A Model for Evaluating the Maturity of a Modular Open Systems Approach

Alfred Schenker, ars@sei.cmu.edu, (412) 389-8484

Nickolas H. Guertin, nhguertin@sei.cmu.edu, (703) 350-1061

Douglas Schmidt, schmidt@dre.vanderbilt.edu, (615) 294-9573

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Abstract

Defense Acquisition leadership has long espoused the benefits of a Modular Open Systems Approach (MOSA). The discussion has been consistent, but the actions have not. We suggest that there is a spectrum of MOSA "compliant" implementations among projects. We refer to this as a spectrum of "MOSA Maturity". The acquisition community would benefit from an evaluation framework – based on a model of MOSA maturity – to characterize how well MOSA-related policy objectives were being met. We suggest that a coherent set of attributes can be investigated, and results assessed to see if a program, system, system-of-systems, or enterprise has made the necessary changes to business, technical, and organizational models.

This paper describes an analysis construct that characterizes how well a weapon (or cyber-physical) system product has progressed in achieving the attributes of a MOSA. We will consider recently published attributes and criteria for MOSA as described by the DoD, the Military Services, and Congress. We tie this work with emerging development practices to determine a more effective means of measuring and comparing MOSA capabilities across programs.

This approach, built on prior research (as well as its measures) aligns with the newest Military Services MOSA policies and the latest *DoD Instruction 5000.02: Operation of the Adaptive Acquisition Framework*. We will identify new findings for the consistent application of MOSA practices in programs.

Introduction

This paper introduces a way to characterize maturity with respect to implementing a Modular Open Systems Approach (MOSA) for Department of Defense (DoD) acquisition. We believe this characterization will lead to an improved evaluation method. We describe a hierarchy of business and technical acquisition aspects related to openness that is aligned to the most recent DoD acquisition policy instruction, *DoD Instruction 5000.02: Operation of the Adaptive Acquisition Framework* (i.e., Adaptive Acquisition Framework), and *The William M. (Mac) Thornberry National Defense Authorization Act for Fiscal Year 2021* (i.e., FY-21 NDAA) (U.S. Congress, 2021). FY-21 NDAA Section 804 (Implementation of Modular Open Systems Approaches) is provided along with a "hand-in-glove" separate section related to technical data rights. These sections together illuminate some specific requirements associated with MOSA for the DoD. We then connect those requirements with a tool that can be used to evaluate the cost of making investments in MOSA-aligned products.

This paper builds on recent work by Carnegie Mellon University's Software Engineering Institute (CMU/SEI) that evaluates open architecture approaches and other prior works on assessing acquisition approaches. Particularly noteworthy in this body of work is the blog post *Addressing Open Architecture in Software Cost Estimation*, which deals with cost estimation in open architecture software-intensive systems (Gagliardi et al., 2020).

Background

Broad application of a MOSA across the DoD and Military Services of the Army, Air Force, Space Force, Navy, and Marine Corps (i.e., the Services) enables effective decision making for U.S. Government in evaluating choices among innovative alternatives and competing technologies. A key motivation for a MOSA is to enable a mechanism for inserting innovative technical solutions from DoD providers (as robust and effective tools) into the hands of the military users (i.e., warfighters) as rapidly and affordably as possible.

At its core, however, a MOSA is an architectural constraint that should be balanced against other architectural constraints (such as performance, safety, security). While principles of modularity and openness can be applied broadly, when it comes to a MOSA, the real benefit of MOSA occurs when the government correctly anticipates the specific pieces of technology that are likely to be upgraded/replaced over the lifecycle and makes the necessary investments in that technology *when the product is being developed* to facilitate those changes/upgrades, thereby proactively reducing technical debt over the lifecycle.

An effective MOSA should be implemented with (1) sound and mature technical characteristics, (2) well-reasoned and nuanced approaches to competitive dynamics, and (3) the thoughtful use of intellectual property rights in technical data. The key benefits of a MOSA-based implementation include the following:

- Enhance competition by employing open architectures with severable modules, allowing open competition of architectural functions/system components.
- Facilitate technology refresh by enabling delivery of new capabilities or replacement technology with minimal impact on system design.
- Incorporate innovation by ensuring operational flexibility to configure and reconfigure available assets to meet rapidly changing operational requirements.
- Enable cost savings/cost avoidance through reuse of technology, modules, or components from any qualified supplier across the acquisition life cycle.
- Improve interoperability by allowing changes and updates to severable software and hardware modules independently.

While it is hard to argue against the benefits of a MOSA from a technical or cost perspective, efforts to achieve them have been inconsistent at best and counterproductive at worst. A reliable and repeatable means of evaluating a MOSA would help guide MOSA implementations. Prior efforts to measure instantiations of a MOSA have had strengths and weaknesses, which we used to inform our approach described in this paper.

Congressional Direction

Congress has provided legislation in the FY-21 NDAA that documents a set of requirements for the DoD to achieve (U.S. Congress, 2021). In FY-21 NDAA Section 804 (Implementation of Modular Open Systems Approaches), a study of this language is instructional to parse the progression of a MOSA:

> *(a) Modular Open System Approach Requirement. — All major defense acquisition programs shall be designed and developed, to the maximum extent practicable, with a modular open system approach to enable incremental development and enhance competition, innovation, and interoperability. Other defense acquisition programs shall also be designed and developed, to the maximum extent practicable, with a modular open system approach to enable incremental development and enhance competition, innovation, and interoperability.*

This legislation has several elements that require an integrated business and technical strategy to achieve modularity, characteristics of the interfaces between those modules, the use of consensus-based standards to design those interfaces, and related acquisition requirements.

This legislation also provides detail with respect to system architecture:

> *(C) uses a system architecture that allows severable major system components and modular systems at the appropriate level to be incrementally added, removed, or replaced throughout the life cycle of a major system platform to afford opportunities for enhanced competition and innovation …*

It is especially noteworthy how this language has been modified from prior DoD instructions and guidance. The word *modified* has been removed from the list of characteristics that a modular approach should be able to provide. The legislation also provides a well-thought-out update to intellectual property rights in technical data that the government should employ for military systems. These rights include the ability to share information related to interfaces regardless of the nature of data rights associated with the underlying module. This change further informs us on how to characterize the maturation of MOSA in a program.

A succinct list of what these practices are expected to yield is also provided:

> *(i) significant cost savings or avoidance;*

(ii) schedule reduction;

(iii) opportunities for technical upgrades;

(iv) increased interoperability, including system of systems interoperability and mission integration; or

(v) other benefits during the sustainment phase of a major weapon system;

This list does not correlate directly to objective characteristics that translate to measurements and can be plugged into a formula to give a numerical result in terms of rating one program against another. However, both technical and business practices can be established that will guide a MOSA for the range of systems that Congress is interested in, including:

- major system platforms
- major system components
- subsystems
- assemblies

Congress makes sure that interfaces are defined in a way that leads directly to business outcomes. The description it provides "goes to the heart" of modules that facilitate flexibility in composing new functions and outcomes that can be decoupled and connected in new ways across an array of military uses.

> *The term 'modular system* interface' *means a shared boundary between major systems, major system components, or modular systems, defined by various physical, logical, and functional characteristics, such as electrical, mechanical, fluidic, optical, radio frequency, data, networking, or software elements.*
>
> *The term 'modular system' refers to a weapon system or weapon system component that—*
>
> *(A) is able to execute without requiring coincident execution of other specific weapon systems or components;*
>
> *(B) can communicate across component boundaries and through interfaces; and*
>
> *(C) functions as a module that can be separated, recombined, and connected with other weapon systems or weapon system components in order to achieve various effects, missions, or capabilities.*

In defining MOSA, Congress established a set of verification criteria for the interfaces of these modular elements, enabling the Government to measure something to ensure that products are meeting MOSA objectives. Specifically, it requires the following:

> *(i) comply with, if available and suitable, widely supported and consensus-based standards; or*
>
> *(ii) (information related to the interfaces are delivered with rights to the technical data that allow sharing such that):*
>
> *I. software-defined interface syntax and properties, specifically governing how values are validly passed and received between major subsystems and components, in machine-readable format;*
>
> *II. a machine-readable definition of the relationship between the delivered interface and existing common standards or interfaces available in Department interface repositories; and*
>
> *III. documentation with functional descriptions of software-defined interfaces, conveying semantic meaning of interface elements, such as the function of a given interface field; and*

This section on data rights makes some distinct changes in rights to data associated with interfaces. It also clarifies a set of business practices that address the right to share information related to interfaces, regardless of the funding source.

In FY-21 NDAA, Section 1833 (Proprietary Contractor Data and Rights in Technical Data) is decoupled from Section 2320, which is the MOSA section that makes substantive changes to the law regarding the government's rights in technical data (U.S. Congress, 2021). These sections provide much clearer statutory authority and identify a preference for rights in data. The union of an intellectual property strategy that is propelled by rights in technical data has long been a correlated practice in achieving MOSA objectives.

This Technical Data Rights section also facilitates sharing the inner designs of a product while seeking to sustain competitive dynamics in the limited Defense market through the use of a little-used but long-established data right type called *Program Purpose Rights*. The context of this particular preference is to align a set of organizations around a collection of like products or technical domains where deep sharing and interaction are needed to field a complex and interoperable capability while preserving competitive pressures outside of those specific circumstances and in unrelated domains.

Taken in aggregate, the message in this legislation is clear:

- The technical architecture should be built on a set of standards that are open and available to any qualified provider.
- A modular construct for weapon systems must comport to business practices that facilitate the government's ability to choose alternatives in a competitive environment.
- Complete details of the interfaces that characterize the interaction between the modules must be made available to the government and can be provided to competitors in a related market.
- Modular designs and related interfaces will be subject to government verification and validation.
- Sharing information that represents the fire of innovation, which is the principal driver of competitive market dynamic, must be preserved (Guertin & Womble, 2012).

Measures of MOSA implementation will need to address the requirements of this legislation.

DoD and Military Services MOSA Instructions and Guidance

In January 2019, the Secretaries of the Military Services signed the *Memorandum for Service Acquisition Executives and Program Executive Officers* (DoD, 2019) on the subject of "Modular Open Systems Approaches for our Weapon Systems in a Warfighting Imperative" (i.e., The Tri-Service MOSA Memo). In this seminal document, these secretaries not only identified an imperative, but they also provided specific examples of how to achieve it.

Here too, these leaders focused on standards for systems architecture and a need to drive data interoperability to "ensure our future weapon systems can communicate and share across domains." This directive provides grounding about mechanisms, which can be built on, to establish MOSA maturity measurements, including data interoperability.

Earlier Efforts at Measurement for MOSA

Modular Open Systems Approach, Program Assessment and Rating Tool (MOSA PART)

The MOSA PART was an early effort by the Open Systems Joint Task Force (OSJTF) (Open Systems Joint Task Force, 2004), which operated from 1994 to 2004. The goal of the MOSA PART was to characterize the degree to which the prior goals of the MOSA initiative were addressed. It identified the following five indicators:

- Enabling Environment
- Modular Design
- Key Interfaces
- Open Standards
- Conformance

Per the OSJTF description,

MOSA PART is intended for use by DoD Program Managers as a means to assess their implementation of MOSA throughout the acquisition life-cycle. The MOSA PART is an analytic tool that evaluates responses to a set of interrelated questions to provide acquisition program executives with an objective and evidence-based assessment of the degree that MOSA is implemented in a program.

The OSJTF established some valuable starting points for evolving the notion of an open system by identifying a distinction between open key interfaces correlated to the use of open standards.

Limitations. Participation in the OSJTF's MOSA PART was strictly voluntary. The MOSA PART was therefore unable to provide discernable metrics for the elements of each of these five measures in a way that could be used as criteria for a detailed assessment.

The Open Architecture Assessment Tool (OAAT)

The Naval Open Archiecture Enterprise Team (OAET) used the MOSA PART as a starting point on which to develop the OA Assessment Model (OAAM), which is illustrated in Figure 1. This model developed two dimensions of program openness along the axes of business and technical openness (OAET, 2009).

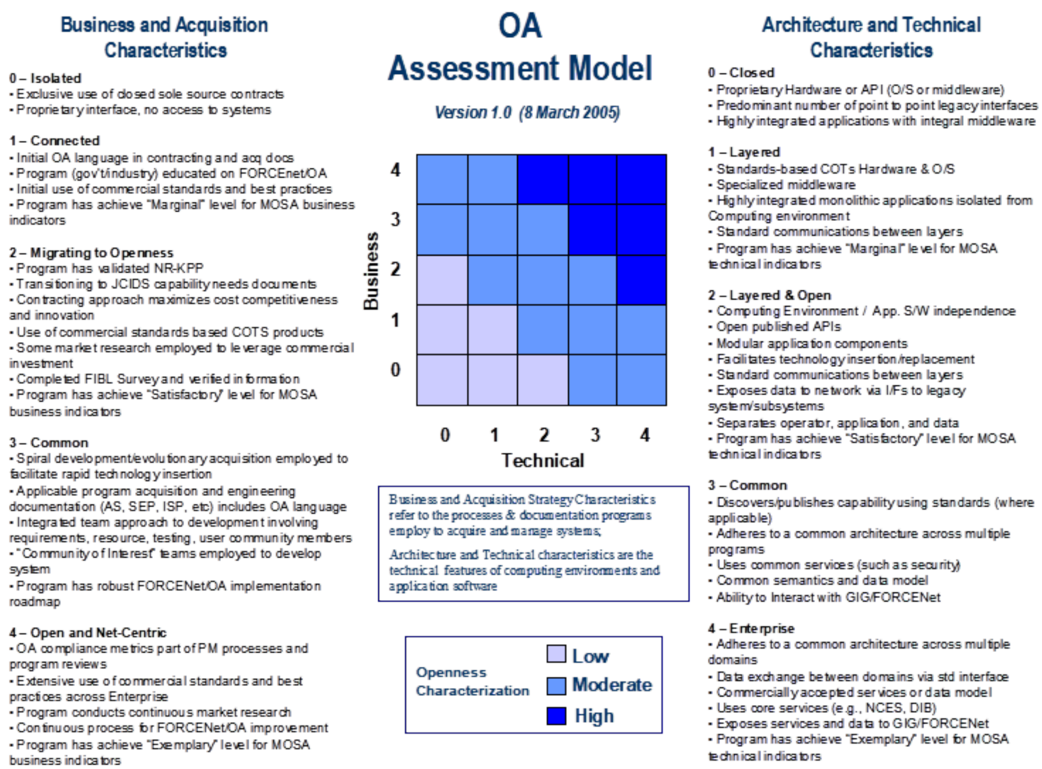

Figure 1: Open Architecture Assessment Model (Image: OAAT User's Guide V3.0, OAET)

The OAAT was developed by the OAET in response to leadership demands for some way to measure a degree of openness for a program. According to the *OAAT User's Guide*,

The OAAT is a tool for the use of Program Managers (PMs) and their OPNAV resource sponsors to assess, on a continuing basis, the OA maturity of a program and its systems. For complex programs, an assessment can be conducted on the whole program or individually on each significant sub-element of the program. In either case, the activity on which the assessment is conducted is called the unit of assessment. The OAAT assessments provide a current state of the unit of assessment that can then be used *in conjunction with other factors, such as remaining service life, stage in the acquisition process, and potential for the system to change over time, to be compared with a desired state of openness.*

The most current version of the OAAT is version 3.0, which was released in 2010. It has 64 questions that are roughly evenly split between business and technical characteristics. While most questions are optional, one-third of the assessment questions must be answered. These questions have a greater impact on the overall score as each one has a three-times multiplier for the scoring algorithm.

In addition, five of those questions were deemed so impactful that if the answers were not addressed above a threshold level, the overall score is capped at 50 percent. These litmus test questions eliminate the possibility of a program doing well in many small ways, while not addressing high-impact areas, yet achieving an artificially high numerical result. The OAAT is still available on DAU's website and referred to in guidance documents used by both the DoD and the Services (Defense Acquisition University, n.d.).

Limitations. The OAAT yields a single, two-dimensional numerical output based on the OAAM after taking in dozens of inputs stretched out over multiple technical, business, and cultural measures. As a tool, it does not provide insight on what measures have the greatest impact on the overall objectives of MOSA, nor does it provide a hierarchy of what measures are most important. Moreover, the OAAT provides a limited ability to compare implementation approaches across programs, thus providing little in the way that metrics can be used to guide cross-program or enterprise behavior.

While the tool was built to evaluate significant sub-elements (i.e., modules) as units of assessment, programs of record have not used the OAAT in this way. This lack of deeper analysis precluded developing any metrics on which to evaluate modular dimensions of openness. This lack of penetration in evaluation further eliminated an approach for characterizing the intersystem, or intra-program interfaces or interoperability performance.

Another limitation is that the business and technical objectives of Congress' requirements and DoD policy have matured significantly since 2010. Modularity and managed interfaces within and across systems and environments were not a factor in designing the OAAM and the subsequent OAAT.

Programs that were using the OAAT sought guidance from the Naval OAET from 2007 to 2013. Each program completing the evaluation was satisfied with the score it received (regardless of outcome) and took no further action to improve its score. The OAET subsequently abandoned the OAAT as an input to the Navy's quarterly OA Report to Congress in favor of the *Naval Open Systems Architecture Questionnaire and Guidance* (i.e., NOA Questionnaire), which was designed to facilitate and advance an updated Naval OA Strategy and provide insight across programs and organizations (U.S. Navy, 2012; Open Architecture Enterprise Team, 2014).

NOA Questionnaire

In 2012, the Navy's Acquisition Executive changed the nature of that Service's plan to achieve an enterprise-level *Open Systems Architecture Strategy* (Open Architecture Enterprise Team, 2014). The Naval OAET developed a related *Naval Open Systems Architecture Strategy* (U.S. Navy, 2012) that was released in that same year. As a part of that strategy, new measures provided a means by which cross-program comparisons could be made at a more detailed level than is facilitated in the OAAM. The NOA Questionnaire (shown in Figure 2) was developed as a limited set of questions that addressed the most impactful elements, many of which were extended from the MOSA PART and the OAAT (Open Architecture Enterprise Team, 2014).

Question	Yes/No
1. Have you developed an open competition acquisition strategy that enables contracting with third-party developers for modules that can be competed? Q1 Guidance	
2. Have you published a data rights/intellectual property strategy? Q2 Guidance	
3. Did you use the Naval OSA or DoD OSA Contract Guidebook for Program Managers to help contract or RFP development? Q3 Guidance	
4. Did your current contract or RFP call for government non-development items and COTS (including open source or community source components)? Q4 Guidance	
5. Did your current contract or RFP disclose the technical architecture and supporting systems Engineering information adequately to enable third-party developers to participate? Q5 Guidance	
6. Did your current contract or RFP call for replaceable/refreshable components that can be re- competed? Q6 Guidance	
7. Does your program acquisition plan call for re-competition of the system and/or components every 3-7 years? Q7 Guidance	
8. Do you plan to issue any RFPs in the next 3 fiscal years? Q8 Guidance	
9. Have you measured the "openness" of your systems (e.g., used the OAAT)? Q9 Guidance	
10. Have you identified potential modules that can be competed? (e.g., that can be replaced, modified, upgraded, or extended) Q10 Guidance	
11. Do you employ a modular, open systems approach (MOSA)? The use of open standards for key interfaces is part of this approach. Q11 Guidance	
12. Did you use open standards-based designs and agreed upon data models that are being used by a different program or are being facilitated by a COI? Q12 Guidance	
13. Have you formally documented the technical framework of your system? Q13 Guidance	
14. Have you developed an asset reuse strategy in accordance with Naval Enterprise Policy? Q14 Guidance	
15. Is your contractor following your Open Systems Management Plan (OSMP)? Q15 Guidance	
16. Does your acquisition strategy or life cycle support plan include periodic technology refresh or capability insertion approaches for life cycle affordability? Q16 Guidance	
17. Have you implemented a training program to educate your acquisition work force on OSA (e.g., continuous learning modules, workshops)? Q17 Guidance	

Figure 2: The NOA Questionnaire (Image: U.S. Navy)

The 17 questions (8 business, 8 technical, and 1 workforce) came with guidance and information needed to understand what characteristics of a program would yield a positive response.

The results were reported to Congress quarterly for the following two years, and these results facilitated cross-organization and cross-program measurements of progress towards achieving the overall objectives of the *Naval Open System Architecture Strategy*.

The NOA Questionnaire results were used by both program managers and their associated Program Executive Offices (PEOs) to understand how to improve overall Open Systems Architecture approaches and achieve the objectives of the *Naval Open Systems Architecture Strategy*.

Limitations. The NOA Questionnaire is built on yes/no responses and was developed to drive reporting and cross-program/organization behavior, not to directly assess details of implementations.

The primary purpose of the questionnaire was to support the *Naval Open System Architecture Strategy* and the Secretary of the Navy's quarterly report to Congress to compare progress across programs. The *Naval Open System Architecture Strategy* and a need to perform these surveys and subsequent analyses were not codified into long-term policy. After these reports were no longer required, the drive to execute an enterprise strategy faded, and the need to participate in the questionnaire was truncated.

OUSD (R&E) MOSA Assessment Criteria

In 2022, as part of the response to the FY-21 NDAA, OUSD (R&E) released criteria for assessing a MOSA (OUSD, 2022). DoD had established a Modular Open Systems Working Group (MOSWG) and in 2018 the MOSWG stood up an Assessment Tiger Team to survey the use of MOSA in DoD acquisition programs. In 2021, the Tiger Team reported that "although it had identified general criteria for assessing the effectiveness of MOSA compliance, it had not agreed on specific criteria that would be applicable across all Service and program types."

The DoD had previously defined a set of MOSA tenets, referred to as "pillars", to guide the use of MOSA in defense acquisition programs. These pillars, defined in 2011, are remarkably like the indicators defined in the previously described Program Assessment and Rating Tool (PART), although they have been elaborated in much more detail.

The MOSWG decided to require the Services to explicitly connect their tailored assessment criteria to these pillars. An example of how to do that was provided in the Assessment Guidance document.

Limitations. The Guidance document and the Assessment criteria were produced relatively recently and have not had the opportunity to be put into practice.

Open System Verification Demonstration (OSVD)

As part of the acquisition plan for the US Army's Future Attack and Reconnaissance Aircraft (FARA), the Army planned a series of open system verification demonstration (OSVD) events to assess the degree to which the FARA contractor's designs met the Army's MOSA standards (Sikorsky, 2023). The Army had provided a set of MOSA scenarios to the contractors as part of the acquisition Government Furnished Information (GFI). The demonstration was to verify the Government could replace a major system component with the following constraints: (1) by using nothing but the contractor's TDP, (2) using an independent third party to implement the component replacement, and (3) performing the work in the contractor's Systems Integration Lab (SIL).

It was expected that there may be training, and orientation required to ensure the independent third party is fluent with the contractor's development environment, so initial demonstrations were focused on learning how to make the change (as opposed to a complicated component replacement) and were therefore relatively simple. When they had demonstrated competency with the development environment, the third party moved on to more challenging component replacements.

This approach resulted in a much more involved demonstration than what had been done in prior MOSA assessment methods. The results, when made available, should make an interesting read. This type of assessment requires a level of financial commitment (by the US Government) to perform the component replacement and demonstrates the importance that the government has placed on achieving a MOSA. Unfortunately, the FARA program was cancelled by the Army in early 2024, so we won't know what the outcome would have been, but clearly the approach is worthy of a mention in a paper on this topic. It was expected that the results of the assessment would have influenced the selection of the winning contractor (as part of the source selection process).

Limitations. The OSVD assessment represents one of the first times that the government has tried to assess openness and modularity in such a tangible way. Prior attempts often focused on design or architecture documentation and review, falling short of actually replacing a major system component. We believe this type of assessment provides direction to becoming the "gold standard" for MOSA assessment, but more experience with performing it is needed. For example, the opportunity to collect data (e.g., effort, issues, lessons learned) regarding the experience of making the change is unparalleled. A standard set of measures must be developed to support this type of assessment.

MOSA Maturity

MOSA does not happen by accident. It requires a deliberate effort by an organization to accomplish specific objectives for their products. The broad benefits of MOSA have been described above, but how do we know that (1) our organization possesses the knowledge and skills needed to develop a strategy to acquire products following MOSA principles, and (2) our source selection process will produce a contractor that correctly applies the MOSA principles to the design and integration of our products. A MOSA Maturity model could be used to help define and assess the competencies of both the acquirer and the contractor and could incorporate the pro forma approaches that have been attempted over the past twenty years.

Is it simply adequate for a project to satisfy the measurement criteria of a particular assessment? Or are there other indicators of an organization's experience with MOSA that would provide more insight for an organization?

For a contractor, hired to develop a "MOSA compliant" product, we believe that there is a spectrum of MOSA compliance that ranges from "box-checking" to "the way we do things around here". We believe that there are qualitative indicators, including such items as:

- How models are used (e.g., data models, MBSE) in the design
- How the interfaces are documented
- How much due diligence was spent on MOSA (i.e., effort spent performing trade-off analyses where MOSA was one of the criteria)
- Experience with product lines and product line governance

There is also an expected level of experience needed on the acquirer side. In fact, a critical element of acquirer competency is to be able to discern the differences between contractors competing on contracts that require a MOSA. Additionally, there may be competency needed in the following areas:

- Experience with product lines and product line governance
- Elaborated scenarios (or use cases) that illustrate the intent of the MOSA
- Existence of data models that are used in the product domain
- Experience with model-based methods for specifying requirements
- Standard measures for how to characterize the MOSA implementation

Maturity of Data and Interfaces

The Tri-Service MOSA Memo and the FY-21 NDAA make clear that interoperability is based on the interfaces between major elements, the standards on which those interfaces are built, and the intelligible structure to the data so that the products can be mixed and matched across a diverse set of military capabilities.

As the use of a module (be it in a system, a platform, or a product) is expanded to other areas, portability and multi-context interoperability are predicated on the ability to consume and provide information in other arenas or domains. Interface documentation, including clarity of semantics and syntactics, is then critical to achieving the objectives of a MOSA strategy.

The Interface Documentation Maturity Levels (IDML) model, shown in Figure 3, was developed to establish a progression of characteristics needed to address how to develop interfaces that support a MOSA strategy (Hand et al., 2018).

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Figure 3: Interface Documentation Maturity Levels

This approach to establishing an interface maturity construct illustrates how to create a MOSA maturity model.

Open Systems Architecture Configurability Rating Checklist Tool

Figure 4 shows the structure of a tool that the SEI developed that enables a program to perform an open systems architecture assessment on a selected software architecture and then provide software cost-estimation inputs, including assessment ratings, to a standard software cost-estimation program. This tool goes into greater depth of the characteristics of MOSA; it examines a product through the lens of a separate Units of Assessment and addresses the following:

- **Modularity**: System architecture key components are encapsulated, cohesive, self-contained, and loosely coupled.
- **Interface Standards**: A widely available document exists that specifies interfaces, including services provided/required, protocols, message and data formats, etc.
- **Layering and Tiers**: A software abstraction provides separation from other software packages and technology.
- **Open and Accessible Standards**: Key interfaces are based on open and accessible standards that are widely used, consensus based, published, and maintained by recognized communities of interest.

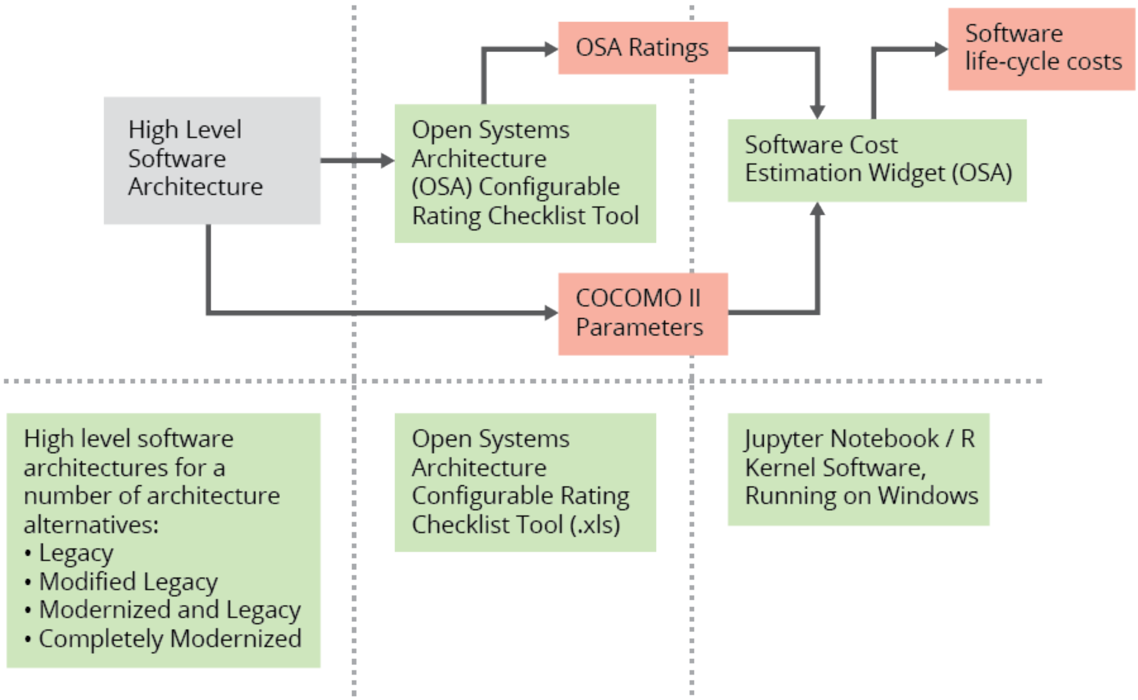

Figure 4: Open Systems Architecture Configurability Rating Checklist Tool

As an example application of this tool, a representative acquisition program was evaluated to assess the cost performance of keeping a legacy design against making an up-front investment to open the program and improve the overall architecture to facilitate improved reliability, maintainability, and upgradability. Figure 5 shows the analysis results.

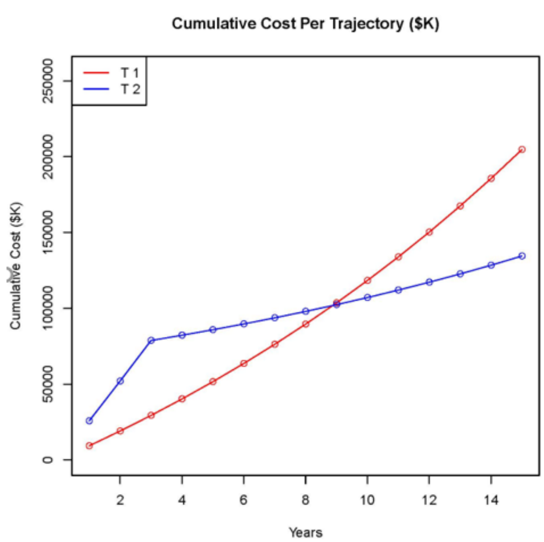

Figure 5: Cost Assessment of Adopting MOSA vs. Staying the Course Using the Open Systems Architecture Configurability Rating Checklist Tool

The goal of this work is to remove uncertainty about cost as a barrier to adopting open systems architecture methods, platforms, and tools. However, this tool is limited by the quality of the input data, which is based partially on the OAAT. To improve this tool and broaden its applicability, a more up-to-date assessment of MOSA maturity will be needed.

MOSA Maturity Model

Informed by these past efforts, we blended the legislative requirements from Congress with the acquisition policy needs of the DoD to create a hierarchy composed of criteria that address the business needs and technical discipline MOSA requires for a product, system, or platform. We continue to assert the need to evaluate the framework of the technical architecture to be as important as the management of the acquisition approach to achieve the objectives of MOSA.

We end this paper with "the model" which is instantiated as a set of scenarios, broken into three tiers, ranked by importance, and split along the dimensions of business and technical characteristics. We can use these scenarios to ascertain how well the MOSA goals are being met, which can be assessed through evidence-based measures and logic tests.

	Business	**Technical**
Growing	Can a new module be added to a product to improve its fielded performance (i.e., innovation) within a week of completing integration testing?	Does the interface of the module have well-defined and published semantics and syntactics (i.e., data model) for interoperability that are addressable by any other defense program?
	Is the technical architecture for the current design documented in a digital model and made available to any qualified party?	Is there sufficient documentation or a digital model so that the role of the system integrator can be competed or subsumed by the government with minimal effort?
		Is there sufficient documentation or a digital model for a module so that the role of the product provider can be competed or subsumed by the government with minimal effort?
Mature	Is the module's performance documented in a digital model that can be used for the competition of existing capabilities?	Can a different module replace an existing module within a day with the same or fewer integration errors?
	Is there an intellectual property strategy that has been validated against the newest data rights legislation, including a preference for Program Purpose Rights?	Can modules be upgraded or replaced quickly either directly or by technicians in the field?
	Are the interfaces of the module, system, or platform published (either in a digital model or in a document) and made available to any qualified organization?	Is the software environment made up of an open platform (e.g., containerization construct or micro-service architecture) that is widely published or available to any qualified competitor?
Compliant	Can an existing module (e.g., major system component) be integrated into a different domain within a month of a new domain being identified?	Is a module sufficiently decoupled from an interface standard so that it can be repurposed or upgraded to use a different interaction mechanism?
	Is there an open competition acquisition strategy that enables nonincumbents to compete and win as alternative providers?	Can an existing module be upgraded to operate in a new environment or a different warfighting domain within three months of that new domain being identified?
	How often is the incumbent's implementation of an Open System Management Plan validated by an independent third party?	Are the modules sufficiently decoupled from their execution platform so that an update to hardware or other infrastructure can be performed in a week?
	Can a module be incrementally changed and deployed with known effects to other modules it interacts with?	Can a module be replaced with an alternative either for programmatic reasons or improved performance?
Progressing		Can the module execute without coincident execution of other specific weapon systems or components?

	Business	Technical
	Can an existing module (e.g., component in a major system platform) be added, removed, or replaced throughout the lifecycle?	If the module has sensitive timing needs, is there a validated model of the interaction with other related modules that others can use to evaluate replacement alternatives?
Early	How often are the members of the systems, development, and operations teams provided with training on the implementation of a MOSA?	How often are the members of the systems, development, and operations teams provided with training on the implementation of a MOSA?
	Can modules of a system or platform be severed from its original deployment for use in other contexts?	Does the module construct exist across implementation domains of electrical, mechanical, fluidic, optical, radio frequency, data, networking, or software elements?
None	How many modules of the system will be competed in the next three to seven years?	Can a product roll back to an older safe state if a replacement becomes unstable or inoperable?

Why This Approach Is Different

MOSA is an evolving practice in both depth and breadth. It has changed since the early days of the OSJTF and other hallmark programs that informed an open architecture approach for the DoD (Guertin & Miller, 1998). The details matter, and measures that address needed change can inform progress. Using a scenario-based approach facilitates the evolution of the methods, while the characteristics of what is to be achieved remains somewhat stable. Any product, system, or platform can be evaluated by starting with basic levels and elevating the characteristics of what constitute both the technical and business steps to achieving the goals of a MOSA.

Road to Adoption. The following activities should be put into place to facilitate a global set of MOSA maturity measurements that inform leadership and elevate best practices for all programs:

- Validate these proposed measures against selected products, programs, and platforms to baseline the nature of MOSA maturity. Have those measures independently verified.
- Use that baseline to inform changes to the measures prior to full deployment to all programs.
- Capture those validated measures as inputs to the DoD and Services.
- Develop and deploy a set of matching DoD and Services policies that require all programs of record, including programs that operate under larger acquisition category arrangements, to perform the new assessment. Have a third party validate the responses.
- Perform a data analysis to identify needed next steps and evaluate efforts that best meet the spirit and the letter of the law and policy.
- Report the findings to Congress to show progress against its requirements.

Barriers to Adoption. If there is not a requirement for assessing all DoD programs with respect to their implementation of MOSA, only those who expect to get a great score will perform the assessment, and enterprise value will not be achieved.

Performing independent validation is a lesson learned from the limited utility of the results from the OAAT and MOSA PART. However, independent validation requires a cadre of competent MOSA validators. Other maturity models (e.g., CMMI) struggled with qualification of the independent validators and, depending on how the validator was contracted (by the government or by the contractor), maintaining their independence. Inconsistently implemented approaches within the Military Services and across the DoD will limit the ability of achieving a whole-of-Government comparison and identification of enterprise value to improve overall robustness and transparency.

Summary

Measurements of MOSA have existed for a long time and have their share of weaknesses. The OAAT builds on the MOSA PART, but the results of a single measure of technical versus programmatic openness is too coarse to provide effective assessment of adherence to MOSA principles and requirements. The NOA Questionnaire is not detailed enough in assessing critical aspects of a program to capture specific measures that can be addressed to improve outcomes, though it did provide a mechanism that facilitated cross-program and cross-organization comparison. The SEI's Open Systems Architecture Configurability Rating Checklist Tool is informative to acquisition managers looking to make a set of clear business and technical choices, but it should be informed by measures that comport to the current requirements of Congress, the DoD, and the Services.

The next step is to take advantage of the lessons learned from these earlier MOSA-based measurement efforts and propel a new set of decisions based on sound technical and business measures that will also be flexible in addressing the evolving implementation methods. The methods applied to develop complex cyber-physical systems are always in motion, and any measurement strategy needs to account for this motion. The approach we use to account for these constantly changing methods is to keep the measures focused on outcomes.

Codifying an approach for measuring MOSA maturity and providing that as an input to new tools, such as the Open Systems Architecture Configurability Rating Checklist Tool, will support informed decisions at the module, system, and platform levels to improve warfighter outcomes.

Keywords

Software Decomposition, Software Patterns, Integration, Modularity, Containerization, Virtualization, Acquisition, Business Model, Interoperability, System-of-Systems, Cyber-Physical Systems, Real-Time, Safety-Critical, Cyber-Secure, Intellectual Property, Modular Open Systems Approach, Open Systems Architecture, Maintainable, Durable, Self-Healing, Automated Testing, Configuration Management, Payloads, Platforms

Author's Biographical Information

Nickolas H. Guertin, PE. The Honorable Nickolas H. Guertin was sworn in as Director, Operational Test and Evaluation on December, 2021, then later in December 2023 as the Assistant Secretary of the Navy for Research, Development, Test and Evaluation. A Presidential appointee confirmed by the United States Senate, he serves as the Navy and Marine Corps Acquisition Executive, in charge of over $150 billion of product developments, fielding and sustainment for the Naval services.

Mr. Guertin has an extensive four-decade combined military and civilian career in submarine operations, ship construction and maintenance, development and testing of weapons, sensors, combat management products including the improvement of systems engineering, and defense acquisition. Most recently, he has performed applied research for government and academia in software-reliant and cyber-physical systems at Carnegie Mellon University's Software Engineering Institute.

Michael Gagliardi. TBD

Douglas Schmidt. Dr. Douglas C. Schmidt is the Cornelius Vanderbilt Professor of Computer Science at Vanderbilt University. He is also a Visiting Scientist at the Software Engineering Institute (SEI) at Carnegie Mellon University (CMU), where he served as the Deputy Director of Research and Chief Technology Officer from 2010 to 2012. He was recently confirmed as the Director of Operational Test and Evaluation, where he evaluates the effectiveness, suitability, survivability and, when necessary, the lethality of systems produced by the United States Department of Defense.

Dr. Schmidt's research over the past four decades covers a range of software-related topics, including patterns, optimization techniques, and quality assurance of frameworks and model-driven engineering tools that facilitate the development of mission-critical middleware for distributed real-time embedded (DRE) systems and intelligent mobile cloud computing applications running over wireless/wired networks and embedded system interconnects.

Alfred Schenker.
Carnegie Mellon University, Software Engineering Institute
ars@sei.cmu.edu
Mr. Schenker works in the SEI's Software Solutions Division and has worked there for over 20 years. He works to improve software acquisition and product development practices throughout the armed services, and other organizations. He has actively worked in software process, architecture, model-based systems engineering, and metrics. Before joining the SEI, Mr. Schenker spent over 20 years in industry as an active contributor in all phases of product development. Mr. Schenker is also an inventor and has obtained patents for a pressure switch (used in automotive airbag applications), and for a manufacturing process to seal gas inside a vessel.

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