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Synergizing the Software Acquisition Pathway (SWP) with the Unified Architecture Framework (UAF) for Operationalization

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Synergizing the Software Acquisition Pathway (SWP) with the Unified Architecture Framework (UAF) for Operationalization

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Abstract

This study analyzes the activities and statutory and regulatory documentation required for the Department of Defense (DoD) Adaptive Acquisition Framework (AAF) Software Acquisition Pathway (SWP) Planning and Execution phases to identify a mapping of Unified Architecture Framework (UAF) model views.

UAF, an enterprise architecture modeling language standard from the Object Management Group®, provides a comprehensive set of views and structured semantics for identifying capability needs, developing enterprise strategies, developing roadmaps, defining architectures, and analyzing value that is prescribed for the SWP.

The study decomposes the Planning and Execution phases of the SWP into a set of 25 scenarios for the use of descriptive and analytical enterprise architecture models in the embedded software sub-path. The mapped views and scenarios establish a basis for performing the prescribed activities of the SWP using a model-based systems engineering (MBSE) approach. The views also provide a deeper understanding of the structured information required as part of the pathways and the interfaces between enterprise activities.

From an operationalization perspective, DoD stakeholders executing the SWP, using the results of this study, will be equipped to transform a primarily document-based method to fully traceable and analyzable models in accordance with DoD Instruction 5000.97 Digital Engineering.

Introduction

Effective model-based systems engineering (MBSE) to support acquisition objectives requires structure and ontology for capturing and transforming information into useful digital assets. Targeted guidance on the use of MBSE as part of the Department of Defense (DoD) Adaptive Acquisition Framework (AAF) Software Acquisition Pathway (SWP) for embedded software systems is needed to inform a consistent technical approach and enable information models to be value-add and more fully integrated into the software development process.

To conduct the research, the Software Engineering Institute (SEI) is performing a review of the enterprise processes defined in the SWP detailed in DoD Instruction (DODI) 5000.87 (Office of the Under Secretary of Defense for Acquisition and Sustainment [OUSD(A&S)], 2020), whereby the SEI is breaking down the activities and output information of the SWP to a set of scenarios for the use of UAF and aligning model views, defined in the UAF Domain Meta Model (DMM) v1.2 specification, that satisfy the needs of the scenario (Object Management Group® [OMG], 2022a). Then, inspired by the Enterprise Architecture (EA) Guide for UAF (OMG, 2022b), the mapped views are operationalized into process activities for the software pathway, guiding the development of models and how model information is used throughout the life cycle of the pathway. This paper is a summary of the research that is being performed; it will be subsequently followed by a more comprehensive technical report that contains a full mapping of the scenarios to the Unified Architecture Framework (UAF) and associated guidance.

The expected research results are foundational blocks for the application of MBSE, specifically use of UAF, in the activities of programs using the SWP. The study identifies the rationale for the mapped views, determines the statutory and regulatory compliance the views provide, and examines the benefits that models provide as part of embedded software acquisition.

This research paper was developed as part of the MBSynergy project sponsored by the Office of the Under Secretary of Defense for Research and Engineering (OUSD[R&E]) and conducted by the Carnegie Mellon University (CMU) Software Engineering Institute (SEI). Through the MBSynergy project, the SEI seeks to equip the DoD with methods and tools to model MBSE processes to evaluate the value they deliver to an organization and to analyze them from a budget, schedule, risks, or personnel resource perspective.

This paper describes the key concepts of the UAF and the SWP as part of the DoD AAF, reviews an example of mapping UAF views to a scenario for MBSE use as part of the SWP, and details SEI's MBSynergy project efforts to provide a better process for analyzing MBSE needs for an enterprise and uncovering its value.

The Problem Space

DODI 5000.97 Digital Engineering, effective December 21, 2023, established that programs initiated after the effective date will incorporate digital engineering capabilities as part of the acquisition strategy (OUSD[R&E], 2023). As part of this digital engineering capability, the instruction articulates that programs need to "move the primary means of communicating system information from documents to digital models and their underlying data. Digital models become ubiquitous and central to how engineering activities are performed" (OUSD[R&E], 2023). This instruction cemented a growing transition that was initiated in the DoD Digital Engineering Strategy published in 2018 (DoD, 2018) and adopted by the DoD military departments. In a 2022 memo from the Department of the Air Force, it states that "the [DAF] strategic vision promotes digitally enabled processes and replaces the linear, document-centric approach of today with a dynamic, model centric approach" (Hunter & Cavelli, 2022). Similar visions were established for other branches in the 2020 United States Navy and Marine Corps Digital Systems Engineering Transformation Strategy (United States Navy and Marine Corps, 2020) and the Army Directive 2024-03 for Army Digital Engineering (Department of the Army, 2024). The policies, strategies, and directives have made it clear that the benefits of MBSE are understood and have been accepted by the DoD enterprise. A model-centric approach is critical to a digital engineering strategy because it structures information in a digital format that can be better leveraged for data-driven decisions in a digital ecosystem.

The DODI 5000.97 (OUSD[R&E], 2023) and digital engineering strategies from each branch are the driving force for this transition, but how is this being accomplished? The primary solution for programs to adopt is a MBSE approach which leverages semantic languages for transforming enterprise and system information, previously formatted as static documents, into a formalized set of models which can be viewed and analyzed using digital tools. MBSE is a key component of establishing a digital thread from concept development to certification and delivery of software, and this digital thread is what enables the dynamic decision-making capabilities that acquisition programs strive towards.

MBSE has been a transformative concept for many organizations aiming to achieve the vision of digital engineering, but it is not without its complexities and drawbacks. A recent study that collected and coded over 2,900 claims on MBSE concluded “the most negative attributes were: Approach Understandability, Acceptability, Familiarity, and Approach Complexity” (Campo et al., 2022). Knowing which languages, tools, and skills required to implement an MBSE can be challenging, but beyond that, collaborating with others on the approach is difficult, as well, because the context between groups can be vastly different. Driving consistency in MBSE is a challenge; different solutions and processes have been developed by different branches and individual program offices that have resulted in stovepipe solutions and disparate methods of implementation.

In this paper, the SEI delivers a consistent approach to map SWP activities to UAF. Our contribution is a uniform, UAF-based, approach to assist the DoD in implementing the pathway, while preparing for MBSE activities. Our contribution is two-fold. First, we review the SWP to identify canonical scenarios to be executed. Then, we show how to leverage UAF to perform. To support our contribution, we have developed a UAF profile resource to better describe and exercise these scenarios for analysis. This aligns with the DoD vision for Digital Engineering to use a model from acquisition to development, test, and evaluation.

The proposed scenarios define what is to be executed: an activity model that defines the goals and objectives of the enterprise, the stakeholders involved with expected competencies, models to be created, and measures associated with desired quality attributes. A program may refine these scenarios to execute SWP with confidence. In other words, we turned the complexity of the SWP guidance documents into a set of models that acts as guidelines.

Unified Architecture Framework

The Unified Architecture Framework (UAF) is a standard and specification published by the Object Management Group (OMG) that provides a structured language and rules for describing enterprise architectures (OMG, 2022a). UAF evolved from previous enterprise architecture standards in the forms of the U.S. Department of Defense Architecture Framework (DoDAF) (DoD, 2010), the U.K.'s Ministry of Defence Architecture Framework (MoDAF™) (Ministry of Defence [MOD], 2012), OMG’s Unified Profile for DoDAF/MODAF (UPDM™) (MOD, 2012), and the North Atlantic Treaty Organization's (NATO) Architecture Framework (NAF) (NATO, 2018), with the intent of providing a comprehensive and widely applicable standard for modeling enterprise architectures.

UAF, along with the Systems Modeling Language (SysML), which the UAF modeling language is extended from, has become the standard specification for MBSE approaches for the DoD. The UAF specification is organized into a Domain Meta Model (DMM) which defines the view specification, the UAF Modeling Language (ML) which defines the implementation of the DMM, and a set of appendices that provide guidance on the use of UAF, including the Enterprise Architecture Guide for UAF.

The UAF DMM Version 1.2 defines 89 model views that are organized by a set of viewpoints and aspects (OMG, 2022a). Viewpoints refer to concerns of the stakeholder such as operational or security considerations. Aspects refer to types of model constructs that stakeholders are viewing such as states, processes, or parameters. The UAF DMM defines the elements and relationship that are required to satisfy the full set of view specifications.

Figure 1 is a depiction of the 89 model views that comprise the UAF DMM. The views cover large breadth of what is required in an enterprise architecture, from capability definition to operational scenarios, project structure, data models, standards traceability, etc., which aligns well with the information needs of the SWP enterprise.

UAF	Motivation Mv	Taxonomy Tx	Structure Sr	Connectivity Cn	Processes Pr	States St	Sequences Sq	Information[c] If	Parameters[d] Pm	Constraints Ct	Roadmap Rm	Traceability Tr
Architecture Management[a] Am	Architecture Principles Am-Mv	Architecture Extensions Am-Tx[e]	Architecture Views Am-Sr	Architecture References Am-Cn	Architecture Development Method Am-Pr	Architecture Status Am-St		Dictionary Am-If	Architecture Parameters Am-Pm	Architecture Constraints Am-Ct	Architecture Roadmap Am-Rm	Architecture Traceability Am-Tr
Summary & Overview Sm-Ov												
Strategic St	Strategic Motivation St-Mv	Strategic Taxonomy St-Tx	Strategic Structure St-Sr	Strategic Connectivity St-Cn	Strategic Processes St-Pr	Strategic States St-St		Strategic Information St-If	Environment En-Pm and Measurements Me-Pm and Risks Rk-Pm	Strategic Constraints St-Ct	Strategic Deployment, St-Rm-D Strategic Phasing St-Rm-P	Strategic Traceability St-Tr
Operational Op	Requirements Rq-Mv	Operational Taxonomy Op-Tx	Operational Structure Op-Sr	Operational Connectivity Op-Cn	Operational Processes Op-Pr	Operational States Op-St	Operational Sequences Op-Sq	Operational Information Op-If		Operational Constraints Op-Ct		Operational Traceability Op-Tr
Services Sv		Services Taxonomy Sv-Tx	Services Structure Sv-Sr	Services Connectivity Sv-Cn	Services Processes Sv-Pr	Services States Sv-St	Services Sequences Sv-Sq			Services Constraints Sv-Ct	Services Roadmap Sv-Rm	Services Traceability Sv-Tr
Personnel Ps		Personnel Taxonomy Ps-Tx	Personnel Structure Ps-Sr	Personnel Connectivity Ps-Cn	Personnel Processes Ps-Pr	Personnel States Ps-St	Personnel Sequences Ps-Sq	Resources Information Rs-If		Competence, Drivers, Performance Ps-Ct	Personnel Availability Ps-Rm-A Personnel Evolution PS-Rm-E Personnel Forecast Ps-Rm-F	Personnel Traceability Ps-Tr
Resources Rs		Resources Taxonomy Rs-Tx	Resources Structure Rs-Sr	Resources Connectivity Rs-Cn	Resources Processes Rs-Pr	Resources States Rs-St	Resources Sequences Rs-Sq			Resources Constraints Rs-Ct	Resources evolution, Resources forecast Rs-Rm	Resources Traceability Rs-Tr
Security Sc	Security Controls Sc-Mv	Security Taxonomy Sc-Tx	Security Structure Sc-Sr	Security Connectivity Sc-Cn	Security Processes Sc-Pr					Security Constraints Sc-Ct		Security Traceability Sc-Tr
Projects Pj		Project Taxonomy Pj-Tx	Project Structure Pj-Sr	Project Connectivity Pj-Cn	Project Processes Pj-Pr						Project Roadmap Pj-Rm	Project Traceability Pj-Tr
Standards Sd		Standards Taxonomy Sd-Tx	Standards Structure Sd-Sr								Standards Roadmap Sd-Rm	Standards Traceability Sd-Tr
Actual Resources Ar			Actual Resources Structure, Ar-Sr	Actual Resources Connectivity, Ar-Cn	Simulation[b]					Parametric Execution/ Evaluation[b]		

Figure 1: UAF View Matrix (OMG, 2022a).

It can be noted that the set of 89 view specifications for UAF and the required elements and relations that should be implemented as part of them can be overwhelming for new users of the specification. This is where the Enterprise Architecture Guide for UAF plays an important role in providing a workflow for architects and model developers for defining an enterprise architecture model in accordance with the specifications. The Enterprise Architecture Guide for UAF is excellent as a general approach and process for creating enterprise models; however, the general process may not always fit the context, or the activities needed for a specific pathway. We claim a targeted guide for the various adaptive acquisition pathways delivers value to DoD model architects and practitioners and this study explores that guidance for the SWP.

Software Acquisition Pathway

The Software Acquisition Pathway (SWP) is part of the AAF that was established in the FY20 National Defense Authorization Act (NDAA) Section 800 and is further defined in DoD Instruction 5000.87 Operation of the Software Acquisition (OUSD[A&S], 2020). The purpose of the SWP is to provide software intensive development programs with a streamlined path for developing and delivering software capability, emphasizing the use of modern software development methods and tools for delivering capability rapidly. As of the time of this paper, there are currently 86 programs utilizing the SWP across all major branches of the DoD and associated services and the utilization of this pathway is increasing in importance. A March 6, 2025, memo titled *Directing Modern Software Acquisition to Maximize Lethality* and signed by the secretary of defense directs the DoD to adopt the SWP as the preferred pathway for all software development programs (DoD, 2025).

The SWP life cycle is separated into two primary phases, planning and execution, each containing a set of enduring tasks that all participants in the SWP implement. The planning phase contains activities for defining capability needs, developing strategies, developing roadmaps and backlogs, establishing development infrastructure, and designing architecture details that will feed into the execution phase. The execution phase contains activities to develop, test, deliver, and assess the value of the software, all the while actively engaging with users to ensure needs are understood and being met.

Figure 2 is an overview of the SWP life cycle and phases that is provided by the Defense Acquisition University (DAU) knowledge base site for the SWP. The DAU site provides valuable details for SWP participants that include descriptions for each of the activities, guidance for the accomplishment of the activities, and templates for documents that will be generated as part of the activity (DAU, n.d.).

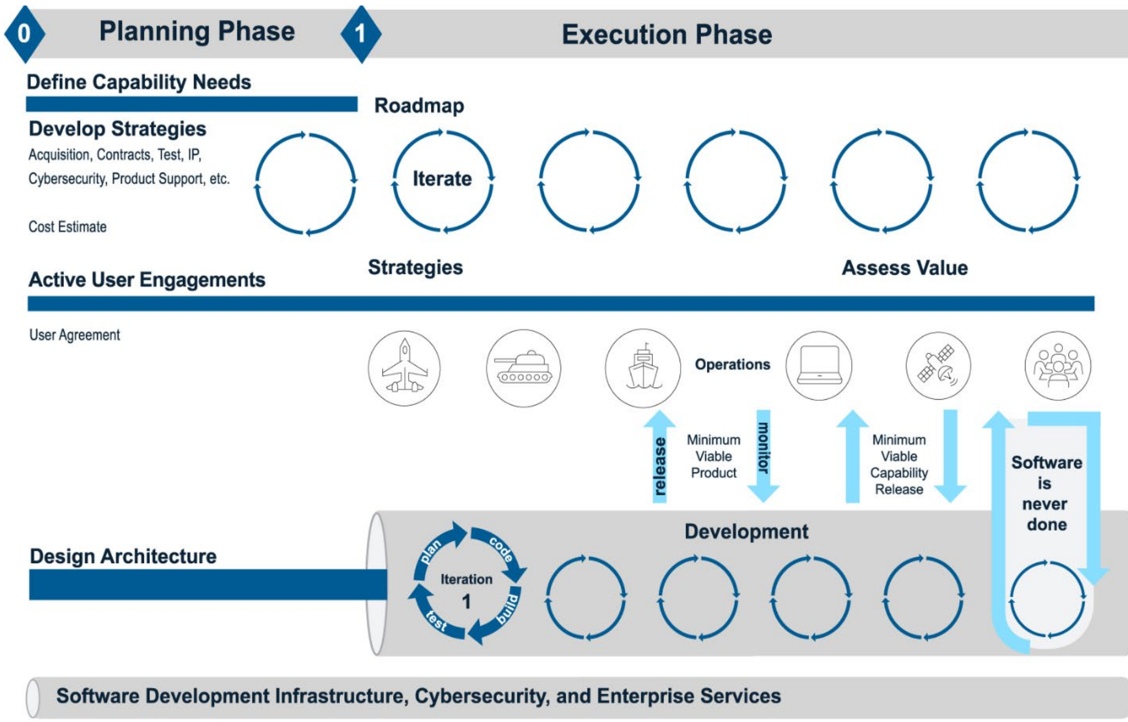


Figure 1: Life Cycle View of Software Acquisition (DAU, n.d.).

The SWP supports several types of software projects as part of the pathway, each with tailored considerations. The types are software applications, embedded software, and Defense Business Systems (DBS). The focus of this study is on the embedded software, which is defined in DODI 5000.87 as "software embedded in weapon systems and other military-unique hardware systems" (OUSD[A&S], 2020). Embedded software supporting weapon systems requires additional rigor and analysis to support certifications for system safety, cybersecurity, and operational use, which is a driving force for the use of MBSE techniques as part of other pathways.

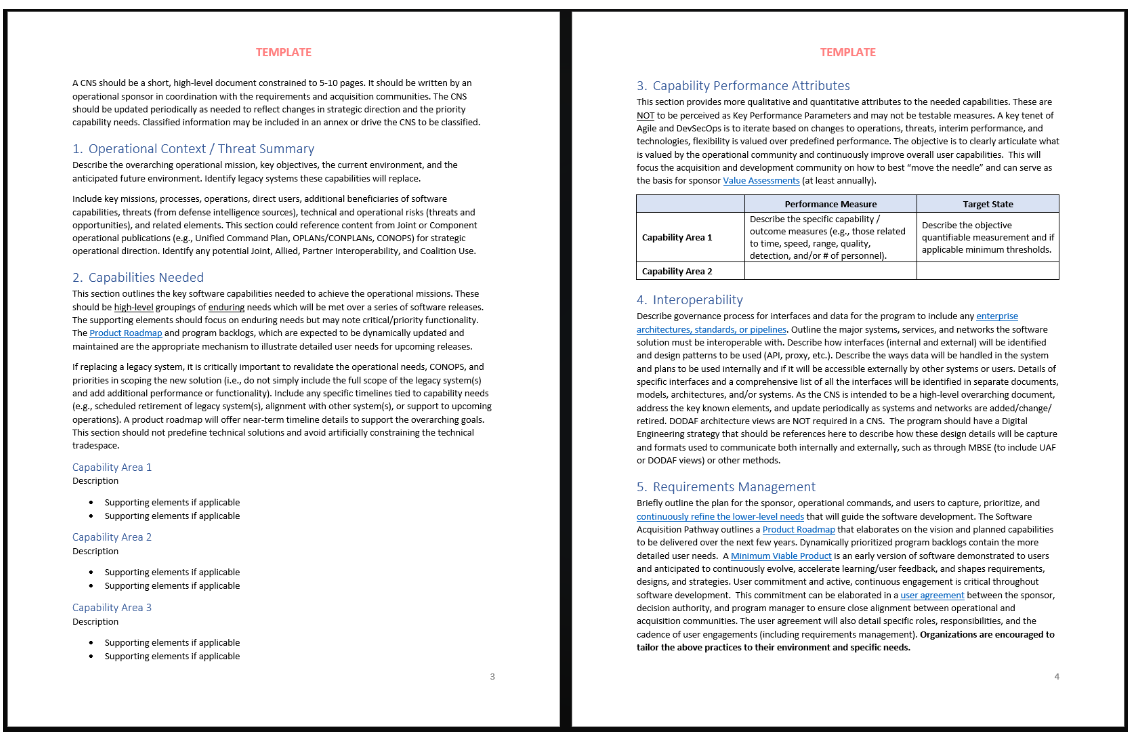
MBSE is not specifically highlighted as an example of "modern tools and techniques" in the policy or guidance information for use on the pathway, except for eight DoDAF views required if the project meets a joint equities threshold for generating a Software Initial Capabilities Document (SW-ICD) (OUSD[A&S], 2020). While not a focus, MBSE techniques can and should be utilized for enterprise and system architecture development. This study intends to inform DoD stakeholders that MBSE can be an effective tool for embedded software programs if performed in a thoughtful, value-driven, and efficient manner.

Required Statutory and Regulatory Documentation

One of the objectives of the pathway is to balance agility with engineering rigor and focus more on the software being developed rather than extensive documentation. To this end, programs using the pathway are not considered major defense acquisition programs and are not subject to the Joint Capabilities Integration and Development System (JCIDS) requirements. While this reduces layers of review and approval processes, as well as the amount of information needed to comply, the SWP must still adhere to a minimal set of statutory and regulatory information as required by law and policy.

The DAU SWP site provides a list of the required information to be compiled to by either the planning or execution phase. In total, there are 34 identified documents or collections of information required with varying applicability based on attributes of the program. This includes artifacts such as a Capability Needs Statement (CNS), User Agreement, Acquisition Strategy, Cybersecurity Plan, System Architecture, Product Roadmap, and Value Assessments to name a few.

To facilitate this formation of documentation, the DAU SWP site provides a collection of templates that SWP program offices and contractors can utilize. For contractor deliverables, it should be noted that Data Item Descriptions (DIDs) requiring specific formats for this information are not prescribed and that SWP programs are encouraged to reduce excessive contract data requirements list (CDRL) deliverables to deliver information in the most efficient way possible. Figure 3 is the template provided for the CNS document that would be developed by the program office.



TEMPLATE

A CNS should be a short, high-level document constrained to 5-10 pages. It should be written by an operational sponsor in coordination with the requirements and acquisition communities. The CNS should be updated periodically as needed to reflect changes in strategic direction and the priority capability needs. Classified information may be included in an annex or drive the CNS to be classified.

1. Operational Context / Threat Summary

Describe the overarching operational mission, key objectives, the current environment, and the anticipated future environment. Identify legacy systems these capabilities will replace.

Include key missions, processes, operations, direct users, additional beneficiaries of software capabilities, threats (from defense intelligence sources), technical and operational risks (threats and opportunities), and related elements. This section could reference content from Joint or Component operational publications (e.g., Unified Command Plan, OPLANs/CONPLANs, CONOPS) for strategic operational direction. Identify any potential Joint, Allied, Partner Interoperability, and Coalition Use.

2. Capabilities Needed

This section outlines the key software capabilities needed to achieve the operational missions. These should be high-level groupings of enduring needs which will be met over a series of software releases. The supporting elements should focus on enduring needs but may note critical/priority functionality. The Product Roadmap and program backlogs, which are expected to be dynamically updated and maintained are the appropriate mechanism to illustrate detailed user needs for upcoming releases.

If replacing a legacy system, it is critically important to revalidate the operational needs, CONOPS, and priorities in scoping the new solution (i.e., do not simply include the full scope of the legacy system(s) and add additional performance or functionality). Include any specific timelines tied to capability needs (e.g., scheduled retirement of legacy system(s), alignment with other system(s), or support to upcoming operations). A product roadmap will offer near-term timeline details to support the overarching goals. This section should not predefine technical solutions and avoid artificially constraining the technical tradespace.

Capability Area 1
Description

- Supporting elements if applicable
- Supporting elements if applicable

Capability Area 2
Description

- Supporting elements if applicable
- Supporting elements if applicable

Capability Area 3
Description

- Supporting elements if applicable
- Supporting elements if applicable

3

TEMPLATE

3. Capability Performance Attributes

This section provides more qualitative and quantitative attributes to the needed capabilities. These are NOT to be perceived as Key Performance Parameters and may not be testable measures. A key tenet of Agile and DevSecOps is to iterate based on changes to operations, threats, interim performance, and technologies, flexibility is valued over predefined performance. The objective is to clearly articulate what is valued by the operational community and continuously improve overall user capabilities. This will focus the acquisition and development community on how to best "move the needle" and can serve as the basis for sponsor Value Assessments (at least annually).

	Performance Measure	Target State
Capability Area 1	Describe the specific capability / outcome measures (e.g., those related to time, speed, range, quality, detection, and/or # of personnel).	Describe the objective quantifiable measurement and if applicable minimum thresholds.
Capability Area 2		

4. Interoperability

Describe governance process for interfaces and data for the program to include any enterprise architectures, standards, or pipelines. Outline the major systems, services, and networks the software solution must be interoperable with. Describe how interfaces (internal and external) will be identified and design patterns to be used (API, proxy, etc.). Describe the ways data will be handled in the system and plans to be used internally and if it will be accessible externally by other systems or users. Details of specific interfaces and a comprehensive list of all the interfaces will be identified in separate documents, models, architectures, and/or systems. As the CNS is intended to be a high-level overarching document, address the key known elements, and update periodically as systems and networks are added/change/retired. DODAF architecture views are NOT required in a CNS. The program should have a Digital Engineering strategy that should be references here to describe how these design details will be capture and formats used to communicate both internally and externally, such as through MBSE (to include UAF or DODAF views) or other methods.

5. Requirements Management

Briefly outline the plan for the sponsor, operational commands, and users to capture, prioritize, and continuously refine the lower-level needs that will guide the software development. The Software Acquisition Pathway outlines a Product Roadmap that elaborates on the vision and planned capabilities to be delivered over the next few years. Dynamically prioritized program backlogs contain the more detailed user needs. A Minimum Viable Product is an early version of software demonstrated to users and anticipated to continuously evolve, accelerate learning/user feedback, and shapes requirements, designs, and strategies. User commitment and active, continuous engagement is critical throughout software development. This commitment can be elaborated in a user agreement between the sponsor, decision authority, and program manager to ensure close alignment between operational and acquisition communities. The user agreement will also detail specific roles, responsibilities, and the cadence of user engagements (including requirements management). **Organizations are encouraged to tailor the above practices to their environment and specific needs.**

4

Figure 2: DAU CNS Document Template (DAU, n.d.).

The CNS template is a Microsoft Word file with the outline of information required for decision-makers of the pathway to approve. The CNS template is useful as pointed guide for capturing information in a localized, static instance. However, if programs wanted to use this information as a driving thread throughout the life cycle of the program, this format would lack the structure and format to do so efficiently. This is where MBSE provides a key advantage.

Required statutory and regulatory information developed as an output of the SWP benefits from transforming from primarily document-based, to model-based. We claim a model-based approach allows for enhanced analysis, decision-making, and collaboration between stakeholders. The use of models as part of the pathway for embedded software systems is key for reducing the documentation burden and developing continuous assurance of software in a rapid development environment.

UAF provides a structured ontology for enterprise architecture definition that can assist in satisfying the goals and objectives of the SWP, assuming the structured views can be effectively mapped to activities and information requirements as part of the pathway. Our study answers the latter in the following sections.

Basis for Mapping SWP Activities to Scenarios

As mentioned in the introduction, this study is being conducted as part of the MBSynergy project sponsored by the OUSD(R&E). The primary objective of the MBSynergy project is to provide DoD stakeholders with the tools and analysis mechanisms to uncover the true value of MBSE techniques within their context. MBSynergy is basing the tools and analysis mechanisms on CMU SEI's Architecture Tradeoff Analysis Method (ATAM), which is a technique for understanding how architectural styles influence the quality attributes of architecture behavior. While typically this technique is applied toward software system architecture, the ATAM principles apply toward analyzing enterprise architectures as well.

MBSynergy has designed a process for using scenario-based analysis for eliciting MBSE value in enterprise activities. This process utilizes a model-based approach to elicit scenarios, capture enterprise goals and objectives aligned to quality attributes, understand the model-based processes and flow of information, and define the measures that will verify that the goals will be achieved. The output is a UAF model defining the scenarios of the enterprise that can be analyzed and used as a reference for the enterprise going forward. This process can be utilized by acquisition programs in the following ways:

- to define an MBSE strategy, define which models to create, and propose relevant model quality metrics;
- to understand the interfaces of MBSE processes and the flow of information between activities, as well as why it is relevant to certain stakeholders;
- to evaluate MBSE process efficiency via simulation, and propose improvements; and
- to ensure scenarios are correctly mapped to acquisition strategies and requirements.

A key element the MBSynergy project is the definition of scenarios for the enterprise architecture as it relates to the use of MBSE. The scenarios focus the context of the use of MBSE to a specific activity the enterprise architecture is expected to perform and allows the exploration of the quality attributes that MBSE helps promote as a feature of the enterprise. The technical report that first introduces this approach, "A Principled Approach to Elicit Digital Thread Specification from User Stories," defines scenarios as an "input/output process within an environment, stakeholders with specific skills [to] achieve a business goal when a stimulus (trigger) is met, producing a response and generating outputs from inputs with measured quality attributes" (Hugues et al., 2025). With scenarios structuring the inputs, outputs, process activities, stakeholders, and measurable elements related to quality attributes, we can conduct scenario-based analysis. In the ATAM technical report, scenario-based analysis is used to "not only to determine if the architecture meets a functional requirement, but also for further understanding of the system's architectural approaches and the ways in which these approaches meet the quality requirements such as performance, availability, modifiability, and so forth" (Kazman et al., 2020). From this analysis, the value and purpose of MBSE can be better articulated and measured in terms of the benefits that it provides in certain scenarios.

The foundation of scenario-based analysis for MBSE being established, the SEI focused on applying this approach toward the SWP, aided by a model resource we developed for the Cameo Enterprise Architecture tool. Figure 4 shows a view of the MBSynergy scenario profile that has been developed. The figure shows the UAF elements and relationships that are created as part of MBSynergy scenario development.

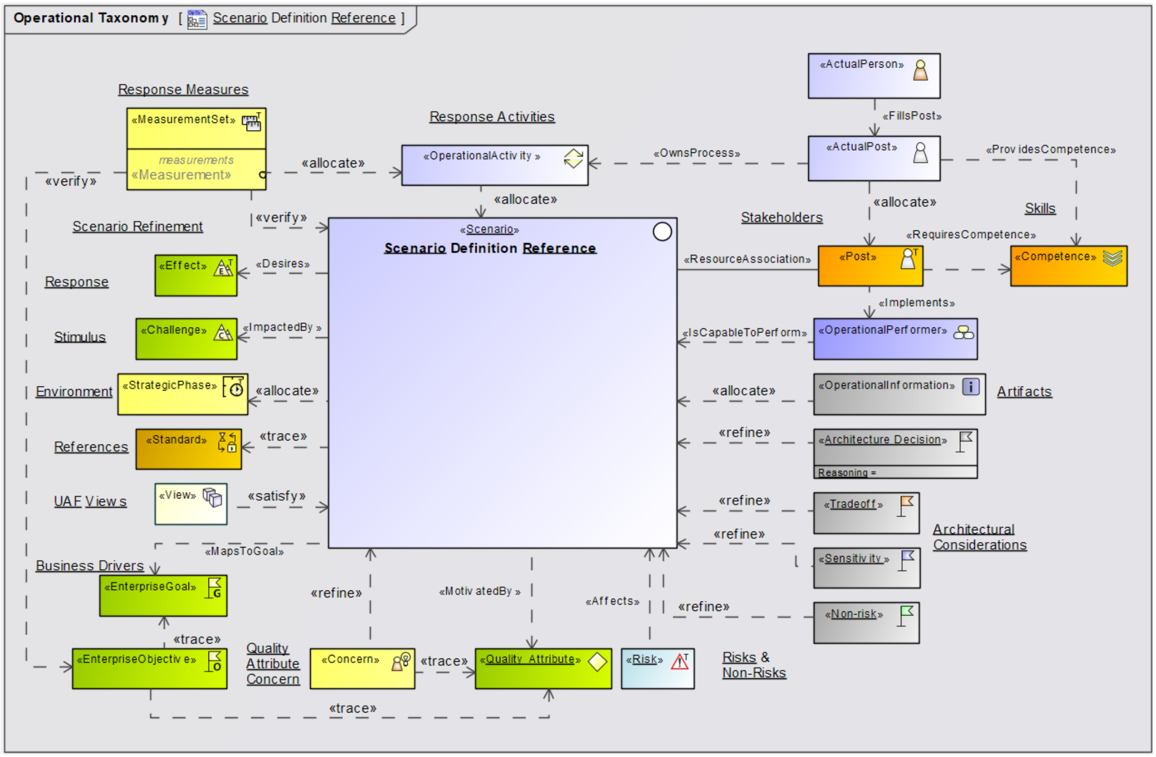


Figure 3: MBSynergy Scenario Profile

The MBSynergy Scenario Profile minimally extends the UAF profile to overlay MBSynergy scenario syntax and context for model developers to leverage for scenario definition. MBSynergy scenarios reference and re-purpose definitions first articulated for scenarios in the ATAM technique used for analyzing software architectures.

This resource was used to capture the 25 scenarios identified for the SWP which will be discussed and exampled in the subsequent sections.

Software Acquisition Pathway Scenarios

For the SWP, scenarios for the use of MBSE were identified by reviewing the activities described in DODI 5000.87 (OUSD[A&S], 2020) and the guidance on the DAU SWP guidance website (DAU, n.d.), in combination with the information requirements that are defined. For each phase, planning and execution, the activities were assessed for the need for having structured information produced or analysis conducted, thus indicating the applicability of model use.

Our assessment produced an initial set of 25 scenarios that capture the major areas of SWP activities that can benefit from being performed using model-based techniques. The scenarios were grouped by the top-level enduring tasks, a term defined by UAF as a common "undertaking recognized by an enterprise as being essential to achieving its goals" (OMG, 2022a).

The enduring tasks identified for the SWP include Define Capability Needs, Develop Strategy, Design Architecture, Plan Roadmap, Engage Active Users, Develop & Test, and Assess Value. It was important to align model-based engineering scenarios to drive home how models provide value to the critical aspects of the software pathway that are common to all. The number of scenarios could continue to expand as different considerations are uncovered as part of the scenario analysis and the operationalization of these scenarios. A high number of scenarios were identified during the planning phase of the SWP, where much of the requirement analysis and design activities are primarily associated. This might be expected considering that typical systems engineering practices aspire to bring much of the design and analysis of software as early in the life-cycle processes as possible to reduce risk.

An example of a scenario is Enterprise Services Definition. The guidance on the DAU SWP describes that programs should define a strategy for managing and leveraging "technical services such as cloud infrastructure, software development pipeline platforms, common containers, virtual machines, monitoring tools, and test automation tools" (DAU, n.d.). One might imagine how invariably useful it would be to have a digital model that defines the enterprise services elements, roles and responsibilities of personnel, service processes related to them, and how these elements interact. The model would be beneficial for a program to design their enterprise fully and continue to manage throughout the various life cycle of the SWP, as well as potentially leverage other enterprise service designs created by other programs. This is just one example of applying a model-based engineering approach to an aspect of the pathway.

Figure 5 shows the collection of scenarios that SEI has identified for the software pathway, grouped by the software pathway phase and enduring tasks.

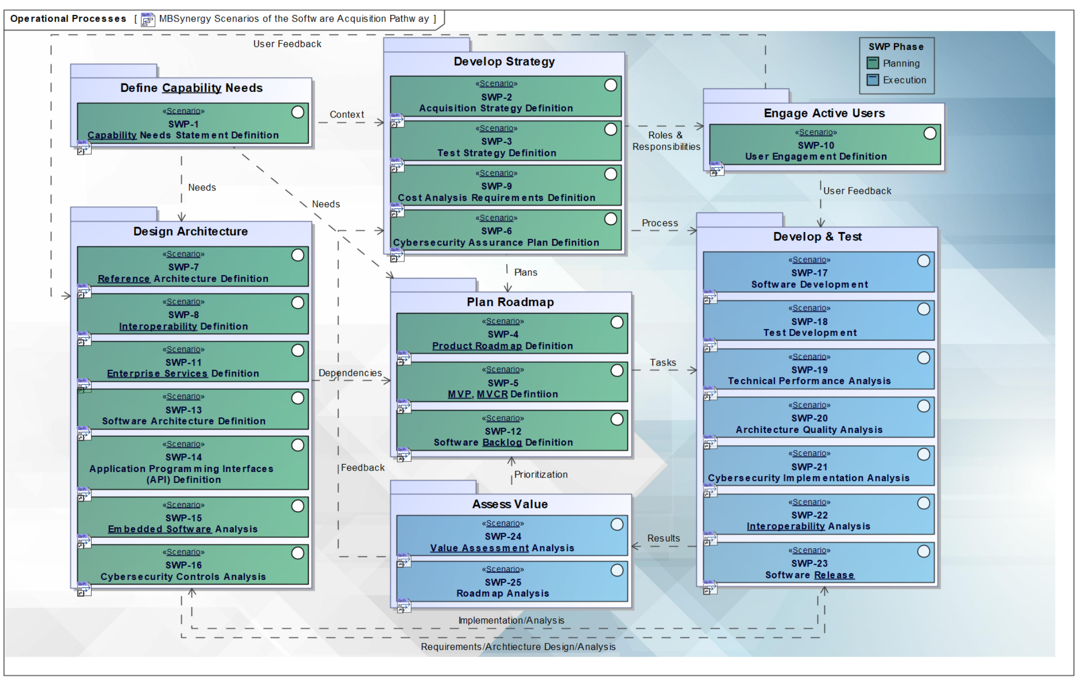


Figure 4: Model View of MBSynergy SWP Scenarios

As shown in Figure 5, the SEI has developed an UAF model that captures detail on the SWP scenarios and maps to the UAF 1.2 DMM. This model synergizes information in the UAF

DMM specification and the SWP guidance to form operationalization guidance and a platform for continued analysis of the value of MBSE applied to the SWP.

Figure 6 is a table developed in the model that shows the mapping of each scenario to the required statutory or regulatory information. The expectation is that some or all of the structured model information produced as part of the scenario satisfies the requirement of the pathway regulations. By mapping the structured information to the scenarios, the flow of information across the life cycle can be analyzed and the rationale for traceability from scenario to scenario can be established. Additionally, since the structured information is contained in the model, it would be feasible to create automated processes for collecting and producing this information in whatever format is most efficient for review and approval.

#	Id	Name	Aligned Documentation	Source	Applicability
1	SWP-1	Capability Needs Statement Definition	OI164 Capability Needs Statement OI171 Clinger Cohen Act (CCA) Compliance OI183 Software Initial Capabilities Document (SW-ICD)	DODI 5000.87 Clinger-Cohen Act (CCA)	Regulatory Statutory
2	SWP-2	Acquisition Strategy Definition	OI158 Acquisition Strategy OI168 Intellectual Property Strategy OI163 Product Support Strategy OI160 Business Case Analysis OI171 Clinger Cohen Act (CCA) Compliance OI169 Periodic updates to strategies	10 USC 2431a DODI 5000.87 Clinger-Cohen Act (CCA)	Statutory for major programs (> ACAT II) Regulatory Statutory
3	SWP-3	Test Strategy Definition	OI150 Test Strategy OI169 Periodic updates to strategies	DODI 5000.87 DODI 5000.96	Regulatory:Programs on DOT&E Oversight list may require a TEMP. Regulatory
4	SWP-4	Product Roadmap Definition	OI161 Initial Product Roadmap OI153 Product Roadmap OI154 Program Backlog	DODI 5000.82, Subtitle III of Title 40 DODI 5000.87	Statutory Regulatory
5	SWP-5	MVP, MVCR Defintiion	OI161 Initial Product Roadmap OI154 Program Backlog	DODI 5000.82, Subtitle III of Title 40 DODI 5000.87	Statutory Regulatory
6	SWP-6	Cybersecurity Assurance Plan Definition	OI156 Cybersecurity Plan OI171 Clinger Cohen Act (CCA) Compliance OI169 Periodic updates to strategies	40 USC 11313 DODI 5000.87 Clinger-Cohen Act (CCA)	Statutory for Mission Critical and Mission Essential IT programs Statutory Regulatory
7	SWP-7	Reference Architecture Definition	OI162 Information Support Plan OI167 Bandwidth Requirements Review OI171 Clinger Cohen Act (CCA) Compliance OI157 System Architecture	DODI 8330.01 §1047, P.L. 110-417 DODI 5000.87 Clinger-Cohen Act (CCA)	Regulatory Statutory for programs > ACAT II; Regulatory for Others Statutory
8	SWP-8	Interoperability Definition	OI157 System Architecture OI167 Bandwidth Requirements Review	DODI 5000.87 §1047, P.L. 110-417	Regulatory Statutory for programs > ACAT II; Regulatory for Others

Figure 5: MBSynergy SWP Scenarios Aligned to Required Documentation

The model is a library or reference architecture for stakeholders of the SWP to use for understanding the mechanisms to efficiently use UAF for structuring information and performing analysis. Each scenario is analyzed for its set of activities, stakeholders' roles, UAF views consumed/produced, quality attributes, enterprise architecture considerations, measures, and risks/non-risks. As a whole, the collection of scenarios defines a MBSE strategy and model development plan for SWP practitioners.

Mapping Scenarios to UAF Views

The mapping of the UAF views to the SWP scenarios was a relatively straightforward process after aggregating the definitions in the UAF DMM 1.2 specification and the information requirements of the SWP. The fact that this was a straightforward process speaks to the applicability of UAF as a framework to satisfy and structure information needs, transforming a document-based approach to a model-based one.

To illustrate the mapping process, we will walk through the operational process flow for the CNS Definition scenario for the SWP. The CNS Definition is a high-level overview of operational context, capability needs, performance measures, and user needs processes. A draft CNS is required to enter into the planning phase of the SWP, and it is expected to be refined and formally approved prior to entering the execution phase.

The template document for the CNS, shown in Figure 3 in a previous section, identifies five areas that should be articulated, including operational context, capabilities needed, performance attributes, interoperability considerations, and an overview of how requirements will be managed in the project. In the scenario, these five areas were transformed into operational activity actions where each action produced a set of UAF views. The UAF view specifications were compared to the text description of the information requested in the template and assessed for alignment. The objective was to select a minimal set of views that could satisfy the collection of information needed and not inundate model architects and developers with too many view specifications to consider.

Figure 7 shows the operational workflow diagram for the CNS definition scenario that is detailed in the model. This is a similar layout and approach to the one described and demonstrated in the Enterprise Architecture Guide for UAF.

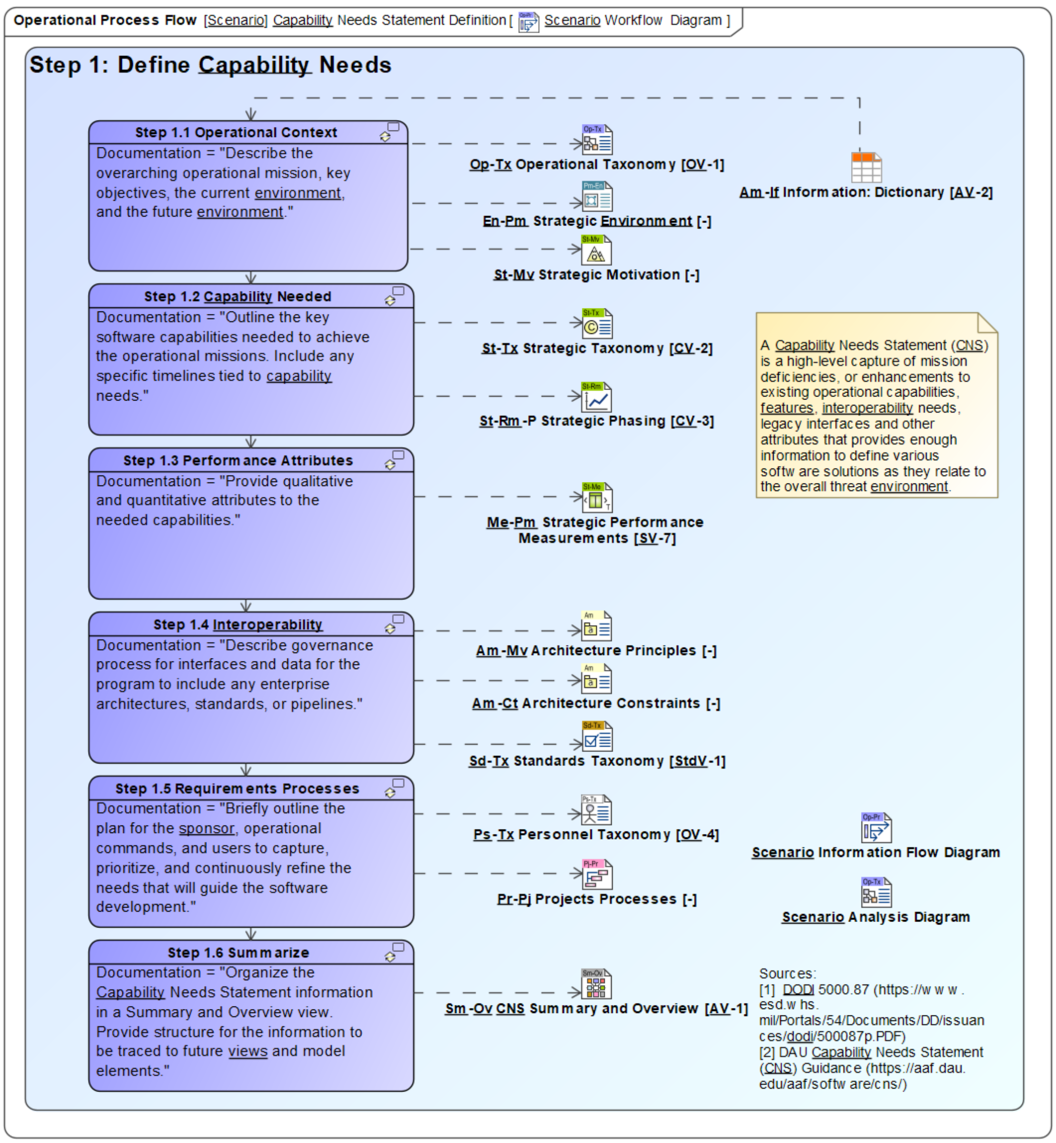


Figure 6: Model View of CNS Scenario

The operational activity actions are intended to be further refined by individual programs into sub-activity process flows identifying the specific roles and responsibilities for project personnel in the process. The UAF view diagrams shown in the figure are intended to be developed as example views that provide an understanding of what and how elements should be modeled. Driving consistency and understandability is a major concern for model use across all SWP users.

Table 1 provides additional commentary for how the UAF view aligns to the "SWP CNS definition" scenario. The UAF Views column contains the abbreviated view name, the full name, and, in closed brackets, the mapping to DoDAF views if available.

Table 1: "Capability Needs Statement" Aligned to UAF Views

Scenario Steps	UAF Views	Rationale for UAF View
1.1 Operational Context	Op-Tx Operational Taxonomy [OV-1]	Op-Tx captures the operational context and problem space, providing the necessary understanding for capability needs.
	En-Pm Strategic Environment [-]	En-Pm captures the current and future environment space of the operational concept, including identification of threats and risks. The view shows the elements and relationships that are involved in defining the environments applicable to capability.
	St-Mv Strategic Motivation [-]	St-Mv captures the key goals and objectives, threat drivers, and opportunities introduced by the software capabilities. The view defines the desired outcomes, goals, and objectives that are motivated by the drivers, and the opportunities that enable the goals and objectives.
1.2 Capability Needs	St-Tx Strategic Taxonomy [CV-2]	St-Tx captures an enumerated and hierarchical list of capabilities with relationships to supporting elements. The view captures the priorities of the capabilities for planning purposes.
	St-Rm-P Strategic Phasing [CV-3]	St-Rm-P captures the strategic timeline details to identify when capabilities are planned for users.
1.3 Performance Attributes	Me-Pm Strategic Performance Measurements [SV-7]	Me-Pm captures a list of strategic qualitative and quantitative attributes as pertaining to the listed capabilities. The view shows the measurable properties expressed in amounts of a unit of measure that can be associated with any element in the architecture.
1.4 Interoperability	Am-Mv Architecture Principles [-]	Am-Mv captures high-level architecture concepts and identifies the systems, networks, and services the software must be interoperable with. The view identifies relevant architectural principles and other guidelines to

Scenario Steps	UAF Views	Rationale for UAF View
		be used in architecture development and evaluation.
	Am-Ct Architecture Constraints [-]	Am-Ct captures interface and data constraints, assumptions, and governance processes to follow. The view depicts and analyzes assumptions, constraints, rules, policies, and guidance that are applicable to aspects of the architecture.
	Sd-Tx Standards Taxonomy [StdV-1]	Sd-Tx captures a list of relevant and/or required technical, operational, and business standards, guidance, and policies applicable to the architecture.
1.5 Requirements Processes	Ps-Tx Personnel Taxonomy [OV-4]	Ps-Tx captures the relevant stakeholders for the project context that participate in user needs processes.
	Pr-Pj Projects Processes [-]	Pr-Pj captures the set of activities that the enterprise will use for refining user needs as part of the software development process. The view describes the activities that are normally conducted during projects to support capabilities.
1.6 Summarize	Sm-Ov CNS Summary and Overview [AV-1]	Sm-Ov captures the set of information views in the previous steps for the CNS. The view allows for quick reference and comparison among projects.

The model views capturing these foundational elements of the CNS will be traceable throughout the planning and execution phase as part of design, development, and value assessments. The model enhances the ability to establish traceability between information early in the life cycle, both within a scenario and from one scenario to another, informing and refining the information that is developed later in the progression.

The process described above for mapping the views was repeated for each of the scenarios. Figure 8 is a snapshot of a portion of the SWP scenario to UAF view matrix diagram that is maintained in the model.

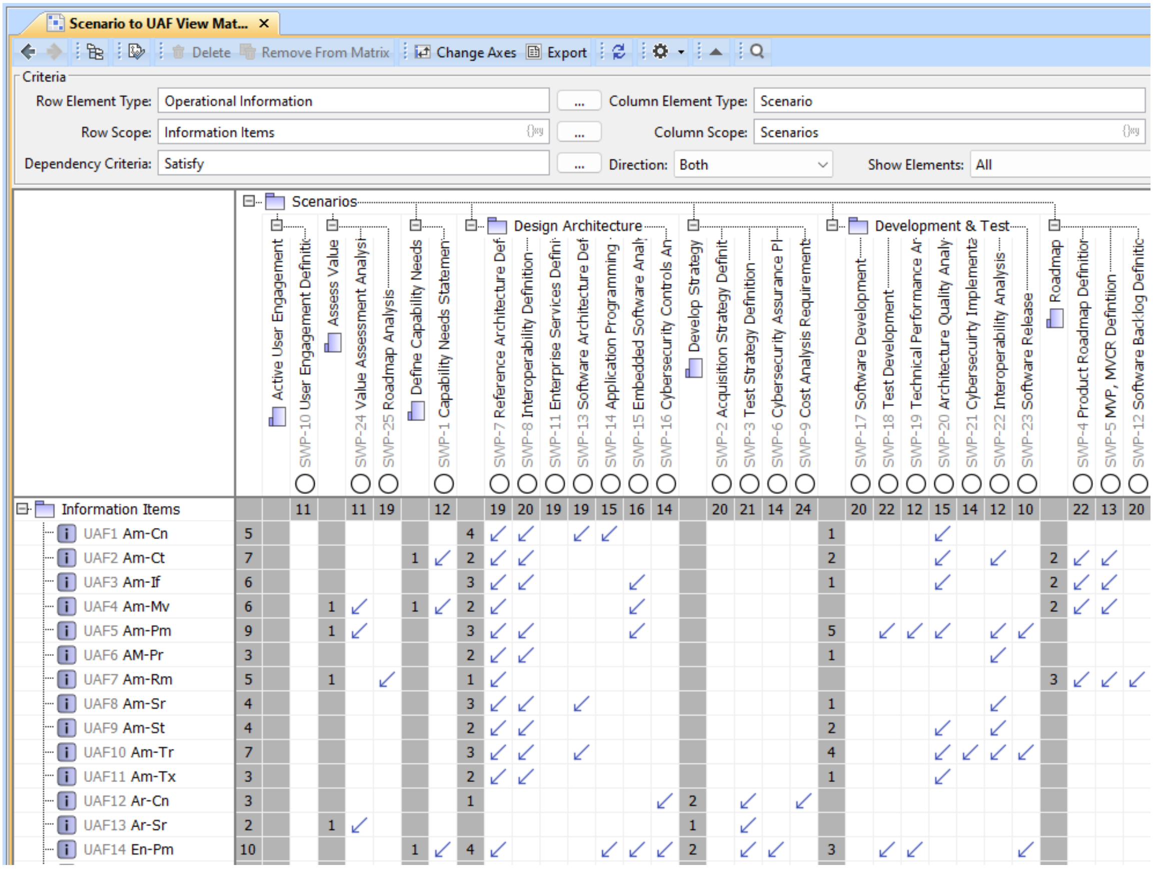


Figure 7: SWP Scenario to UAF View Matrix

This exercise found that many of the views were applicable to multiple scenarios, indicating how the information is used, refined, and matured across the life cycle of the SWP. This information flow, who uses it, and how it gets used is an aspect we explore as part of the detailed analysis we plan to perform for each scenario. Figure 9 shows a scenario connectivity diagram showing the flow of information that transfers from the Capability Need Statement Definition scenario to other scenarios to consume or refine.

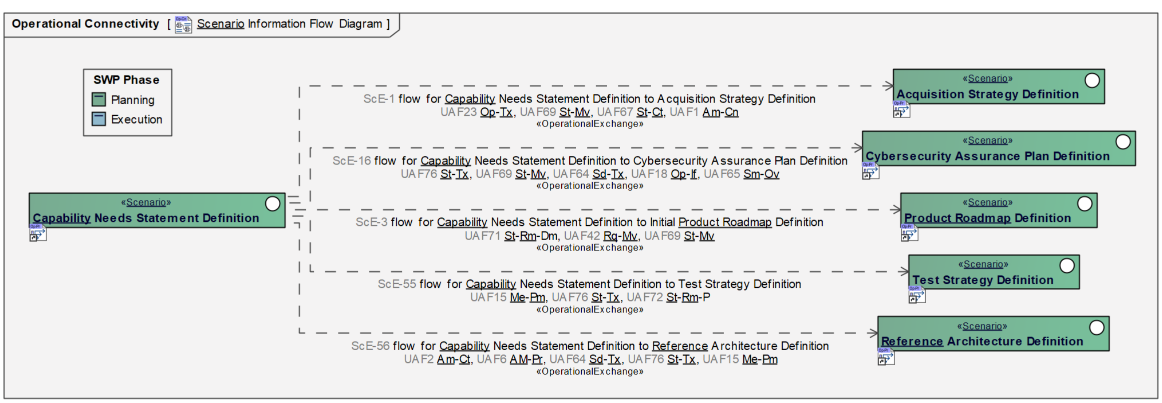


Figure 8: Scenario Connectivity Diagram - UAF Information Flow Analysis

The analysis of MBSE process interfaces assists in risk reduction of the enterprise by pinpointing where critical information is developed and transitioned. Risk reduction actions can be more precisely allocated to scenarios where the impact is greatest and ensure that high-quality information is established for the enterprise, leading to higher confidence and assurance.

Conclusion

The research presented in this paper is part of the foundational blocks for a consistent application of MBSE in DoD programs using the SWP, specifically with the use of UAF. The paper identified 25 scenarios for the operationalization of UAF as part of the SWP Planning and Execution phases for an embedded software sub-path and discussed the alignment of those scenarios to the information requirements of the pathway. To demonstrate the alignment, the paper discussed the UAF views that aligned to the development of a CNS with rationale for not only the satisfaction of the information needs, but also the value of capturing the information as part of an enterprise architecture model. The paper then introduced SEI's MBSynergy approach to analyzing scenarios and detailed how the analysis informs the value proposition of models within the context of the software pathway.

The full mapping of UAF views to SWP scenarios lays the groundwork for the operationalization of MBSE as part of the pathway. With the understanding of how regulatory and statutory information can be captured in UAF, stakeholders of the pathway can build common processes, policy, automation, and training to reduce the burden of model development and fully realize the benefits that MBSE can provide.

For SWP programs, this study and related artifacts aim to be resource for achieving a part of their digital engineering strategy, providing the ability to:

- structure and aggregate life-cycle information in a well-organized model, moving away from document-based information, to support communication and better understand interfaces between information needs
- generate robust traceability in life-cycle artifacts to support the concept of digital threads
- provide a foundation for analysis to occur early in the SWP, enabling more informed decision-making and higher levels of assurance for the desired quality attributes of the enterprise and the software capability being developed
- align with policy (DODI 5000.97) and digital engineering directives from each of the DoD military departments

Next Steps

The SEI plans to develop a technical report capturing the full breadth of content related to the scenarios developed for the SWP. This includes the full mapping of the software pathway scenarios to the UAF view, rationale for the view mapping, and high-level process and information flows from scenario to scenario. The technical report will be supplemented by a UAF model that can be made available to DoD stakeholders and the SWP community for reference and contribution. The SEI plans to continue to build out the scenarios for the software pathway and analyze the enterprise architecture within the scenario context, resulting in a set of quality attribute considerations and a value proposition for each scenario.

The SEI is interested in collaborating with active programs of the SWP to conduct additional studies and workshops relating to the use of MBSE during the pathway activities. Specifically, the SEI is interested in pilot projects to demonstrate the use of the UAF views and to explore the required resources needed to fully operationalize the approach.

The study informs future research into the use of models as part of the SWP, including how models can be continuously developed and monitored alongside software to inform value assessments and increase software assurance, how artificial intelligence (AI) agents and large language models (LLMs) can be utilized to automate aspects of model development and analysis, and how UAF model data can be effectively incorporated into software factory decision pipelines.

Legal Markings

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