time - Target\ Acqusition\ Time$$

4. Target Destruction Pct

$$Target\ Destruction\ (Percentage) = \frac{Target\ Destroyed}{Total\ number\ of\ Targets\ encountered} \times 100\%$$

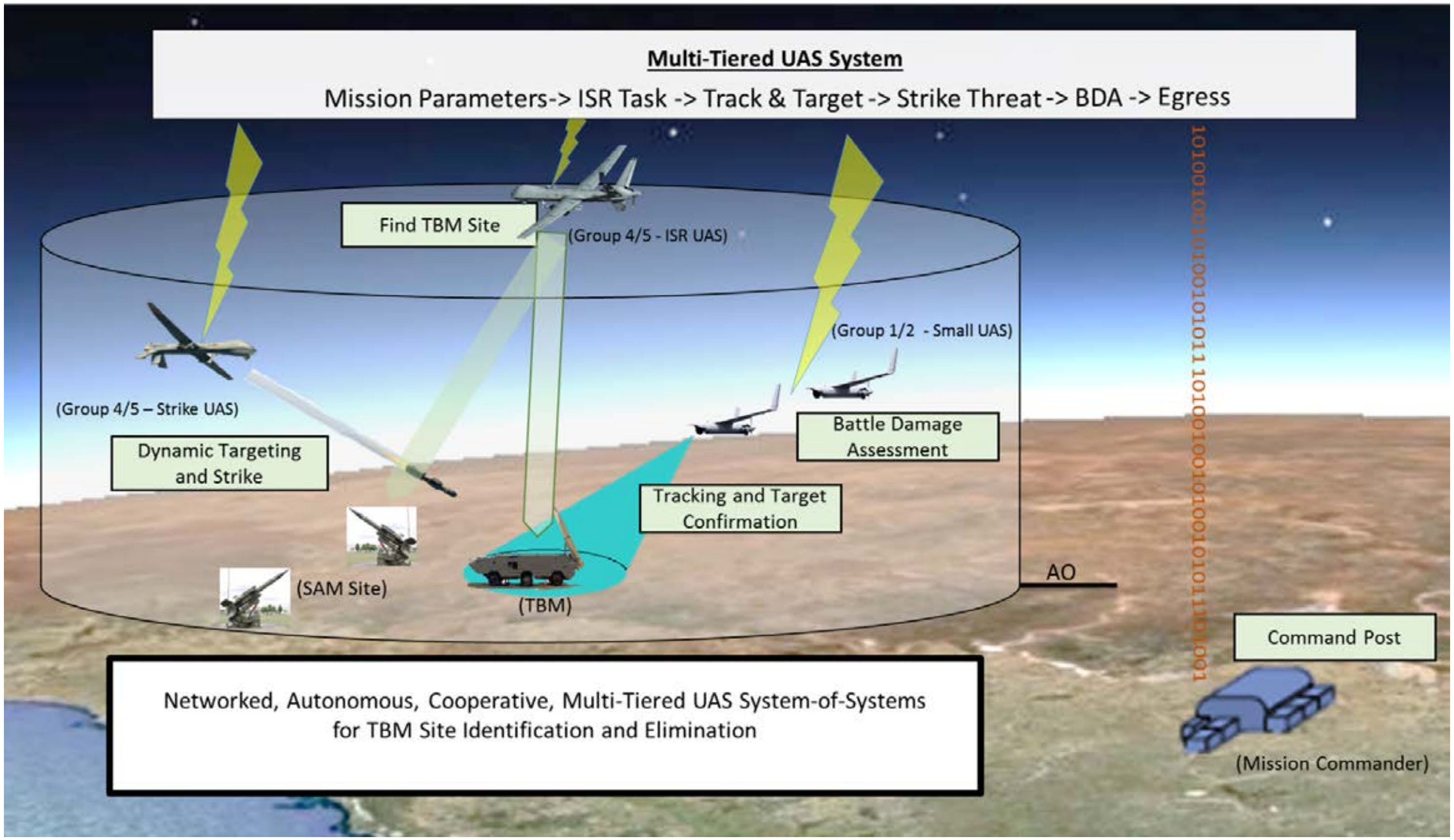
Implementation of Methodology

High Level DoDAF Architectural Products

1. AV-1 : Overview and Summary Information
2. OV-1 : High-level Operational Concept Graphic
3. OV-2 : Operational Resource Flow Description
4. OV-5a : Operational Activity Decomposition Tree
5. OV-5b : Operational Activity Model
6. OV-6a : Operational Rules Model
7. DIV-2 : Logical Data Model

Implementation of Methodology

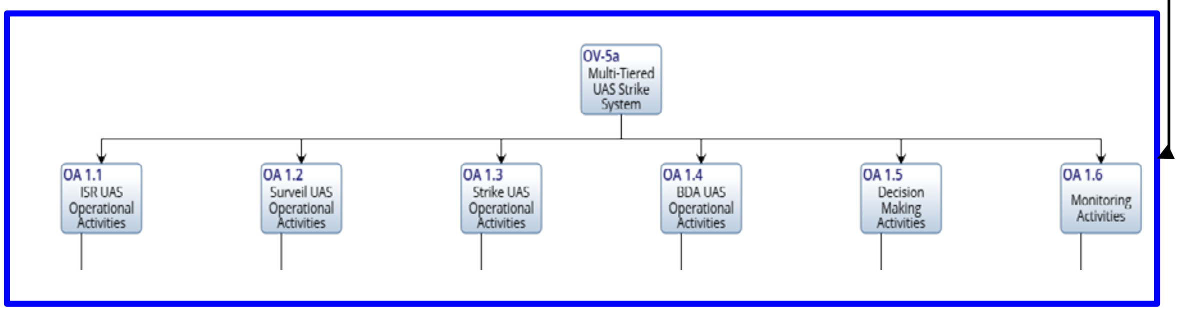
OV 1: High-level Operational Concept Graphic



Implementation of Methodology

OV 5a: Operational Activity Decomposition Tree

Decomposed into 4 levels to provide level of depth required for effective development of EA.

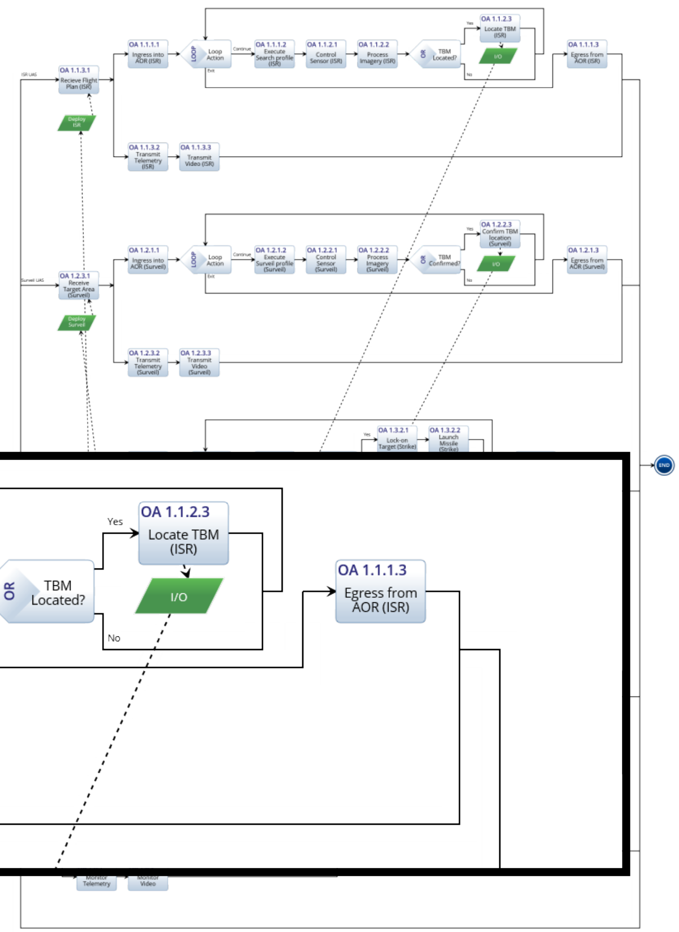


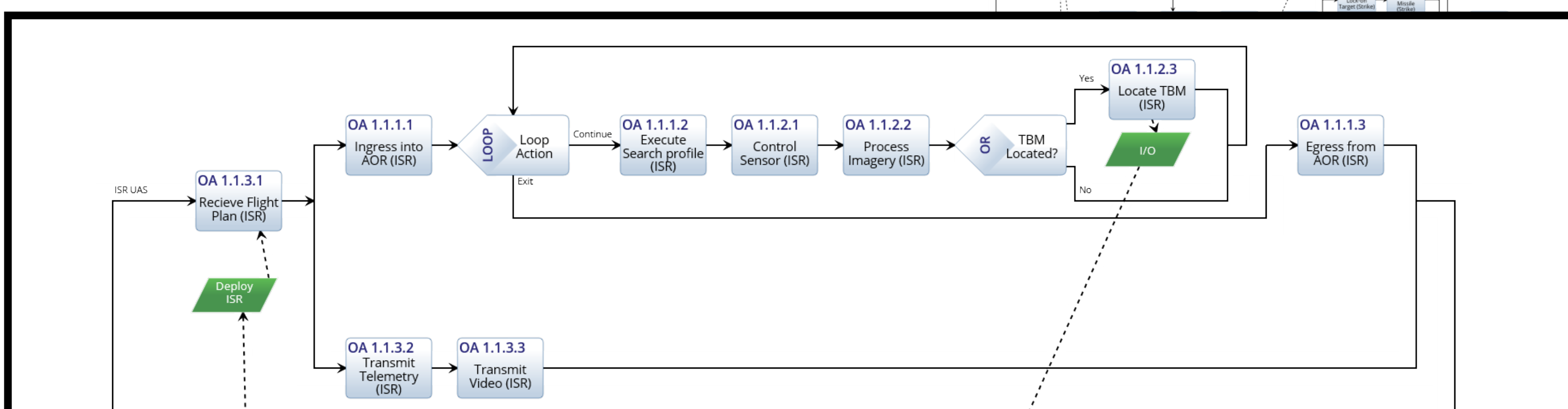
Implementation of Methodology

OV 5b: Operational Activity Model

5 Swim-lanes

- ISR UAS
- Surveil UAS
- Strike UAS
- BDA UAS
- Decision Makers





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Implementation of Methodology

OV 6a: Operational Rules Model

Operational Activity	Rules
Receive Flight Plan (ISR)	Activate by Decision Makers through the Assign ISR UAS activity. Signify the activation of the Multi-tiered UAS SoS,
Assign Surveil UAS	Activated by Decision Makers if TBM Located = TRUE.
Receive Flight Plan (Surveil, Strike or BDA)	Activated when Assign Surveil/Strike/BDA UAS = TRUE The time delay is dependent on Type of C2 and associated distribution.
Ingress into AOR	Activated after UAS Receive Flight Plan. The duration required for Ingress into AOR is dependent on Type of C2 and associated distribution.
TBM Located?	IF TBM located, activate Locate TBM (ISR) activity which updates Decision Makers, THEN Decision makers assign appropriate Surveil UAS through Assign Surveil UAS activity, ELSE continue TBM Located? Task UNTIL search is completed. The probability of TBM located is dependent on the Type of Sensors.
TBM Confirmed?	IF TBM confirmed, activate Confirm TBM confirmation activity which updates Decision Makers, THEN Decision makers assigned appropriate Strike UAS through Assign Strike UAS activity, ELSE continue TBM Confirmed? Task UNTIL search is completed. The probability of TBM Confirmation is dependent on the Type of Sensors.
Target Lock-on?	IF TBM lockon, activate Lock-on Target (Strike) activity that updates Decision Makers, THEN Decision makers activate Send Strike Confirmation activity and Strike UAS executes Launch Missile (Strike) Activity. The Decision makers are updated and activate Assign BDA UAS activity.
TBM Destruction Confirmed?	IF TBM destruction confirmed, the scenario ends, ELSE Decision makers assigned second Strike UAS if scenario dictates. The probability of TBM Destruction Confirmation is dependent on the probability of destruction of the Strike UAS.

Implementation of Methodology

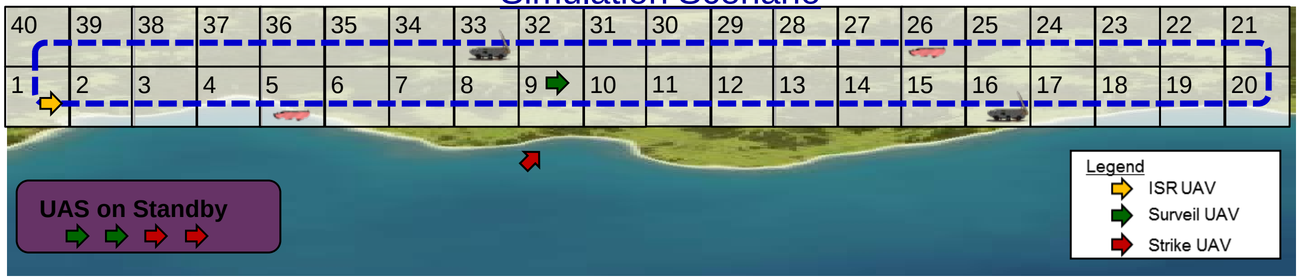
Design Parameters	Variants		Effects
Decision-Capability	Manual C2	Autonomous C2	1. Speed of decision making 2. Quality of decision making
Sensor Capability	Normal Sensor	High End Sensor	1. Target acquisition 2. False Alarm
Number of Strike UAS deployment	1 x Strike UAS	2 x Strike UAS	1. Time-to-strike 2. Target destruction

Implementation of Methodology

Design Parameters	Effects	Affected Activity Nodes	Parameter
Decision-Capability	Speed of decision making	Receive Target Area (Surveil)	Time Delay
		Receive Target Coordinates (Strike)	
		Receive Strike Area (BDA)	
	Quality of decision making	Ingress into AOR (Surveil)	
		Ingress into AOR (Strike)	
		Ingress into AOR (BDA)	
Sensor Capability	1. Target acquisition 2. False Alarm	Locate TBM (ISR)	• Probability of Positive Detection • Probability of False Detection
		Confirm TBM Location (Surveil)	
Number of Strike UAS deployment	Target destruction	TBM Destroyed	Probability of Destruction

Implementation of Methodology

Simulation Scenario



Threat Assessment shows possible TBM deployment within Area of Operations (AO)
During each run, 2 x Targets and 2 x False targets randomly deployed over the 40 grids

Simulation Scenario

- 1 x ISR UAS deployed to conduct ISR [marked by ➪]. Follow anti-clockwise search pattern over AO.
- When potential target are located, small UAS are deployed to Confirm and track target. Simulation limited to 2 x Surveil UAS [marked by ➪].
- Strike UAS deploy to strike target, once target confirmed [marked by ➪].
- Small UAS to conduct BDA [marked by ➪].

Total of 50 runs carried out per cycle, generating 100 targets and 100 false targets.
Total of 50 cycles executed as part of Monte Carlo simulation for each scenario.

Total of 8 Simulation Scenarios

	Centralized Manual C2	Autonomous C2 Operations
Normal ISR Sensor	1 x Strike UAS	1 x Strike UAS
	2 x Strike UAS	2 x Strike UAS
High End ISR Sensor	1 x Strike UAS	1 x Strike UAS
	2 x Strike UAS	2 x Strike UAS

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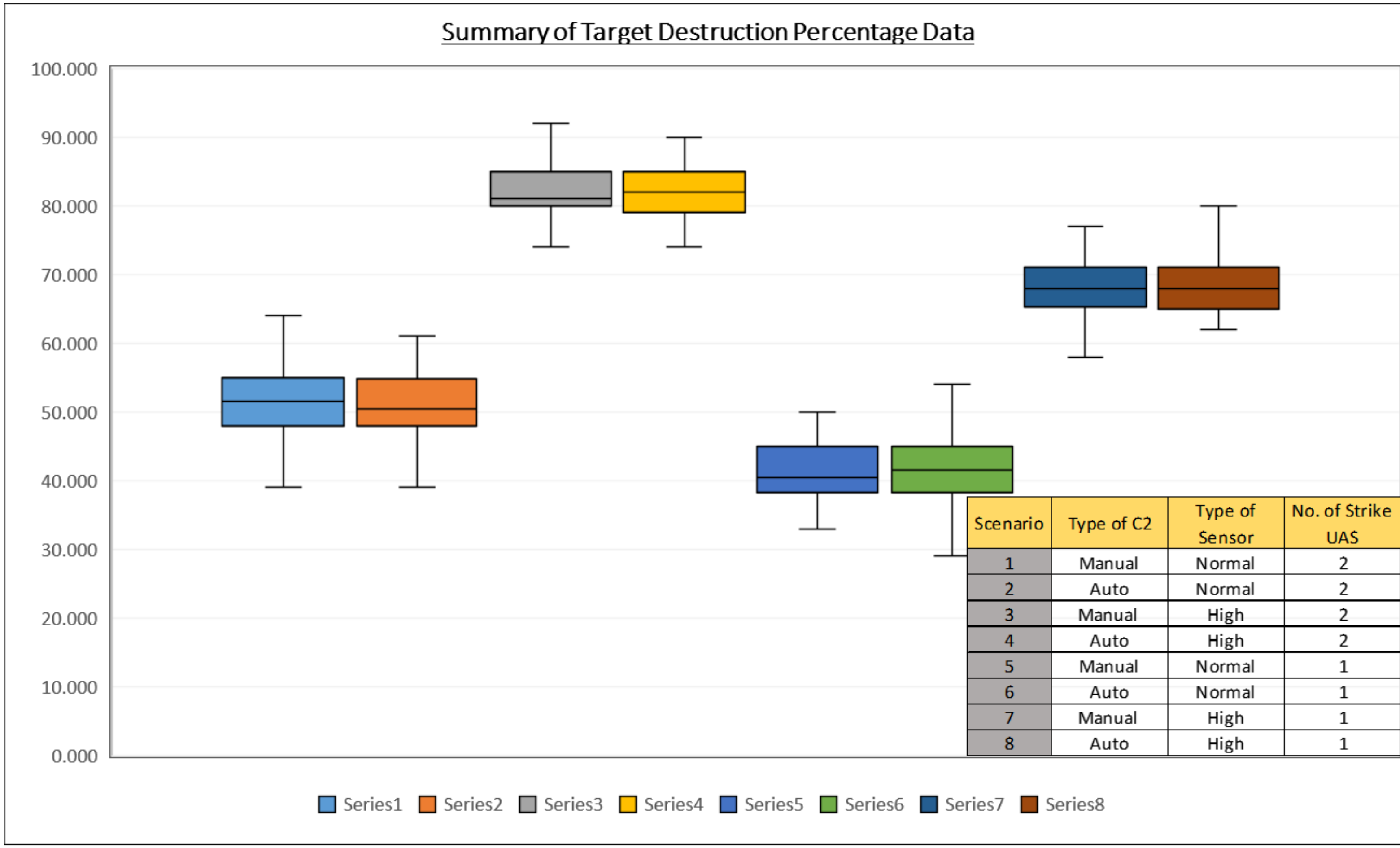
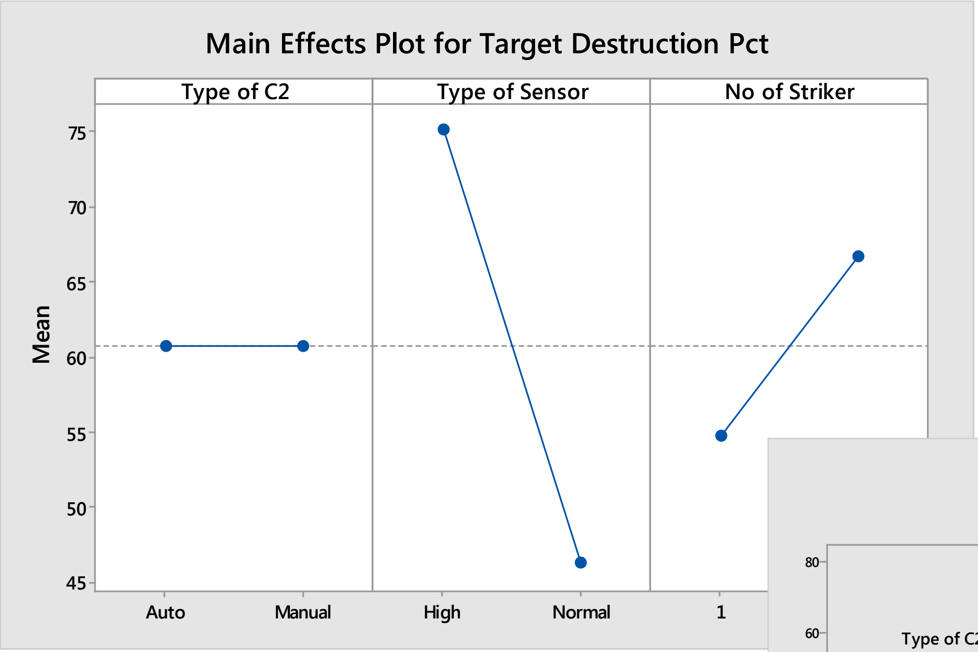
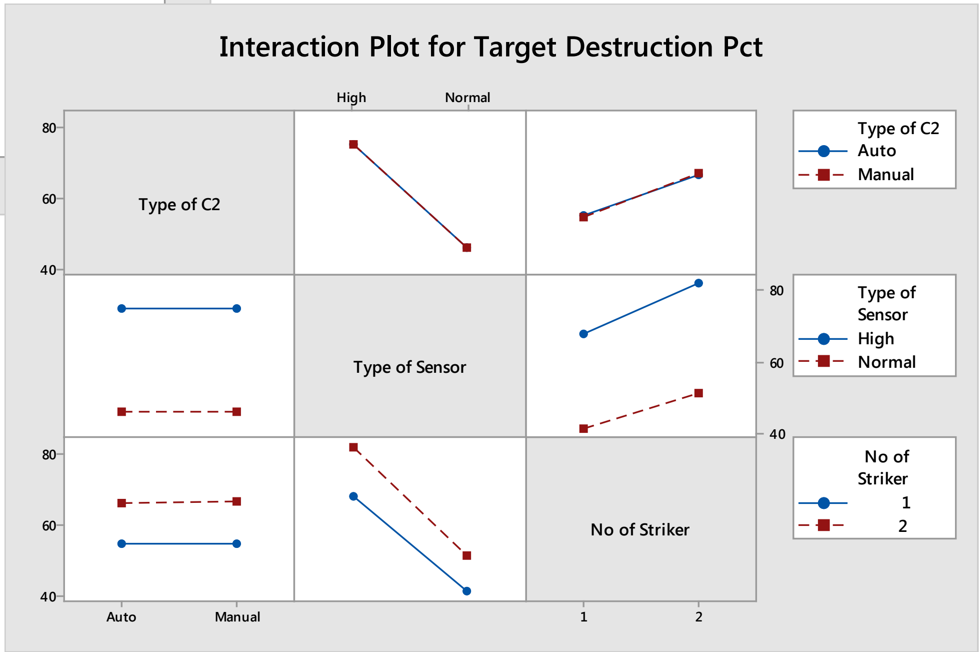
MOP 4: Target Destruction Percentage



Scenario	Type of C2	Type of Sensor	No. of Strike UAS
1	Manual	Normal	2
2	Auto	Normal	2
3	Manual	High	2
4	Auto	High	2
5	Manual	Normal	1
6	Auto	Normal	1
7	Manual	High	1
8	Auto	High	1

MOP 4: Target Destruction Percentage





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MOP 4: Target Destruction Percentage

$$Target\ Destruction\ (Percentage) = \frac{Target\ Destroyed}{Total\ number\ of\ Targets\ encountered} \times 100\%$$

- Simulation confirmed significant impact in difference in Design Parameters:
  - Type of Sensors
  - Number of Strike UAS
- Need to maintain High Resolution Sensors to meet Threshold value.
- Need to maintain both High Resolution Sensors and 2 x Strike UAS to meet Objective values

Summary of Results

MOP	Design Parameters	Simulation Results	Pct Improvement
Target Acquisition Percentage	Type of Sensor	High: **85.5%** Normal: **52.9%**	61.5% improvement over Normal Sensor
False Alarm Percentage	Type of Sensor	High: **0.4%** Normal: **9.6%**	95.6% improvement over Normal Sensor
Time-to-Strike	Type of C2	Autonomous: **91.2 mins** Manual: **100.1 min**	9.8% improvement over Manual C2
	Number of Strike UAS	1 x Strike UAS: **94.6 min** 2 x Strike UAS: **96.9 min**	2.1% improvement over 2 x Strike UAS
Target Destruction Percentage	Type of Sensors	High: **75.1%** Normal: **46.3%**	62.2% improvement over Normal Sensor
	Number of Strike UAS	1 x Strike UAS: **54.8%**	21.7% improvement over 2 x Strike UAS

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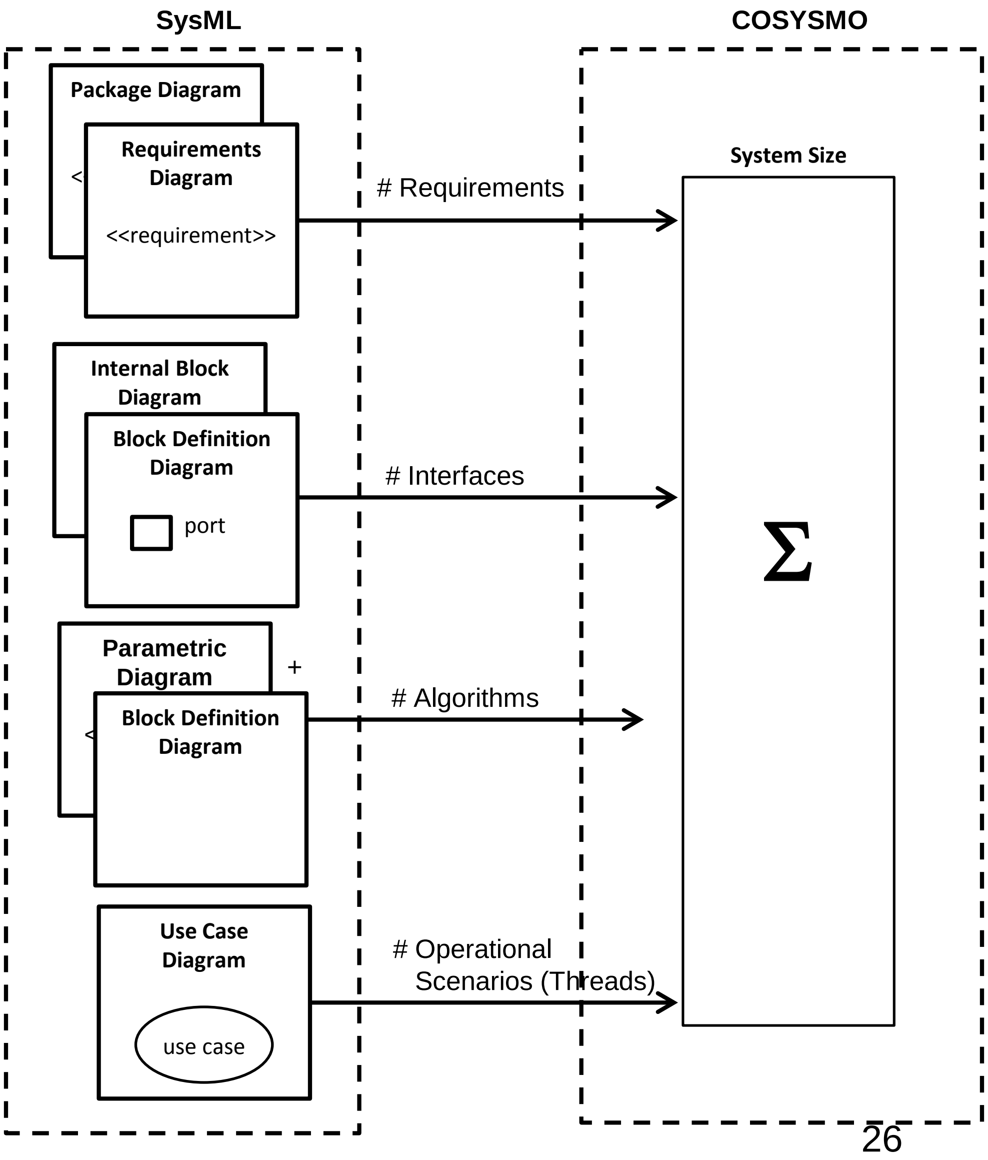
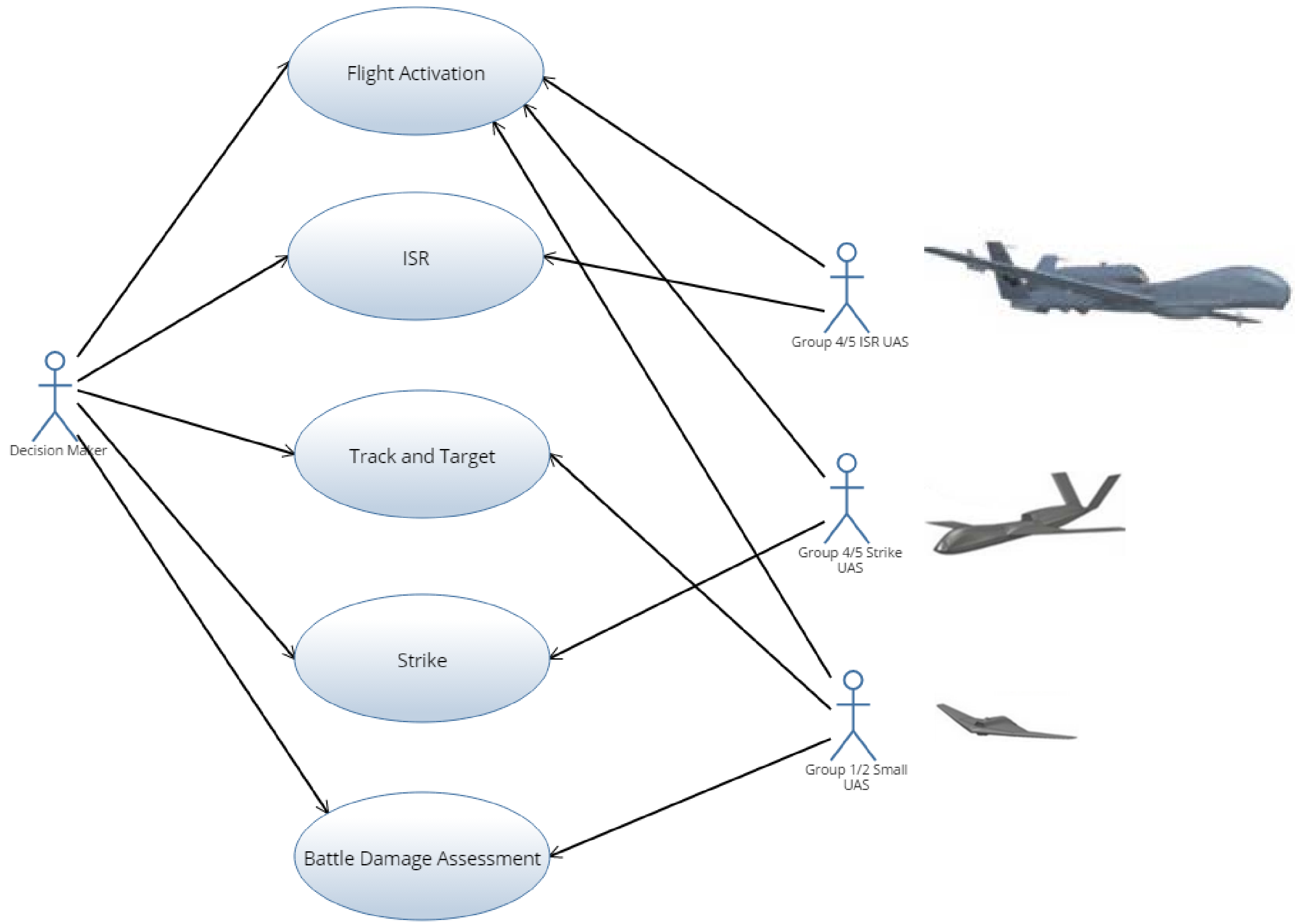
COSYSMO Size Inputs

Size Type	Description
Requirements	The number of requirements for the system-of-interest at a specific level of design. Requirements may be functional, performance, feature, or service-oriented.
Interfaces	The number of shared physical and logical boundaries between system components or functions (internal interfaces) and those external to the system (external interfaces).
Algorithms	The number of newly defined or significantly altered functions that require unique mathematical algorithms to be derived in order to achieve the system performance requirements.
Operational Scenarios (Threads)	Operational scenario threads that a system must satisfy, including nominal and off-nominal threads.

SySML to COSYSMO Mapping

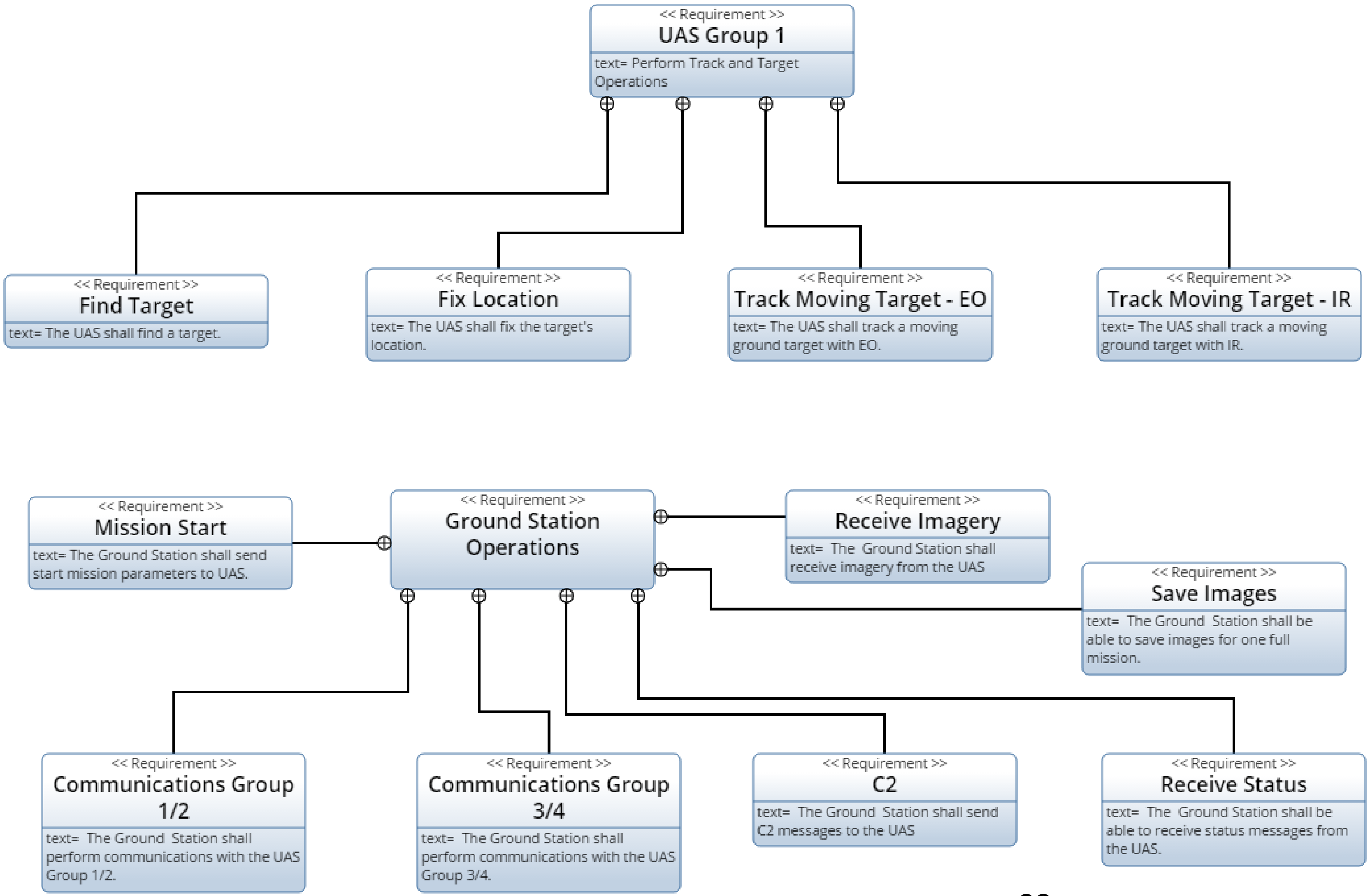


TBM 3-Tier UAS Scenarios (Use Cases with Threads)

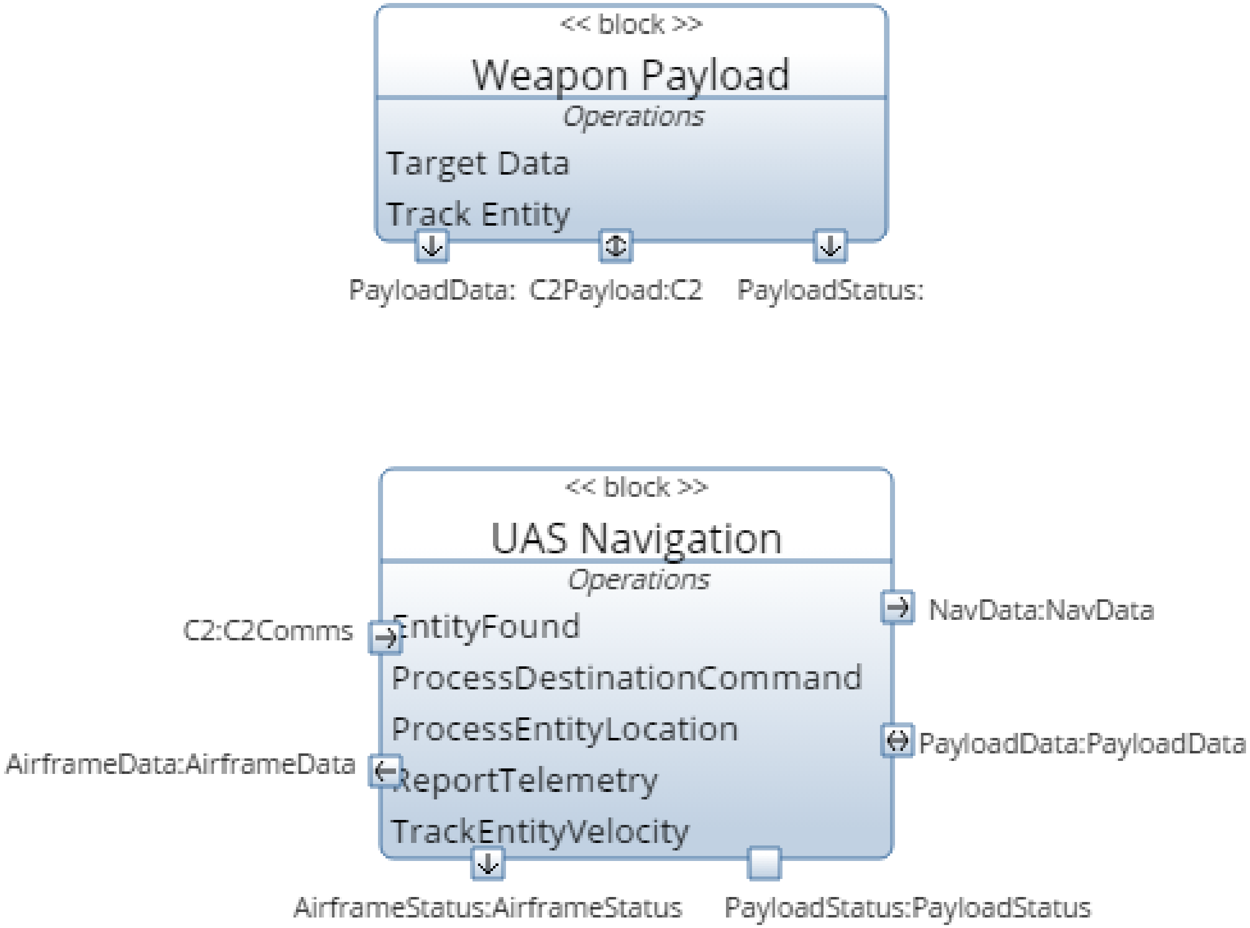


27

TBM 3-Tier UAS Example Requirements



TBM 3-Tier UAS Example Interfaces (Ports)



29

XML Interface Processing


```
...

- <entity id="e4RWJH">
      <name>Flight Activation</name>
      <description/>
      <hidden>false</hidden>
      <locked>false</locked>
      <schemaClassId>C1</schemaClassId>
      <number/>
    - <doubleAttribute schemaPropertyId="P4">
          <doubleValue>0.0</doubleValue>
      </doubleAttribute>
    - <durationAttribute schemaPropertyId="P2">
          <doubleValue>1.0</doubleValue>
          <units>HOURS</units>
      </durationAttribute>
      <labelId>L60</labelId>
    - <simulationData>
          <type>SERIAL</type>
        - <controlStructure id="57bcf94d-cb13-42e5-9e5b-72dfd2a9fc17">
              <type>START</type>
            - <sucessorStructure id="fe494a8a-d37b-44d1-9ffd-614416e6111e">
                  <type>END</type>
              </sucessorStructure>
          </controlStructure>
      </simulationData>

...
```


System Size Input Method File Input Select Input File

UAS scenario 1.xml contains:
Size Type: entity name labelId

use case: Battle Damage Assessment L60
use case: Track and Target L60
use case: Strike L60
use case: Flight Activation L60

...

30

Example COSYSMO Estimate

SysML COSYSMO

System Size Input Method: File Input | Select Input File | *distiller.xml*

	Easy	Nominal	Difficult
# of System Requirements	28	2	1
# of System Interfaces	29	2	1
# of Algorithms	3		
# of Operational Scenarios	1		

System Cost Drivers

Requirements Understanding	Nominal	Documentation	Nominal	Personnel Experience/Continuity	Nominal
Architecture Understanding	Nominal	# and Diversity of Installations/Platforms	Nominal	Process Capability	Nominal
Level of Service Requirements	Nominal	# of Recursive Levels in the Design	Nominal	Multisite Coordination	Nominal
Migration Complexity	Nominal	Stakeholder Team Cohesion	Nominal	Tool Support	Nominal
Technology Risk	Nominal	Personnel/Team Capability	Nominal		

Maintenance Off

System Labor Rates

Cost per Person-Month (Dollars) 10000

Calculate

Results

Systems Engineering

Effort =25.6 Person-months

Schedule = 4.4 Months

Cost = $255525

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Ongoing Results

- 2016
  - Increasing complexities of Multi-Tier UAS missions
  - Baseline case study: TBM 3-Tier UAS SoS
  - Alternative approaches to CONOPS modeled – evaluated against MOEs/MOPs
  - Demonstrated cost model interfaces for SysML and Monterey Phoenix
- 2015
  - Demonstrated architectural tradespace with simpler UAV swarm models for further elaboration in next phase
    - Base models of simple UAV scenarios developed with Innoslate and Monterey Phoenix
  - Innoslate model used to evaluate behavior and performance of architectural variations
  - Initial assessment of Monterey Phoenix (MP) for automatically providing cost information from architectural models.
  - Cost models were integrated in different ways with MBSE architectural modeling approaches and as web services for tool interoperability.

Systems Engineering Cost Model Sizing Correlation in MBSE Tools

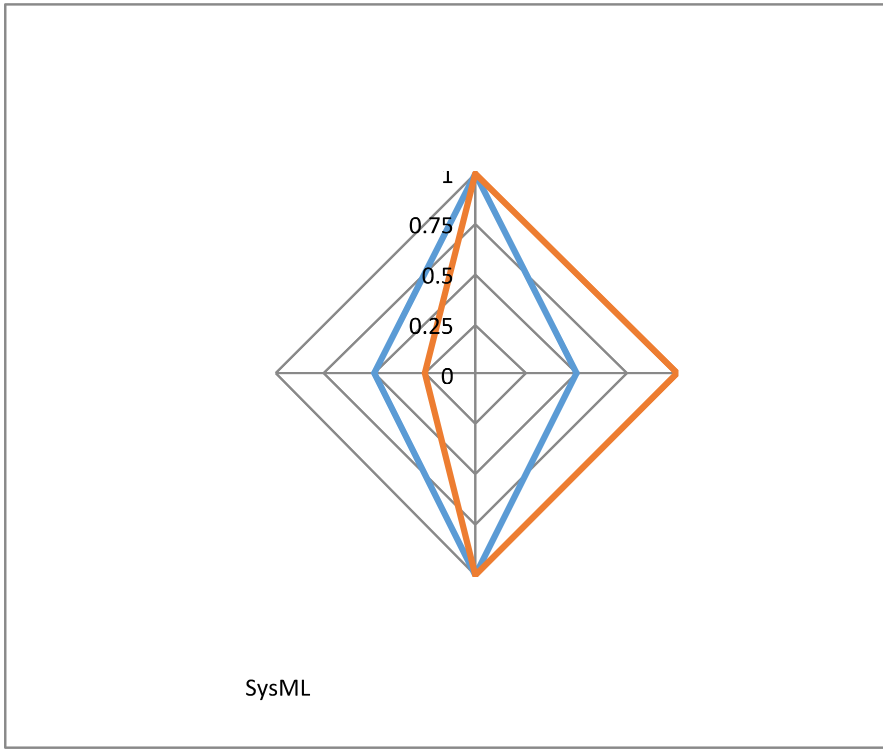
- **Requirements**
  The number of requirements for the system-of-interest at a specific level of design.

- **Interfaces**
  The number of shared physical and logical boundaries between system components or functions (internal interfaces) and those external to the system (external interfaces).

- **Algorithms**
  The number of newly defined or significantly altered functions that require unique mathematical algorithms to be derived in order to achieve the system performance requirements.

- **Operational Scenarios**
  Operational scenarios that a system must satisfy, including nominal and off-nominal threads.

- These size drivers are further weighted for complexity levels.



Conclusions and Future Work

- We have found a strong correspondence between SysML constructs and system size measures of requirements, interfaces, algorithms, and operational scenarios.
  - Still comparing approaches for complex algorithm representations in SysML
  - Require additional attributes for modeling complexity levels of size drivers
- Continue transcribing all UAS architectural variations into SysML for cost tradeoffs to evaluate with other Measures of Effectiveness
  - Expanded mission sets to include heterogeneous UAS teams and more complex scenarios
- Apply method and case study with other MBSE tools, evaluate and compare
  - More detailed modeling to support thread, requirements, functions, algorithms and interface definition
- Develop guidelines with examples for practitioners on modeling decomposition levels of detail
- Collaborate with RT-166 providing shared UAS CONOPS and related SysML artifacts

Completed Student Theses

- Maj. Zhongwang Chua (Singapore AF), "Application of Executable Architecture in Early Concept Evaluation using DoDAF", M.S. Thesis, AFIT, September 2016
- Maj. Ryan Pospisal (DTRA/A9, Kirtland AFB), "Application of Executable Architectures in Early Concept Evaluation", M.S. Thesis, AFIT, December 2015
- Monica Farah-Stapleton, "Resource Analysis Based On System Architecture Behavior", Ph.D. thesis, NPS, September 2016
- CPT Dennis Edwards (USArmy), "Exploring the integration of COSYSMO with a model based system engineering methodology in early trade space analytics and decisions", M.S. thesis, NPS, June 2016

References

- K. Giammarco and M. Auguston, "Well, You didn't Say not to! A Formal Systems Engineering Approach to Teaching an Unruly Architecture Good Behavior", Complex Adaptive Systems Conference, 2013
- M. Auguston and C. Whitcomb, "Behavior Models and Composition for Software and Systems Architecture", ICSSEA 2012, 24th International Conference on Software & Systems Engineering and their Applications, 2012
- R. Madachy, *Systems Engineering Cost Estimation Workbook*, Naval Postgraduate School, October 2015
- D. Jacques and R. Madachy, "Model-Centric UAV ISR Analysis," presented at Systems Engineering Research Center, 7th Annual SERC Sponsor Research Review, Washington, DC, December 3, 2015.
- Peak, R.S. and Lane, J.A., "SysML Building Blocks for Cost Modeling: Towards Model-Based Affordability Analysis", INCOSE International Workshop (IW14), Torrance, California, 2014

Backups

Monterey Phoenix Overview

- Monterey Phoenix (MP) is approach to formal software and system specification based on behavior models
- A view on the architecture model as a high level description of possible behaviors of subsystems and interactions between subsystems
- The emphasis on specifying the interaction between the system and its environment
- The behavior composition operations support architecture reuse and refinement toward design and implementation models
- Executable architecture models provide for system architecture testing and verification with tools
- See http://wiki.nps.edu/display/MP