Mission Engineering – Extending Systems of Systems Engineering to Mission

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The MITRE Corporation

Abstract

34th Annual INCOSE international symposium
hybrid event
Dublin, Ireland
July 2 - 6, 2024

As the INCOSE Visions 2020 and 2035 have emphasized, the application of systems engineering continues to expand to provide the same discipline and systems approaches to capabilities beyond technical systems. Mission engineering is one current example, now an area of emphasis for Defense, but with clear potential across domains.

This presentation discusses the origins and motivations for mission engineering, the current mission engineering methodology and how it leverages systems engineering approaches and tools to address the unique challenges posed by mission engineering, and the relationship of mission engineering to systems and systems of systems engineering. It provides several examples to illustrate the mission engineering application. Finally, the presentation explores opportunities for applying mission engineering beyond defense.

Mission engineering is applying systems engineering to missions – that is, engineering a systems of systems broadly-defined (including organizations as systems) to provide desired impact on broad mission or capability outcomes. Traditionally, systems of systems engineering focus on designing systems or systems of systems to achieve specified technical performance. Mission engineering goes one step further to assess whether the system of systems when deployed in a realistic user environment, achieves the user mission or capability objectives. Mission engineering applies digital model-based engineering approaches to describe the sets of activities in the form of 'mission threads' (or activity models) to needed to execute the mission and then adds information on players and systems used to implement these activities in the form of 'mission engineering threads.' These digital 'mission models' are then implemented in an operational simulation to assess how well they active user capability objectives. Gaps are identified and models are updated to reflect proposed changes which offer candidate solutions, and these are assessed in terms of mission impact.

The presentation will provide examples to illustrate this approach to mission engineering and highlight the benefits and challenges experienced to date, highlighting the INCOSE working groups (particularly SoS, MBSE, Complexity, Socio-Technical Systems, Education and Training) which address areas relevant to addressing the challenges. Finally, while mission engineering has been largely focused on defense, examples of ways this approach can be applied to no defense areas will be explored.

Expanding Vision for Systems Engineering

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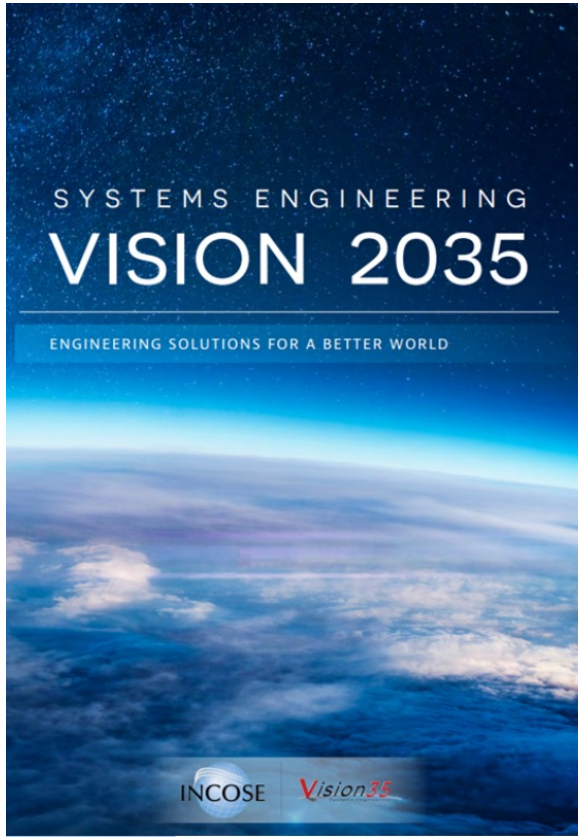
- Mission engineering is one current example, now an area of emphasis for Defense, but with clear potential across domains.



Origins and Motivations for Mission Engineering

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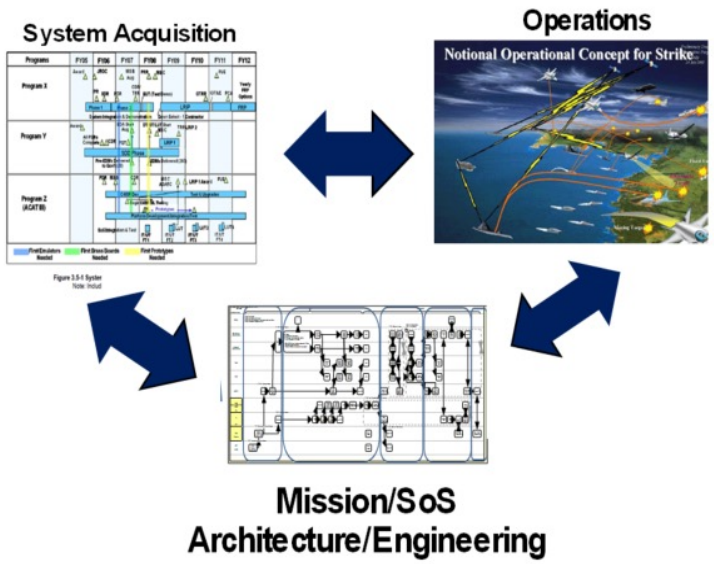
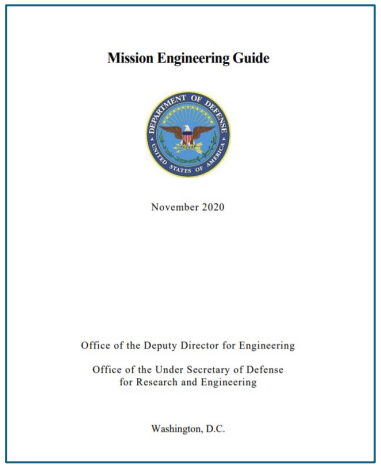


Presentation draws from current US DoD Methodology

- Mission Engineering (ME) describes the application of systems engineering to the planning, analysis, and designing of missions, where the mission is the system of interest. (SEBoK Original)
- Current emphasis on ME comes from US Defense, but is applicable to other domains

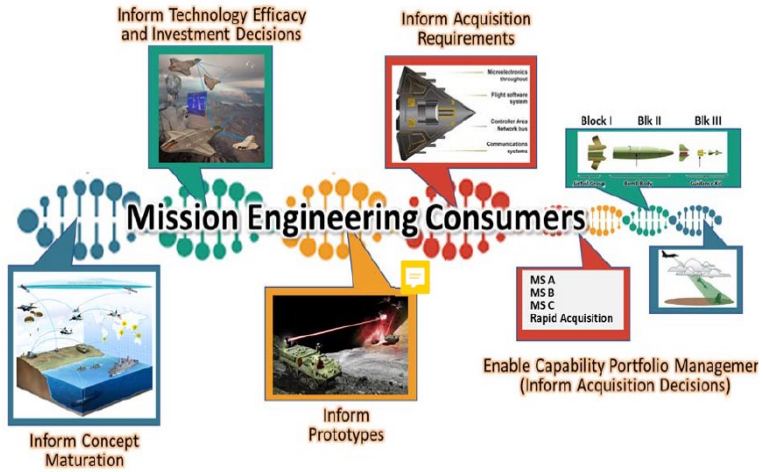

Mission Engineering Guide

November 2020

Office of the Deputy Director for Engineering
Office of the Under Secretary of Defense for Research and Engineering

Washington, D.C.

DoD ME Guide describes the foundational elements and the overall ME methodology, including a set of ME terms and definitions that should be part of the common engineering parlance for studies and analyses



DoD ME Guide, 2.0, Nov. 2023

Why ‘Mission Engineering’?

Proactive: ME …

- Is initiated based on the recognition of the **primary importance of mission** or enterprise outcome
- Addresses the ‘**health**’ of the ‘end-to-end mission’ to identify gaps, issues or opportunities to maintain or enhance mission outcomes
- May lead to **the identification of gaps or issues** which may be affecting the mission outcomes or may do so in the future (risks)

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Reactive: ME …

- Is triggered by **issues or gaps** identified in the mission performance or an element supporting the mission
- Identifies the **sources** of mission gaps or the **effects** of problems with systems or other elements on mission outcomes
- Assesses the **impact of possible changes** to address issues or gaps on other elements or systems supporting the mission

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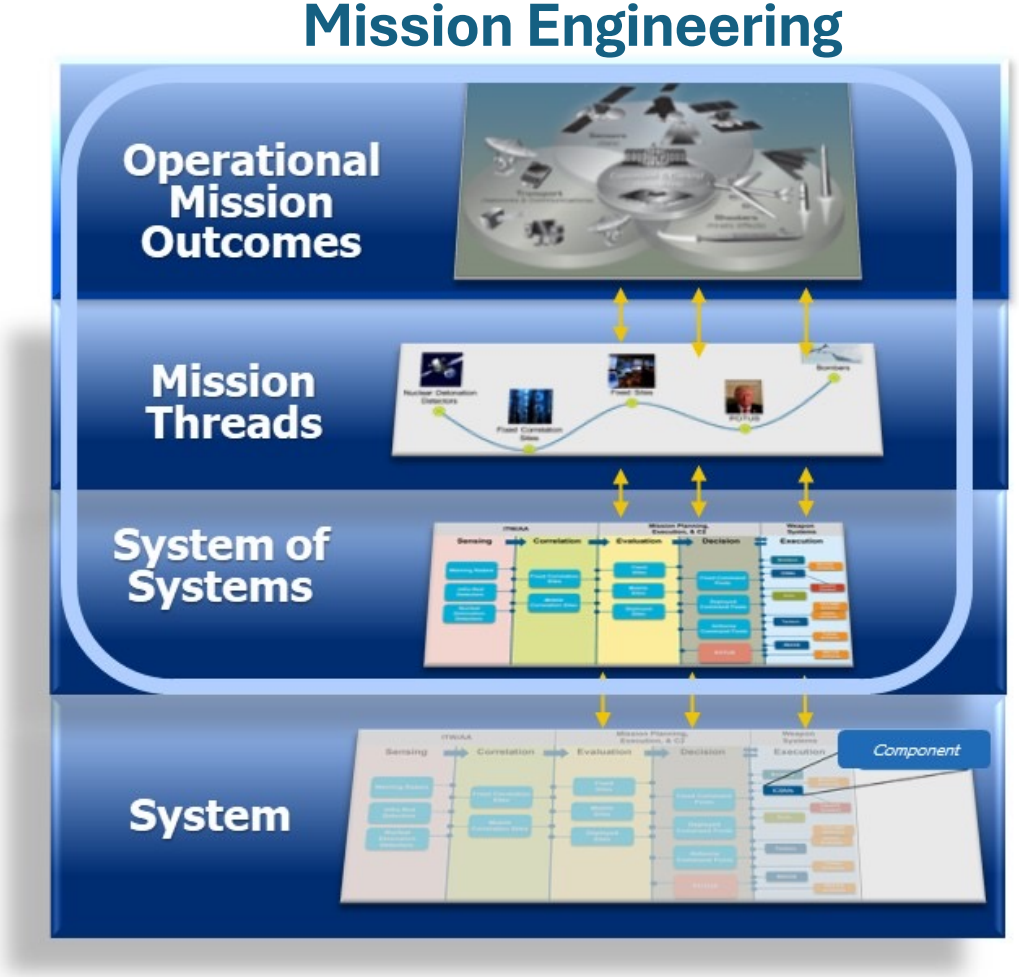
Opportunistic: ME…

- Responds to a potential **new** technology or other **change** which offers potential mission advantage technology
- Addresses the question of the **impact on mission outcomes** by introducing new technology, systems or processes

Mission Engineering In Context

- Systems engineering traditionally addresses systems
- Today systems are typically employed as part of a larger system of systems (SoS) which provides user 'mission' capability
- Mission engineering addresses the ability of the SoS to perform critical actions (aka 'Mission Threads') needed to achieve mission outcomes
- Mission threads are the construct which links systems and technology deployed as systems of systems to warfighting mission outcomes
  - Mission Threads (MTs) define the essential sequence of activities in the execution of the mission – key elements of the operational mission architecture
  - Mission Engineering Threads (METs) are used to define are used to define the systems / SoS in the execution of the mission activities
- MTs/METs link systems engineering to operational outcomes



Dahmann, 2019

Current Mission Engineering Methodology

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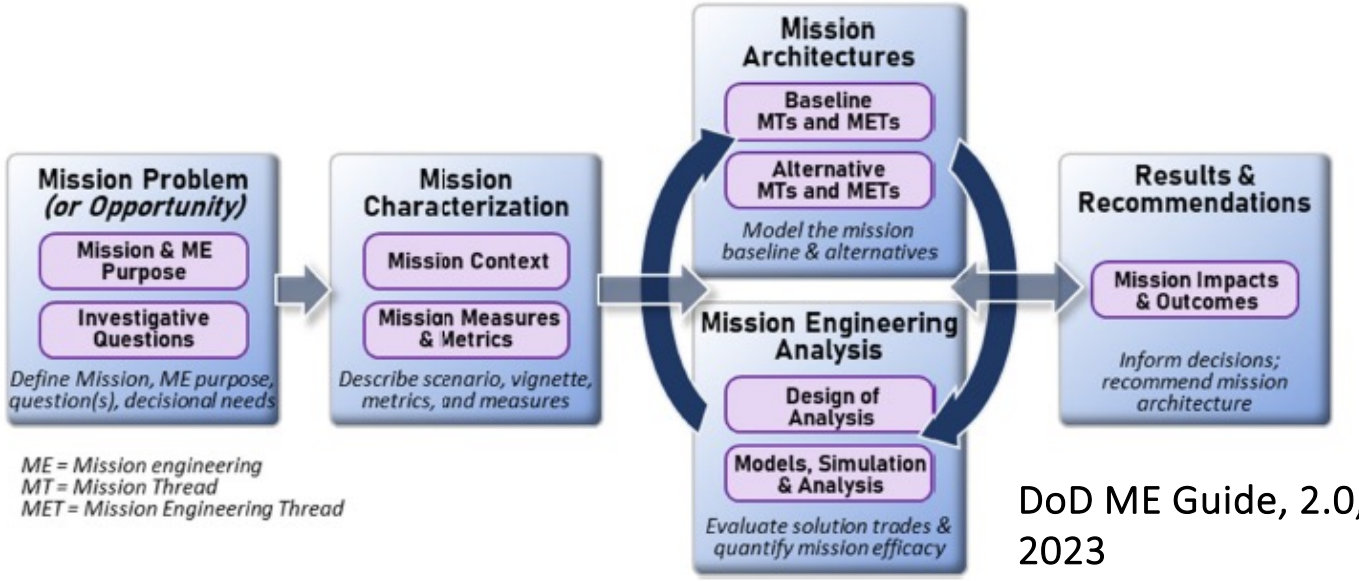

DoD ME Guide, 2.0, Nov. 2023

Current Mission Engineering Methodology

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Problem Statement

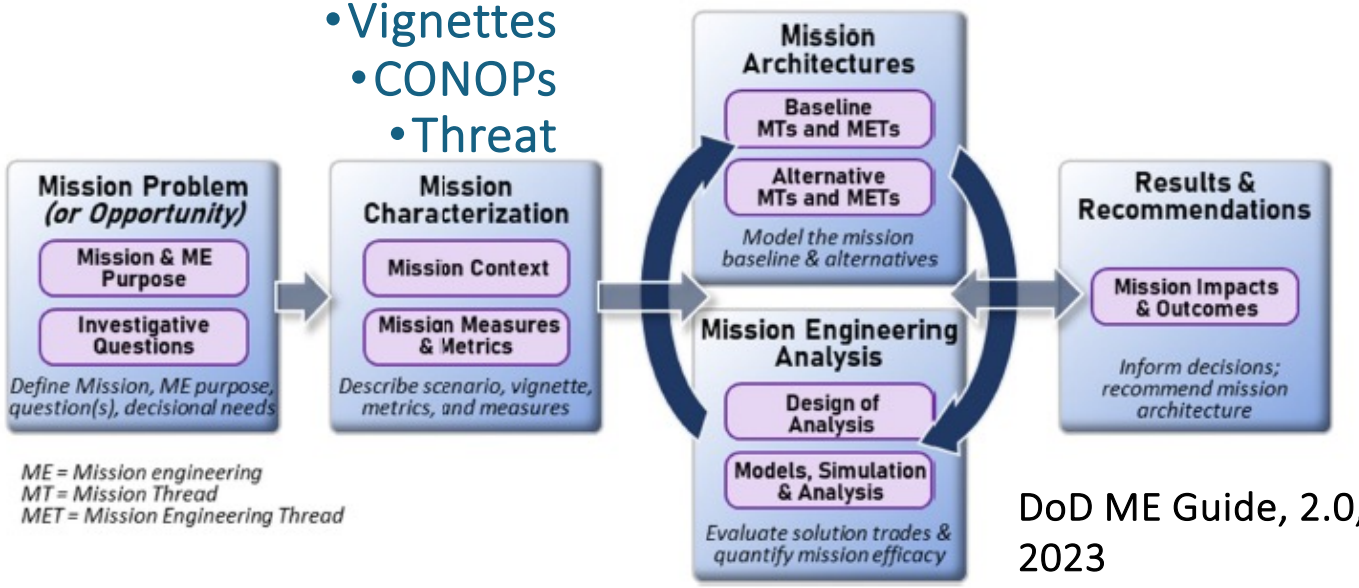
- Questions
- Gaps
- Concepts

Mission Context

- Scenarios
- Vignettes
- CONOPs
- Threat

Develop MTs & METs

- Baseline
- Alternative



DoD ME Guide, 2.0, Nov. 2023

Results

- Document
- Inform decisions

Mission Metrics

- Define mission outcome measures

Operational Analysis

- Implement baseline
- Implement alternatives
- Assess impact on mission metrics

Current ME Digital Engineering Implementation

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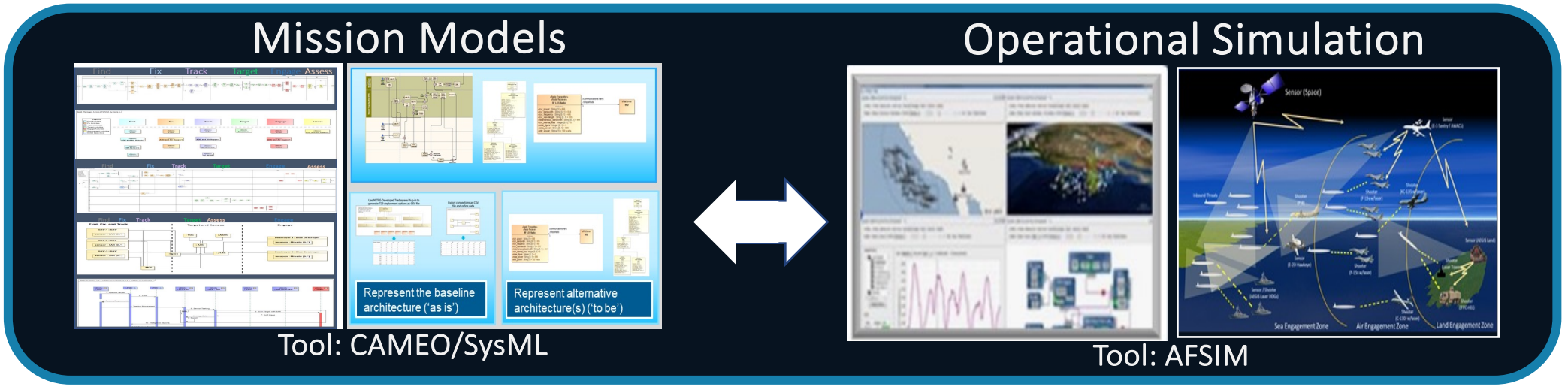

Baseline

- Digital representation of the baseline Mission Threads (MTs) scenario independent activities and Mission Engineering Threads (METs) adding scenario specific organizations and activities

Alternatives

- Updated MTs and METs to include new Concepts with associated changes

MISSION THREAD ALIGNMENT [TRACEABILITY]

- Representation of the baseline MTs/METs within scenario including threat, systems' attributes and behaviors – conduct baseline analysis of mission metrics
- Update the systems' attributes and behaviors as specified in concepts and assess impact on mission metrics

QUANTITATIVE ANALYSIS [MISSION METRICS – OUTPUTS]

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Baseline Mission Thread – Joint Targeting

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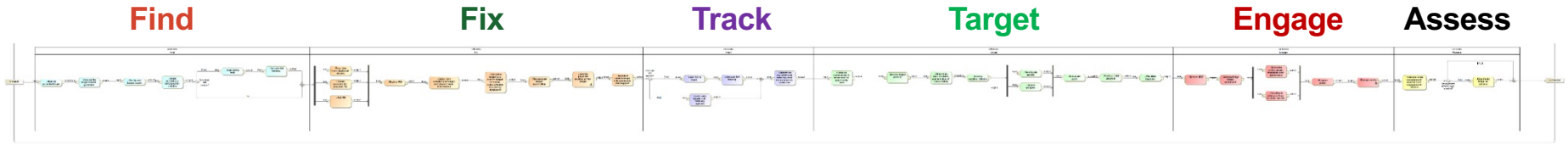
Mission Thread – lays out the set of actions needed to accomplish the mission



Unclassified model

- This core mission thread provides context for representing the activities and systems

Views of Digital Mission Models

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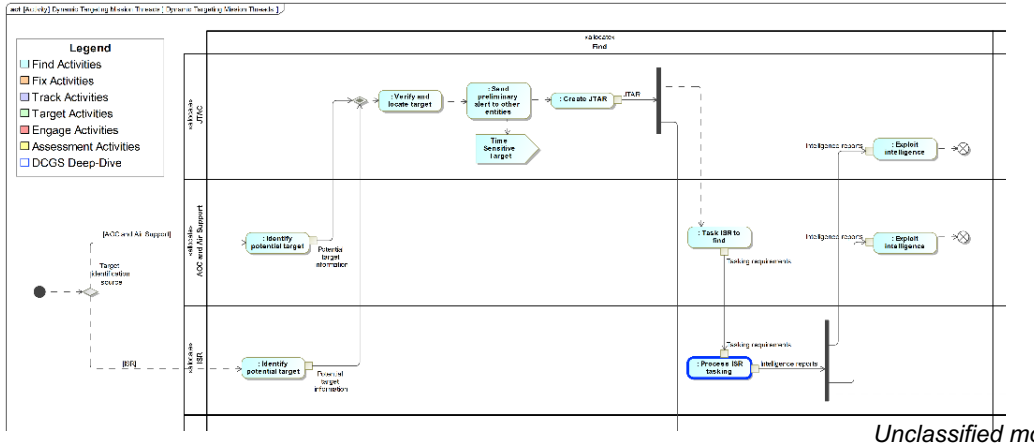
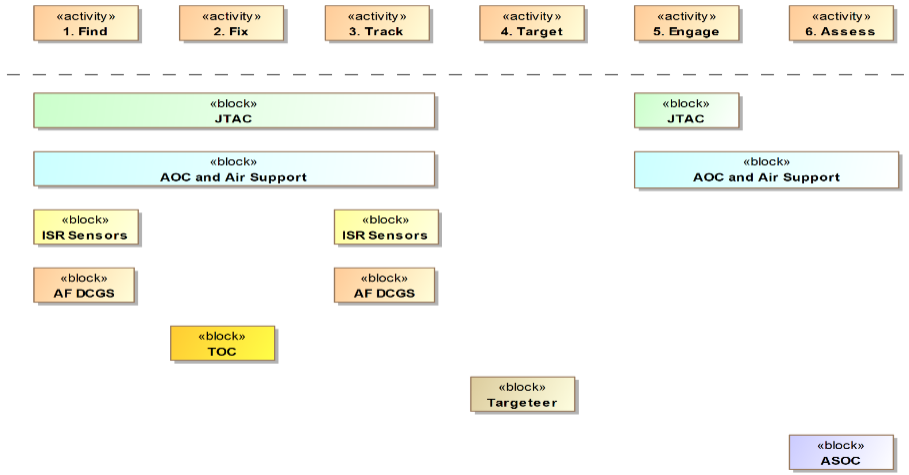
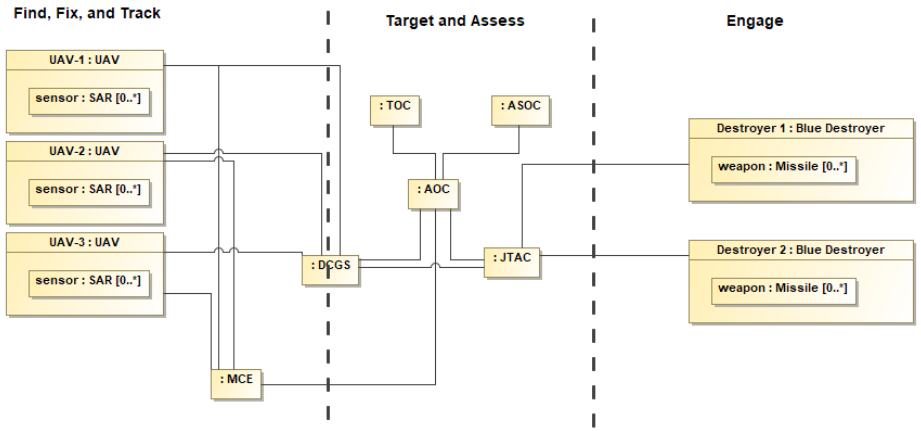


Unclassified model

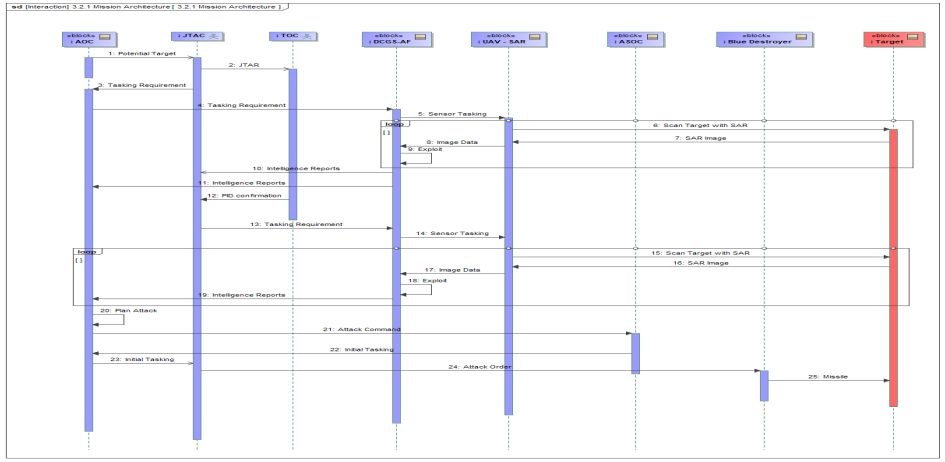
Apply systems and organizations to base MT



Systems employed to execute MT activities



MET: End-to-end flow of systems interaction



MET: Sequence of system to system interactions

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Digital Mission Architecture Development Process

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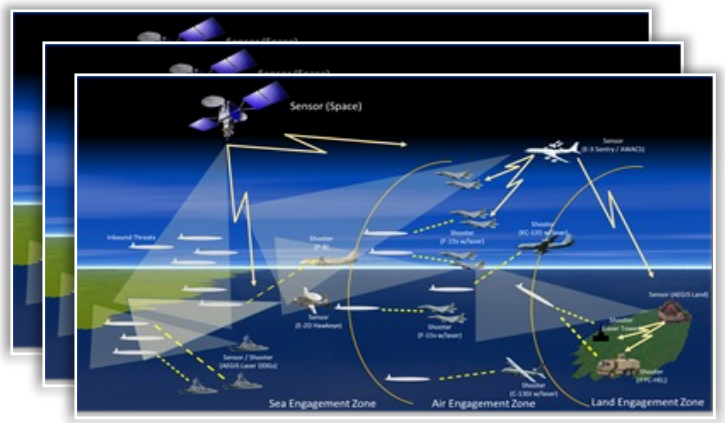
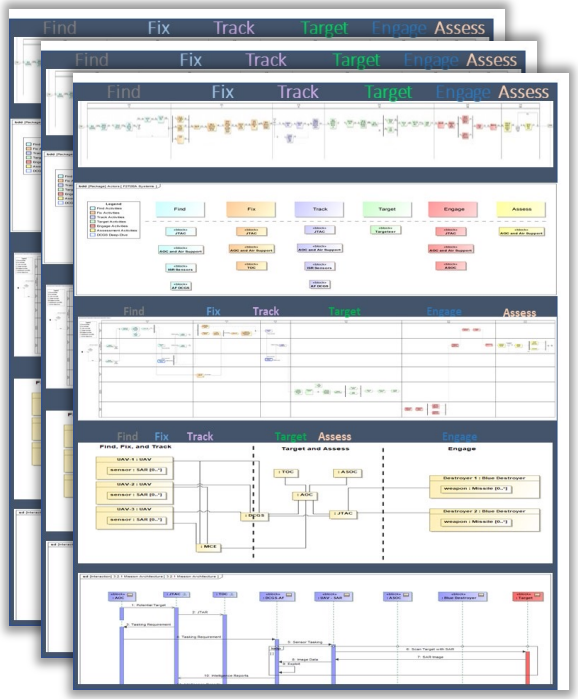
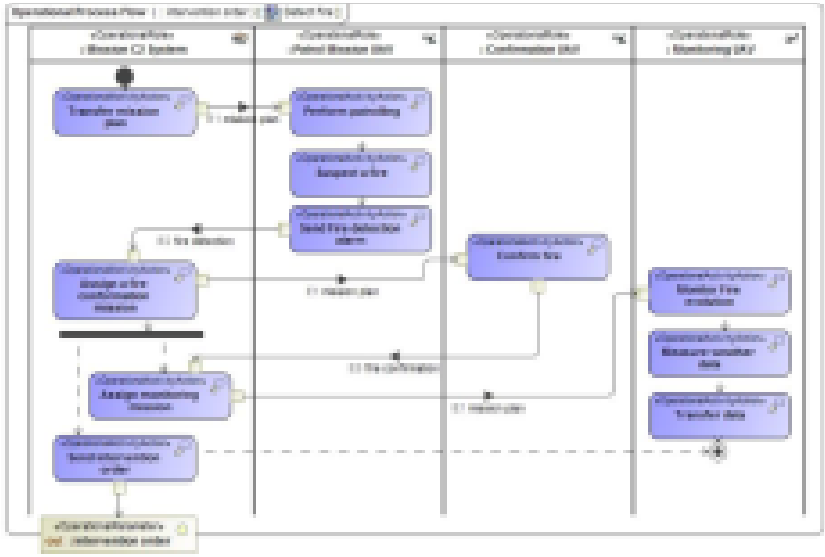


Graphic or Textual Source Depictions of Mission



Digital Representations of Individual Effects Chains (METs)



Integrated Effects Web

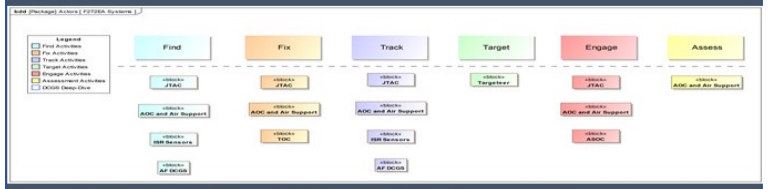
ME Digital Mission Models

- How are activities implemented in this scenario?
  - Identify mission threads and develop mission engineering threads (Baseline METs)
- How will these change when we introduce new concepts?
  - Update the baseline METs to add concepts (Alternative METs)

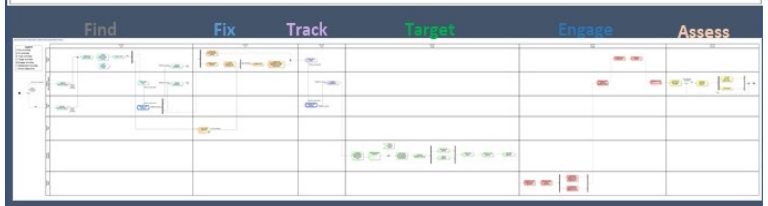
Baseline MT and MET Models

Activities

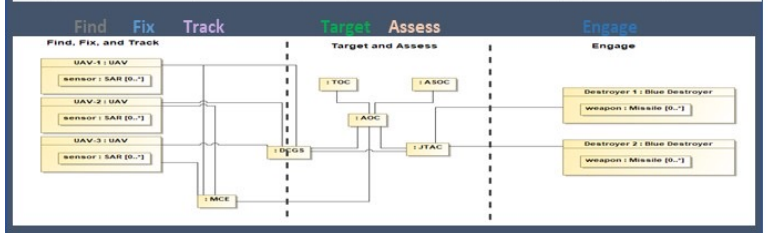
Systems supporting Activities



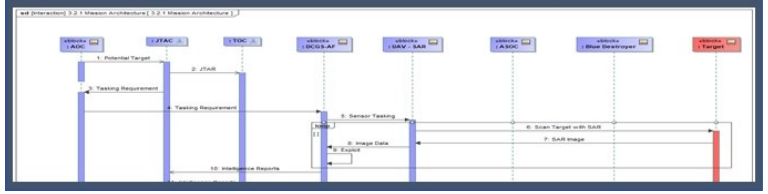
Organizations executing activities



End-to-end flow of SoS



Sequence of actions



New Concepts

What new activities are now needed to execute the mission?

What new systems does the concept require?

What different organizations are now part of mission execution? Which activities do they execute?

How does this change the execution of the End-to-end (E2E) SoS?

How does this change the sequence of actions?

Mission Engineering Workflow

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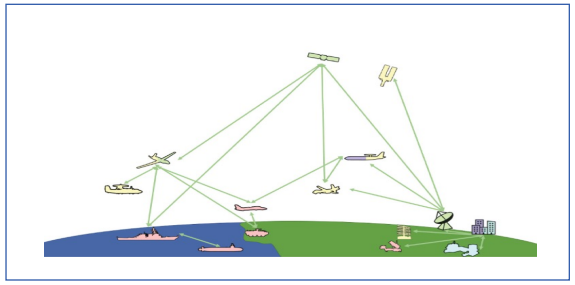
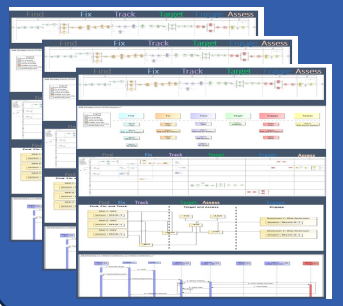
Obtain Mission Thread Source Information (i.e., OPLAN) For selected Scenario

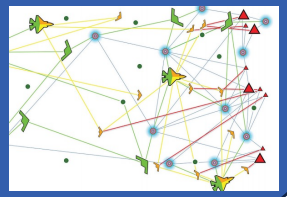


Informs

Baseline Mission Architecture - METs



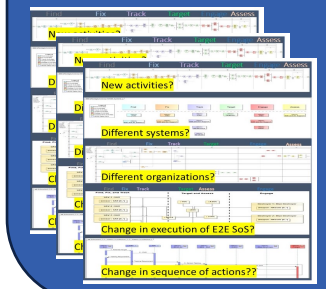
Baseline Effects Web



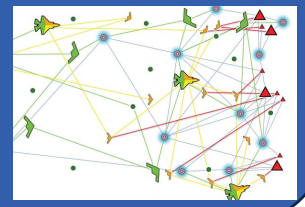
Represented in AFSIM

Provides basis for

Updated Mission Architecture Alternatives Represented as Changes in the METs

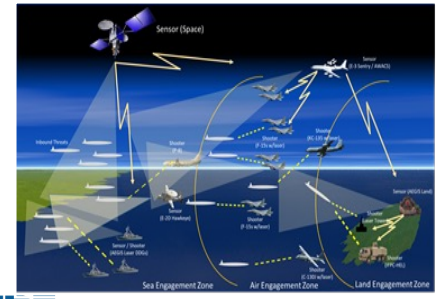


Alternative Effects Web



Represented in AFSIM

Alignment with Scenario Documentation (i.e., JFOS)



Informs

Analysis of Baseline Compared to Concept on Mission Outcome Metrics In Selected Scenario

Baseline

Operational Mission Analysis

Alternative

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Overview of Operational Mission Analysis

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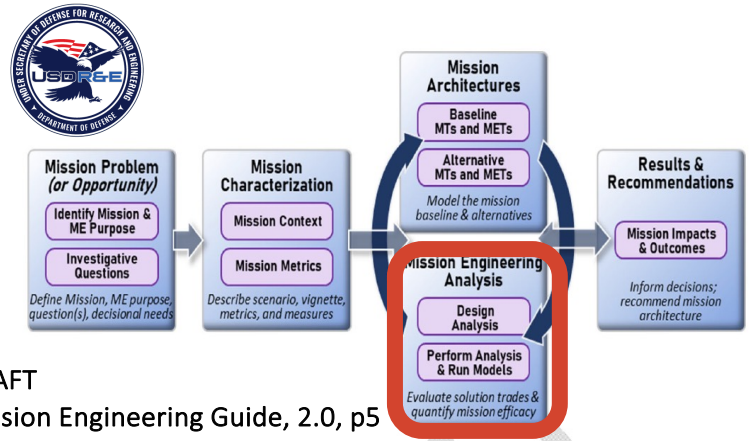

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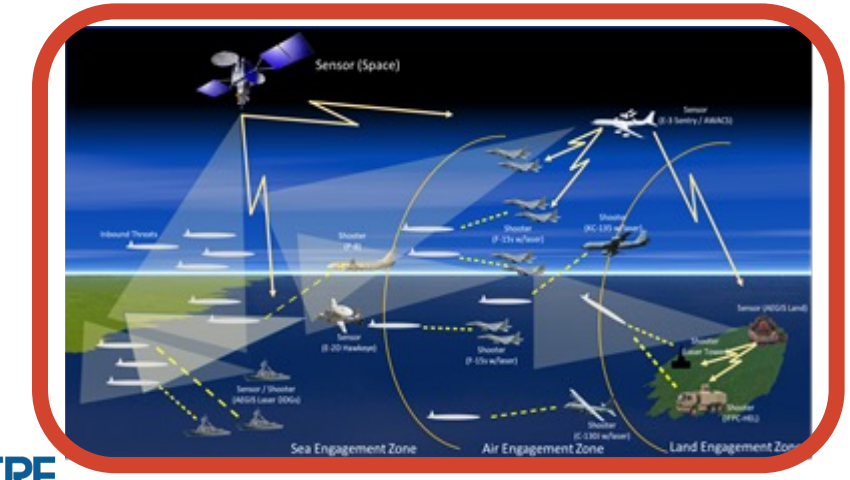
Mission Engineering Guide, 2.0, p5



- MTs and METs provide blueprint for operational analysis
- Represent baseline in the operational context for analysis and generate the baseline mission metrics
  - Operational laydown
  - Threat representation
  - Systems performance and behavior
- Represent the changes made in the baseline to represent each concept to:
  - Compute the impact on mission metrics of the concept
  - Compute metrics on the performance of the particular concept as represented in the scenario and analysis
- Use appropriate analysis tool (e.g., AFSIM)

Operational analysis is key to Mission Engineering – provides quantitative assessment of mission outcomes

ME Analytical Approach

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- How is the mission executed in baseline case? (mission and supporting metrics)
- How is the new concept to be implemented in the scenario (across Mission Engineering Threads)?
- What is the objective of the concept (e.g., increased ISR coverage, increased weapons platform survivability)? How is this expected to impact the mission and supporting metrics?
- Under what conditions do we expect the concept to impact mission outcomes (e.g., day without space)?
- What are the concept dependencies on baseline (organic) systems?
- What is the performance of each element in the concept?

Drive the run matrix

Example Run Matrix

Case	
Baseline A - Uncontested (run once)	Do nothing to respond to adversary *(Green only)*
Baseline B - Baseline Scenario (run once)	Implement the baselines METS
Baseline C - Tailored Scenario (each concept)	Conditions addressed by concept (e.g., no space)
Alternative 1 - Baseline Scenario (B) with New Concept Excursions to explore tradespace	Concept implemented in updated METs (specific for each Concept)
Alternative 2 - Tailored Scenario (C) with New Concept Excursions to explore tradespace	

Comparative results provide basis for recommendations

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Expanding on Current Mission Engineering Approach

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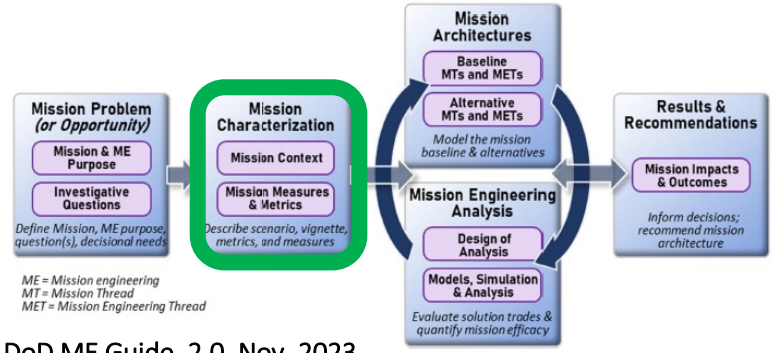

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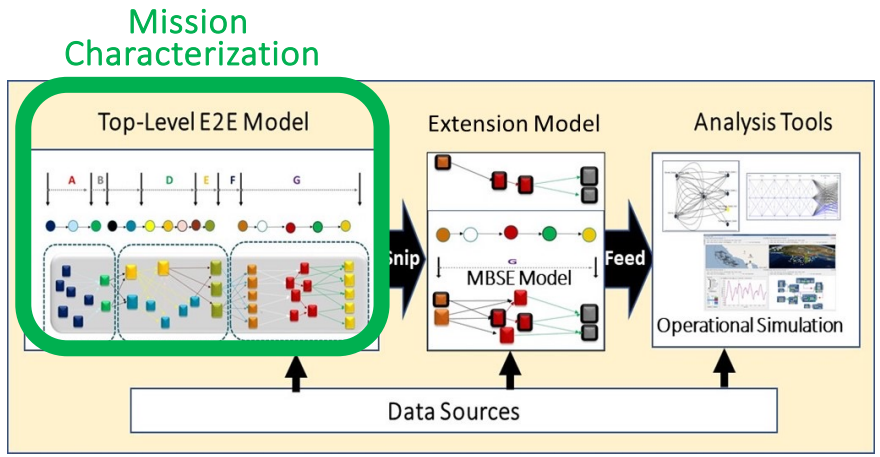

Add citation

- Current DoD ME approach assumes an existing mission architecture as the starting point for ME
  - The current or baseline architecture is used as point of comparison /trades with alternatives
  - Based on view that in most cases these exist or are developed by operational users
- However, increased interest in applying mission engineering to development of future or new architecture
  - Operational Planning, Future Force Design, Other ….
  - It has been argued that just like SE includes mission analysis, ME should include mission characterization
- There are existing approaches which would support use of mission level models as the basis for developing specific scenario/vignette METs for ME analysis

-- Example --

Reactive:

Integrated Air/Missile Defense

Mission:

Defend against air and missile attack

How can insertion of technology impact mission outcome?

To assess value requires understanding

- *In the selected scenario, how would blue forces implement a defense against a prospective enemy air and missile attack?*
- *The impact on the outcomes: does the blue force approach successful stop the enemy attack?*

Mission Related Data

- Mission (Engineering) Thread(s)
  - Descriptions of blue force end to end mission tasks and systems (MTs/METs)
- Scenarios
  - Descriptions of the red scenario
- External Environment factors
  - Geographic, physical, electronic, legal factors affecting the mission
- Measures of SoS performance and mission effectiveness

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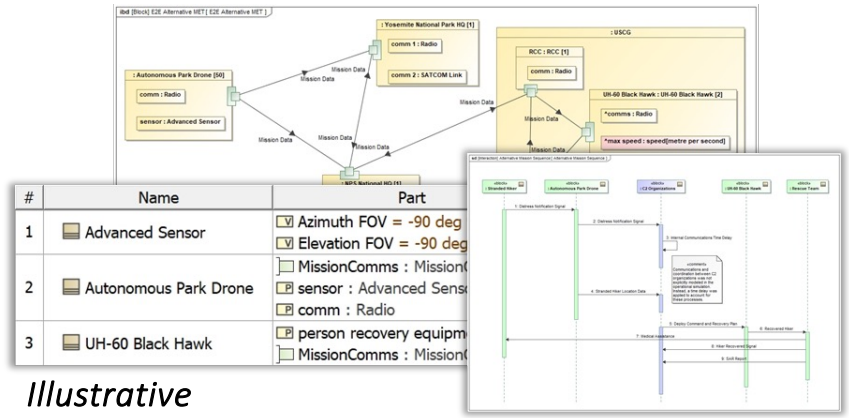
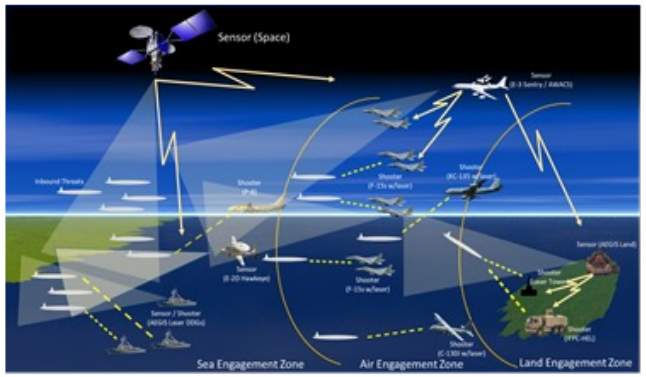
- Joint engagement –Find-Fox-Track-Target-Engage (F2T2EA) (Mission METs/Kill Web)
- Operational outcome measures, e.g.
  - Blue force losses over time



Illustrative



-- Example --

Opportunity:

Biometrics Technology

Mission:

Airport safety through passenger screening

How can insertion of technology impact mission outcome?

To assess value requires understanding

- *How would technology be integrated into the current SoS and the passenger screening sequence of actions ('mission engineering thread')?*
- *What is the impact on the outcomes: do we increase the likelihood of identifying risks?*

Mission Related Data

- Mission (Engineering) Thread(s)
  - Descriptions of activities and dependencies, systems and actors
- Scenarios
  - Descriptions of the scenario context(s) for executing mission
- External Environment factors
  - Current and projected external environment (e.g. threat, legal, social) actions and behaviors
- Measures of SoS performance and mission effectiveness

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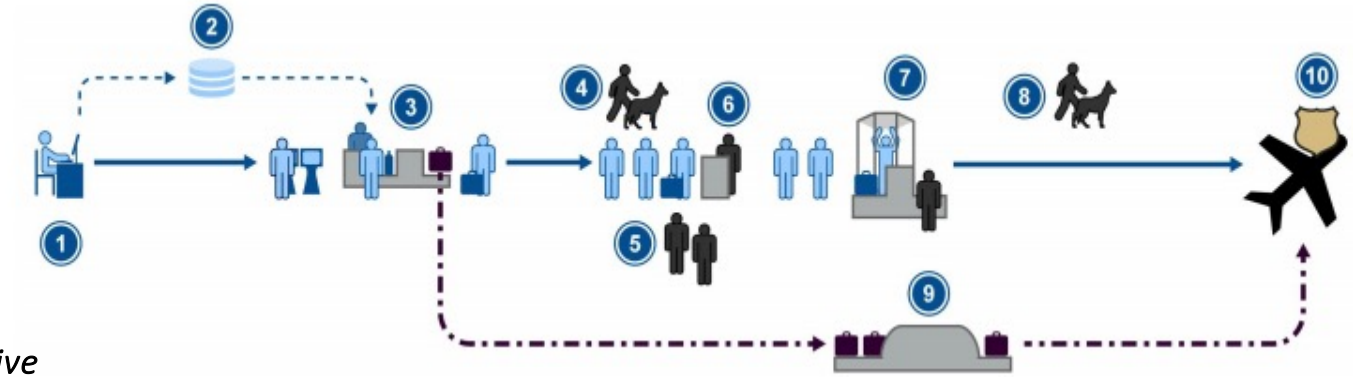
- Passenger screening mission engineering thread (MET)
- Operational outcome measures, e.g.
  - Time through queue
  - Average wait time at checkpoints
  - Screening 'success rate'



Illustrative

INCOSE Relationships – ME and INCOSE Working Groups

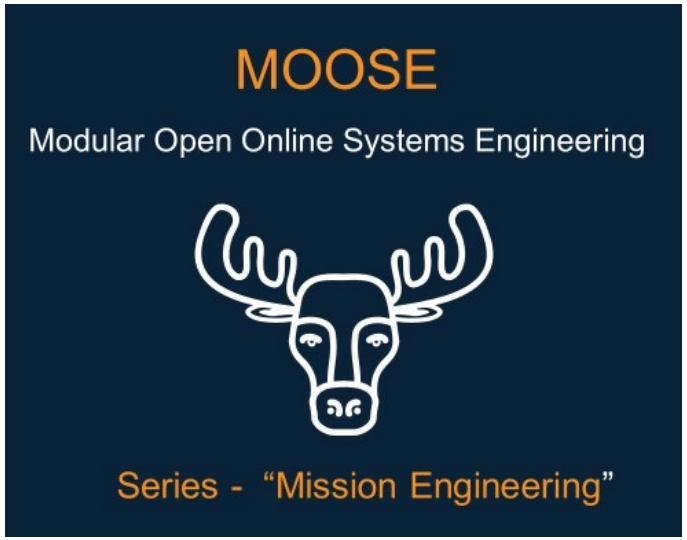
- ME draws on technical approaches across systems engineering
  - Systems of Systems
  - MBSE/Digital Engineering
  - Architecture
  - Complex Systems
  - Decision Analysis

- ME could be applied across different domains
  - Critical Infrastructure
  - Transportation Defense
  - Smart Cities
  - Automotive
  - Defense Systems
  - Healthcare
  - Space Systems
  - Information Communications Technologies

More information?

Mission Engineering Series Available on MOOSE

MITRE's Modular Open Online Systems Engineering Initiative

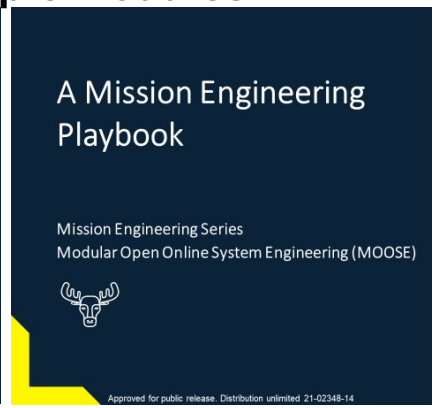


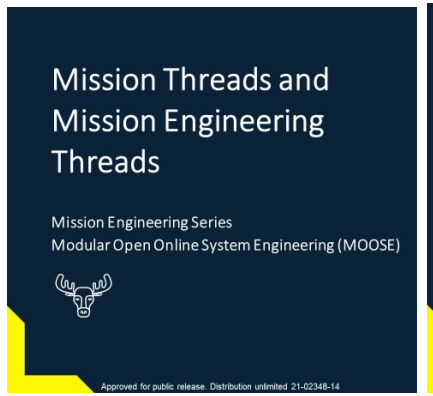
Modular Online Open SE Education and Training (MOOSE) is a MITRE initiative to make Systems Engineering material available in a more accessible way.

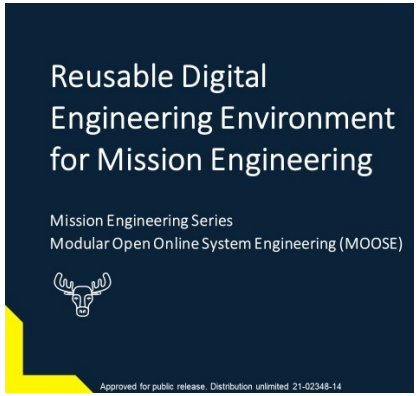
The MOOSE concept is to offer an on-demand, self-paced learning experience based on sets of short course video modules, which will each focus on a specific topic and take 30 to 60 minutes to complete.

MOOSE is open to the broad SE community, so share this with sponsors and colleagues. Link for external access is https://mitre.tahoe.appsembler.com/

Example Modules







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