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.

Mission Engineering Guide

Office of the Under Secretary of Defense for Research and Engineering
3030 Defense Pentagon
Washington, DC 20301
osd.r-e.comm@mail.mil
https://ac.cto.mil/engineering

Approved by

MAGNUS.SANDRA.H.1567971763 Digitally signed by MAGNUS.SANDRA.H.1567971763 Date: 2020.11.30 14:14:08 -05'00'

Sandra H. Magnus
Deputy Director for Engineering
Office of the Under Secretary of Defense for Research and Engineering

Date

Mission Engineering Guide Change Record

Date	Change	Rationale

This page is intentionally blank.

CONTENTS

Figures

Tables

1 INTRODUCTION

1.1 Guide Objectives

This guide describes the foundational elements and the overall methodology of Department of Defense (DoD) Mission Engineering (ME), including a set of ME terms and definitions that should be part of the common engineering parlance for studies and analyses, building upon already accepted sources and documentation from the stakeholder community in the Office of the Secretary of Defense (OSD), Joint Staff, Services, and Combatant Commands. The guide will:

- Describe the main attributes of DoD ME and how to apply them to add technical and engineering rigor into the ME analysis process;
- Enable practitioners to formulate problems, and build understanding of the main principles involved in performing analysis in a mission context; and
- Provide users with insight as to how to document and portray results or conclusions in a set of products that help inform key decisions.

The Office of the Under Secretary of Defense for Research and Engineering (OUSD(R&E)) prepared the guide for both novice and experienced practitioners across DoD and industry. The guide is a living document that will evolve in parallel with engineering best practices. The authors will continuously mature the guide to include relevant information to conduct mission-focused analyses and studies in support of maturing new joint warfighting concepts, warfighter integration, and interoperability of systems of systems (SoS), as tools and infrastructure evolve to support ME.

1.2 Mission Engineering Overview

The National Defense Authorization Act (NDAA) for Fiscal Year 2017, Section 855, directed DoD to establish Mission Integration Management (MIM) as a core activity within the acquisition, engineering, and operational communities to focus on the integration of elements that are all centered around the mission. The DoD Joint Publication 3-0 (Joint Operations) defines *mission* as *the task, together with the purpose, that clearly indicates the action to be taken and the reason thereby*. More simply, a mission is a duty assigned to an individual or unit.

OUSD(R&E) defines MIM as *the synchronization, management, and coordination of concepts, activities, technologies, requirements, programs, and budget plans to guide key decisions focused on the end-to-end mission.* ME is the technical sub-element of MIM as a means to provide engineered mission-based outputs to the requirements process, guide prototypes, provide design options, and inform investment decisions.

The DoD report to Congress on MIM (March 2018) and the Defense Acquisition Guidebook (DAG) define ME as ***the deliberate planning, analyzing, organizing, and integrating of current and emerging operational and system capabilities to achieve desired warfighting mission effects.*** ME is a top-down approach that delivers engineering results to identify enhanced capabilities, technologies, system interdependencies, and architectures to guide development, prototypes, experiments, and SoS to achieve reference missions and close mission capability gaps. ME uses systems and SoS in an operational mission context to inform stakeholders about building the right things, not just building things right, by guiding capability maturation to address warfighter mission needs. Figure 1-1 illustrates the various consumers of ME products from concepts to capability development to acquisition.

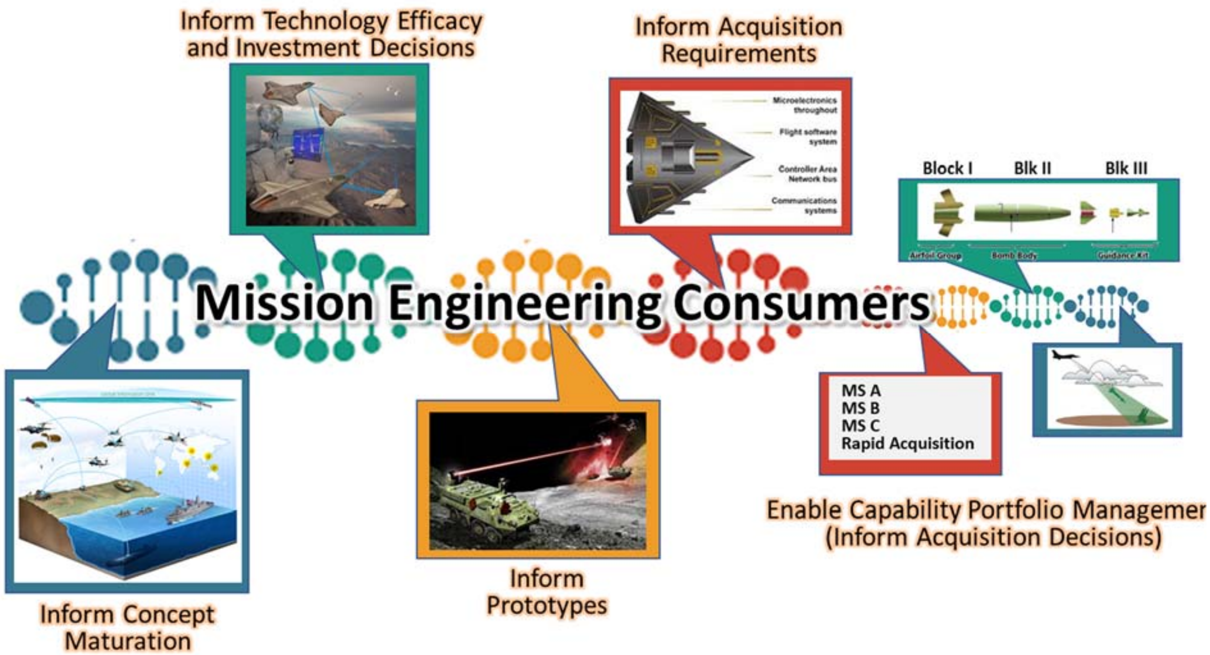


Figure 1-1. Consumers of Mission Engineering Outputs

ME uses validated mission definitions and trustworthy and curated data sets as the basis for analyses to answer a set of operational or tactical questions. Shared assessments of conclusions and understanding of analysis inputs helps leadership pursue the best course of action for decisions in support of the warfighter and joint mission.

Key questions for the ME process include the following:

- What is the mission?
- What are its boundaries and how must it interact with other missions?
- What are its performance measures?

- What are the mission capability gaps?
- How can new capabilities change the way we fight?
- What do changes in capabilities or systems mean to missions and architectures?
- What is the sensitivity of the mission performance to the performance of the constituent technology, products, and capabilities? How do the new capabilities best integrate with, or replace, legacy systems? And how do we optimize that balance to provide the most lethal and affordable integrated capabilities for any particular mission?

The major products from ME analyses include the following:

(1) Documented results in the form of analytical reports, curated data, and models for continued reuse and further analysis;

(2) Visualizations and briefings to inform leadership on key decisions; and

(3) Government Reference Architectures (GRAs) (in the form of diagramed depictions of missions and interactions among elements associated with missions and capabilities).

Together, these products identify and quantify mission capability gaps and help focus attention on technological solutions to meet future mission needs, inform requirements, and support capability portfolio management.

It is essential that ME analyses be consistent – both within themselves and with previous relevant studies using the same scenarios, assumptions, constraints, system attributes, and data – curated periodically or as necessary based on source updates. It is also essential to keep track of the sources of data and the requirements used as inputs for the analysis.

Digital engineering principles should be used when conducting ME as they can help promote consistency in the ME process through the effective use and reuse of curated data and models along with identification and utilization of digital tools throughout ME analyses. Digital engineering is an essential foundational element of ME that allows for sustainment of mission threads (MTs) and architectures, integrated analytical capabilities, common mission representations, and an extensible set of tools.

As illustrated in Figure 1-2, ME is a balancing act among the time frame, analytical rigor to be used, and the complexity of the problem to be addressed. Reaching too far in one or more dimensions, say predicting outcomes 50 years in the future or increasing the complexity of the mission to be addressed, will impact the confidence-level that can be expected in the ME products. It can also affect the rigor and validity of the analytics based on the availability and accessibility of data.

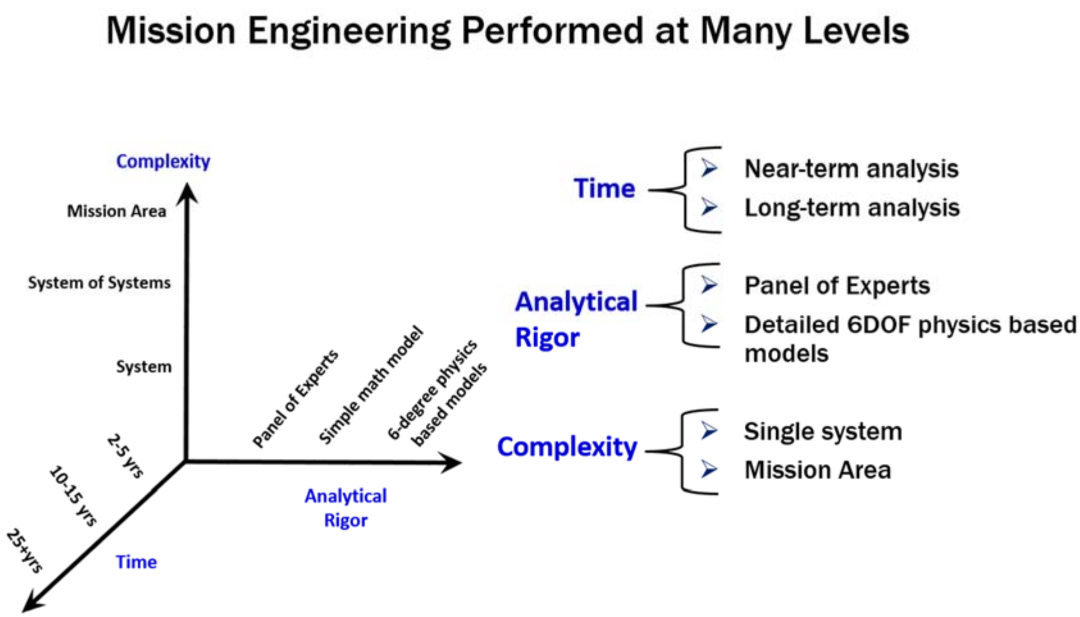


Figure 1-2. Three Axes of Mission Engineering

2 MISSION ENGINEERING APPROACH AND METHODOLOGY

ME is an analytical and data-driven approach to decompose and analyze the constituent parts of a mission in order to identify measurable trade-offs and draw conclusions. Based on the question asked, and the level of understanding of a given scenario and related contexts, an ME analysis (part of a study) may hypothesize a new concept, system, technology, or tactics that may yield superior "value" in a future military operation. The ME practitioner then designs an analytical experiment to measure and compare the baseline approach to complete the mission to each alternative case (also referred to as a trial case).

Since the number of contributing aspects of a mission is infinite, the majority of ME is an empirical investigation. Therefore, to discover meaningful relationships between inputs and end effects, it is critical for the practitioner to thoroughly document and fully understand: the definition of the mission, underlying assumptions and constraints, the measures of mission success (metrics), and source data used as inputs to the models. These elements are critical for quantitative analysis to isolate the merits of the proposed approaches. As sufficient trials are conducted, mission drivers may emerge to then form the basis of sensitivity analyses of specific parameters. For example, isolating and changing just the speed of a weapon across many mission trials could be organized to depict a sensitivity relationship of speed versus mission success.

As illustrated in Figure 2-1, the ME process begins with the end in mind, a carefully articulated problem statement, the characterization of the mission and identification of metrics, and working through the collection of data and models needed to analyze the mission and document the output results.

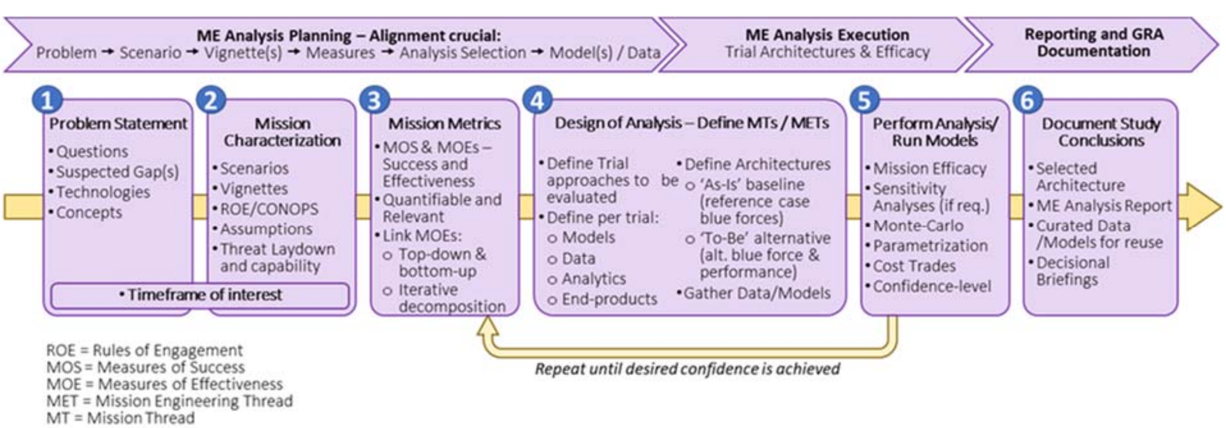


Figure 2-1. Mission Engineering Approach and Methodology

The problem statement, mission characterization, and mission metrics should be identified and clearly understood ahead of time and documented. Developing a plan with this level of detail will greatly facilitate the execution of a thorough engineering analysis to explore outcomes of mission approaches and support collaboration on subsequent recommendations.

2.1 Problem Statement – Identifying the Key Questions

To ensure the analysis is designed correctly, it is essential to initiate an ME study by articulating the purpose and developing questions of interest to be answered. This information is key as it drives other factors throughout the ME analysis such as identification of stakeholders, collection of the appropriate data and models, and identification of meaningful and measurable metrics – all of which will be used to obtain results that will inform significant decisions. When developing questions, one should consider the following: What exactly do we want to find out? What do we want to learn? What decisions is leadership seeking? Moreover, the problem statement should fully articulate the mission or technology area of concern and desired answers that are being sought out.

Following are examples that can help guide practitioners to identify study questions:

- What missions or concepts are we interested in exploring?
- Which technology or capabilities are to be evaluated?
- What mission capability gaps do we suspect/hypothesize?
- What technologies, products, and capabilities support the mission?
- What is assumed about the maturity, demonstration and fielding timelines for constituent technologies, products, and capabilities?
- How do the constituent products interact?
- Are existing interfaces and standards for interaction adequate or are updates (or potentially new standards) required?

Some specific study questions can be:

- What is the optimal force mix of long-range fires?
- What is the mission utility of using directed energy?
- How can we optimally integrate emerging technology (i.e., Artificial Intelligence) into mission threads?

2.2 Mission Definition and Characterization

The mission definition and characterization provide the appropriate operational mission context and assumptions to be used as the input of the analysis of the problem to be investigated. Whereas the problem statement describes what we want to investigate, the mission definition and characterization describe both the entering conditions and boundaries such as the operational environment and the commander's desired intent or objectives for a particular mission.

For the ME analysis to be effective, the mission definition must be identical throughout all the alternative approaches to be tried and evaluated. Once set, the mission definition should not change throughout the ME analysis and should be included in all products resulting from the ME method. Without this consistency, researchers cannot accurately compare the efficacy of the options.

One can think of the mission definition and characterization as the stage for a play that addresses the following information:

- **The Mission:** Definition of the mission starts with defining the Commander's Intent with linkage to the National Defense Strategy, Defense Planning Guidance, Campaign Plan, Combatant Command Operational Plan, Joint Warfighting Concept, or other similar operational purpose documents that provide military functions, the geopolitical context of operations, the overall definition(s) of mission success or mission objectives, or operational stakeholder input. The grounding of the mission definition to these overarching planning documents provides a consistent basis from which to derive necessary details of interest. A critical element of the mission definition that should either be defined in the problem statement or derived from the overall context of the planning documents is the time frame of the intended operations (i.e., what year in the future are we going to investigate?).
- **Operational Environment:** Linkage to Defense Planning Scenario or other military/DoD references. The specific setup of the mission to include the detailed aspects of the mission scenario and vignette(s) of interest that contain the geographic area, conflict, threat laydown, red and blue forces, Order of Battle (OOB) and the overall rules of engagement. Key references are the Concept of Operations (CONOPS) and Concept of Employment for blue forces and adversary or red forces.
- **Operational Assumptions and Constraints ("Entering Conditions"):** The assumed or derived environmental conditions and resource or force limitations are stressors to the context of the mission or of specific interest by stakeholders (e.g., contested environment, weather, logistic constraints (e.g., no access to aircraft assets), stationary or moving targets, and operational constraints [e.g., EMCON state]). Documenting these assumptions in an organized manner is imperative to enable results from one ME study to be compared with those of other ME studies, to enable future traceability when the analysis needs to be updated, and to enable leadership to make accurate and informed decisions.

In defining the mission and problem space it is important to clearly separate the mission "what" from the solution "how". The goal of ME is to identify mission capability gaps and optimal solutions sets by fairly evaluating alternative mission execution concepts, variations, and trade space. Overly constraining the mission definition will artificially influence potential solutions that are not necessarily optimal.

As illustrated in Figure 2-2, a mission includes all the details necessary to frame the objectives, operational environment, assumptions, and constraints that impact operational approaches and systems to be used.

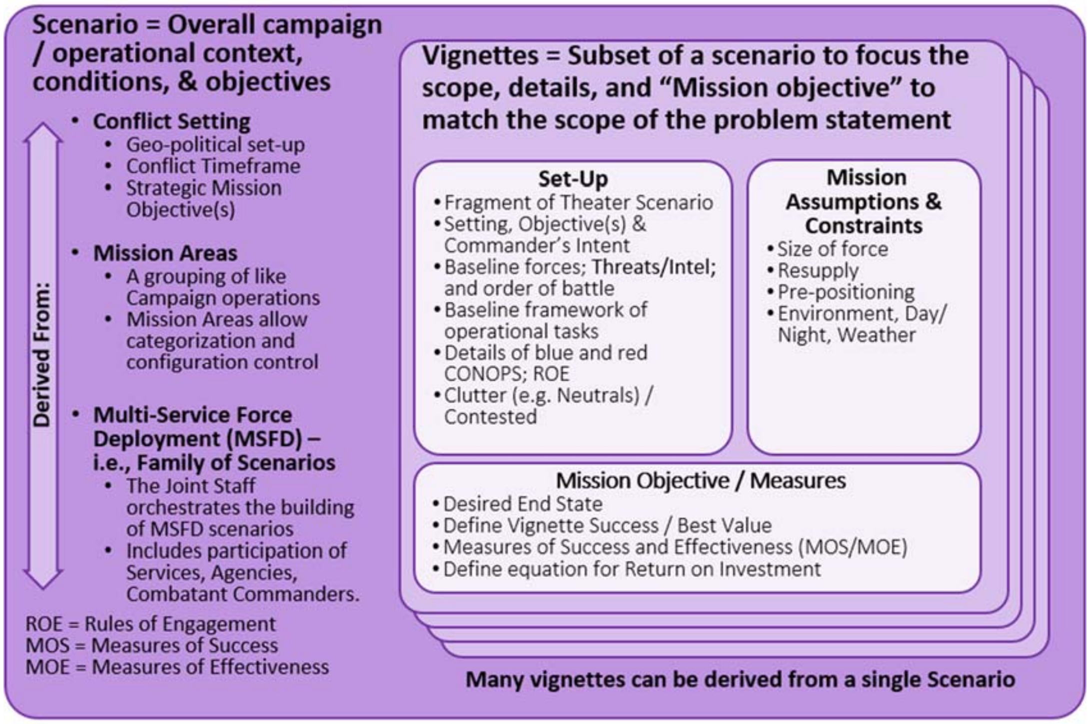


Figure 2-2. Mission Characterization and Mission Metrics

2.2.1 Time Frame

A critical element of the mission definition is the time frame for which a mission approach will be evaluated. The time frame should reflect a particular year when the mission will take place. It might be "present" day (today or current) or a "future" day (forthcoming time – near or distant). Most likely the time frame will be grounded in a Multi-Service Force Deployment (MSFD) family of scenarios that already define possible theater conflicts and challenge scenarios set in specific planning time frames.

Since ME is focused on supporting investment decisions, using the predefined National Defense Strategy, the Defense Planning Guidance, the National Military Strategy, MSFDs, and Future Years Defense Program (FYDP) time frames are useful to provide consistency and enable trades between different missions set in the same time frame. The chosen time frame should be relevant to the problem statement/hypothesis being answered or defended. For example, an acquisition decision is likely to involve the system initial operational capability or final operational capability time frames. Similarly, epoch technology changes may be set decades in the future. From a specific time frame many other mission details can be derived, such as expected threat capabilities, expected performance of blue forces, technology maturity, etc. Therefore, scenarios will have a time frame associated with them since the adversaries' capabilities continuously evolve and change over time.

2.2.2 Mission Scenarios and Vignettes

Missions are hierarchical from strategic down to tactical. For the purposes of ME, we define two broad categories of mission setups to help ensure the proper elements (or variables) are included in the mission definition: *scenarios* and *vignettes*.

The scenario provides the overall context to the ME analysis and can be derived from the Campaign Plan, Defense Planning Guidance, MSFD, or family of Joint Operations Concepts. It provides the geographical location of operations and time frame of the overall conflict. It should include information such as threat and friendly geopolitical contexts and backgrounds, assumptions, constraints, limitations, strategic objectives, and other planning considerations. In addition, the scenario will define and describe the overall mission objective or mission success criteria of U.S. operations.

Vignettes represent a more narrowly framed subset of the scenario. There can be many vignettes within a single scenario. A vignette could be thought of as a magnifying glass looking at just one aspect of the scenario. The purpose of a vignette is to focus the analysis and the necessary detailed information, such as the ordered set of events, behaviors, and interactions for a specific set of systems. A vignette includes blue capabilities and red threats (threat laydown and expected systems and capabilities of our adversaries) within an operational environment, as inputs or variables to the analysis. Some ME analyses may seek answers at the campaign or mission level, but this level of analysis can be accomplished only after the researchers understand and account for the details of the vignettes.

The mission scenario and vignette should be properly selected and refined to match the needs of the problem statement to ensure the analysis focuses on the questions and concerns of interest. It is essential to be mindful of the chosen input parameters of the scenario as they will have varying impact to the analysis results and outputs, for example, "the most likely, representative, real-world" scenario versus "most" or "least" stressing scenario.

Figure 2-3 shows the interdependencies among the mission definition, scenario, vignette, and mission metrics (metrics are defined in Section 2.3 below). If the details of these key elements of ME are not aligned to the questions of interest, then the results will not be suitable for the decision the questions are intended to inform.

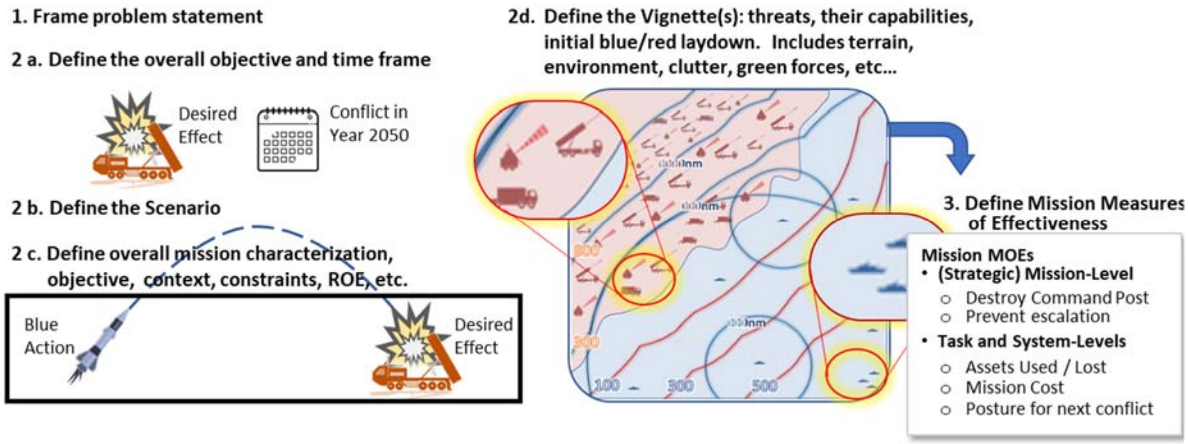


Figure 2-3. Mission Definition Elements and Identified Metrics

2.2.3 Assumptions and Constraints

An ME study should be carefully framed to address the problem under consideration. It is appropriate at times to conduct a narrowly focused ME study in which practitioners want to control all but a few limited variables. There may be inputs to the analysis that researchers do not specifically know or for which they have no valid source, or due to limited resources and scope the analysis may require bounding to a specific set of questions. It is very important practitioners thoroughly document the assumptions and constraints.

Assumptions and constraints should be realistic and reasonable to ensure that one obtains useful results. Assumptions and constraints can be made about the scenario or vignette that set the initial conditions and mission context (e.g., operational, task activities, resources, OOB) or about the performance characterization of the technologies, systems, or capabilities within the analysis. Assumptions are constrained variables that otherwise could be allowed to be traded to set a baseline from which to do analytical excursions when less than perfect data is available.

Clearly identifying the baseline assumptions and constraints may later help facilitate a sensitivity analysis around the initial inputs and their impact on the results. For example, within an analysis the definition for "contested environment" should be consistent across every approach under consideration to ensure results can be compared. In such a case, the "contested environment" might be defined as "no communications are available," with each trial approach reflecting the impact of this assumption.

In summary, for any ME analysis, one must:

- Identify and understand the assumptions, how they will be validated, and how they translate into the variables that propagate through the analysis,
- Identify and understand the limitations, such as constraints, that need to be considered,
- Identify and elaborate on risks associated with assumptions and constraints, and
- Identify and explore the areas of uncertainty in the mission definition.

2.2.4 Mission Definition Summary

The mission definition should be documented considering the categories listed in Table 2-1. This table should serve as an outline of the information and special considerations that may be necessary to scope the analysis or study.

Table 2-1. Categories of Mission Definition

Linkage to "Strategic" Constructs	
◆ National Defense Strategy (NDS) ◆ Defense Planning Guidance (DPG) ◆ National Military Strategy (NMS) ◆ Defense Planning Scenario (DPS) (Strategic Scenario)	◆ Multi-Service Force Deployment (MSFD) (Operational Scenario derived from DPS) ◆ Mission Areas ◆ Campaign Objective ◆ Joint or Service Concept of Operations (CONOPS) and Tactics, Techniques, and Procedures (TTPs)
Scenario and Vignette Specifics	
<u>Mission Setting</u> ◆ Time frame (year) ◆ Phase of conflict ◆ Time available ◆ Theater/setting ◆ Objective(s) and Commander's Intent ◆ Geopolitical considerations ◆ Environmental (contested, dust, weather, terrain, day/night, weather, moon, solar, etc.) ◆ Allied, commercial, and neutral forces ◆ Civil considerations	<u>Threat (Red) Forces</u> ◆ Threats/capabilities/intel ◆ Baseline forces and Order of Battle (OOB) ◆ Threat CONOPS, Rules of Engagement (ROE), doctrine, or TTPs <u>Blue (to include coalition) Forces Baseline Capability (in time frame of interest)</u> ◆ Systems/capabilities/performance ◆ CONOPS, return on investment, doctrine, etc. ◆ Baseline framework of operational tasks
Mission Assumptions and Constraints	
◆ Performance or capabilities of systems ◆ Force OOB and deployment, movement and sustainment (prepositioning); logistical considerations	◆ Constituents of the mission and how it must interact with other mission areas

2.3 Mission Metrics (Measures of Success and Effectiveness)

Metrics are measures of quantitative assessment commonly used for assessing, comparing, and tracking performance of the mission or system. Measurable outputs help commanders determine what is or is not working and lend insights into how to better accomplish the mission. The ME practitioner needs to identify a well-established set of metrics that can be used to evaluate the completeness and efficacy of the components of mission-enabling activities. The mission metrics represent the criteria that will be used to evaluate each of the alternative approaches in conducting the mission.

Analytical documentation uses several similar terms to refer to mission metrics, including Measures of Success, Measures of Suitability, Measures of Utility, Measures of Efficacy, Measures of Effectiveness (MOEs), and Measures of Performance (MOPs). To simplify terminology, this guide uses two broad categories of measures: MOE to indicate a measurable attribute and target value for success within the overall mission; and MOP to indicate performance characteristics of individual systems used to carry out the mission. Figure 2-4 illustrates the relationship among types of measures.

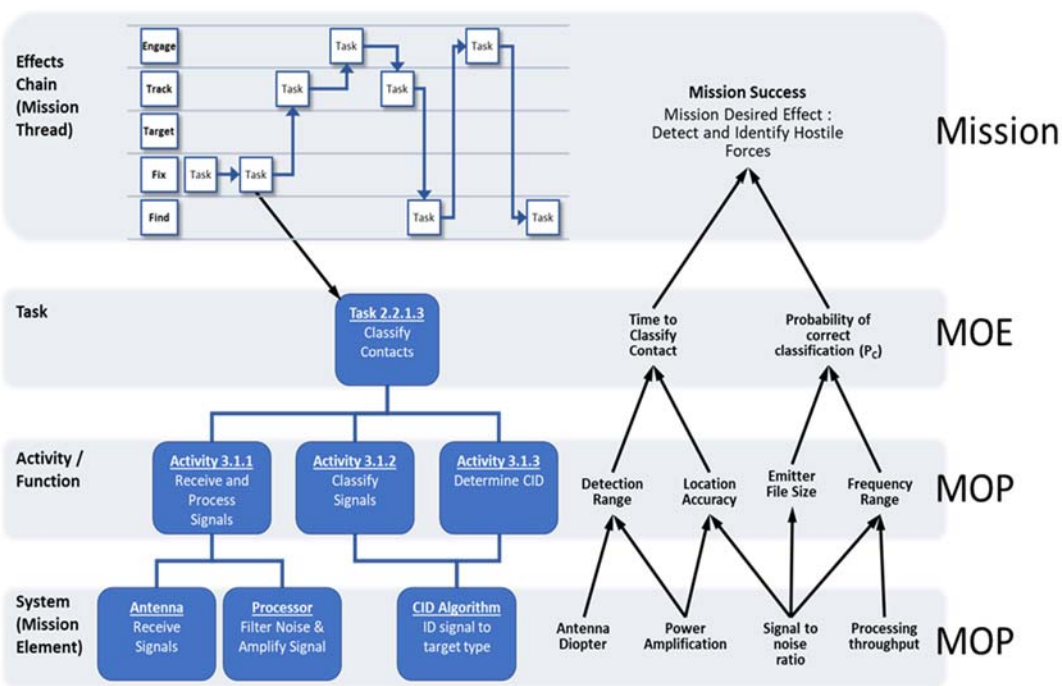


Figure 2-4. Relationship of Measures

Mission efficacy is the ability to produce a desired result or effect and is measured through criteria in the form of MOEs. MOEs help determine if a task is achieving its intended results. An MOE is a criterion used to assess changes in system behavior, capability, or operational environment that is tied to measuring the attainment of an end state, achievement of an objective, or creation of an effect.

MOEs help measure changes in conditions, both positive and negative, such as “Accomplish without loss of a capital asset.” MOEs help to answer the question “Is the system doing the right things?” Examples of MOEs for the objective to “Provide a safe and secure environment” may include (1) Decrease in insurgent activity and (2) Increase in population trust of host-nation security forces.

MOPs help measure the accomplishment of a system task. They answer questions such as “Was an action taken?” or “Is the system doing things right?” MOPs will be discussed in relation to the systems employed in an MT or Mission Engineering Thread (MET) which is discussed further below in Paragraph 2.4.1.

For the purposes of this guide, an MOE is considered a function of contributing MOPs. Table 2-2 provides examples of MOEs and MOPs that could be used in an ME analysis. Figure 2-5 provides examples in a hierarchical relationship.

Table 2-2. Examples of MOEs and MOPs

MOEs define a desirable measurable outcome linked to the objective (Commander’s Intent) of the mission. Examples:
• Number / percentage of targets effected (killed/ disrupted/ spoofed): goal 70% o Probability of kill o Targets held at risk • Time to Defeat Target: goal less than 90 minutes • Weapons Required to Defeat Targets: goal less than 4 • Assets Lost: goal minimize, less than 10% • Operational Cost per Target Destroyed: goal $100K/target • Posture for next conflict: goal maximize, 50% of forces did not have to move from pre-conflict placements
MOPs measure how well the mission is accomplished. Examples:
• Probability to Track • Probability to ID • Range • Accuracy of weapon • Probably to avoid detection

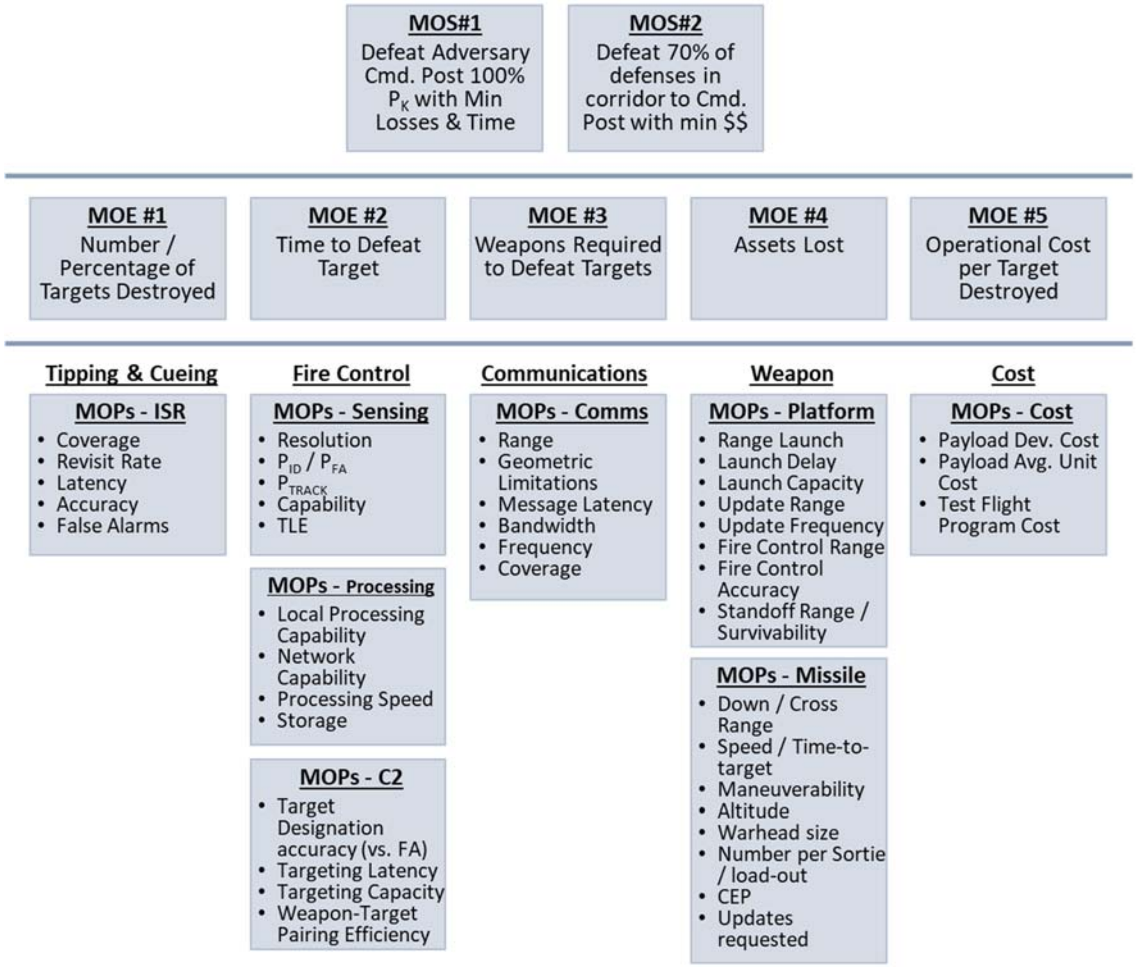


Figure 2-5. Hierarchy Examples of MOEs and MOPs

2.3.1 Selecting Measures of Effectiveness

Starting with the overall objective(s) of a scenario or vignette in the mission definition, the mission MOEs need to be defined in detail to answer the stakeholders' questions of interest. The metrics will vary depending on the level of analysis (i.e., campaign-level or mission-level).

For MOEs to be useful, they must be both quantifiable and relevant. A key tenet of ME is to quantify the efficacy of alternative approaches in conducting a mission. As such, the MOEs should reflect the Commander's Intent and objectives and include measurable criteria to answer the analysis or study questions. For example, a commander's mission objective may be to disable a truck convoy, and the quantifiable measures derived from that objective could be the number of trucks destroyed or the probability of defeat/kill of a single truck.

MOEs should indicate the target value of success or favorable result (either threshold or objective). Whenever possible, a range or specific value should be set for the goal. In addressing quantifiability, MOEs should address “win”-type measures (metrics to be maximized), “loss”-type measures (metrics to be minimized or avoided), and ratios (comparison of two values or metrics).

For an MOE to be relevant, it must link clearly to the mission being analyzed. MOEs are based on two main factors: (1) the top-down derivation from the problem statement through the mission definition to represent the mission objective (i.e., Commander’s Intent) and (2) a bottom-up explanation to characterize the constituent approaches and systems proposed to execute the mission (red, blue, architecture, etc.) and associated availability of modeling and analytics.

The MOEs are closely linked to the MOPs in order to adequately reflect how the systems, systems-of-systems, or capabilities are used to achieve the mission objectives. As depicted in Figure 2-6, developing relevant MOEs is an iterative process that requires balancing the inputs of top-down and bottom-up inputs to match the level of interest.

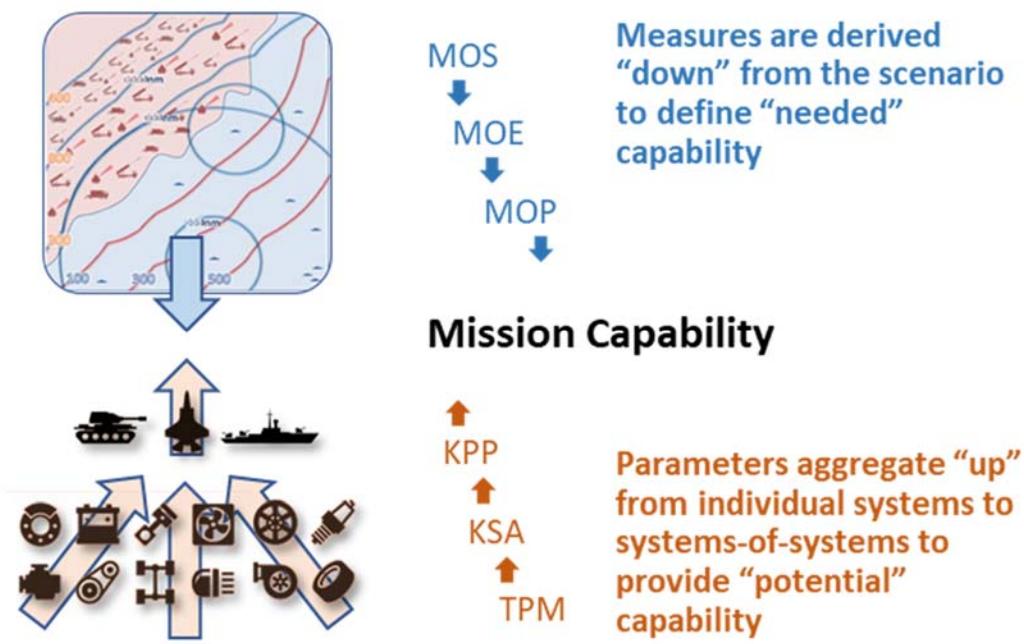


Figure 2-6. Succession of Measures

While MOEs are specific to each scenario or vignette, several universal categories of MOEs could be considered:

- Mission satisfaction – achievement of end objective
- Losses – loss of equipment, personnel, to adversary actions
- Expenditures – consumables depleted during operations; for example, how many assets used to relay a message or destroy a target.

- Cost (dollars) – a. cost of development of systems/technologies/concepts used in the operational alternative, b. cost of operations
- Time – duration of the mission operation
- Repetition – number of mission passes to achieve acceptable mission satisfaction
- Readiness – posture of forces to readily engage
- Uncertainty – uncertainty in the above measures
- Mission Return on Investment (ROI) – ratio of one metric / measure to another metric / measure. Mission ROI evaluates the efficiency to achieve success to one or more different MOEs, for example, the number of targets destroyed versus the number of assets expended. ROI ratios are especially useful to help resolve cost-benefit efficacy based on type and number of weapons used and the (amortized) cost of each. A primary purpose of conducting an ME analysis is to inform the Planning, Programming, and Budgeting Execution (PPBE) process. Cost type ROIs are useful to inform acquisition or technology investment decisions either as a materiel or non-materiel solution.

2.3.2 Traceability of Metrics

It is natural for metrics to iteratively evolve as each of the alternative approaches are developed. Useful measures emerge only when the questions to be answered, the mission (i.e., objectives), and the activities, tasks, and systems under evaluation are understood. In ME the questions to be answered are contained in the problem statement; however, the elements under evaluation, which are initially extracted from the mission definition, can be further expanded and verified as one designs the analysis (Paragraph 2.4) and develops the alternative (or trial) mission approaches (or MTs or METs (as defined in Section 2.4.2)) to be assessed.

As each of the alternative approaches (varied systems) are developed and refined, one may revisit the MOEs to ensure the selected measures are relevant to answer the study questions. Measures should be selected to expose potential trades within the activities, tasks and systems of importance to the overall mission objective. Figure 2-7 illustrates the lineage of metrics (i.e., MOEs and MOPs) to MTs and METs (i.e., from tasks to functions to systems). This balance ensures that good MOEs are being used in the analysis (as discussed in detail in Section 2.3.1 above).

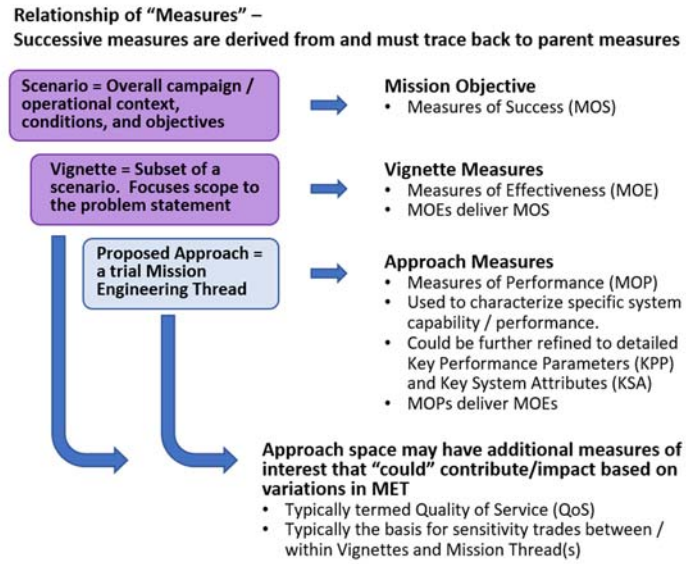


Figure 2-7. Example of Mission Engineering Thread and Associated MOEs and MOPs

2.4 Design of Analysis

In its simplest form, ME analysis evaluates missions by examining the interaction between the operational environment, threat, activities/tasks, and capabilities/systems used in current (today) or future missions. The mission architecture represents the detailed structure of the conduct of the mission. In all cases, the architecture is the means to fully document all mission elements in relationship to other elements, the activities, threats, and the overall situational context.

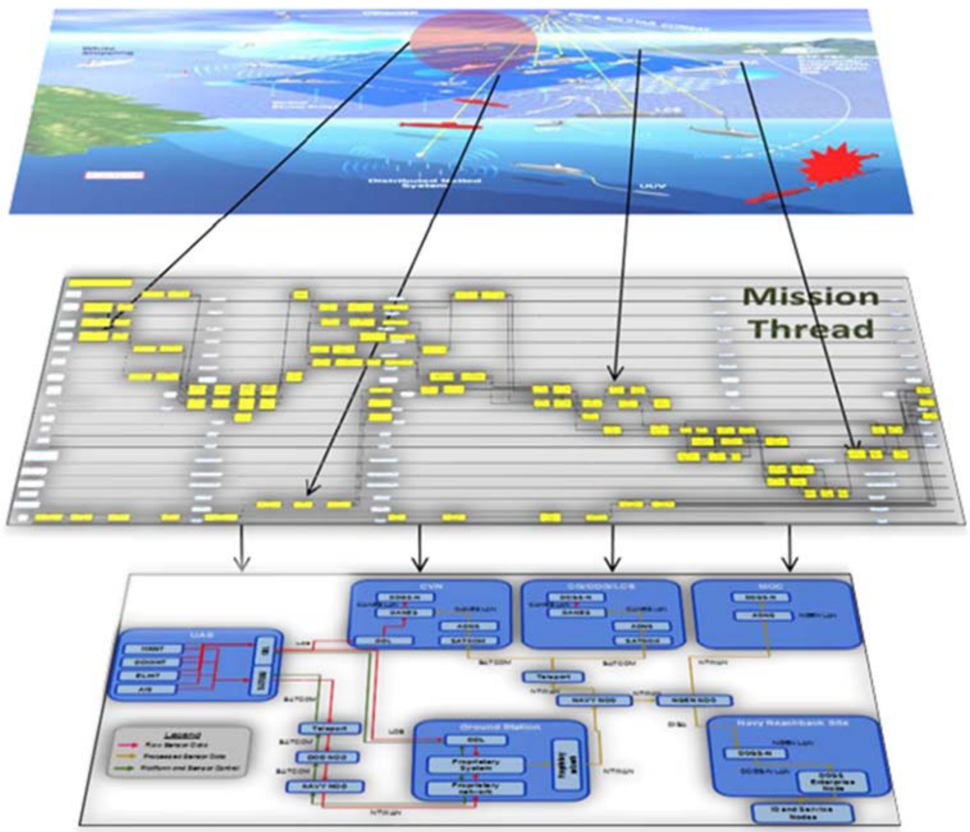
Obtaining trustworthy data for the analysis and mission architecture is essential and should include information from the mission definition (i.e., operational environment, threat laydown, red characterization, etc.) as well as the blue force capabilities that are of primary interest to be evaluated and linked to the questions to be answered. As shown in Figure 2-7, the end-to-end sequence of blue activities/tasks can be depicted through an MT.

Once decomposed a level to include relevant systems and/or capabilities to execute end-to-end missions, an MT is then referred to and depicted as a MET. These activities/tasks and systems/capabilities can be varied to develop alternative approaches through runs and trials. Furthermore, once MTs and METs are identified and sufficient data is collected, the appropriate analysis is then conducted to obtain and document results to draw conclusions to answer the problem. For ME purposes, this process is termed "design of analysis."

2.4.1 Mission Architectures

Mission architectures can be seen as "business models" for the conduct of the mission. As such, the selected architecture must fit within larger constructs of the mission at the scenario, force deployment, and campaign levels. For each approach, the "As-Is" and the hypothetical "To-Be" thread can be described in architectural terms (referred to simply as "views") – Operational, System and/or Technical View – of mission elements, showing the communication layers and nodal linkages among each major element of a mission construct.

The methodical depiction of views and their relationships helps identify what data is needed, what additional assumptions and constraints need to be made, and what models are appropriate for the analysis. In this way, the mission architecture provides a thorough and methodical way of defining the operations, systems, and data flow within the constraints of the scenario. As shown in Figure 2-8, a selected mission architecture depicts the detailed structure of the conduct of the mission. It should include a series of interdependent views of the assets, organization, functions, interactions and sequencing of the mission operations approach.



*A **Mission Architecture** is a conceptual modeling of concepts, approaches, and systems of systems that enables details of the process flow, timing, interactions, data, capabilities, and performance to be examined in relation to the other processes, entities, and systems that contribute to achieving the mission objective. It enables organized information sharing across the department.*

A Mission Architecture can address an overall campaign of many concurrent processes and entities or narrowly focus on just one entity and flow.

A Mission Architecture is represented by a series of "views" to illustrate/highlight specific details. For example, a common illustration is the operational overview that depicts overall intended military operations of equipment and personnel. Another view is the sequenced flow of each task and activity to achieve those operations. Another is the schematic of information exchanges to enable and trigger those tasks and activities.

Figure 2-8. Tenets of Mission Architecture

2.4.2 Define Mission Thread and Mission Engineering Thread

A sub-element of mission architectures is an MT, which comprises the end-to-end tasks or activities to accomplish a mission within a scenario or vignette. It can be simply referred as a "mission approach." It includes the tasks to be executed to conduct or carry out the mission to satisfy a defined objective. Threads define the task execution sequence in a chain of events of how systems, people, data, methods, tactics, timing, and interfaces will interact to complete necessary tasks against threats and other variables to achieve mission objective(s). Examples of this end-to-end mission construct are *kill chains (kinetic)* or *effects chains (non-kinetic)*. There may be multiple MTs linked over time to execute missions within a scenario or vignette. Figure 2-9 shows how selected MTs can be seen as building blocks for the development of METs.

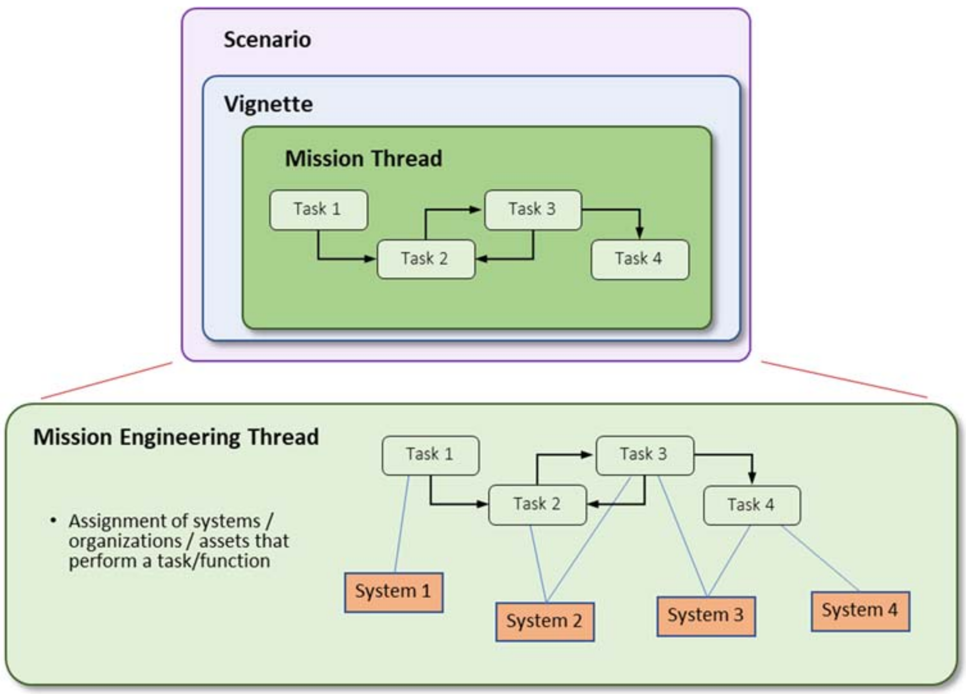


Figure 2-9. An Architecture of Mission Threads

As details associated with specific systems, technologies, or people are added, the generic MTs become METs. This distinction between MT and MET is important because Joint Staff planning documents have pre-defined generic MTs as planning constructs in the Universal Joint Task Lists (UJTLs). In order to be useful for ME analysis, decomposition from MTs to METs and the lower-level layer that maps systems to functions is needed.

Mission approaches should be constructed of narrative descriptions and architecture artifacts (views) characterizing and defining the variables under study. This includes how operations are executed today and hypothetical or future alternative approaches. It is important to identify the variables of interest to explore in the analysis, which can be derived from the problem statement and the mission definition. Once the variables are identified, one can choose to change a single or multiple variables to observe and explore the impact on the mission outputs.

The variables that can change are either tasks, capabilities, technology, or systems within a MT or MET. By doing so, one is able to explore how the input variables impact and change the output (mission success). Ideally, one would identify the most critical variable of interest engaged in executing the mission to determine what works or not. The analysis should include approaches that will output metrics that will be useful to answer the questions of interest. The problem statement along with the specific details of the mission, scenario, and/or vignette (mission characterization), will drive the inputs (i.e., tasks and/or systems) that will be varied across the "alternative" approaches. The alternate mission approaches are driven by the specific trades in capabilities, technology, tactics, systems, Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, and Facilities (DOTMLPF), and concepts that are to be evaluated. This helps lead to the ultimate goal – "How can we better accomplish and execute the mission?"

The "baseline" mission approach, commonly defined as the "As-Is" mission approach, represents the current thinking as to the way to execute a mission within a given scenario and provides a reference point for analysis and evaluation. Changes to the variables (i.e., systems, performance, tactics, etc.) will lead to alternate approaches referred to as potential "To-Be" mission approaches that are the alternate approaches to be evaluated. They do not account for changes in the environment, threats, or scenario because those changes would require an entirely new mission definition. As alternatives are evaluated and analyzed, the ME practitioner can identify a more "optimal" approach that can be referred to as the "preferred" approach, which can form the new reference for future analyses.

Note: The term "As-Is" does not necessarily mean the operations as they exist today; it is simply a baseline from which to start the analysis.

2.4.3 Define and Gather Supporting Models, Data, and Analytics

ME is facilitated by the use of analytical and computational-based models that aid in the representation of the operational and technical means to execute a mission. Use of models provides for consistency and reuse of analytical constructs among ME practitioners. Crucially, ME practitioners must take care to curate, or manage, the models they employ so that data elements, hypothetical realizations, and assumptions are captured and archived with traceability to authoritative sources.

Models should be constructed to include traceability of data, from concept through disposal. Per DoD Modeling and Simulation standards and to understand all associated risks, practitioners should take care to specify that the models developed for the study support the specific intended use of the analysis, undergoing a verification, validation, and accreditation process.

Models are not only traditional simulations, they also include mathematical representations, logical expressions, and conceptual process steps or combinations of one or all of these elements. For example, models or representations can be used to predict how a system might perform or survive under various conditions or in various environments or how they might interact with one another to conduct a mission. Models provide useful visualizations to support various analyses and studies (e.g., trade space, sensitivity, gap, or military utility analyses).

Figure 2-10 represents examples of types of models that are developed, collected, integrated, and used as part of ME.

Figure 2-10. Example Models for Use in Mission Engineering

The digital models that support ME are driven by the representation of data and the type of approach most suited to the analysis (i.e., physics-based, Monte-Carlo).

Models vary in their levels of fidelity (i.e., "realism") and in their associated uncertainties. ME analyses need to determine which models should be brought together to answer analytic questions and to balance the time, cost, and uncertainties in each study. ME stakeholders need to understand and articulate the underlying fidelity and confidence in the chosen models to adequately determine the impacts on the analysis and resulting decision-making process.

A model can be highly complex, and as a result, its relationships between inputs and outputs may be poorly understood. In such cases, the model can be viewed as a black box, that is, the output is an "opaque" function of its inputs. Often, some or all of the model inputs are subject to sources of uncertainty, including errors of measurement, absence of information, and poor or partial understanding of the driving forces and mechanisms. This uncertainty imposes a limit on the confidence in the response or output of the model. Analysis is required to minimize uncertainty (discussed in the Analysis section, 2.5.1, below).

Model development, integration, use, analysis, and curation are core elements of ME activities. The ME process, as described in Section 2.2, begins with a problem statement/analytic questions. During the initial phase of the ME process, it is essential to determine what models, data and tools already exist within the digital ecosystem. Additional considerations before commencing the study include:

- What domain(s) (Air, Surface, Subsurface, Space, Cyber, etc.) are involved in this study?
- How much fidelity is required in the model to adequately respond to the problem statement/analytic question?
- What models are required to conduct the analysis? (e.g., 6-DOF, Physics-Based)
- What models are already accessible? Do the required models already exist?
- What is the pedigree of the model (verification, validation, accreditation, etc.)? Did we build the right model for use?

The responses to these questions will trigger requests for additional models, data, tools, access to other digital ecosystems, and updates to the ME digital ecosystem. When selecting models for the ME process, it is essential to remember models are representations of reality. In the case of ME, the reality may be an actual or conceptual system, or it may be the operational scenario in which the system will participate.

ME activities are conducted within a digital ecosystem. The contents of the digital ecosystem include:

- Cyber-ready environment to include:
  - Adequate computer power; if required, access to high-performance computing
  - Multi-layer security; work space in unclassified, secret, and/or above secret
  - Configurable/adaptable software framework
- Access to models and data to include:
  - Tools or software applications required for analytical or computational analyses
  - Technical data (e.g., system performance, test results)
- Hardware and software infrastructure to manage the ME process

2.5 Perform Analysis/Run Models

ME analysis includes evaluation of vignettes, mission threads in a vignette, or concepts across vignettes/threads through analytical and computational means using data and models. The choice of the most advantageous type of analysis will be driven by the problem statement, MET, and the metrics of interest. The output may identify mission capability gaps and will provide metrics to inform investment decisions in new capabilities or new ways to fight the future fight. Figure 2-11 (an extract of Figure 2-1) illustrates the methodology around the analytical design for ME.

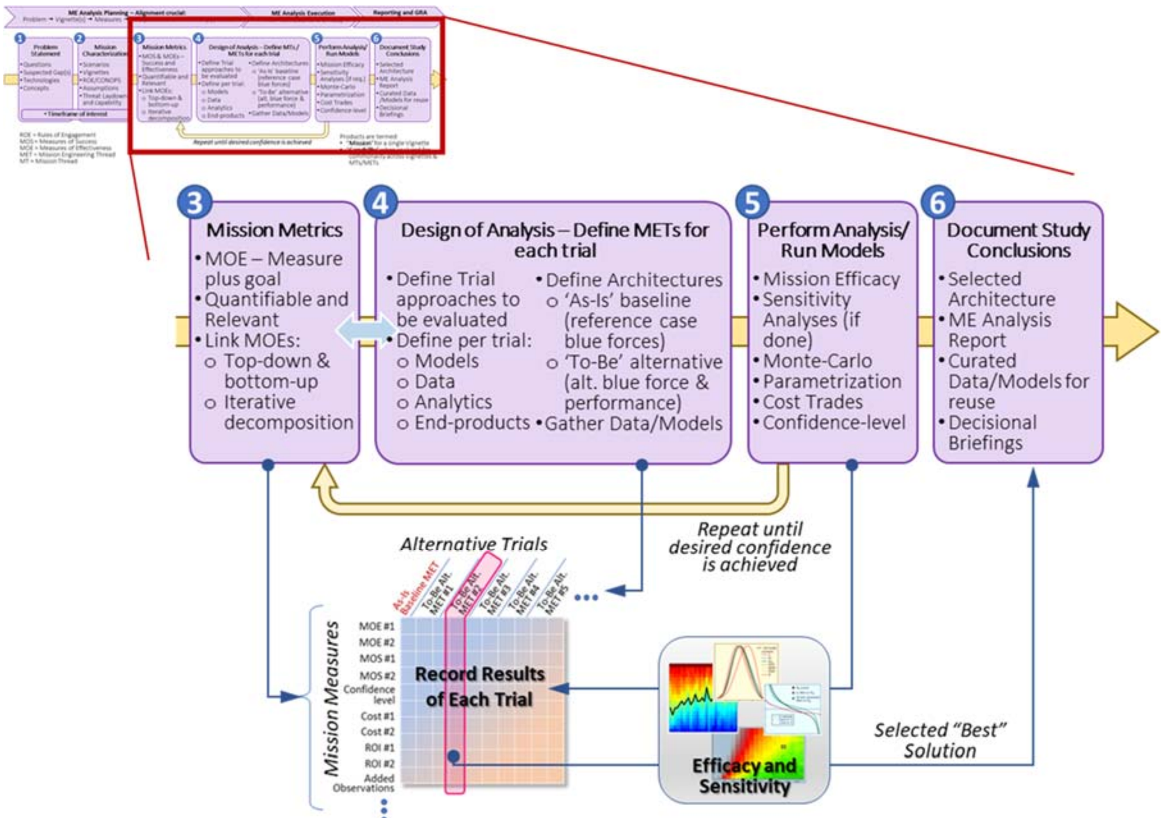


Figure 2-11. Mission Engineering Analysis

In order to conduct ME analyses, adequate and trustworthy (validated) data are required to represent and model the mission and systems.

Below are items that the ME practitioner should take into consideration when identifying and conducting the most appropriate analysis(es) for the study:

- Identify the sensitivity analysis that should be performed. Understand sensitivity around the baseline assumptions that influence the inputs and how they impact the outputs.
- Address whether one needs to perform optimization and/or parametrization around the assumptions or inputs.

- Determine the most applicable analytical methods. Examples include: simulation tools, Monte Carlo analysis, Markov chain, regression analysis, cost/cost-benefit analysis, etc. (Figure 2-12).
- Identify and understand error and uncertainty propagation across the system of models.
  - Track and measure error/confidence levels of data used in the analysis and results of the analysis; understand fidelity of data and models
  - Understand assumptions, approximations, models used, fidelity, etc.

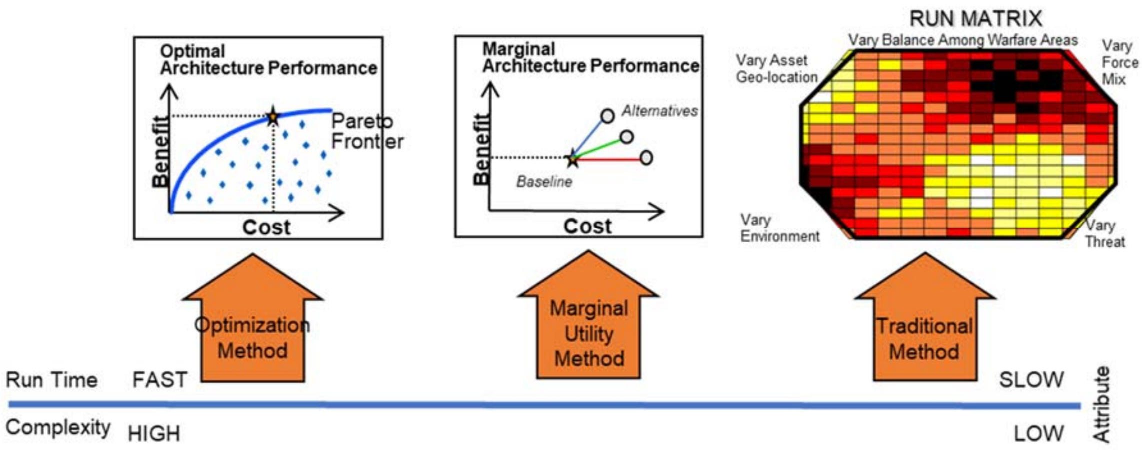


Figure 2-12. Examples – Types of Analysis

A variety of analyses may be used depending on the question to be answered and the desired metrics or outputs required. For example, optimization analysis can be used to find the optimum value for one or more target variables, under certain constraints.

It is important to track the propagation of error and levels of confidence in findings against the various metrics in all levels of analysis. Error and uncertainty can be introduced in an analytic effort because of varying fidelities of models or the use of different types of models (parametric versus statistical, for example). Among the most important tasks for an ME study team is to understand the relationship among models, the input data (i.e., sources) to develop the models, and the propagation of error throughout the analysis so the team can adequately define the confidence level in the outputs/results.

In some instances, statistical analysis is a tool that practitioners can employ to determine correlations between inputs and outputs. There are a number of methods (e.g., use of p-values) to determine a threshold for statistical significance. Although threshold values may be subjective, there are "generally accepted" values (e.g., a p-value of 0.05 or 5 percent probability of the result being due to chance).

Another method to determine confidence levels in results is performing a sensitivity analysis on key baseline assumptions. Practitioners should consider employing sensitivity analysis to help determine how different values of an input variable affect a particular output variable under a given set of assumptions, identifying impacts on the MOEs or *Measures of Success* (MOS) of a mission. Sensitivity analysis tests the robustness of the results of a model or equations in the presence of uncertainty and reveals any first-order or second-order relationships between input and output variables.

Sometimes an adequate sensitivity analysis can be performed by parametric means as opposed to exercising a system of models. Using bounding case data (as in a case study) to drive the analysis can provide insight into the solution space for a given analytical condition. Regardless of the methodology, a properly designed sensitivity analysis will provide insight into the fidelity of the results. Identifying the level of confidence in results is a key output for ME studies to help leadership weigh the results of a given excursion or study against other factors when making important decisions.

2.6 Document the Study and Conclusions

As noted in the Introduction, the major products from an ME analysis include:

- Documented results in an analysis report and decision briefing(s),
- Reference or recommended mission architectures, and
- Curated data models for reuse (as derived from the reference architecture).

These ME products and artifacts identify and quantify mission capability gaps and help focus attention on technological solutions to meet future mission needs; inform requirements, prototypes, and acquisition; and support capability portfolio management. They help explain the relational attributes of an SoS vital to mission success.

It is important that the products of an analysis align with the original question(s) being asked and highlight any need for extra work, or follow-on analysis. As a general rule, the outputs should draw conclusions from study analysis and data outputs, discuss observed trends and implications, and discuss relationships or correlations that can be made from the results. As such, these outputs, discussed in more detail in the subsections below, form the basis for informing DoD leaders on technology maturation plans, investment strategies, and preferred materiel solutions to close warfighting capability gaps.

2.6.1 Analysis Report / Decisional Briefings

The final analysis report and associated decisional briefing materials should discuss the overall purpose of the analysis as defined by the stakeholders at the outset of the study. The report should include the upfront planning (Problem, Mission Definition, Scenario and Vignette, MTs/METs, Metrics, Design of Analysis, and Outputs) and should discuss what influenced or drove the analysis framework, assumptions, and execution. Appendices A and B (Government Reference Architectures) provide the recommended level of detail.

The report should accomplish the following:

- Define the questions and mission
- Define metrics for mission success – this can include MOEs
- Identify threats and operational environment and source of information
- Identify dependencies and impacts of mission/architecture on adjacent missions
- Identify key assumptions about the mission, technology or capabilities
- Explain the analytical methodology
- Describe the architecture products
- Explain the results obtained from the analysis
- Identify any issues or uncertainties with the results
- Discuss how the results apply to the problem statement
- Describe the conclusions from the analysis
- Recommend actions leadership or decision makers should take
- Recommend further analysis or next steps

2.6.2 Reference Architecture

The Reference Architecture (RA) depicts the preferred mission architecture resulting from the analysis and describes the mission definition, assumptions, and constraints, methodology, levels of confidence, uncertainty, and other analytical justifications to clearly convey the results. The modifier "reference" highlights the one particular architecture that is preferred, based on the results of the analysis. The RA and its justifying analysis should be thought of as an integrated product and evolve from the analysis of one or more MTs/METs, which in turn are composed of interdependent views of the mission. The use of architectures provides a way to explicitly compare and contrast mission elements and attributes within and across many missions. For example, future technologies can be assessed across missions to reveal the value they provide and to inform decisions regarding the priority of investments.

If the Government maintains ownership of the RA, this further designates it a *Government Reference Architecture* (GRA). In ME, two other architecture terms should be defined:

- **Government Mission Reference Architecture (GMRA):** Applicable to a single, end-to-end mission; the preferred or selected architecture describing the MET.
- **Government Capability Reference Architecture (GCRA):** Applicable to multiple mission threads, optimizing common capabilities (functions or tasks) and attributes across multiple METs; more narrowly focused on an enabling capability (e.g., seeking to optimize a communications network to enable many METs).

Figure 2-13 shows the MET relationship between GMRAs and GCRAs. Appendices A and B define the content and the applicability of each of the GRAs.

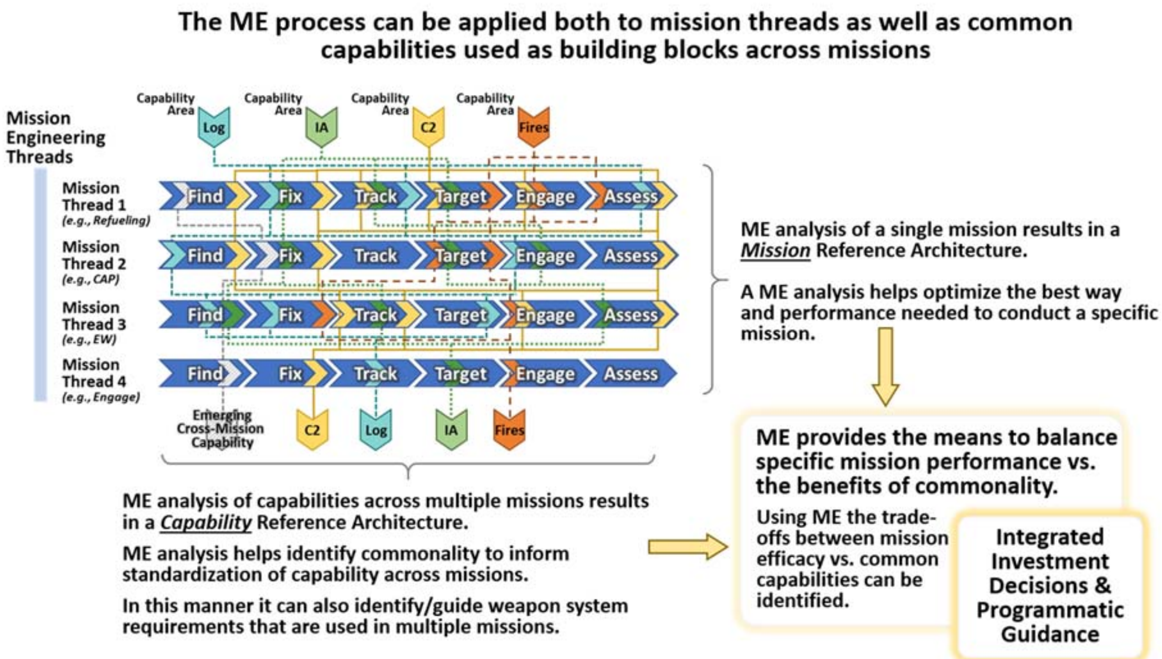


Figure 2-13. Integration and Trades of Mission Threads and Capabilities

Government Reference Architectures are used to convey results depicting the capabilities required to meet mission objectives. Two types of linked and "cross-cutting" architectures are "Capability" and "Mission" Reference Architectures.

2.6.3 Curated Data, Models, and Architectures

As analyses are developed and completed, the data, models, and architectures need to be properly collected and organized to be preserved, shared, and discovered for future analyses. For the purposes of ME, the term "data" means information related to the scenario or vignette, OOB, force structure, system parameters or performance, threat, models, and analytical results. Data are the "building blocks" and "backbone" behind models, MTs/METs, and GRAs.

It is incumbent upon each ME practitioner to curate data to ensure the value of the data is maintained over time, and the data remains available for reuse and preservation. Risks of poor or no data curation include factually inaccurate information, incorrect guidelines, and knowledge gaps. As technology or capability design and development mature and systems are tested and evaluated in exercises and experimentation, one collects valuable data that provides a more trustworthy representation of system performance and capability development efforts. ME practitioners should make sure there is a "feedback" mechanism to use this data to redo or repeat their analysis to identify whether the developed technology or capability has a positive or negative impact on the mission objectives (MOEs), whether it truly closes mission capability gaps, or if it changes the mission architecture(s) or assumptions used in the analysis. This feedback allows ME to be a repeatable process that outputs more reliable results.

Initially, the curation and standardization of data will be based on collaboration with immediate peer analysts in answering immediate reuse questions: How should one label and organize the data and the results to best facilitate the next analysis? As ME evolves, cross-Service working groups, OSD, and Joint Staff will publish more rigorous guidelines. While some general rules and best practices apply, the data curator must make an educated decision about which data assets are appropriate to use. At a minimum the following should be addressed for all data used or generated:

- Timeliness: When was the data last updated?
- Lineage: Where did the data come from? Source?
- Validity: How confident are we in the quality of the data?
- Accuracy: Is the data complete and how does it match agreed-upon definitions?
- Linkage: How was the data generated, converted, or collected? To what ME use was it associated?
- Profile: How would one catalogue the data to retrieve it later – to what other ME data is it topically associated?

Appendix A: Government Mission Reference Architecture (GMRA) (Template)

Purpose

Government Mission Reference Architectures (GMRAs) should be used to guide and constrain systems of systems that are required to carry out an operational or tactical mission.

Definitions

Mission: a set of objectives and goals to be achieved in a specific operational environment. Examples include Time-Sensitive Target, Close Air Support, Suppression of Enemy Air Defenses, Air Refueling, or Undersea Warfare.

Architecture: a unifying or coherent form or structure of components and either relationships; simply a depiction or view.

Mission Thread: synonymous with "mission architecture," a coherent form or structure of activities or systems to execute an end-to-end mission. The mission thread or mission architecture shows the components and tasks and their relationships.

Government Reference Architecture: a Government-owned, authoritative source of information about a specific subject area that guides and constrains the instantiations of multiple mission architectures and solutions.

Outline

Executive Summary

- Include the title of the mission.
- Include a brief overview of the mission to include scenario, the origin of the mission requirement and supporting reference documents, a description of the proposed mission architecture, key assumptions and the sensitivity analysis around those assumptions.
- Outline potential next steps for implementation.
- Identify owner/configuration manager; discuss the update cycle and decision points/events that may drive an update to the GMRA.

Mission Definition

- Describe the mission.
    - Define the mission objectives
    - Explain the overall concepts of operations and employment

  - Include time frame, domain, theater or other details as needed
  - Describe the scenario
  - Identify the Mission Threads and/or Mission Engineering Threads
    - Include activities/tasks and/or systems
- Identify the stakeholders for the mission.
  - For example: Services, Agencies, allies that are part of the mission; depending on the mission, there may be other integral non-traditional organizations
- Define metrics for mission success, including Measures of Effectiveness (MOE).
- Identify relevant family of Joint Operations Concepts or Commander's Intent (if applicable).
  - List specific concepts, such as the Joint Warfighting Concept (JWC), that are being used to define the mission

Foundational Assumptions and Dependencies

- Identify threats and operational environment and source of information.
- Identify dependencies and impacts of mission/architecture on adjacent missions (GMRAs).
- Identify key assumptions about the mission, technology or capabilities.
  - Explain how the study team determined these assumptions and why they are realistic / reasonable
- Describe assumptions with variables, if applicable

Analytical Methodology

- Describe the analytical and computational tools used, including the type of methods (e.g., parametric, probabilistic, physics based, subject matter expert, table-top).
- Describe the models used, identify pedigree and fidelity.
- Identify the data collected and used to populate the models and include source.
- Describe the integrated uncertainties across the whole modeling environment and impact on the precision/accuracy of the answer.
- Define trade space analysis – What parameters or variables were held constant and which ones changed.
- Explain the sensitivity analysis around the baseline assumptions.
- Include cost analysis techniques/methods, if appropriate.
- Perform gap analysis to determine if there are any issues or risks to obtain mission success.

Architecture Overview

- Describe the architecture products that guide and constrain the GMRA.
  - Describe the As-is state of the mission and the To-be state of the mission
  - Depict gaps within the architecture
  - Include an OV-1 view if applicable; this can be depicted as a Mission Thread or Mission Engineering Thread
  - List the components and their technical and performance attributes
    - Include how the components or systems are interfaced/communicate with one another
  - Discuss trades or alternatives (related to sensitivity analysis/uncertainties)
    - Identify capability solutions that can close mission capability gaps

Conclusions

- Describe the GMRA metrics for success.
  - Explain the results obtained from the analysis
  - Identify any issues or uncertainties with the results
- Identify next steps required to instantiate the GMRA.
- Identify any recommended follow-on studies.

Appendix B: Government Capability Reference Architecture (GCRA) (Template)

Purpose

Government Capability Reference Architectures (GCRAs) should be used to guide and constrain a set of common capabilities within a specific domain (e.g., Space, Electromagnetic Spectrum, Cyberspace) or technical functions and processes (e.g., Command and Control, Communications or Positioning, Navigation, and Timing). These capabilities, either domain specific or by technical functions/processes, will be required to carry out *multiple* operational or tactical missions. GCRAs will depict the current and future architecture to determine where mission capability gaps exist and guide future investment decisions for new game-changing capabilities to ensure the United States can counter or outmatch adversaries in the future fight. Warfighters require capabilities that operate in the mildest to extreme operational environment (low to highly contested environments). The threat will continuously change, therefore the GCRA must be able to be updated based on the scenarios and evolving threat.

Definitions

Architecture: a unifying or coherent form or structure of components and either relationships; simply a depiction or view. For the purpose of a GCRA, the architecture shows the current and future set of mission or capabilities and their design and evolution over time.

Capability Architecture: a unifying or coherent form or structure depicting the various capability options/alternatives to include components, relationships, and principles.

Government Reference Architecture: a Government-owned, authoritative source of information about a specific subject area that guides and constrains the instantiations of capability architectures and solutions.

Outline

Executive Summary

- Include a brief overview of the Capability Area that the GCRA describes.
    - Include background on the purpose of the GRA, list of the various missions used to inform the development of the GCRA, key assumptions, and other reference documents
- Describe overall Concept of Operations of the GCRA.
- Outline potential next steps for implementation.
- Identify owner/configuration manager; discuss the update cycle and decision. points/events that may drive an update the GCRA.

Capability Area Definition

- Describe the Capability Area.
  - Define the objective
  - Explain the overall context of operations and employment
  - Include the time frame, domain, theater, or other details as needed
  - Describe the scenario
  - Define or reference all missions analyzed in creating the GCRA
- Identify the Mission Threads and/or Mission Engineering Threads.
  - Include activities/tasks and/or systems
- Identify the stakeholders.
  - For example: Services, Agencies, allies that are part of the mission. Depending on the mission, there may be other non-traditional organizations integral to the mission.
- Define metrics for mission success – this can include mission Measures of Effectiveness (MOE).

Foundational Assumptions and Dependencies

- Identify threats and mission environments and source of definition.
- Identify dependencies and impacts of capability architecture (GCRA) to various missions (GMRAs).
- Identify key assumptions about the missions, technologies, or capabilities.
  - Explain how the analysts determined these assumptions and why the assumptions are realistic/reasonable
- Describe assumptions with variables if applicable.

Analytical Methodology

- Describe the analytical and computational tools used, including the type of methods (e.g., parametric, probabilistic, physics based, subject matter expert, table-top).
- Describe the models used, identify pedigree, and fidelity.
- Identify the data collected and used to populate the models, include source.
- Describe the integrated uncertainties across the whole modeling environment and impact on the precision/accuracy of the answer.
- Define trade space analysis – what parameters or variables were held constant and which ones changed.
- Explain the sensitivity analysis around the baseline assumptions.
- Include cost analysis techniques/methods, if appropriate.

- Perform gap analysis to determine if there are any issues or risks to obtain mission success.

Architecture Overview

- Describe the architecture products that guide and constrain the GCRA.
    - Describe the As-Is state of the capability architecture and the To-Be state of the capability architecture
    - Include the list of capabilities and their technical and performance attributes
    - Describe the technology readiness level, agency responsible for each capability/technology, and planned deployment date
- Describe the approach to mature or develop each capability, system, technology, etc.
- Describe the risks associated with each of the capabilities.
    - Risks can be associated with data exchange, interoperability, system performance against threat or in operating environment(s), schedule
- The following table shows notional GCRA artifacts:
    - NOTE: Department of Defense Architecture Framework (DoDAF) products are used only to illustrate EXAMPLES of the various architecture artifacts that may be required for a GCRA

Example GCRA Artifacts

<table>
<tr><th>Content</th><th colspan="2">Example Views/Models</th></tr>
<tr><td>Purpose: Introduction, overview, context, scope, goals, purpose, why needed, and when and how used</td><td colspan="2">• AV-1 Overview & Summary Information
• CV-1: Vision – overall strategic concept and high level scope
• OV-1 High Level Operational Concept Graphic – executive operational summary level of what the preferred alternative (solution) architectures are intended to do and how they are supposed to do it</td></tr>
<tr><td>Technical Positions & Policies</td><td colspan="2">• StdV-1 Standards Profile – standards, specifications, guidance, policy applying to elements of the preferred alternative (solution) architectures</td></tr>
<tr><td rowspan="2">Architectural Patterns: generalized patterns of activities, and system functionality and their resources, providers and information/ data resource flows

Generalized scenario patterns of sequenced (sequential/ concurrent) responses by activities, services and system functions (together with their resources) to synchronous/ asynchronous timed events</td><td><u>Operational Patterns</u>
• OV-2 (multiple) Operational Resource Flows
• OV-5 {a, b} Activity diagrams
• OV-6c Event-Trace Description</td><td><u>System Patterns</u>
• SV-1 (multiple) System Interfaces
• SV-2 System Resource Flows
• SV-4 System Functionality
• SV-10b System State Transitions
• SV-10c Systems Event-Trace Description</td></tr>
<tr><td colspan="2"><u>Event-Based Scenario Patterns of Dynamic Behavior</u>
• OV-6c Event-Trace Description
• SvcV-10c Services Event-Trace Description
• SV-10c Systems Event-Trace Description</td></tr>
</table>

Conclusions

- Describe the GCRA metrics for success.
  - Explain the results obtained from the analysis
  - Identify any issues or uncertainties with the results
- Identify next steps required to instantiate GCRA.
- Identify any recommended follow on studies.

Method to Evaluate Completeness and Quality of a GRA

This section provides more open-ended evaluation criteria for the practitioner and is intended to prompt the development of measures of effectiveness/measures of performance by which the GRA should be assessed.

The GRA should be a tool, forming a baseline structure that can be applied to various analyses under a given scenario, to assess their efficacy. As such, the ME practitioner should apply some general measures of effectiveness to evaluate (1) the quality of the GRA, as such, and (2) the validity relevance of the GRA to the scenario under analysis.

- Does the GRA address both functional and operational constituents?
- Does the GRA describe the scenario, time frame, operational environment, and threat?
- Is there a clear and documented set of artifacts that describe the requirements (e.g., interface requirements, data exchange requirements) that the Government Reference Architecture satisfies?
- Is there a clear and documented architecture model which describes both functional and infrastructure components and their relationships?
- Does the architecture describe how components would be built to realize services and their operations?
- *Does the Government Reference Architecture provide quantified measures to guide design, selection, and development of materiel solutions?*
- *Are there clear steps that identify how to instantiate Government Reference Architecture and whether additional analysis or studies are required?*

Definitions

Architecture – The structure of components, their relationships, and the principles and guidelines governing their design and evolution over time. (DAU Glossary)

Assumption – A specific supposition of the operational environment that is assumed to be true, in the absence of positive proof, essential for the continuation of planning. (JP 5-0, DoD Dictionary)

Baseline – An integrated set of data used by the DoD Components as an agreed upon starting point for studies supporting the development and implementation of defense strategy and DoD (PPBES) activities. Baselines are produced and reviewed in an open, collaborative, and transparent environment. (DoDD 8260.05)

Capability – The ability to complete a task or execute a course of action under specified conditions and level of performance. (CJCSI 5123.01H, DAU Glossary)

Concept of Operations (CONOPS) – A verbal or graphic statement that clearly and concisely expresses what the commander intends to accomplish and how it will be done using available resources. Also called CONOPS. (JP 5-0, DoD Dictionary)

Constraint – In the context of planning, a requirement placed on the command by a higher command that dictates an action, thus restricting freedom of action. (JP 5-0; DoD Dictionary)

Experiment – In context of ME, future-oriented testing of proposed solutions to evaluate their ability to enable preferred ways of operating in the anticipated future operating environment. ("Guide for Understanding and Implementing Defense Experimentation," 2006; CJCSI 3030.01)

Fidelity – The degree to which a model or simulation represents the state and behavior of a real world object or the perception of a real world object, feature, condition, or chosen standard in a measurable or perceivable manner; a measure of the realism of a model or simulation. (Defense Modeling and Simulation Coordination Office M&S Glossary)

Government Reference Architecture (GRA) – Government-owned Reference Architectures; the authoritative [Government] source of information to guide and constrain mission architectures and solutions. It integrates the data, information, boundary conditions and rules that describe the mission capability needed by the warfighter in sufficient detail to allow for transition of technology-based solutions. (ME Guide)

Kill Chain – Mission thread with a kinetic outcome. Dynamic targeting procedures, often referred to as find, fix, target, track, engage, assess (F2T2EA) by air and maritime component forces; decide, detect, deliver, and assess methodology by land component forces. (JP 3-09)

Mission – 1. The task, together with the purpose, that clearly indicates the action to be taken and the reason therefore. (JP 3-0) 2. In common usage, especially when applied to lower military units, a duty assigned to an individual or unit; a task. (JP 3-0) 3. The dispatching of one or more aircraft to accomplish one particular task. (JP 3-30). (DoD Dictionary)

Mission Approach, "As-Is" – The "as-is" mission approach represents the baseline reference case to which comparisons of alternatives will be evaluated. (ME Guide)

Mission Approach, "To-Be" – The "to-be" mission approaches are the many alternate approaches being evaluated; these account for changes in systems, performance, tactics, etc. They do not account for changes in the environment, threats, scenario, etc. Those changes would require an entirely new mission definition. (ME Guide)

Mission Architecture – The detailed structure of the conduct of the mission. A series of interdependent views of the assets, organization, functions, Interactions and sequencing of the mission operations approach. The mission architecture is a "business" model of the conduct of the mission vignette and must fit within lager constructs of the mission at the scenario, force deployment and campaign levels. (ME Guide)

Mission Capability Gap – The inability to execute, carry out, or complete a specified mission. The gap may be the result of no current or existing capability, a lack of proficiency or sufficiency in a current or existing capability, or the need to replace an existing capability to prevent a future gap such as interoperability. (Adapted from CJCSI 3010.02E)

Mission Definition – The elements that describe the context of the mission. The definition of the mission to be accomplished in a specific time frame, its success factors, the threats and constraints (environment, socio-political, allies/enemies/neutrals, etc.). Changes in any of the components of a mission create a new mission definition. (ME Guide)

Mission Efficacy – The ability to produce the desired or intended result of the operational approach. (ME Guide)

Mission Element – A platform or system that performs a task; a combination of platform, system and/or subsystems that provides a functional performance using specific technical characteristics to perform a specific task. (ME Guide)

Mission Engineering (ME) – The deliberate planning, analyzing, organizing, and integrating of current and emerging operational and system capabilities to achieve desired warfighting mission effects. (DAG Chapter 3/FY 2017 NDAA Section 855 Report to Congress)

Mission Engineering Thread (MET) – Mission threads that include the technical details of the capabilities and systems required to execute the mission. (ME Guide)

Mission Integration Management (MIM) – The management, synchronization, and coordination of concepts, activities, technologies, requirements, programs, and budget plans to guide key decisions focused on the end-to-end mission. (ME Guide)

[Mission] Return on Investment (ROI) – An evaluation of the cost incurred against the benefits realized. Evaluating the ROI of MS&A in such roles involves weighing the costs against the benefits. Costs include the construction, operation, and maintenance of [mission] capabilities. Benefits include time savings, improved training, and safety [and qualitative or quantitative measures of mission success -- e.g., target(s) destroyed]. (National Research Council 2006.

Defense Modeling, Simulation, and Analysis: Meeting the Challenge. Washington, DC: The National Academies Press. https://doi.org/10.17226/11726.)

Mission Tasks – A clearly defined action or activity specifically assigned to a system, individual or organization that must be done. (Adapted from JP-01).

Mission Thread (MT) – A sequence of end-to-end activities and events presented as a series of steps to achieve a mission. (ME Guide)

Model – A primarily quantitative or computational system employing mathematical equations that specify parametric relationships and their associated parameter values as a function of time, space, and/or other system parameters. (A Practical Guide to SysML (Third Edition))

Operations – 1. A sequence of tactical actions with a common purpose or unifying theme. (JP 1) 2. A military action or the carrying out of a strategic, operational, tactical, service, training, or administrative military mission. (JP 3-0, DoD Dictionary) There are *operations* - sequences of tactical actions with a common purpose or unifying theme; *major operations* - series of tactical actions to achieve strategic or operational objectives; and *campaigns* - series of related major operations aimed at achieving strategic and operational objectives within a given time and space. (JP-1)

Reference Architecture (RA) – An authoritative source of information about a specific subject area that guides and constrains the instantiations of multiple architectures and solutions (DoD Reference Architecture, June 2010)

Scenario – Description of the geographical location and time frame of the overall conflict. It should include information such as threat and friendly politico-military contexts and backgrounds, assumptions, constraints, limitations, strategic objectives, and other planning considerations. (ME Guide)

Sensitivity Analysis – Determines how different values of an independent variable affect a particular dependent variable under a given set of assumptions. (Investopedia)

Strategic – In the context of national interests, the level at which national, multinational, and theater objectives are addressed. (Adapted from JP 3-0, Chapter 1, 6.b.)

Tactical – The level of employment, ordered arrangement, and directed actions of forces in relation to each other, to achieve military objectives assigned to tactical units or task forces (TFs). (Adapted from JP 3-0, Chapter 1, 6.d.)

Threat – The sum of the potential strengths, capabilities, and strategic objectives of any adversary that can limit U.S. mission accomplishment or reduce force, system, or equipment effectiveness. It does not include (a) natural or environmental factors affecting the ability or the system to function or support mission accomplishment, (b) mechanical or component failure affecting mission accomplishment unless caused by adversary action, or (c) program issues related to budgeting, restructuring, or cancellation of a program. (DAU Glossary, CJCSI 5123.01H)

Verification – The process of determining that a model or simulation implementation and its associated data accurately represent the developer's conceptual description and specifications. (JP 3-13.1, DoD Dictionary)

Validation – The process of determining the degree to which a model or simulation and its associated data are an accurate representation of the real world from the perspective of the intended uses of the model. Applicable to an expressed user need and consistent with program concept of operations. (SMC Mission Engineering Primer and Handbook)

Vignette – A narrow and specific ordered set of events, and behaviors and interactions for a specific set of systems to include blue capabilities and red threats within the operational environment. Vignettes can represent small, ideally self-contained parts of a scenario. (ME Guide)

Acronyms

CONOPs	Concept of Operations
DOTMLPF	Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, and Facilities
DoD	Department of Defense
DPG	Defense Planning Guidance
DODAF	Department of Defense Architecture Framework
FYDP	Future Years Defense Program
GCRA	Government Capability Reference Architecture
GMRA	Government Mission Reference Architecture
GRA	Government Reference Architecture
ME	Mission Engineering
MET	Mission Engineering Thread
MOE	Measure of Effectiveness
MOP	Measure of Performance
MOS	Measure of Success
MSFD	Multi-Service Force Deployment
MT	Mission Thread
NDS	National Defense Strategy
NMS	National Military Strategy
OOB	Order of Battle
OSD	Office of the Secretary of Defense
PPBE	Planning, Programming, and Budgeting Execution
RA	Reference Architecture
ROI	Return on Investment
TTP	Tactics, Techniques, and Procedures
UJTL	Universal Joint Task Lists
USD(R&E)	Under Secretary of Defense for Research and Engineering

References

CJCSI 3030.01, Implementing Joint Force Development and Design, December 3, 2019.

CJCSI 5123.01H, Charter of the Joint Requirements Oversight Council (JROC) of the Joint Capabilities Integration and Development System (JCIDS), August 31, 2018.

Defense Acquisition Guidebook (DAG), Chapter 3, Systems Engineering, Defense Acquisition University.
https://www.dau.edu/tools/dag

Defense Acquisition University (DAU) Glossary.
https://www.dau.edu/tools/t/DAU-Glossary

Defense Modeling and Simulation Coordination Office (DMSCO) M&S Glossary.
https://www.msco.mil/MSReferences/Glossary/MSGlossary.aspx

DoD Dictionary of Military and Associated Terms, June 2020.
https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/dictionary.pdf

DoD Digital Engineering Strategy, Office of the Under Secretary of Defense for Research and Engineering, June 2018.

DoD Directive 5135.02, "Under Secretary of Defense for Acquisition and Sustainment (USD(A&S))," July 15, 2020.

DoD Directive 5137.02, "Under Secretary of Defense for Research and Engineering (USD(R&E))," July 15, 2020.

DoD Directive 8260.05, "Support of Strategic Analysis (SSA)," July 7, 2011.

DoD Instruction 5000.UJ, "Engineering of Defense Systems," Forthcoming.

DoD Reference Architecture Description, Office of the Assistant Secretary of Defense, Networks and Information Integration (OASD/NII), 2010. Accessed November 5, 2020.
http://www.acqnotes.com/Attachments/Reference%20Architecture%20Description,%20June%202010.pdf

Friedenthal, S., A. Moore, and R. Steiner. A Practical Guide to SysML, 3rd Edition. Waltham, MA: Elsevier/Morgan Kaufmann, 2014.

Guide for Understanding and Implementing Defense Experimentation (GUIDEx), The Technical Cooperation Program, Version 1.1, February 2006.

Investopedia.
https://www.investopedia.com/terms/s/sensitivityanalysis.asp

Joint Publication 1, Doctrine for the Armed Forces of the United States, March 25, 2013, Incorporating Change 1, July 12, 2017.

Joint Publication 3-09, Joint Fire Support, April 10, 2019.

Joint Publication 3-30, Joint Air Operations, July 25, 2019.

Joint Publication 3-85, Joint Electromagnetic Spectrum Operations, May 22, 2020.

Joint Publication 5-0, Joint Planning, June 16, 2017.

"Mission Integration Management." Report to Congress in response to National Defense Authorization Act for Fiscal Year 2017, Section 855. Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, March 2018.

National Defense Authorization Act for Fiscal Year 2017, Public Law 114-328, 114th Congress, December 23, 2016.

National Research Council. Defense Modeling, Simulation, and Analysis: Meeting the Challenge. Washington, DC: The National Academies Press, 2006. https://doi.org/10.17226/11726

Space and Missile Systems Center (SMC) Systems Engineering Primer & Handbook, 2nd Edition. Los Angeles Air Force Base, El Segundo, CA: SMC, U.S. Air Force, 2004. http://www.acqnotes.com/Attachments/SMC%20System%20Engineering%20Handbook.pdf, last accessed November 5, 2020.

Mission Engineering Guide

Office of the Under Secretary of Defense for Research and Engineering
3030 Defense Pentagon
Washington, DC 20301
osd.r-e.comm@mail.mil
https://ac.cto.mil/engineering