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

Darth Vader's Secret Weapon: Implementing Mission Engineering with UAF

Matthew Gagliardi
System Strategy, Inc. SSI
1221 Bowers St, #50
Birmingham, MI 48012
MGagliardi@Systemxi.com

Matthew C Hause
System Strategy, Inc. SSI
1221 Bowers St, #50
Birmingham, MI 48012
MHause@systemxi.com

James N Martin
The Aerospace Corporation
14745 Lee Road, Chantilly, VA, USA
James.N.Martin@aero.org

Mark A Phillips
Raytheon | An RTX Business
9000 S. Rita Road, Tucson, AZ 85747
mark.phillips@rtx.com

Abstract. When planning and conducting a Mission Engineering (ME) study, it is important to have a complete, correct, and coherent model of the mission architecture. The Unified Architecture Framework (UAF) has been found to be effective for this purpose. The OUSD (R&E) Mission Integration office is exploring how to use UAF for their ME architectures. This paper will explore some of the required modeling features and constructs that will enable this to occur. The paper "Implementing Mission Engineering with UAF" was presented at a previous conference and this paper will expand on that presentation and will discuss additional work that has been accomplished since then. This paper will also explore the proposed extensions for UAF to better support ME. We created a prototype model using the Battle of Hoth from Star Wars as a proof of concept for these modeling extensions and used the process and ME concepts defined in the Mission Engineering Guide (MEG). Since then there have been several concepts that were explored such as compatibility with the Model-Based Acquisition (MBAcq) approach, recent initiatives from the Office of the Assistant Secretary of Defense for Mission Capabilities, Enterprise Systems Engineering (ESE) process and methods, detailed resource engagement, use of different modeling languages (e.g., Systems Modeling Language (SysML), SysML v2 and UAF v2), Effects and Outcomes, variety of measures, additional attributes/stereotypes such as differentiation between enemy/friendly/neutral - Blue Force, Red Force, etc., provenance/confidence of enemy resources, and so forth. This paper will summarize the research and modeling done to date and explore these additional concepts as well as new ideas introduced in the MEG v2.

Keywords. Mission Engineering, Mission Architecture, Enterprise Architecture, Unified Architecture Framework, Model-Based Acquisition

Contents

Introduction

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. (DoD, 2023) US DoD capability gap analysis is a form of mission analysis whereby feedback from operational stakeholders, comprehensive evaluations of warfighting effects which a potential enemy may employ, estimations of current enemy capacity, current estimations of US and joint force capacity, and current tactics training and procedure are considered. The identification and consideration of these scenarios and gaps is the starting point for Mission Engineering (ME).

The Defense Acquisition Guidebook (DAU, 2023) defines 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.” (DAU, 2023) Of course, any engineering/analysis process can begin and end at various stages. Often it is the top-down/bottom-up/meet in the middle approach that is necessary to ensure that a clear purpose is defined and the elements in the model are included to meet that purpose. Finally, mission analysis is the process of identifying and understanding the problem. ME is the process for engineering a way to address it.

Mission Integration for the US Department of Defense

The Deputy Assistant Secretary of Defense for Mission Integration in the Office of the Under Secretary of Defense for Research and Engineering (OUSD R&E) recently briefed the NDIA Systems and Mission Engineering conference on ME research and development activities taking place within the Department of Defense. In addition, the Mission Integration Office is also working with the branches of the armed forces, industry, and academia to determine best practice for ME. (Roman, Dahmann, 2022) The current guidance from the OUSD (R&E) Mission Integration office is to evaluate implementation of UAF for ME. This paper and the example model are assisting in that effort.

Mission Engineering Guide (MEG)

Dr. James Moreland was appointed the first Executive Director for Mission Engineering after his publication on ME in Leading-Edge Technical Digest (Moreland, 2014). He wrote the first ME guide, released on November 11, 2019. This was followed by a re-release and rewrite in November 2020 (DoD, 2020). The ME guide "describes the foundational elements and the overall methodology of Department of Defense (DoD) 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:

- Describes the main attributes of DoD ME and how to apply them to add technical and engineering rigor into the ME analysis process.
- Enables practitioners to formulate problems, and build understanding of the main principles involved in performing engineering analysis in a mission context; and
- Provides 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." (DoD, 2020)

Mission Engineering Guide V2 (MEG V2)

The second edition of the MEG was released in October, 2023 (DoD, 2023a). It clarified the purpose of the MEG as well as added information regarding reuse, curation, and other topics. The five steps of the ME approach are illustrated in Figure 1 (DOD, 2023a). The paper will demonstrate how these steps can be realized with the proposed extensions for ME planned for the UAF.

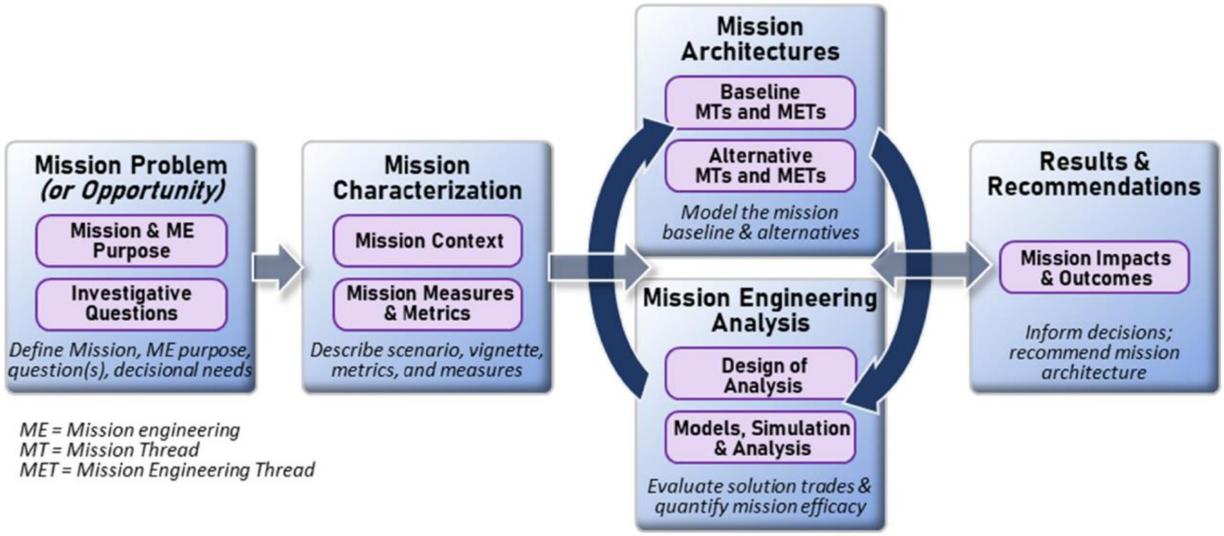


Figure 1. Mission Engineering Process.

The Purpose of the MEG. There were many changes, not all of which can be included for reasons of space. Some are listed below. The change record states: "The MEG is not a DoD Manual, DoD Instruction, or a DoD Directive; rather the MEG offers practitioners a disciplined approach to the process of ME. A methodology which is extensible, scalable, and based on the practitioner's purpose, focus, and questions related to assessing systems or systems of systems within a mission context to inform the design and integration of current and emergent properties capabilities to yield desired mission outcomes." This clarification is useful as it ensures that it is used as a guide rather than a prescriptive process manual.

Model Curation and Reuse. Section 2.3.3 covers Reuse – Storing, Documentation and Curation. It states that "Mission engineering adds value to the DoD's engineering acquisition and operational enterprises by facilitating the preservation and maintenance – the curation – of data products from current and prior mission engineering efforts." The MEG emphasizes results, models, and data need curation. It recommends "developing a library of models that are developed and used throughout the ME activity…." The final point in the section is that "Over time, properly curated results from mission engineering analysis will yield valuable data for future use – providing authoritative data and improving the fidelity of data models." (DoD, 2023a) This will improve results and accelerate the development of ME models, studies, and fielded capabilities in the form of systems. Given the number of complexity of the models generated within the DoD and its contractors, model, component, and artefact reuse and curation is essential. The need for central or federated repositories, curated reuse libraries, discovery, harvesting and publicizing assets, etc. needs to be deployed. Otherwise, enterprises like DoD will end up with assorted, disparate models that cannot be reused effectively, or are simply misused.

The need for model curation has been identified in multiple papers and projects - (Hause, 2014), (Rhodes, Ross, 2015), (Reymondet et al, 2016), (Rhodes, 2019), etc. Model curation was recently highlighted in (Ademola et al, 2023) which looked at building libraries of model patterns, interfaces, reference architectures, etc. Further presentations of this subject at INCOSE and the OMG have instigated a project within the OMG to update the Reusable Asset Specification (RAS) to provide a standard means of model curation and reuse and supporting infrastructure. This is part of the Model-Based Acquisition (MBAcq) managed community at the OMG. (Hart, Hause, 2024) Further information is available at https://www.omg.org/communities/model-based-acquisition-user-community.htm

Implementing ME with the UAF

The Unified Architecture Framework (UAF) provides a standard set of architecture views for describing various aspects of an enterprise and major entities in the enterprise (OMG, 2022a, 2022b, 2022c). Since the DoD is an enterprise of enterprises, UAF works well as it highlights both materiel and non-materiel (doctrine, organization, training, leadership, personnel, facilities) solutions. The 82 view specifications in UAF are organized in a two-dimensional grid as shown in Figure 2.

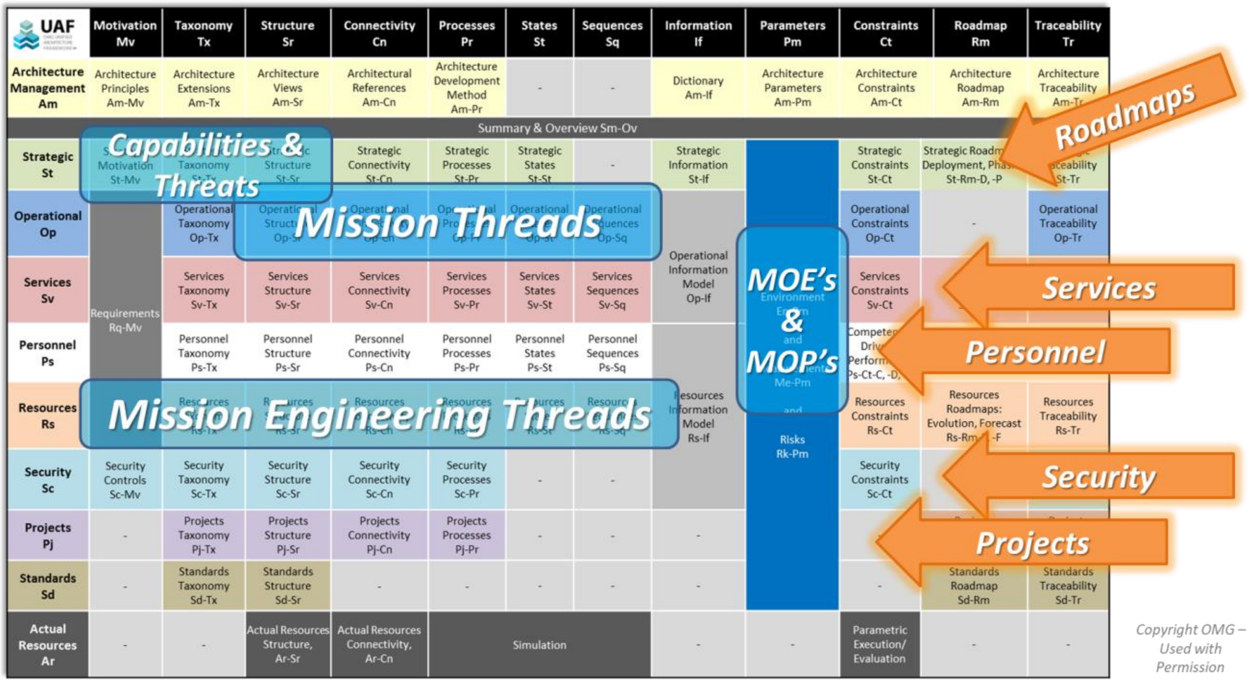


Figure 2. Mission Engineering Views in UAF.

The Mission Problem definition and the Mission Characterization aspects of the mission, along with the Mission Thread (MT) elements and views to be used in ME, map mainly to the Strategic and Operational viewpoints in UAF as illustrated in Figure 2 (Martin & Alvarez, 2023). The Mission Engineering Threads (METs) are an implementation of the MTs, so these are primarily depicted in the Resources viewpoint. However, notice that there are several other UAF viewpoints and their associated modeling views that could be readily used in an ME study and in related activities such as capability planning, enterprise portfolio management, annual budget formulation, program assessment and evaluation, system requirements development, etc.

Proposed Extensions

UAF provides a UAF Modeling Language (UAFML) that is especially designed for modeling an enterprise and as such it is appropriate for modeling a large and complex mission architecture along with its variety of scenarios, vignettes, MTs, METs, etc. The paper "Implementing Mission Engineering with UAF" (Gagliardi, Hause, 2023) described the current state of the art regarding ME using the UAF. This paper will build on that effort. First however, it is worth summarizing the main points of the previous paper. That paper summarized the definition of ME as well as UAF and its applicability for use with ME. It spelled out a set of extensions to UAF that will be released in the next version of the UAF to provide a means for improved support of ME and alignment with the MEG. Some of the structural extensions are shown in Figure 3.

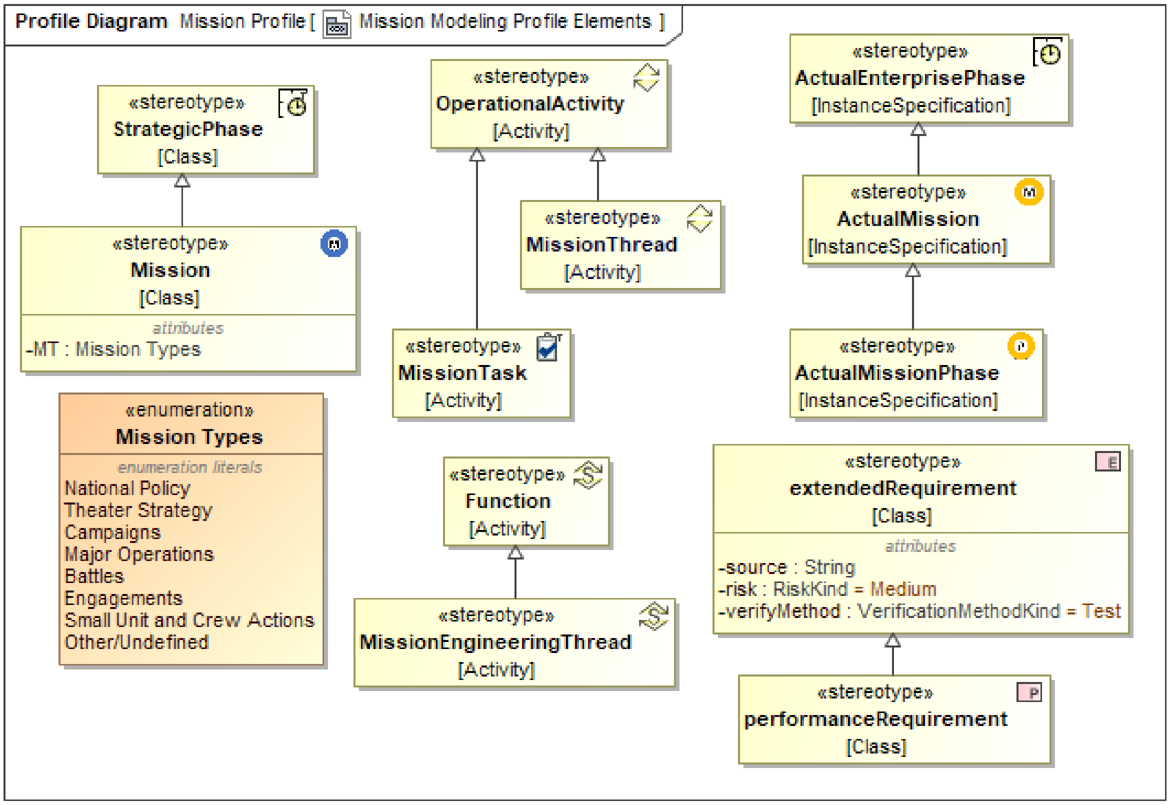


Figure 3. Mission Modeling Profile View.

These elements used in ME modeling that extend the Domain Metamodel in UAF are described in Table 1.

Table 1. Modeling Elements for Use in a Mission Architecture Model.

Modeling Element	Description
Mission	A Mission element is a generalization of an Enterprise Phase element in the UAF Domain Metamodel
Actual Mission	An Actual Mission is a generalization of an Actual Enterprise Phase element in the UAF Domain Metamodel
Actual Mission Phase	An Actual Mission Phase is generalization of an Actual Mission providing an instance specification of a Mission and a Mission Phase
Mission Thread	A Mission Thread is a generalization of an Operational Activity
Mission Task	A Mission Task is also a generalization of an Operational Activity, with Mission Threads being made up of other Mission Threads or Mission Tasks
Mission Engineering Thread	Mission Engineering Thread is a generalization of a Function and describes the implementation of Actual Mission Phases. Traceability between the MET and MT uses the standard UAF implements relationship

Domain Specific Languages (DSL)

The modifications necessary for UAF to support ME were not very extensive since UAF already has many of the necessary concepts. For example, the Operational views can be used to define the required structure and behavior of the mission in a solution independent manner, i.e., the MT. The Resources views are then used to define the MET and how it implements the MT to meet the goals of the mission. The extensions defined in Figure 3 are necessary to explicitly state which elements in the model correspond to the domain specific elements, otherwise, it becomes more difficult to validate the model. For example, a MT is made up of Mission Tasks, which use new and existing Operational Activities to describe the sequence of the MT.

Defining the elements of MT, Mission Task and their corresponding activities means that model validation rules can readily be created to ensure that the hierarchy is maintained. MTs are executed as part of a mission. Validation rules can ensure that the MT is linked to a Mission Phase and that Mission Phases all have MTs and so forth. Otherwise, the user needs to do all this by manual model inspection. This ensures that the model is "done right". When combined, these new concepts create a DSL for ME. Fowler (2010) defines a DSL as a "…a computer language that's targeted to a particular kind of problem, rather than a general-purpose language that's aimed at any kind of software problem." SysML (OMG, 2019) is an example of a DSL for systems engineers. SysML is also a general-purpose language upon which a DSL can be built. In fact, when most organizations have institutionalized the use of SysML, they create common libraries of types and components, as well as profiles of common stereotypes and tag definitions. The UAF is a DSL for Enterprise Architecture and SoS built upon SysML. See also Hause (2006).

Mission Threads and UJTLs. Section 5.1 of the MEG v2 on MTs provides guidance on sourcing them. "There is no singular source to derive MTs: however, ample discussion with stakeholders to fully characterize the mission is critical. It is noteworthy that the Joint Staff uses the Unified Joint Task List (UJTL) as one of several starting points for developing Joint MTs. Other potential starting points include Service-specific task lists." To preserve the original source, the UAF contains the concept of a Standard Operational Activity. It was originally included from MODAF to define standards-based operational activities. This concept could be used as-is with no extensions to capture this concept. (DoD, 2020a) Mission Engineering and its use of the Operational Viewpoint helps resolve confusion of how DoDAF and MODAF intended the Operational Viewpoint to be used.

Example Model – "A long time ago in a galaxy far, far away..."

The example used in this paper, as well as in the paper "Implementing Mission Engineering with UAF" (Gagliardi & Hause, 2023), is the Battle of Hoth from the second Star Wars movie, "The Empire Strikes Back". We are using this as an example because it is well known, contains a rich source of systems, strategies, missions, and behavior as well as illustrates joint operations. As it is based on a movie, there are no issues of classified materials or problems relating to the release of information. For further background information see (Fandom, 2023) or better yet, grab some popcorn and watch the movie. The purpose of the Hoth model is to provide a proof of concept of planned additions to UAF, explore missing modeling concepts described in best practice and guidance documents and provide a working example. The work done so far has concentrated on the Strategic and Operational views, defining the concepts of missions, mission phases, MTs and operational architectures. It provided an overview of existing reporting views available in the UAF that provide a means of validating the architecture. Finally, it defined the resource and organizational structures and functionality. For further information see (Gagliardi & Hause, 2023).

Defining the Purpose of the Mission

Identifying enterprise drivers, challenges, and opportunities helps understand its motivations and measures of success (MOS). The A MOS is determined by knowing how well the desired effects (i.e., downstream results) will be achieved when certain capability enhancements are put into place. The UAF metamodel version 1.1 did not have the requisite model element types that represent these key up-front management concepts. These additional elements in the EA model were added in UAF version 1.2 to provide the proper justification for new and enhanced capabilities. (Martin 2021, 2022; OMG, 2022c; Hause, Kihlström, 2022; Hause et al, 2023) Definitions for the key concepts discussed so far are shown in Table 2 and the elements in Figure 3.

Table 2. Strategic Motivation Elements.

Concept	Description
Concern	A matter of relevance or importance to a stakeholder regarding an entity of interest.
Driver	Thing that forces to work or act; that which urges you forward
Challenge	A demanding or stimulating situation; a call to engage in a contest or fight
Enterprise State	Condition with respect to circumstances or attributes
Capability	Ability to achieve a desired effect under defined conditions and environments
Opportunity	A possibility due to a favorable combination of circumstances
Risk	A source of danger; a possibility of incurring loss or misfortune
Effect	A phenomenon that follows and is caused by some previous phenomenon
Outcome	Something that happens or is produced as the final consequence or product
Goal	A statement about a state or condition of the enterprise to be brought about or sustained through appropriate Means
Objective	A statement of an attainable, time-targeted, and measurable target that the enterprise seeks to meet in order to achieve its Goals

Stakeholders, Concerns, Goals, and Drivers

A Stakeholder is an individual organizational resource, or a type of organizational resource (both internal and external to the enterprise) who has an interest in, or is affected by, outcomes or intermediate effects generated or influenced by the enterprise. Stakeholders of the mission likely have enduring concerns that are independent of the mission but relate to its goals. The Legion Commander is concerned about his loss of position or possibly his life, which typically happens when failure occurs in the service of the Empire.

He wishes to prevent a rebel resurgence and to ensure a decisive victory. Darth Sidius and Darth Vader wish to control the Galaxy and establish dark side dominance. Darth Vader also wishes to protect Luke Skywalker. These Concerns relate directly to the mission goals, which then link to the Drivers which have forced the Empire to act. These will be discussed further on in the paper.

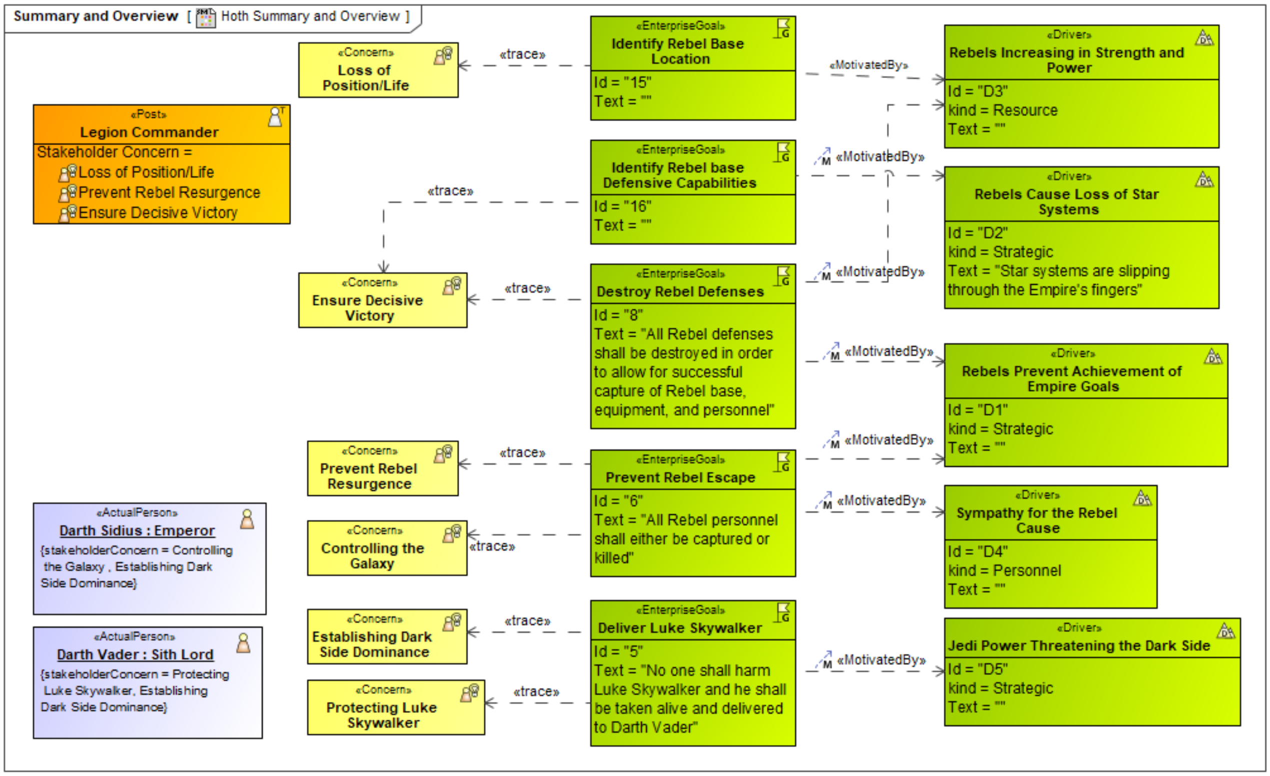


Figure 4. Hoth Summary and Overview: Stakeholder Concerns and Goals.

Mission Definition

The Empire Mission structure shown in Figure 5 illustrates the complexity required to model missions. Empire doctrine proscribes that every military mission has two phases to it: Planning and Execution. A Planetary Invasion Mission is comprised of separate Scout, Landing, and Attack Missions, each with their own Planning and Execution Phases. These are all types of Invasion Missions. Each of these have a defined Mission Type. The Execution and Planning Phases both inherit Mission Tempo and Phase attributes. Mission type attributes have been defined for several of the mission types. Scenario and Vignette types have been linked to the missions that when instantiated define the parameters and context of the mission. These are detailed in the next section. Specific MTs can and should be linked to the various missions to define the functional aspects.

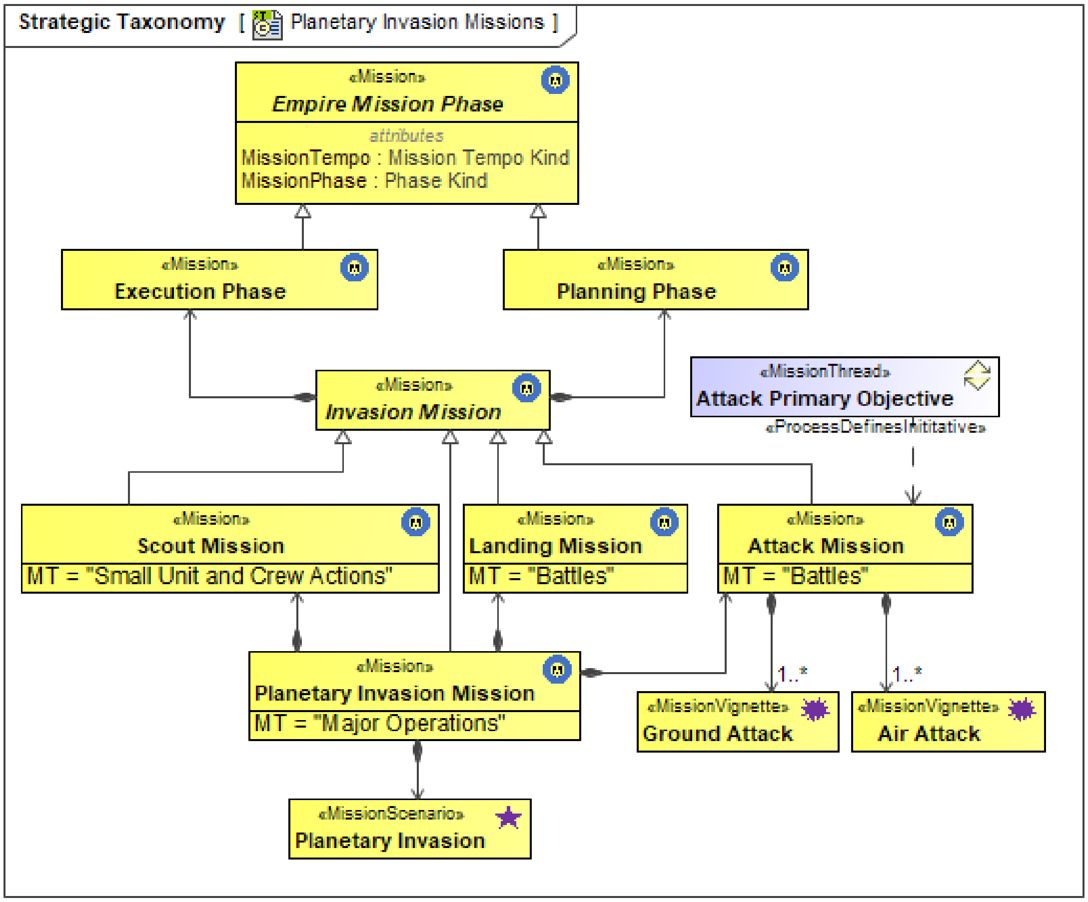


Figure 5. Mission Definitions.

Campaign, Scenario and Vignette

The Mission Types noted in Figure 6 below include National Policy, Theater Strategy, Campaigns, etc. . These are types of Missions (generic or actual), so there is little value in creating stereotypes to identify them, when the name of the mission could simply include the mission type (e.g., Hoth Campaign, Hoth Scouting Operation, or Hoth Ground Battle) and the mission structural hierarchy can show what mission is comprised of other missions. Additionally, at the Engagement and Small Unit and Crew Actions mission levels, those would likely get described by the specific mission (e.g., Screen, Hasty Attack, etc.) the organizational unit that is doing it, and would require a large set of stereotypes to capture all the possibilities. For this reason, these types are defined in an enumeration and modeled as an attribute for the Mission Types in Figure 3. Values chosen for the Hoth example are shown in Figure 5.

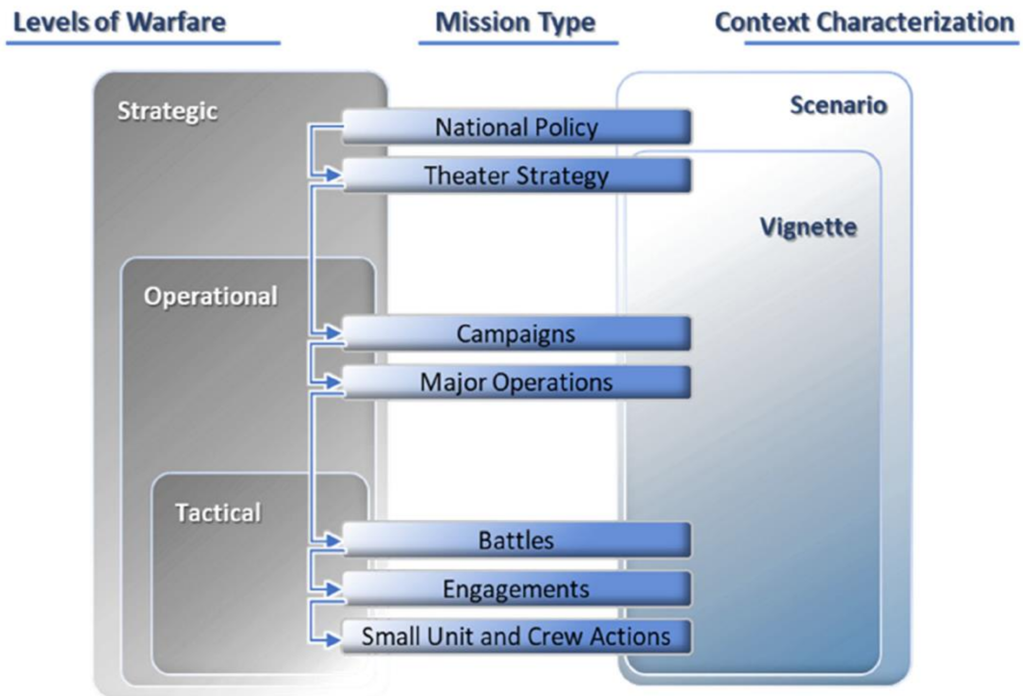


Figure 6: Generalized Hierarchical and Overlapping Relationships Between Levels of Warfare, Mission Type, and Context Characterization. (DoD, 2023).

For the concepts of Scenario and Vignette, there was a distinct need to create new stereotypes to be used to describe the necessary context information for the mission(s) being described in a model. The MEG describes these two concepts as such:

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. (DoD, 2023)

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. (DoD, 2023). The added elements to the ME Profile are shown in Figure 7, below:

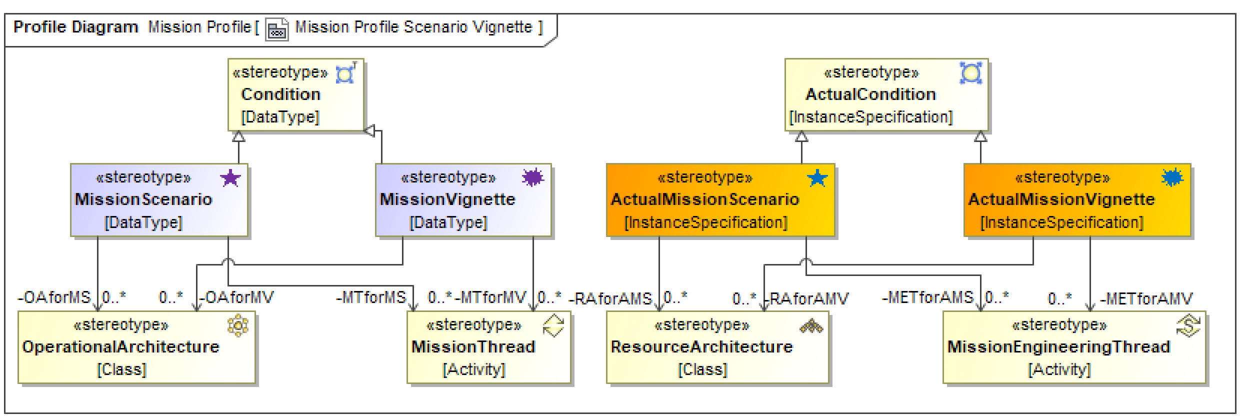


Figure 7: Scenario and Vignette Extensions to UAF.

Since both concepts describe a set of information relative to a mission, the most useful stereotype to extend was a Condition, with each of them having their own elements that relate to the contextual information described in the MEG. Modelers can then create Actual Conditions that have specific values for the appropriate Scenario and Vignette, as well as the thresholds for determining success, and then apply them to the specific Actual Missions within their model, providing the necessary traceability to their missions. Since Scenario and Vignette can be applicable to any Mission Type, (as seen in Figure 6), the Scenario should get applied to the top-level Actual Mission in the model, and Vignettes should get created and applied to each Actual Mission below the top-level one. Other configurations are also possible.

Both missions, mission scenarios and mission vignettes can contain references to the operational architectures as well as MTs. Also, actual missions, actual mission phases, actual mission scenarios, and actual mission vignettes can contain references to resource architectures and METs. This provides more flexibility when configuring missions.

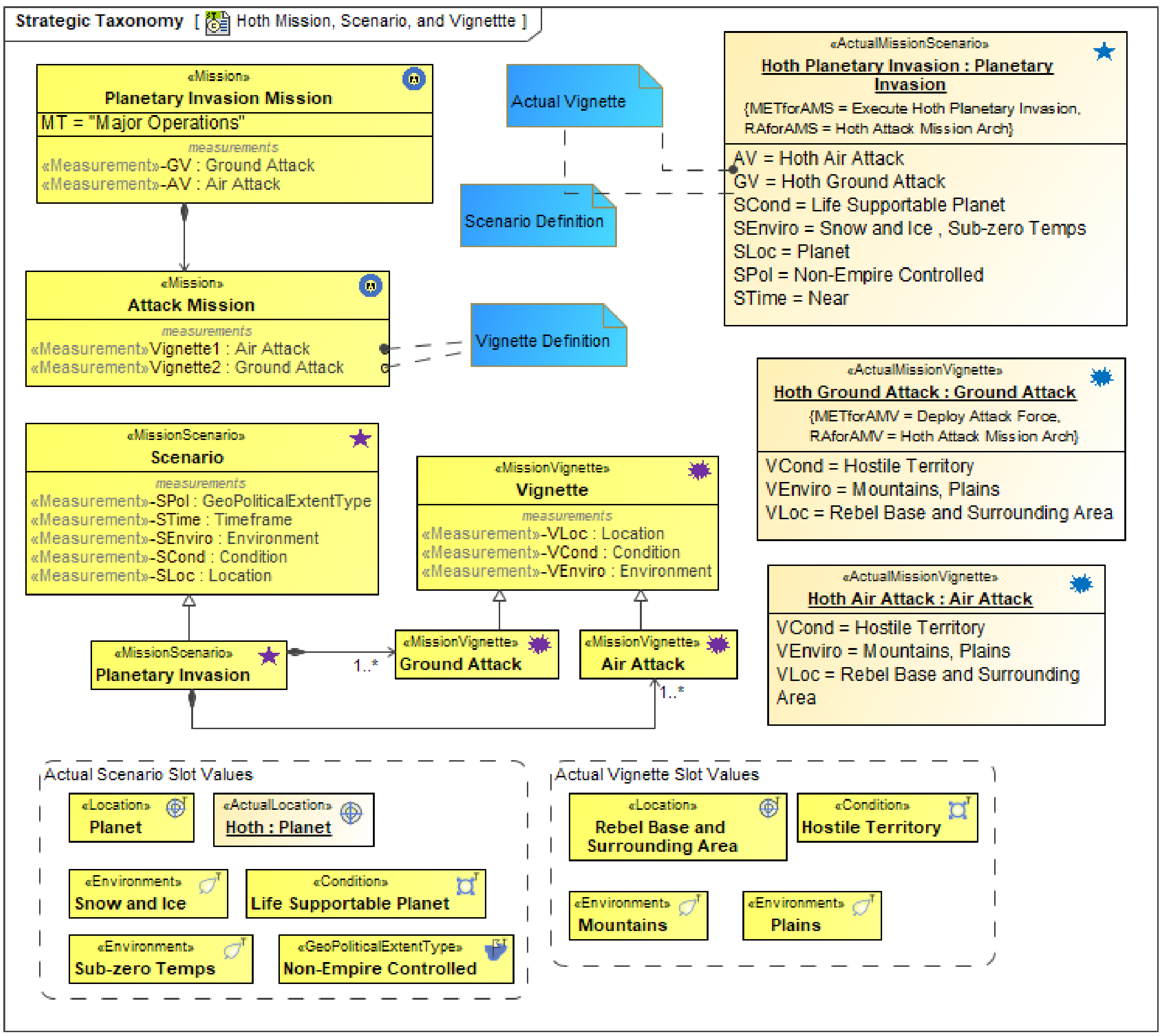


Figure 8: Definition of Scenario and Vignette.

In the Hoth example, Figure 8 shows how the Scenario and Vignette elements get defined and applied to the appropriate missions. On the left are a default Mission Scenario and Vignette. These elements will be included in the profile as examples in the same way as DLOD and DOTMLPF projects are. These have been extended for the Hoth Battle for a Planetary Invasion scenario, Ground Attack vignette, and Air Attack vignette. These can include additional conditions and values. Along the bottom are a set of conditions that can be used throughout the model regarding the environment, topography, and political situation. These are used by the instances of scenario and vignette on the right. These are then linked to the Mission definitions so that the Mission actuals can reference the Vignette and Scenario actuals. In this example, the actual scenario contains the vignettes.

Mission Relationships

Two relationships have been added to connect mission types to MTs (Process Defines Initiative) shown in Figure 9, and actual missions to METs (Process Adapts to Initiative) shown in Figure 10.

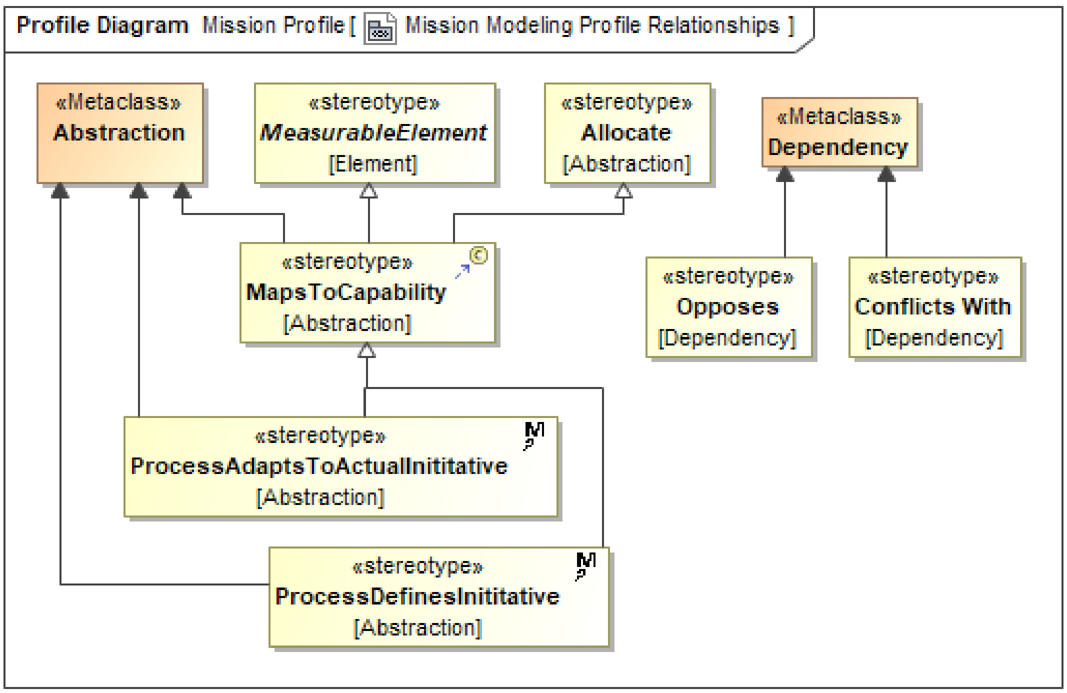


Figure 9. Mission Relationships.

Figure 10 shows the structure of the Hoth Invasion, which is an instance of the Planetary Invasion Mission defined in Figure 5. This Actual Mission is made up of the Planning and Execution Phase as well as the Landing Mission, Attack Mission, and Scout mission. These Missions each have Planning and Execution Phases. The Execution phases all have METs mapped to them. The Hoth AMEP Execution Phase has defined goals as well as Operational and Resource Architecture. These are further described in Figure 11 and Figure 12.

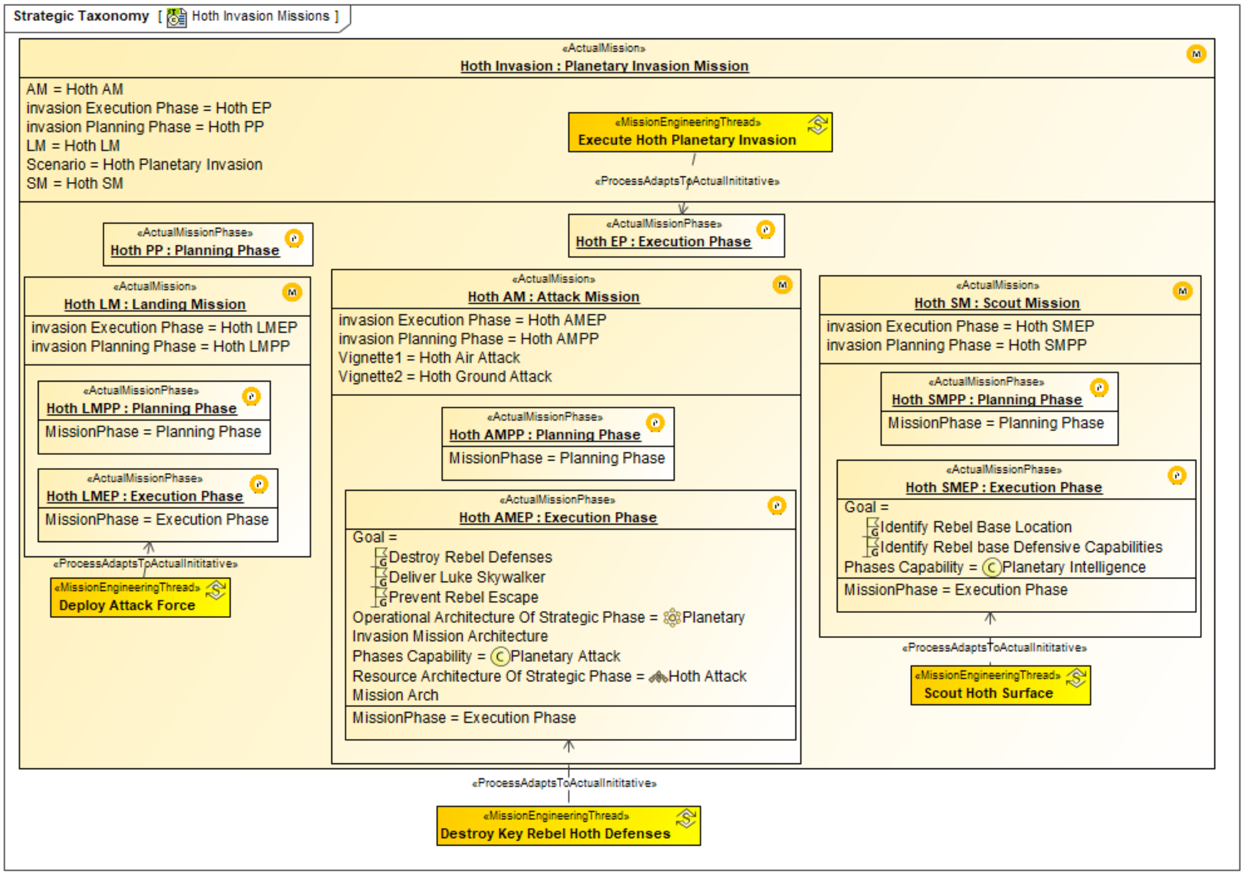


Figure 10. Actual Missions and Mission Phases.

Conflicting Elements – Goals, Systems, Activities, Capabilities, etc. Opposition and Conflict are inherent in ME. Some of these are obvious in the context of this mission: the Empire Forces attack the Rebel Forces, Energy Cannons attack the Defense Shield, etc. Others are not so obvious, such as the conflict within the Goals of the Mission shown in Figure 11. The Goal to Capture Luke Skywalker reduces the chances of Destroy Rebel Defenses and Prevent Rebel Escape. Normally, the Empire executes its missions with extreme prejudice, preferring to destroy a planet rather than allowing enemies to escape or information to be released. Since they had to attack with conventional forces and to do so with great care, they were unable to destroy the forces or prevent the Rebel escape. Highlighting these conflicting elements would help to ensure a successful outcome and provide a means of mitigating risk and other aspects. Each goal is further decomposed into its objectives. Objectives define short term accomplishments while goals are long term.

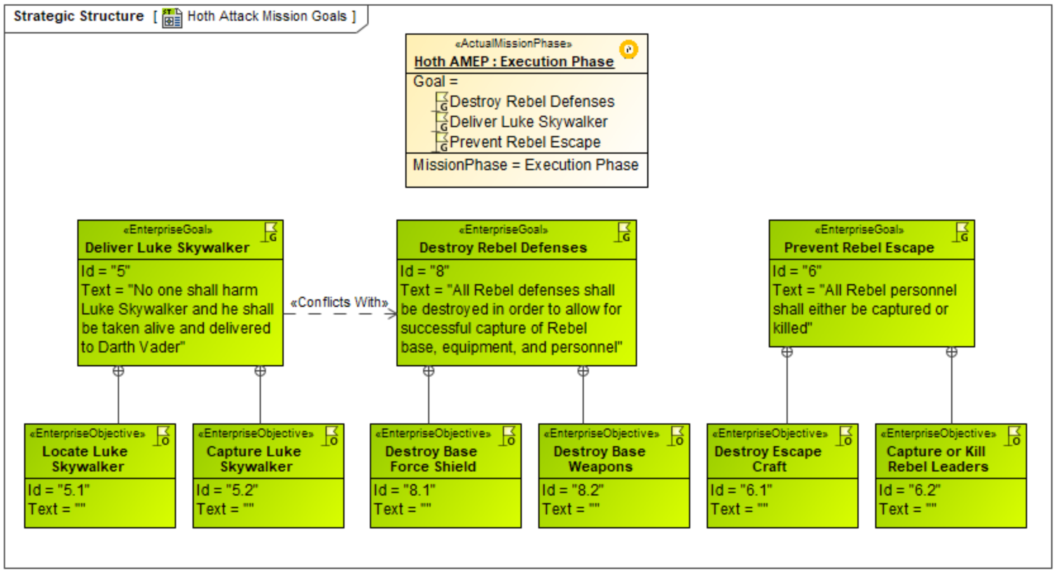


Figure 11. Mission Goals and Objectives.

Linking Strategy to Execution. The goals, drivers, challenges, opportunities, mission phases, capabilities, and systems are linked together in Figure 12. The Hoth AMEP execution phase phases the goals of Destroy Rebel Defenses, prevent Rebel Escape, and Deliver Luke Skywalker and the Planetary Attack capability. This means that they are realized during this phase. The Resource and Operational Architectures implement the mission phase and the MET is executed. Risks of the Loss of Empire Forces and Rebel Forces Escape are identified for the opportunities. Mitigation strategies can be developed for these risks.

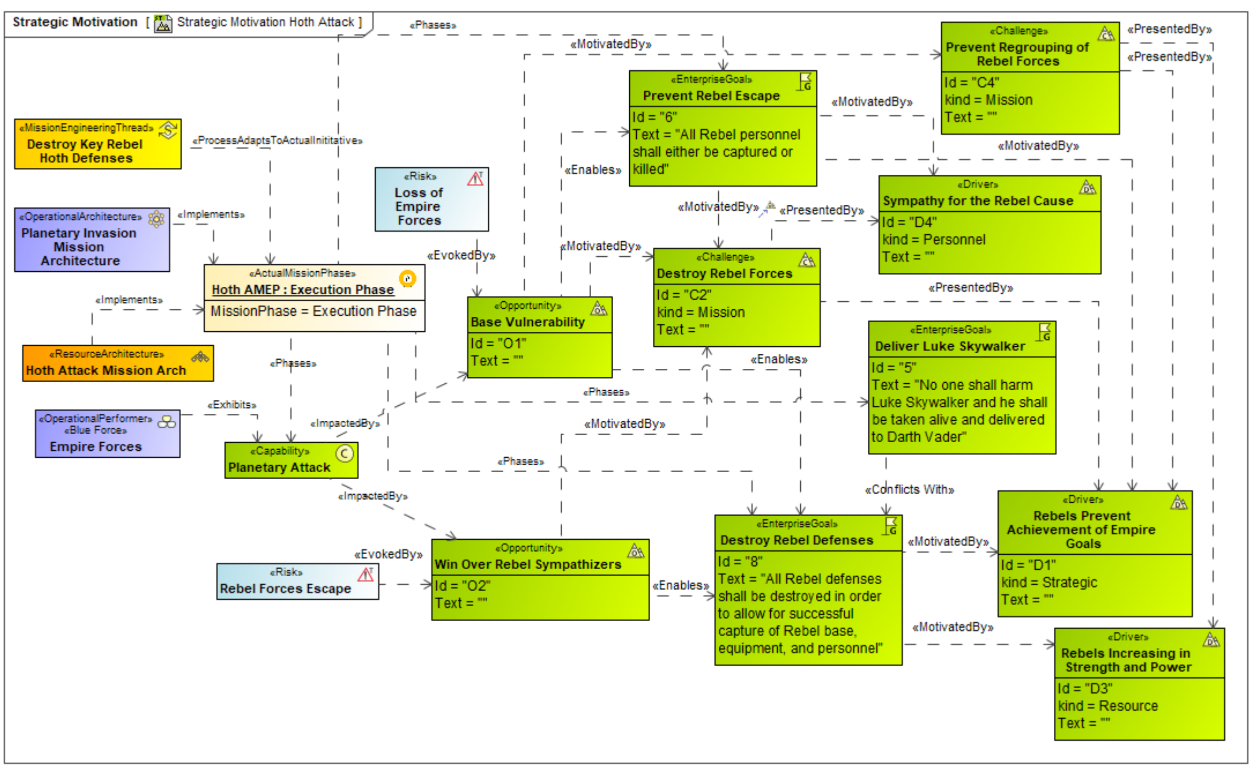


Figure 12. Mission Drivers, Goals, Challenges, Opportunities and Capabilities.

Differentiation Between Enemy/Friendly/Neutral - Blue Force, Red Force, etc.

ME models require the identification of the different forces such as enemy, friendly, neutral, etc. This can correspond to individual elements as well as organizations and groups. The most useful way of accomplishing this is through a set of stereotypes that allow for tracking these elements easily within the model, as well as allowing for unique formatting (e.g., colors) that clearly identify them in diagrams. The ME Profile adds 5 of these Force Designation stereotypes, with an overarching stereotype that they specialize, as seen in Figure 13. This also allows for modelers to add additional stereotypes by simply inheriting from the overarching Force Designation stereotype. The term “Force Designation” was chosen as the term “Force Type” implies Army, Navy, Air Force, etc., and could be confusing. These types could be added by an engineer to extend the profile, or they may be added in a future version.

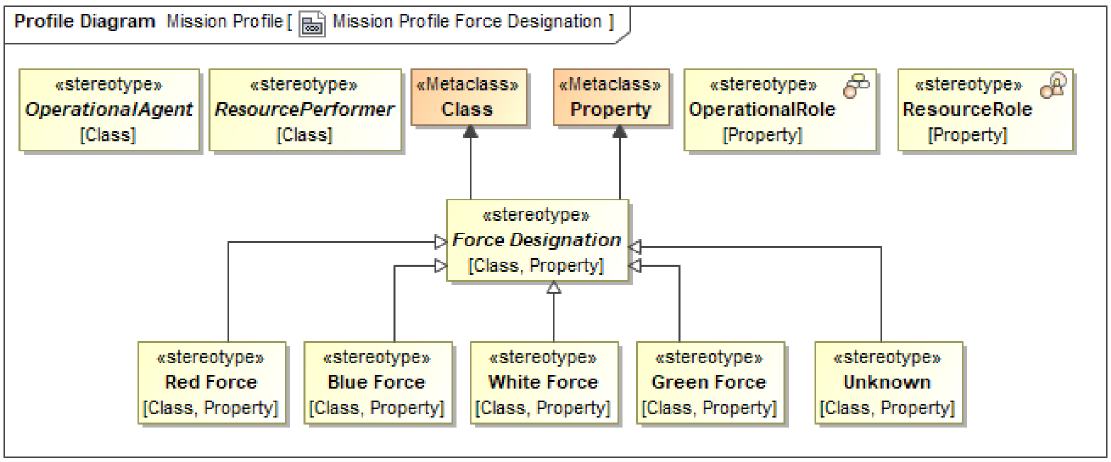


Figure 13. Force Designation Definition Profile Diagram.

Figure 14 shows the opposing Empire and Rebel forces. The Rebel forces are shown at the top in red. Empire forces are shown in blue. The force designations can be applied to either the definition as shown here or to the role elements in an internal connectivity diagram. Other force designations may include civilians, commercial operations, allies, etc. The opposes relationship originally defined in Figure 9 shows mission elements that will contend/attack/fight one another.

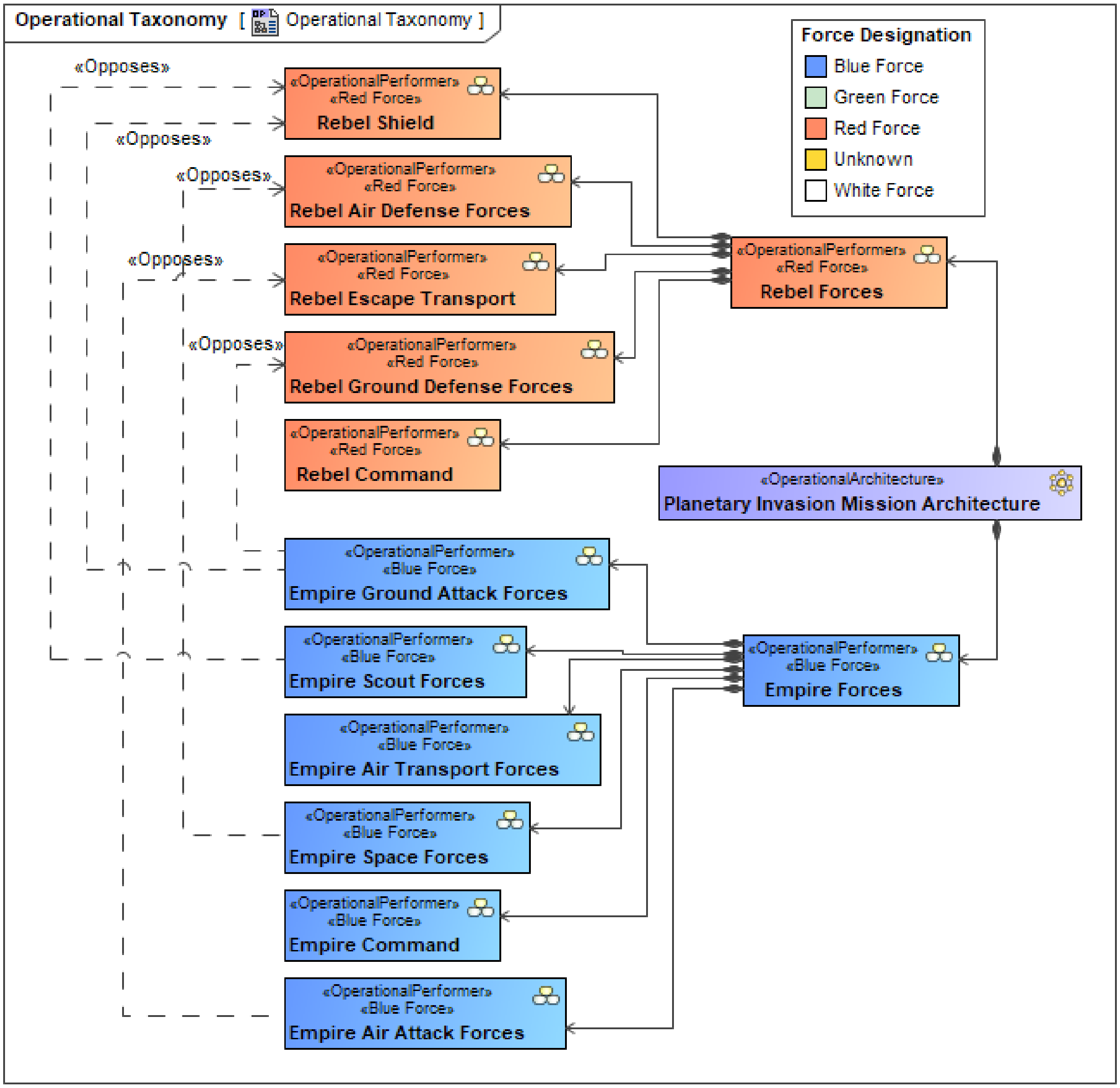


Figure 14. Red and Blue Mission Performer Elements.

Goals, Objectives, Effects, and Outcomes

As mentioned previously, goals and objectives are types of requirements. As such, the come with unique identifiers, can be nested, and can make use of all the relationships afforded to requirements. Figure 11 listed the goals and objectives of the attack mission. A portion of the Execute Planetary Invasion MT is shown in Figure 15. The different mission tasks satisfy the outcomes and objectives of the mission. In this way, it demonstrates that a ME solution should also be able to achieve the goals and objectives. Gagliardi, Hause (2023) shown the traceability relationships between the steps of the MT and the MET.

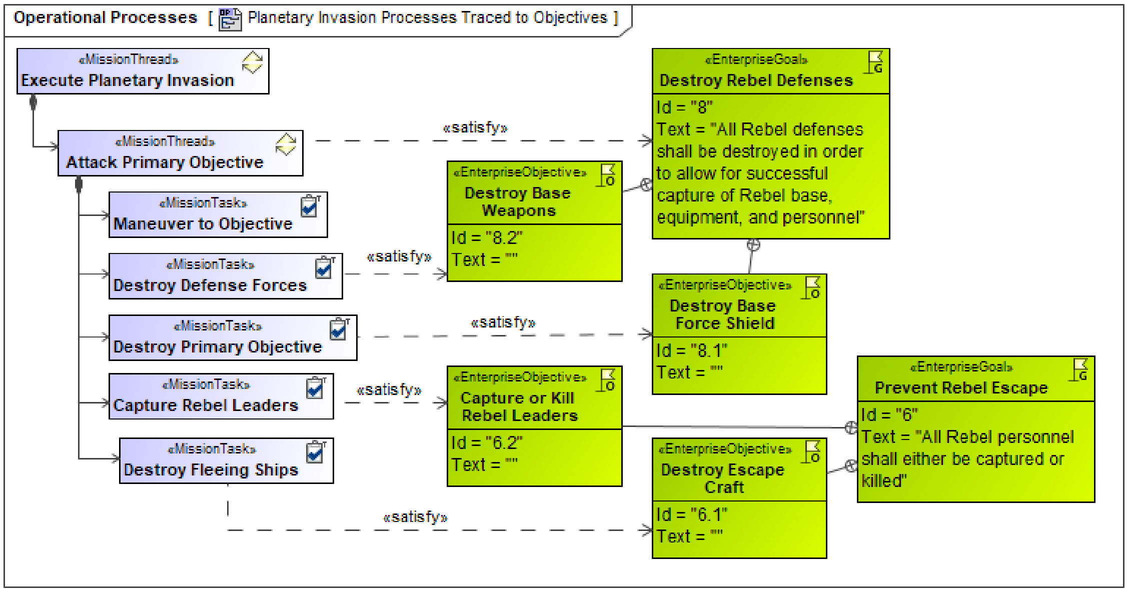


Figure 15. Mission Threads and Tasks Linked to Goals and Objectives.

Figure 16 shows the objectives of the intelligence gathering mission as well as the effects, outcomes and the systems that will achieve those effects and outcomes. The effects and outcomes are sequences corresponding to deploying drones and spies, gathering information, sensing signals, analyzing those signals and finally synthesizing that intelligence to show the location of the rebel base.

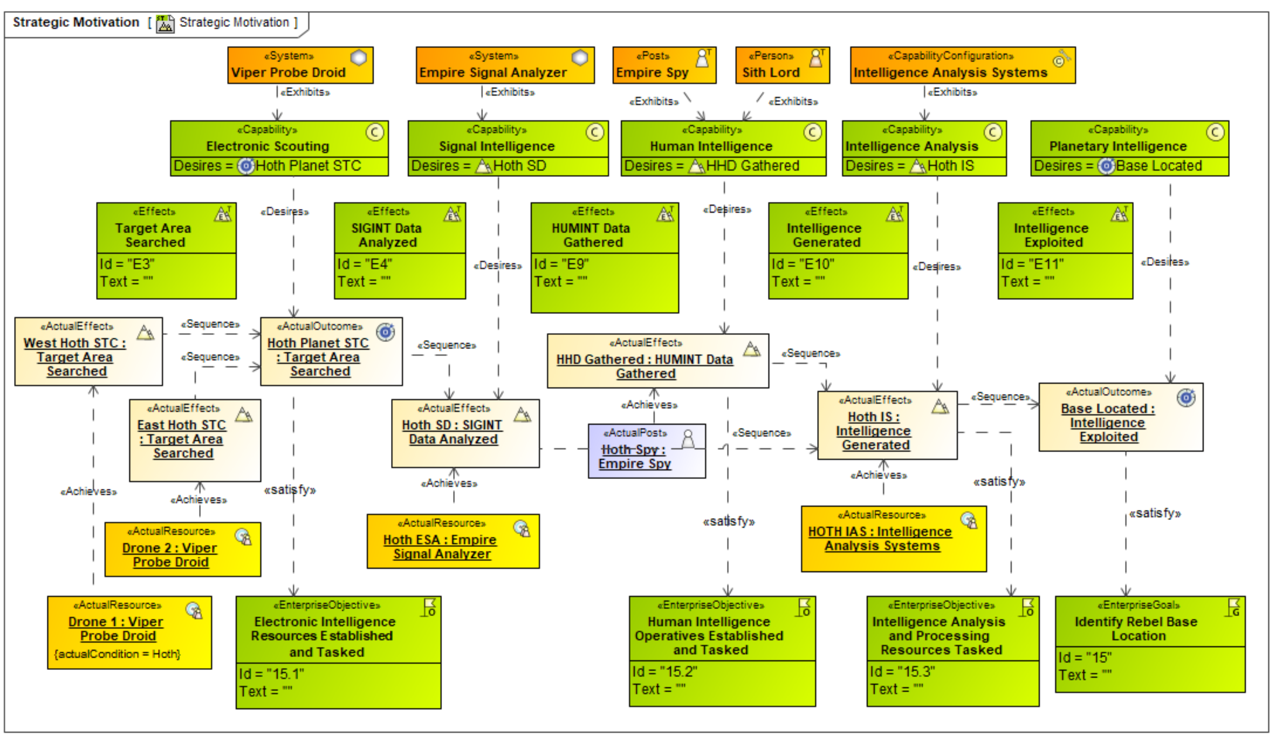


Figure 16. Mission Objectives, Effects, Outcomes and Achieving Elements.

Provenance/Confidence of Enemy Resources. The rebel forces capabilities, forces, activities, strength, etc., have been discovered via the intelligence services. Two aspects of any intelligence are the provenance of the information and the level of confidence in the information as well as the source. The structure and behavioral elements created based on that intelligence should refer to the source (provenance) and corresponding confidence. Figure 17 shows a portion of the rebel forces. Information on the rebel forces has been collated by drones and spies. Enumerations have been defined for the profile providing Intel Confidence and Intel Type. Attributes corresponding to the resource elements. These are instantiated as a fielded capability and specific values associated with them. In this case, the intelligence was gathered by an intelligence probe droid, the type is unknown and the confidence level is medium.

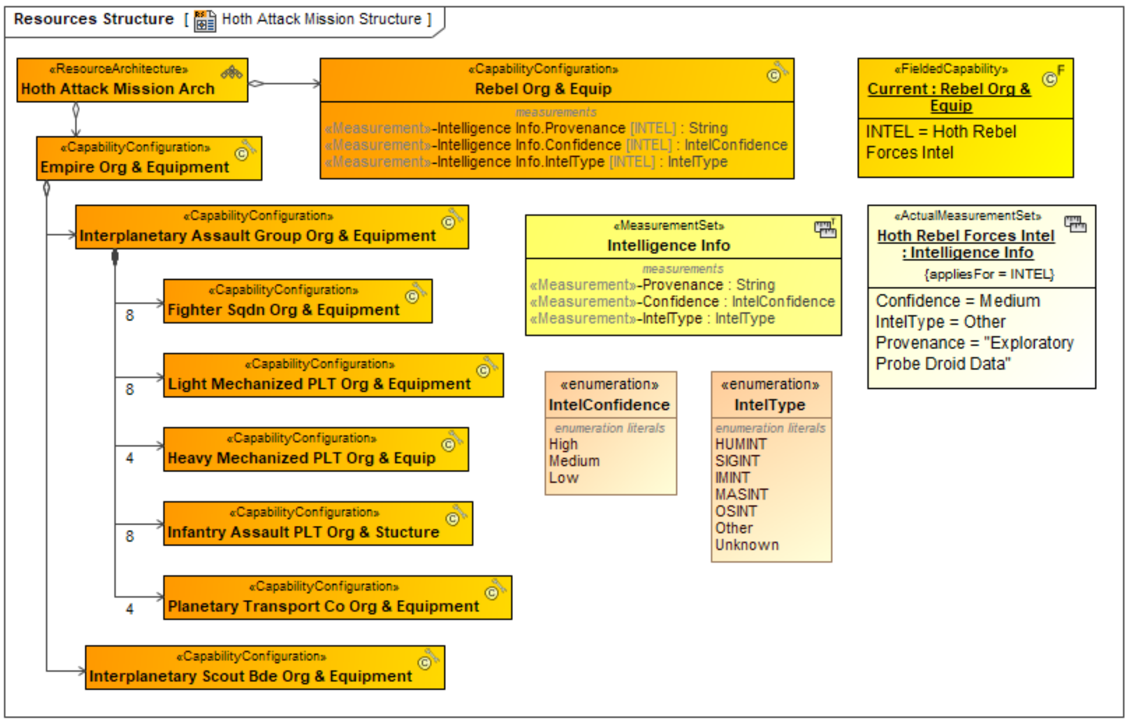


Figure 17. Mission Resource Elements and Intelligence Information.

Compliance/Conformance to Doctrine/Standards. The SysML requirement elements has been extended to provide concepts of Ref Doctrine, Ref Publication, and Ref Standard (not shown for reasons of space). These provide the ability to link specific steps in an MT or MET, mission elements or the entire mission to atomic elements of doctrine. This can be crucial to ensure that proper procedures are followed when constructing missions. The UAF standard concept is also available but is typically at a more *"macro"* level of an entire document.

Key Measurements and Traceability

A well-defined model will contain quantifiable measurements for success, defined prior to selection of systems and based on analysis of the situation. At the very least, it will describe how to measure a successful outcome for the various mission phases and mission essential tasks. These will be modeled at the levels of the mission, mission phase, MET, and mission essential tasks. These measures are also defined for the desired effects and outcomes defined previously and assessed against the allocation of systems to mission essential tasks within the MT. For a well-formed model, these measurements need to coincide, link, and trace to one another from system level Measures of Performance (MOPs) focused on performance of the individual constituent systems, to Measures of Effectiveness (MOEs) defining mission success at each mission essential task, to Measure of Success (MOS) defining the desired end state (Figure 18). In addition, these critical measures should be drafted during mission planning to inform combatants about priorities, risk tolerance, and the order of battle.

These key measures must flow down from a clear understanding of mission and mission execution as defined by the MOS and lead into the MOEs from which MOPs and Measures of Suitability (MOSu) can be derived. Though, to trace these measures through a system-of-systems (SoS) they need to be linked to statements of importance. In this case since we are in the military domain, we can refer to these statements as critical operational issues (COIs), derived from analysis of the adversarial force laydown, environmental factors and threat through a course of action analysis (COA) and aligned with mission success criteria derived from the MOS. Examples of critical operational issues for a weapon system, might be:

1. Will the SoS/system (or subsystem/equipment) detect the threat in the Hoth combat environment at the adequate range to allow a successful mission?
2. Will the SoS be safe to operate in the Hoth combat environment?
3. Can the SoS/system (or subsystem/equipment) accomplish its critical missions on Hoth?
4. Is the SoS/system (or subsystem/equipment) ready for combined Empire operations?

For each of these COIs there may be one to many MOSs, MOEs, and further one to many MOPs and MOSu as shown in Figure 18. This diagram is purely notional, as these metrics are largely stochastic, only estimable through advanced simulation, and often represent emergent properties of a complex system of systems, making a deterministic 'roll-up' impractical or impossible.

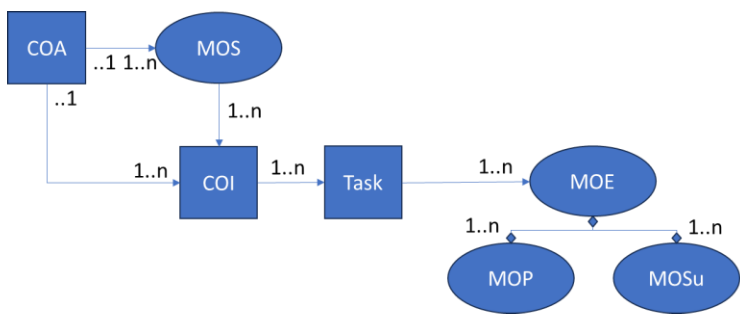


Figure 18: Relationship Between Critical Operational Issues and Measures of Effectiveness.

Depending on the mission and the criticality of the SoS we may find redundancy in the MET to support attrition or to increase the Probability of Kill (P_k) depending on the SoS functionality. We would trace these metrics using SysML parametric views to provide verifiability to the model. It should be noted in advance that the MET is designed with the MOS defined in advance as shown in the lower illustration of Figure 19. Therefore, we define MOSs and MOEs based on the threat and its ability to counter our warfighting capabilities. Examples of mission success might be:

1. Destruction of Rebel cruiser with 10 percent rebel attrition
2. Less than 20 percent attrition of inbound weapons prior to terminal engagement
3. Location and destruction of Rebel base/assets within a predetermined time window

Using a formal, model-based ME approach produces better solutions to the operational capability gaps than the traditional JCIDS approach. This approach uses the standard systems engineering principles such as needs and requirements decomposition, metrics allocation, and functional analysis. The US DoD is already fielding new capabilities because of the advances in this disciplined approach. If we traverse the lower illustration in Figure 19 from right to left then we develop the MOEs for the mission essential tasks better known as the MT, that are often derived from a UJTL for the DoD, and for the Universal Imperial Task

List for the Battle of Hoth. These MOEs, are directly related and traceable to the critical operational issues (COIs) developed when analyzing the COA of the opposing force based on a military appreciation process (MAP - Australia, UK) also known as the military decision-making process (MDMP - US). This process accounts for preliminary analysis and intelligence preparation of the battle space, meteorological and terrain information, mission analysis (red and blue forces), course of action development, and course of action analysis followed by deliberate planning for execution of a plan. The appreciation/decision making process does not typically consider the selection of systems based on defined mission essential tasks and how those systems will integrate as a SoS. This is the difference between building a MT and a MET as the latter has allocation of capabilities to systems and systems to tasks.

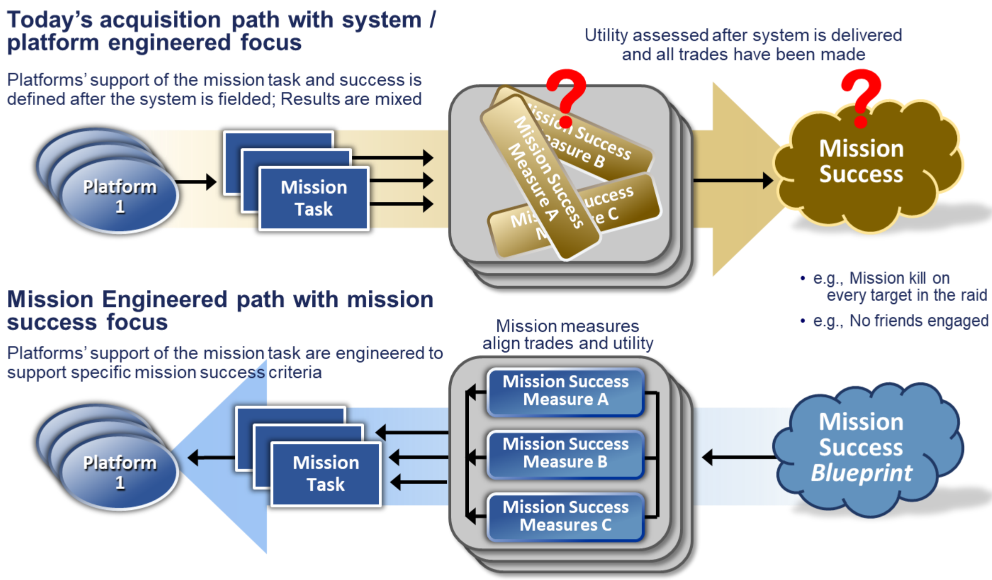


Figure 19: Aligning Mission success through Mission Engineering (Moreland, 2023).

The MOEs should be measurable and traceable back to the MOSs for the mission.

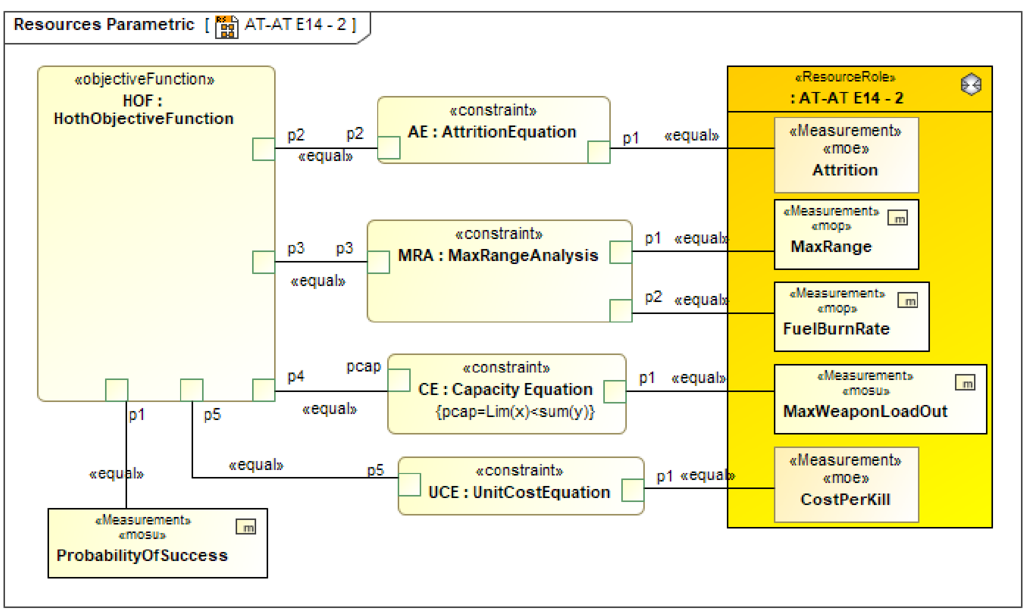


Figure 20: Typical MOEs through an ME SoS Lens.

Following on from COIs we would then trace to MOE (MOP, MOSu) to map systems to functions required for each mission essential tasks within the MT to support the execution of these tasks, for example: Battle Damage Indicators are necessary and essential in determining the impact achieved or occurrence of effects towards satisfying MOEs and MOPs, better known as Battle Damage Assessment. This provides a mechanism to assess or measure progress during a snapshot in time to determine the extent to which change occurs. In short, this is the variable you want to see changed. Understanding the change you bring about, is only useful if you have pre-defined how much change you want, and if you know what the level is before you introduce your intervention. Thresholds should be defined for the Battle Damage Indicators of effects as well as for the indicators of MOE.

Future Opportunity: ME and Enterprise Systems Engineering (ESE)

In the best cases, ME activities fit within a larger context of Enterprise Systems Engineering. Due to federal acquisition regulations and the alignment of defense funding to specific materiel solutions rather than fielded capability, the DoD has yet to realize this opportunity, however, the following section highlights the benefits which could be realized through this alignment. The Enterprise is at a higher level (or scale) than a System of Systems as illustrated in Figure 21 (Martin, 2010, 2023; Martin and Minnichelli, 2020). Enterprise Systems Engineering is focused on MTs that are capability-based and that deal with net-centric operations. On the other hand, System of Systems Engineering (SoSE) is focused on METs that are an implementation of the MTs (at the Enterprise scale) using a variety of resources such as systems hardware, software, technologies, natural resources, organizations and personnel (Martin & Alvarez, 2023).

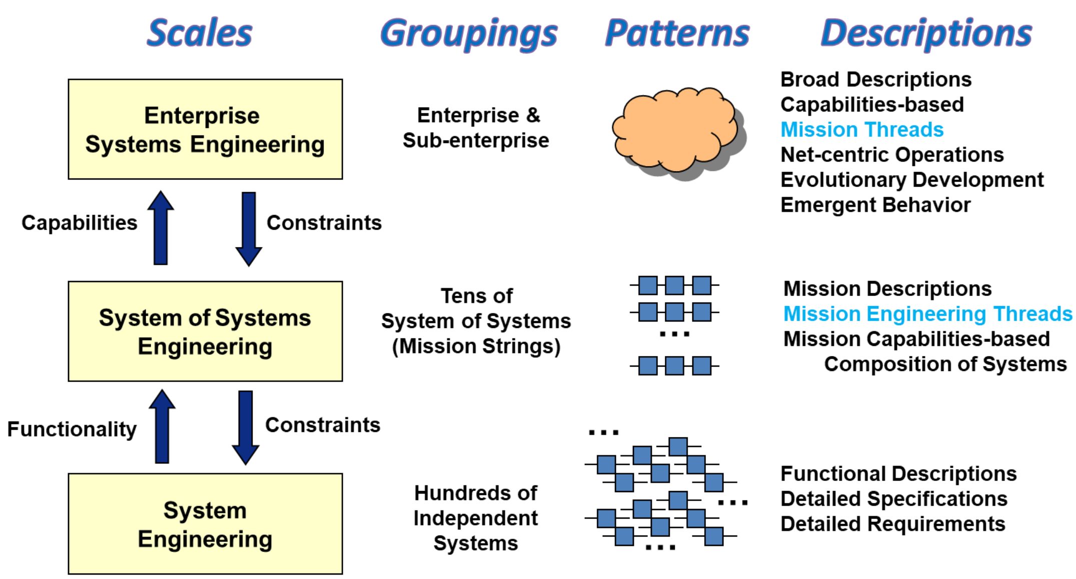


Figure 21. Different Groupings and Patterns Revealed at Different Scales.

Enterprise Systems Engineering has many specialized processes for dealing with the enterprise and its MTs as illustrated in Figure 22 (Martin, 2023a). ESE will convert the enterprise strategic plans and priorities into a set of strategic technical plans that will in turn drive capability-based planning and definition of the enterprise architecture and its related conceptual design. This "conceptual design" is equivalent to the MTs in the ME practice (Martin, 2023b).

The enterprise architecture will identify and characterize the underlying systems and other resources needed by the enterprise to deploy capabilities that achieve the desired effects and outcomes. ESE will establish the architecture objectives that drive the ME study efforts. The results of the ME study can be used to provide recommendations to enterprise portfolio management and influence enterprise resource allocation and budgeting (Martin, 2022).

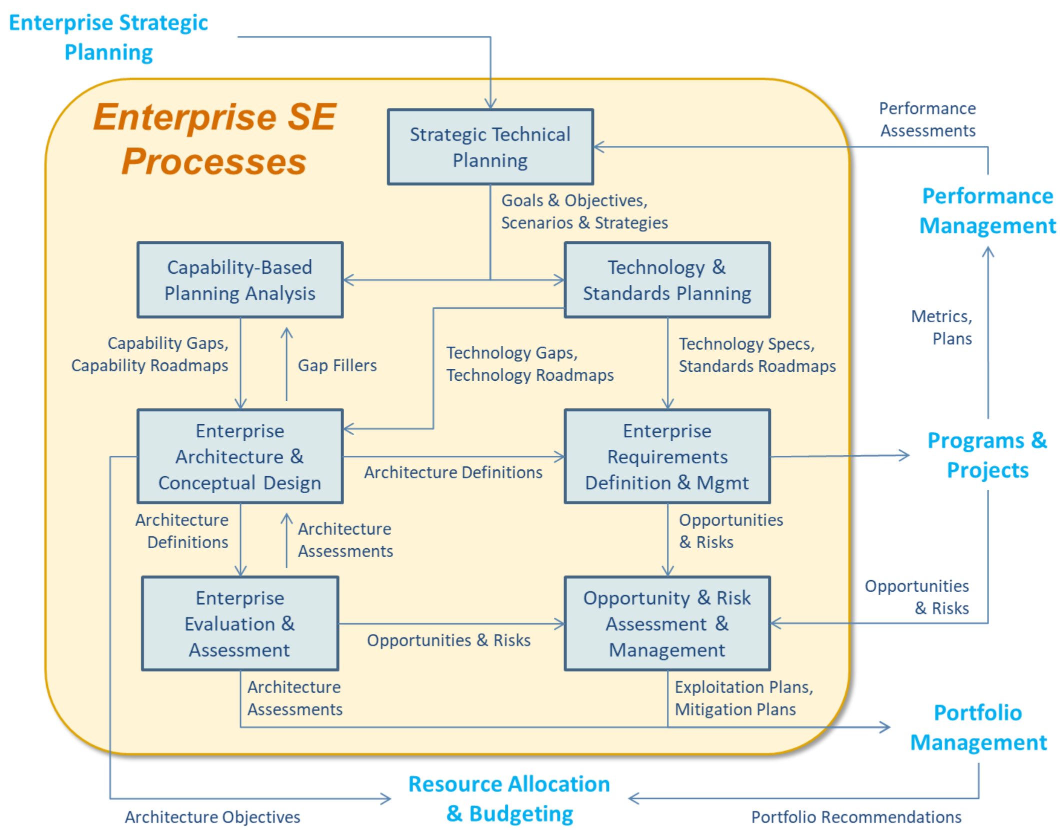


Figure 22. Enterprise Systems Engineering Processes.

Modeling and Tools

Integration with Specialist Simulation Tools

The use of software tools to develop METs (Moreland, 2014) as part of a larger ME Architecture are essential to managing complexity and avoid loss or misinterpretation of critical information. The use of tools in a digital tool chain is well understood and there are many examples that provide value through export and import of models and data, though mostly focused on static view translation and interpretation. Given that ME is a dynamic process in that the mission success is dependent on countering opposing actions and plans the use of static analysis is not sufficient to understand the complex interactions of many systems against the many tasks that comprise the MET with a thinking and active adversary.

One way to apply a dynamic model is to connect architectural tools to constructive simulations. Constructive simulations are representations of the world that comprise virtual systems and virtual operators. These constructive simulations can have wildly varying levels of detail, so the selection of a simulation to execute a MT should be made with an eye for the correct level of detail and functionality whether operating as a Monte Carlo simulation in an automated/scripted fashion or as a man in/on the loop run where variability is anchored to human decision making.

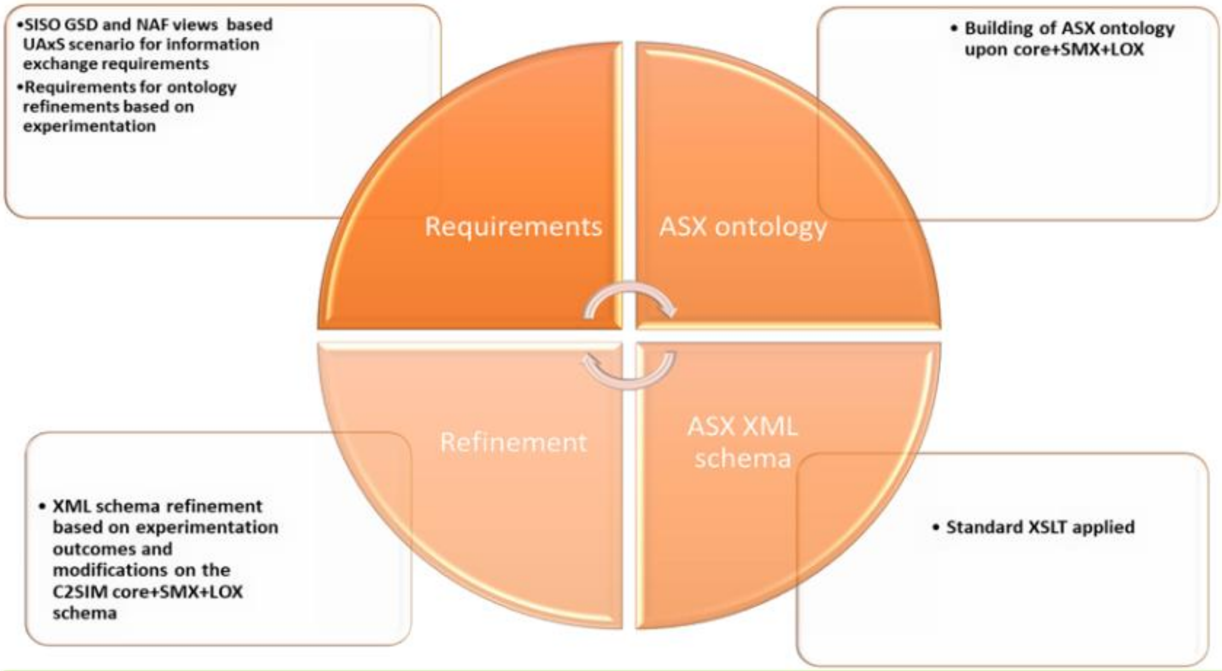


Figure 23: Autonomous System Extension (ASX) Development Process

When we connect constructive simulations to tools like an architectural tool such as Cameo Systems Modeler for example, we could provide a connection that is persistent and operates using a distributed interactive simulation (DIS) protocol such as IEEE 1278.1:2012. This is appropriate if an active connection is needed for constant query and update. It should be noted that all information that transitioned through DIS can be logged and post processed.

A more appropriate way to integrate with constructive simulation is through transition of scenarios and associated meta-data that can be aligned with the simulation data dictionary provided through Military Scenario Definition Language (MSDL) (SISO, 2008) that provides the representation codes and initialization states for a simulation scenario. The use of C2Sim (STANAG MSG-145) specification goes further to provide actionable direction to simulation entities. Although the existing dictionaries provide for a wide range of terms there is still the need to build extensions that allow for rich representation across several ME domains (Koski & Moreland, 2022). The process provided in Figure 23 provides an approach to tool to simulation integration, although this could be service based, it does not need to be and can be achieved through structured file exchange. By integrating the tool chain with a constructive simulation through an application programming interface (API), it would be possible to test the static architecture in a realistic (dependent on validation) environment.

Use of SysML and UAFML

There is an established base of mission engineers using SysML. SysML provides many ME concepts but needs extensions. Some have added the necessary elements already in the UAF to support ME as well as adding their own elements. This results in a variety of different implementations for ME. Understanding the model will first require understanding the profile and its relationships. Standardization of MBSE concepts in a profile is beneficial. This reduces the learning curve, miscommunication, confusion, etc. There is a history of this in model-based standardizations. UML was created to standardize SW engineering, SysML extends UML for systems engineering, UPDM/UAF extends SysML/UML to support

DoDAF/MODAF/NAF. Also, RAAML (OMG, 2023) was created for safety and security in SysML model evaluation and is used by the UAF.

Release of UAF Support for ME

The expected release of UAF v2 supporting SysML v2 and these ME concepts would likely not take place until at least the last part of 2025. To promote a consistent approach to ME across the industry, the UAF group will be releasing UAF 1.3 in December 2024, containing support for the mission profile extensions described in this and the previous paper. The example model will be in both XMI format as well as different versions of the various UAF modeling tools.

All Models are Wrong, Some Models are Useful….

As noted in the Gagliardi & Hause (2023), even a relatively simple Resource Architecture model requires significant time and effort to develop, if everything in the architecture is modeled. As with any model, understanding what questions the model is intended to answer, what information is available to model, and what resources you have available do the modeling (people, time, money, and tools) will help frame what needs to be modeled. Of course, once the modeling scope has been decided, any modeling scope changes must be well managed; otherwise, unintended risk to developing a useful model will be introduced.

It is likely that the entire scope of the modeling effort will not be known, as required information may not be available at the start of the modeling effort, or significant, unplanned architecture changes occur. Identifying modeling risks from the start is key to managing the modeling effort and maintaining its usefulness. It is highly recommended that prior to starting a model effort some time is spent conducting a Problem Framing exercise as described in (Martin, 2019).

Organizations will need to determine what model libraries they want to develop, share, and maintain. Although there are infinite ways to separate ME models into reusable and case-specific information, UAF already segments model information such that one could simply create separate models based on the top-level packages: Strategy, Operational, Services, Personnel, Resources, Security, Projects, Standards, and Actual Resources. Of course, a model library approach will need to be made specific to how an organization wants to do modeling. A model federation plan, even just a simple one, should be devised prior to the start of modeling to help partition the large model into smaller modeling projects to facilitate model management and governance. This also helps improve time to query the model, reduce model access conflicts among team members, allow for greater control over model changes and configuration control.

Future Research

Mission Engineering Thread. We will continue to build the model and examine the issues of resource architecture complexity, scale, and detail and build behavioral models at both the detailed and high levels.

ME and the Security Views. Using the UAF security views, risks can be identified, and mitigation strategies developed at each stage of the mission. This will not involve changes to the views themselves. Instead, examples will be built to demonstrate how this helps.

Mission Engineering Guide for UAF. A special ME Guide for UAF will be developed to supplement the already published Enterprise Architecture Guide for UAF (OMG, 2022c; Martin and O'Neil, 2021). This ME Guide for UAF will provide guidance and instructions on how to use the ME Profile and associated modeling patterns and templates described in this paper. It will also provide guidance on how to link a Mission Architecture model in UAF with pre-existing system models created in SysML (Martin & Alvarez, 2023; Martin and Brookshier, 2023).

Traceability to Model-Based Acquisition (MBAcq). ME ensures that the right systems are being built in the right way to deliver strategic capabilities needed by our warfighters. More fundamentally, ME also helps to answer the question: "Can we do what we need to do with what we have, or do we need to acquire something else?" ME also helps to determine what that "something else" should be with a clear definition of the capability gap. The identified capability gap can be used as input into a MBAcq initiative. (Hart & Hause, 2023)

Conclusions

This paper has built upon Gagliardi & Hause (2023) by adding additional profile elements as well as examples in the model. Additional concepts in the ME Guide were covered such as Scenario and Vignette, MOEs, MOPs, etc. The subject of co-simulation and integration with specialty tools was explored making use of standardized tools interfaces. The relationship between MBAcq and ESE were discussed and explained. Finally, guidance was given on creating an eco-system and processes for supporting ME. There is still much work to be done and the DoD, industry and the OMG will continue to investigate and provide standards and guidance to support ME.

Finally, the authors wish to thank Jon Holt and Simon Perry who created the original Battle of Hoth model in UPDM some 15 years ago. This model addresses different aspects than their original model but was certainly inspired by them.

References

DAU, Defense Acquisition University, Defense Acquisition Guidebook, Chapter 3, "Systems Engineering," current edition.

DoD, 2017, Public Law 114-328, "National Defense Authorization Act for Fiscal Year 2017," December 23, 2016, Section 855

DoD, 2020, DoD OSD Mission Engineering Guide (MEG), Available online at https://ac.cto.mil/wp-content/uploads/2020/12/MEG-v40_20201130_shm.pdf, Accessed March 2023.

DoD, 2023a, DoD OSD Mission Engineering Guide (MEG), Available online at https://ac.cto.mil/wp-content/uploads/2023/11/MEG_2_Oct2023.pdf Accessed November 2023.

DoD, 2023b, DoD Joint Publication 3-0 (Joint Operations), Available online at https://irp.fas.org/doddir/dod/jp3_0.pdf , Accessed March 2023

DoD, 2023c, DoD Directive 7045.20, "Capability Portfolio Management", Available from https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodd/704520p.pdf?ver=Y_7TIls2RHyUIYVGHOH6iA%3D%3D Accesses November 2023

Fandom, 2023, Battle of Hoth, Reference information Available online from https://starwars.fandom.com/wiki/Star_Wars:_Episode_V_The_Empire_Strikes_Back#The_Battle_of_Hoth

Fowler M., 2010, Domain-Specific Languages, published by Addison-Wesley Professional, New York

Gagliardi M., Hause M., "Implementing Mission Engineering with UAF" In Proceedings of the Ground Vehicle Systems Engineering and Technology Symposium (GVSETS), NDIA, Novi, MI, Aug. 16-18, 2022.

Garrett, Robert K., Fairbanks, James P., Loper, Margaret L., Moreland Jr. James D. (2023). The application of applied category theory to quantify mission success. SIMULATION. 2023;99(2):201-220.

Hart L., Hause M., 2023, Model-Based Acquisition (MBAcq): Uniting Government and Industry around a Common Standard, presented at the INCOSE International Symposium, Honolulu, Hawaii

Hause M., 2006, Cross-Cutting Concerns and Ergonomic Profiling Using UML/SysML, The 1st Conference for Autonomous Unmanned Air Vehicles, Lincoln, UK, 2006

Hause, M. 2014. “SOS for SoS: A New Paradigm for System of Systems Modeling.” Paper presented at the IEEE, AIAA Aerospace Conference, Big Sky, US-MT, 1-8 March.

Hause, M., F. Dandashi, 2015. “UAF for System of Systems Modeling , Systems Conference (SysCon).” Paper Presented at the 9th Annual IEEE Systems Conference, Vancouver, CA-BC, 13-16 April.

Hause M., Kihlström M., 2022, Tilting at Windmills: Drivers, Risk, Opportunity, Resilience and the 2021 Texas Electricity Grid Failure, presented at the INCOSE International Symposium, Detroit, Michigan

Hause M., Russell J. EISE, CSEP, Kihlstrom L., 2023, Keeping People First in the Smart Cities Enterprise, , presented at the INCOSE EMEA Symposium, Seville, Spain.

Koski, S. R., & Moreland, J. D. (2022). Performing information extraction and ontology development for mission engineering applications. Journal of Integrated Design and Process Science, 25(1), 25–37. https://doi.org/10.3233/jid-210012

Martin, J. (2010). An enterprise systems engineering framework. INCOSE International Symposium.

Martin, J. (2019). Problem framing: Identifying the right models for the job. INCOSE International Symposium. Orlando, Florida, USA.

Martin, J. (2022). Extending UAF for model-based capability planning and enterprise portfolio management. INCOSE International Symposium.

Martin, J. (2023a). Enterprise systems engineering: Overview [Training class]. Aerospace University.

Martin, J. (2023b). Leveraging UAF for mission engineering. UAF Summit, Mar 22, 2023.OMG, 2019, Object Management Group (OMG), 2019. OMG2012-06-01.

Martin, J., & Alvarez, K. (2023). Using the Unified Architecture Framework in support of mission engineering activities. INCOSE International Symposium.

Martin, J., & Brookshier, D. (2023). Linking UAF and SysML models: Achieving alignment between enterprise and system architectures. INCOSE International Symposium.

Martin, J., & Minnichelli, R. (2020). Strategy for implementing and enterprise systems engineering capability. INCOSE International Symposium.

Martin, J., & O’Neil, D. (2021). Enterprise architecture guide for the unified architecture framework (UAF). INCOSE International Symposium.

Moreland Jr., James D. (2014), “Mission Engineering Integration and Interoperability.” NSWCDD Leading Edge Technical Digest, NSWCDD-MP-15-00096 01/15: pp. 4-15. https://www.navsea.navy.mil/Home/Warfare-Centers/NSWC-Dahlgren/Resources/Leading-Edge/I-I-Leading-Edge/Moreland/.

OMG 2019, *Systems Modeling Language, Version 1.6*, Object Management Group, https://www.omg.org/spec/SysML/About-SysML/.

——— 2022a, *Unified Architecture Framework, Version 1.2*, Object Management Group, https://www.omg.org/spec/UAF/About-UAF/.

——— 2022b, *Unified Architecture Framework Modeling Language, Version 1.2*, Object Management Group.

——— 2022c, *Enterprise Architecture Guide for the Unified Architecture Framework (Informative), Version 1.2*, Object Management Group.

OMG, 2023, Risk Analysis and Assessment Modeling Language (RAAML), Available from https://www.omg.org/spec/RAAML/1.0/PDF

Pullen. J.M & Corona F. (2013), Preparing for Operational Use of C2-Simulation Interoperation. Retrieved 29 November 2023, from https://c4i.gmu.edu/wp-content/uploads/MSG171-paper-Pullen-Corona-submit-rev1.pdf.

Reymondet, L., Rhodes, D.H. and Ross, A.M. (2016, April). Considerations for Model Curation in Model-Centric Systems Engineering. 10th Annual IEEE Systems Conference, Orlando, FL.

Rhodes, D, 2019, Model Curation: Requisite Leadership and Practice in Digital Engineering Enterprises 17th Annual Conference on Systems Engineering Research (CSER)

Rhodes, D.H. and Ross, A.M. (2015). Interactive Model-Centric Systems Engineering Pathfinder Workshop Report. MIT. Cambridge, MA

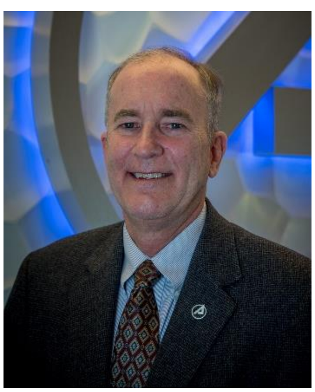
Roman E., Dahmann, J., 2022, “Applying Mission Engineering to the U.S. Department of Defense Rapid Defense Experimentation Reserve”, Presented at the NDIA Systems & Mission Engineering conference, Orlando, FL, November, 2022

Simulation Interoperability Standards Organization, 2008. Military Scenario Definition Language (MSDL), SISO Inc.

Biography

Matthew Gagliardi. A Principal at SSI, Matt Gagliardi has over twenty years of experience in Systems Engineering in the Automotive and Defense sectors. His expertise includes vehicle development, system integration, systems engineering processes and tools, and new technology development. Matt currently provides MBSE support and guidance to multiple PEO Ground Combat Systems programs, as well as to DEVCOM’s Ground Vehicle Systems Center. Matt received a Bachelors in Mechanical Engineering and a MS in Mechanical Engineering at Purdue University. Matt has achieved SPRDE Level 3 from Defense Acquisition University and is an OMG Certified Systems Modeling Professional Model Builder and has been an INCOSE CSEP. His role at SSI includes Consulting, mentoring, conference presentations, and developing and presenting training courses.

Matthew Hause. A Principal Engineer at SSI, a chair of the UAF group, a member of the OMG SysML specification team, a co-chair of the OMG Reusable Asset Specification (RAS) team, and a thought leader in the use of MBSE. He has been developing multi-national complex systems for over 45 years as a systems and software engineer. He started out working in the power systems industry then transitioned to command and control systems, process control, communications, SCADA, distributed control, Military systems, and many other areas of technical and real-time systems. He has authored over 100 technical papers on a diverse range of subjects. His role at SSI includes Consulting, mentoring, standards development, presentations at conferences, and developing and presenting training courses. He is also a proud recipient of the INCOSE MBSE Propeller Hat Award.



James N Martin is a member of the UAF Revision Task Force with OMG and was lead editor for the ISO 42020 standard on Architecture Processes. He is an Enterprise Architect and a Distinguished Systems Engineer at The Aerospace Corporation developing solutions for information systems and for space domain enterprises. He was a key author on the BKCASE project in development of Enterprise Systems Engineering articles for the SE Body of Knowledge (SEBOK). Dr. Martin led the working group responsible for developing ANSI/EIA 632, a US national standard that defined the processes for engineering a system. He previously worked for Raytheon Systems Company and AT&T Bell Labs on airborne and underwater systems and on mobile telecommunication systems. His book, Systems Engineering Guidebook, was published by CRC Press in 1996. Dr. Martin is an INCOSE Fellow and was leader of the Standards Technical Committee. He was founder and was until recently leader of the Systems Science Working Group. He received from INCOSE the Founders Award for his long and distinguished achievements in the field.

Mark Phillips. is a Technical Fellow in the Systems Integration and Test organization in Raytheon and the Chief Engineer for Precision Strike Weapons (AGM-65, AGM-88, AGM-176). Mark is a former Australian Army and Royal Australian Air Force Officer and served in many roles concerning the development of modeling and simulation environments to support warfighting training, experimentation, and test in many countries. He led the Live, Virtual and Constructive (LVC) efforts for 4^{th} and 5^{th} Generation Fighters at Lockheed Martin from 2012 – 2019 and worked on the National Cyber Range as a Principal Architect. Mark is a Doctoral Candidate in Mission Engineering at Old Dominion University focusing on the development and validation of measures to support mission engineering threads. Mark is also the current Chairman of the International Test and Evaluation Association (ITEA).