Modular Open Systems Approach (MOSA)
Reference Frameworks in Defense Acquisition Programs

MAY 2020

Deputy Director for Engineering

Office of the Under Secretary of Defense for Research and Engineering,
Director of Defense Research and Engineering for
Advanced Capabilities

Washington, D.C.

Distribution Statement A. Approved for public release. Distribution is unlimited.
DOPSR Case # 20-S-1275.

Modular Open Systems Approach (MOSA) Reference Frameworks in Defense Acquisition Programs

Office of the Under Secretary of Defense
Research and Engineering
3030 Defense Pentagon
Washington, DC 20301-3030

Distribution Statement A. Approved for public release. Distribution is unlimited.
DOPSR Case # 20-S-1275.

Contents

Figures

Tables

Executive Summary

In response to the 2018 National Defense Strategy and 2017 legislation (P.L. 114-328 2017), the Department of Defense (DoD) Office of the Under Secretary of Defense for Research and Engineering (OUSD(R&E)) is working with the defense community to develop guidance for implementing modular open systems approaches (MOSA) in defense acquisition programs. This document, focusing on MOSA reference frameworks, is part of a planned body of work that will support defense programs as they implement MOSA.

Programs have long incorporated MOSA in varying forms, but the body of work is intended to promote effective use of MOSA across the enterprise by providing guidance and examples of best practices. Additional guidance will address integrating new technologies, mitigating component obsolescence, and improving sustainment of the mission capabilities Warfighters need. The body of work will promote a holistic approach to address architecture and standards in MOSA implementation.

The DoD Modular Open Systems Working Group (MOSWG), under the leadership of the OUSD(R&E) Deputy Director for Engineering, is responsible for developing the MOSA body of work. In 2016 the MOSWG conducted a Technical Standards Working Group, which defined a "MOSA framework" as *a collection of modular open systems mechanisms (tactics, patterns, methods) with associated guidance for proper application and consistent implementation of MOSA on systems or programs in a domain.*

In 2018 the MOSWG organized a MOSA Frameworks Tiger Team to further survey MOSA implementation practices in DoD programs. The team developed the concept of a MOSA "reference framework" to apply not just to a single program but to a domain of similar programs or systems across an enterprise.

Section 1 of this document discusses the precedent and motivation for DoD MOSA efforts. Section 2 discusses the MOSA Frameworks Tiger Team's development of the reference framework concept. Section 3 discusses the essential elements of a MOSA reference framework, and Section 4 offers descriptions of two exemplary MOSA reference frameworks. Appendix A includes additional descriptions of reference frameworks the Tiger Team collected during its survey.

This document is intended to guide engineering staff and decision makers in common ways to recognize and use MOSA elements to support the technical performance and sustainment of acquisition systems. The authors note the need to balance the business and technical aspects of a MOSA reference framework.

Acknowledgments

Contributors to this document include representatives of OUSD(R&E), U.S. Air Force (USAF), U.S. Army (USA), U.S. Navy (USN), National Reconnaissance Office (NRO), Defense Acquisition University (DAU), and the Joint Tactical Networking Center (JTNC).

1 Introduction

The Department of Defense (DoD) has employed modular open systems approaches (MOSA) for nearly 20 years, but recent legislation (P.L. 114-328 2017) has formally mandated the use of MOSA to enhance the Department's ability to modify major weapon systems efficiently. Modularization simplifies system design by making complexity manageable, enables programs to conduct parallel development efforts, and accommodates future uncertainty by allowing for incremental changes to a system (Baldwin 2006).

Successful MOSA implementations have proved that proper application of modular approaches and flexible, open-system architectures allow for system components to evolve to respond to changing "technology, threat, or interoperability need" (P.L. 114-328 2017). Accordingly, the Department is moving from unique architectures and closed systems that are inflexible and cost-prohibitive to architectures that include the use of open interface standards with modular systems to facilitate continuous adaption and upgrades (Mattis 2018).

MOSA provides an integrated business and technical strategy for competitive and affordable acquisition and sustainment of a new or legacy system (or a component within a new or legacy system) over the system life cycle. The modular approach uses an architecture that separates the system into major functions and elements, which work together across interfaces in conformance with widely supported, consensus-based standards (Zimmerman et al. 2018).

1.1 Purpose of DoD MOSA Guidance

The Department intends its MOSA guidance to facilitate the adoption, integration, and refresh of defense capabilities through the use of consensus-based standards, appropriate business practices, and articulation of necessary data rights (P.L. 114-328 2017). MOSA should be at the foundation of an acquisition program's design strategy and architecture to address modernization, threat response, mission integration, competition, resource savings, and security.

When implementing MOSA, programs must balance technical methods and business drivers. Technical enablers such as standard interfaces allow architecture elements to evolve separately and to interface with minimal impact to other system elements. MOSA couples the technical design with open business practices such as selection and access to appropriate data, creating opportunities to improve a system's warfighting ability. In addition, programs need to balance MOSA with safety and cybersecurity design characteristics, essential to maintaining a secure, resilient system. The components can be incrementally added, removed, or replaced to provide opportunities for cost savings or cost avoidance, resource reduction, technology refresh, capability change, increased interoperability, increased competition, and easier sustainment of the system.

1.2 Preceding MOSA Efforts

The Department conducted earlier MOSA efforts through the Open Systems Joint Task Force (OSJTF), which was established to provide focus and initial momentum to open system design and use in DoD. At the time the Department defined open systems architecture as *a characteristic of* *a system that uses a technical architecture that adopts open standards supporting a modular, loosely coupled, and highly cohesive system structure that includes the publishing of key interfaces within the system and relevant design disclosure* (DAU Glossary 2020).

The MOSA principles were integrated into DoD systems engineering guidance, and the OSJTF was disestablished in 2004. Since that time, there have been varying applications of MOSA in DoD acquisition programs.

In 2016, at the request of the Defense Standardization Council (DSC), a DoD MOSA Technical Standards Working Group (TSWG) led by the DoD Systems Engineering office examined the role of the Defense Standardization Program (DSP) in supporting MOSA and related standards being employed across the Department.

The TSWG identified the role and criticality of standards in enabling the effective, appropriate adoption of MOSA in the development and sustainment of weapon systems and national security systems. The TSWG identified common barriers and enablers to the effective adoption of MOSA, discovered common standards in use across DoD, and assessed whether new standards should be developed. The TSWG engaged with industry to discover MOSA that was industry driven or co-developed with government initiatives related to defense, and to capture issues related to the development or employment of MOSA from the industry perspective.

The TSWG identified the use of technical frameworks as a helpful reference to Program Managers as they develop modular and open systems. The TSWG suggested defining a MOSA framework specifically for standardization as *"a collection of standards and architectures with implementation guidance and conformance verification criteria for a specific array of functions within the standard"* (DoD MOSA TSWG 2016).

1.3 Modular Open Systems Working Group

The DoD Modular Open Systems Working Group (MOSWG), under the leadership of the OUSD(R&E) Deputy Director for Engineering, is currently responsible for leading DoD MOSA guidance efforts. The MOSWG is developing implementation guidance that supports MOSA across the participating Services and Agencies.

In 2018, the MOSWG initiated a MOSA Frameworks Tiger Team to survey the use of MOSA in DoD acquisition programs. The team met from April 4 to October 31, 2018, including representatives of the Military Services and DoD Agencies, to address a DSC suggestion to "develop and maintain a list of recommended MOSA frameworks, supported with guidance on the development and maintenance of additional frameworks" (DoD MOSA TSWG 2016). The team examined MOSA frameworks and best practices in use, and it developed the core elements of a MOSA "reference framework" to facilitate MOSA implementation on programs. The team drew on known efforts such as the Navy Future Airborne Capability Environment (FACE™), Air Force Open Mission Systems/Universal Command and Control Interface (OMS/UCI), and the Army's Vehicle Integration for C4ISR/EW Interoperability (VICTORY).

2 MOSA Framework Development

2.1 MOSA Framework

DoD has used the term "framework" to identify proposed MOSA solutions that satisfy similar technical requirements and common elements across related applications within a domain (DiMario, Cloutier and Verma 2008; Fuchs and Golenhofen 2019). The MOSWG currently considers a framework as applicable to a single program but is developing a concept of "reference framework" to refer to a framework that applies across multiple applications or programs. This section discusses existing concepts, sources, and working definitions relating to MOSA architecture, framework, and reference framework.

A MOSA framework includes (1) architecture, (2) standards, (3) implementation, and (4) conformance, as well as the use of (5) data models and (6) additional tools (Figure 2-1).

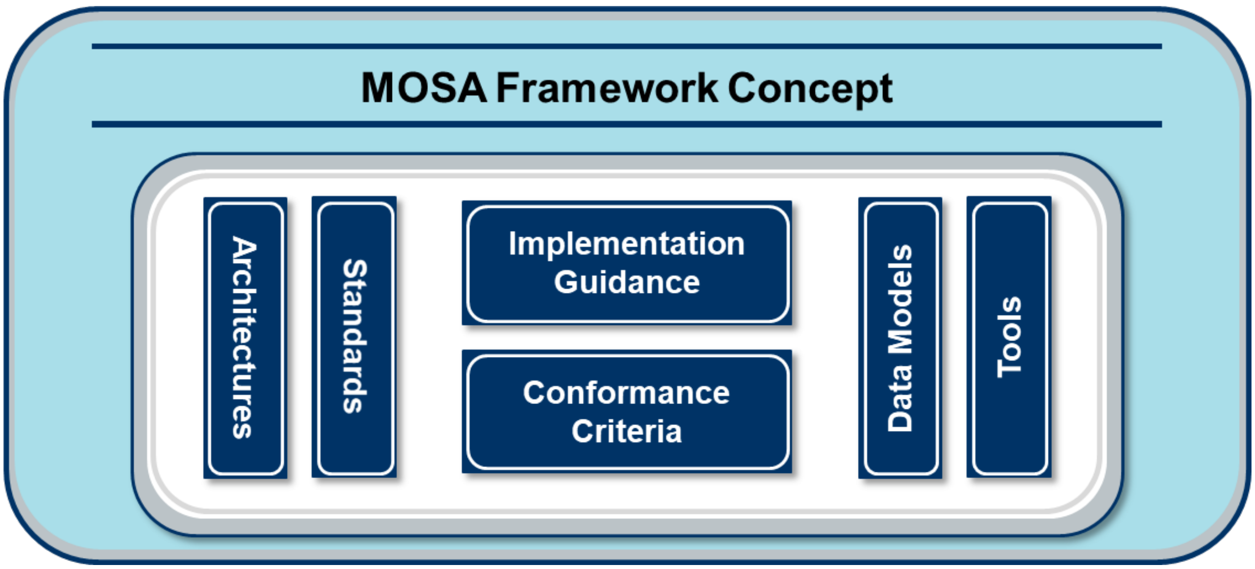

Figure 2-1. General MOSA Framework Concept

The MOSWG Tiger Team identified MOSA frameworks currently in use throughout DoD. The team examined the business and technical enablers defense acquisition programs employed when implementing a MOSA framework; captured best practices that assist programs in reducing the cost and time of integrating new and existing capabilities throughout the acquisition life cycle; and identified relevant terminology, policy, and guidance for architecture and standards (Table 2-1).

Table 2-1. Architecture Definitions

Term	Definition / Proposed Definition	Source	Coordinated / Pending
Architecture	(System) fundamental concepts or properties of a system in its environment embodied in its elements, relationships, and in the principles of its design and evolution The arrangement of elements and subsystems and the allocation of functions to them to meet system requirements	ISO/IEC/IEEE 42010:2011 Systems and Software Engineering Architecture Description INCOSE Systems Engineering (SE) Handbook 2006	Coordinated
Architecture Description (AD)	Work product used to express an architecture.	ISO/IEC 42010:2011	Coordinated
Architecture Framework	Conventions, principles, and practices for the description of architectures established within a specific domain of application and/or community of stakeholders.	ISO/IEC/IEEE 42010:2011	Coordinated
Architecture View	Work product expressing the architecture of a system from the perspective of specific system concerns.	ISO/IEC 42010:2011	Coordinated
Architecture Viewpoint	Work product establishing the conventions for the construction, interpretation, and use of architecture views to frame specific system concerns.	ISO/IEC 42010:2011	Coordinated
DoD Architecture Framework (DoDAF)	The overarching, comprehensive framework and conceptual model enabling the development of architectures to facilitate the ability of Department of Defense (DoD) managers at all levels to make key decisions more effectively through organized information sharing across the DoD, Joint Capability Areas (JCAs), Mission, Component, and program boundaries. The DoDAF serves as one of the principal pillars supporting the DoD Chief Information Officer (CIO) in his responsibilities for development and maintenance of architectures required under the Clinger-Cohen Act [1996]. It also provides extensive guidance on the development of architectures supporting the adoption and execution of Net-centric services within the Department.	Defense Acquisition University (DAU) Glossary 2020	Coordinated

Term	Definition / Proposed Definition	Source	Coordinated / Pending
Framework	[Overarching term encompassing technical and business architecture, models, and guidance]	Multiple	Pending Coordination
MOSA Reference Framework	A collection of modular open systems mechanisms (tactics, patterns, methods) with associated guidance for proper application and consistent implementation of MOSA on systems or programs in a domain.	DoD MOSA TSWG 2016	Coordinated
Reference Architecture (RA)	An authoritative source of information about a specific subject area that guides and constrains the instantiations of multiple architectures and solutions.	DoD Chief Information Officer (CIO) 2012	Coordinated
Reference Framework (RF)	[Overarching framework to] • Identify those things that need to be common • Create consistency where needed • Indicate where individual projects can diverge from the RF where appropriate • Provide a structured approach to managing standards, policies, patterns in order to deliver on objectives	Wilkes 2012	Pending Coordination
Reference Model	An abstract framework or domain-specific ontology consisting of an interlinked set of clearly defined concepts produced by an expert or body of experts in order to encourage clear communication.	SOA-RM Technical Committee 2006	Coordinated
Technical Reference Framework (TRF) (U.S. Navy)	A framework incorporating (1) architectures, (2) standardized specifications and protocols, (3) data models, and (4) tools that enable programs to: • Provide reusable architecture for a family of applications. • Deliver an integrated set of profiles for the development of components. o Technical profiles are a set of (implementation-agnostic) attribute profiles that allow components to operate within the context of systems and platforms. • Promote a product line of “best of breed” capabilities to the Warfighter.	Guertin et al.	Pending Coordination

The Navy's historical concept of MOSA Technical Reference Frameworks (TRFs) used (1) architectures, (2) standardized specifications and protocols, (3) data models, and (4) tools that enabled programs to:

- Provide reusable architecture for a family of applications
- Deliver an integrated set of profiles for the development of components
    - *Note:* The technical profiles are a set of (implementation-agnostic) attribute profiles that allow components to operate within the context of systems and platforms
- Promote a product line of "best of breed" capabilities to the Warfighter

The Navy successfully implemented MOSA using TRFs in defense acquisitions such as the Program Executive Office (PEO) Submarines (SUB)–Submarine Warfare Federated Tactical System (SWFTS) Command, Control, Communications, Computers and Intelligence (C4I) Consolidated Afloat Networks and Enterprise Services (CANES) program and the PEO Integrated Warfare Systems (IWS) Open Systems Product Line Architectures approach (Guertin 2015).

2.2 Technical Reference Architectures

The Tiger Team observed that the Military Services apply elements of (1) reference frameworks, (2) reference architectures, and (3) reference models for platforms and systems across specific domains and organizations.

Wilkes (2012) described the concept of a reference framework as "an authoritative guide for building of something that expands the structure into something useful. The framework often contains a model, process, architecture, and organizational governance." Practitioners may include aspects of a reference architecture (blueprint) and reference model (domain-specific ontology) when developing a reference framework. Thus a MOSA reference framework can assist in guiding the development, management, and deployment of modular and open systems (Figure 2-2).

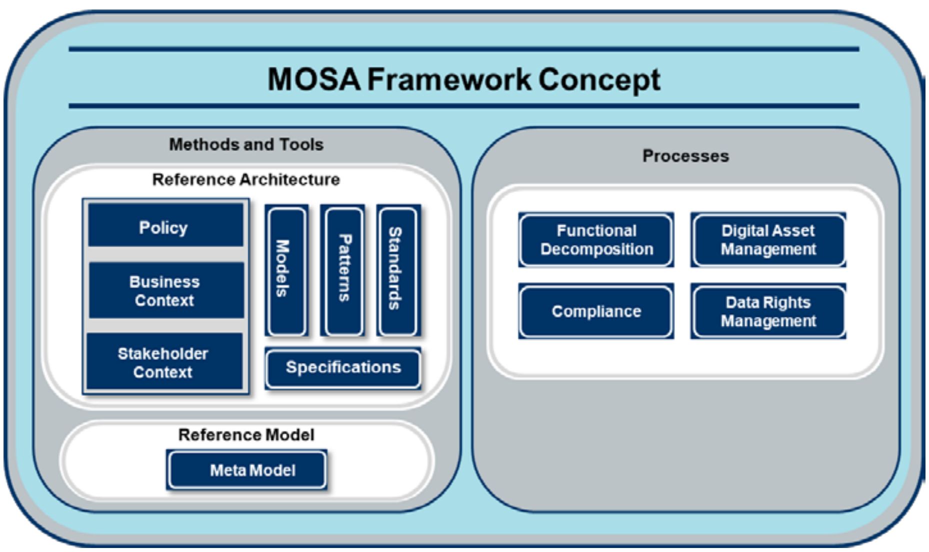

Figure 2-2. MOSA Reference Framework Methods, Processes, and Tools

As illustrated in Figure 2-2, a MOSA reference framework provides a structured approach to manage standards, policies, and patterns that achieve business and technical objectives. A reference model provides concepts, principles, and common terms. A meta model defines the rules for building the reference model; for example, a meta model would define deliverables or the subject of a policy (Wilkes 2012). Architectural frameworks provide users with guidance and rules "for structuring and organizing architectures" (DoD CIO 2010). For instance, the DoD Architecture Framework (DoDAF) Version 2.02 provides more than 52 models, a meta model, and a standard framework for developing architectural views and capturing and presenting architectural data to support DoD stakeholders (DoD CIO 2010).

2.3 Business and Stakeholder Context

Organizational roles and responsibilities across the domains may not be codified or well understood; therefore, organizations may neglect the impact of their product or system in relation to evolving changes in the wider enterprise. The practice of examining and codifying the impacts of business objectives as well as technical considerations can be captured in enterprise architectures (Pereira and Sousa 2004) (Figure 2-3).

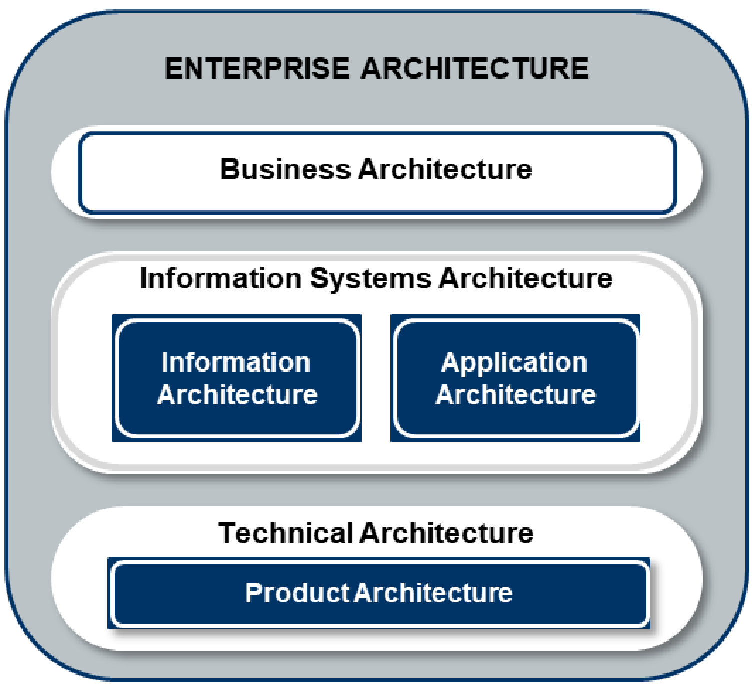

Figure 2-3. Relationships among Architectures in an Enterprise Architecture

To successfully implement MOSA, acquisition professionals must be able to understand clearly the respective acquisition processes, cultural behaviors, and desired outcomes across multiple domains. The MOSA reference framework begins to consider both business and stakeholder concerns as well the technical design (Cloutier et al. 2010) (Figure 2-4).

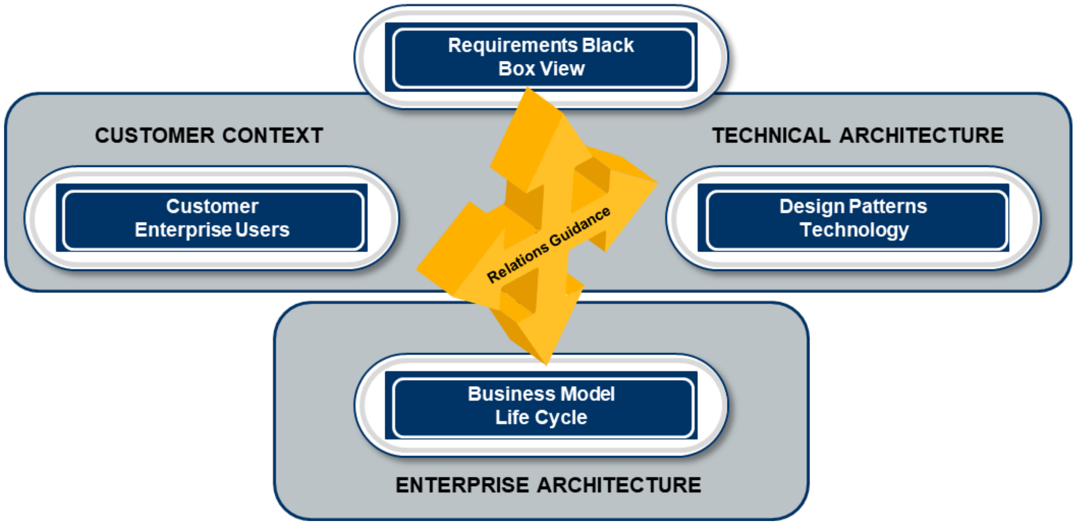

Figure 2-4. Relationships among Business Objectives and Technical Design Considerations

Acquisition programs using MOSA as a foundational practice have achieved a degree of modernization (e.g., technology refresh, inclusion of innovative technology); cost savings (e.g., cost avoidance, savings realized from increased competition); and interoperability. If programs are organized to incorporate MOSA, then MOSA reference frameworks can enable DoD engineering and business communities to structure technology investments, upgrades, and innovation opportunities for insertion into programs during design and at regular refresh cycles.

To ensure programs include MOSA considerations, adequate incentives must exist for both the government program offices managing the effort and the contractors involved. For the government program offices, the requirement and programming must be in place. The applicable standards, along with appropriate training and compliance documentation and test cases, should be readily available. For contractors, the government program office must articulate required data rights and intellectual property information early. The government must clearly document in the contract which standards or architecture considerations contractors should follow, and the contract should include appropriate incentives and disincentives (fees, withholding item acceptance, etc.).

2.4 Modular Architectures: Form Follows Function

In the modular approach of "designing a modular architecture," the architecture (form) is used to describe modularization (the function of modularity) (Alberto and Tollenaere 2005). The concept of a modular architecture adheres to the systems engineering principle of form following function, as the primary function is modularization and the architecture is the form used to represent the modular design. The modular architecture is the *product* that depicts (1) functional decomposition of functions into modules, (2) de-coupled interfaces between modules, and (3) interface specifications and standards that define the primary interactions across/between modules (Ulrich 1995). The architecture serves as a blueprint for developing and maintaining a product or system, or a product line or family of systems, across its life cycle.

Creating a modular architecture requires *functional decomposition* (Figure 2-3) as a systems engineering practice across the System Development Life Cycle (SDLC) to enable the planning of flexible modularization and control of interfaces. The practice of functional allocation enables functional modules to serve as building blocks in a system. In addition, minimizing the dependencies between modules by de-coupling interfaces enables loose coupling. Finally, the practice of specifying well-defined interfaces that use consensus-based standards results in standardized interfaces. The functional decomposition process is paramount in implementing a modular approach to system development. De-coupling helps eliminate unnecessary interfaces, which then makes it easier to identify the interfaces that are good candidates for standardization.

2.4.1 Modularity, Interfaces, Specifications, and Standards

Modularization provides the opportunity to mix and match components in a product design in which the standard interfaces between components can be verified as compliant with law and are specified to allow a range of variation in components to be substituted in a product's architecture. Researchers Sako and Murray (1999) described modularity as "a bundle of characteristics that define, first, interfaces between elements of the whole, second, a function-to-function component (or task-to-organization unit) mapping that defines what those elements are, and, third, hierarchies of decomposition of the whole functions, components, and tasks" (Table 2-2).

Table 2-2. Definitions of Modular Terms

Term	Published Definitions	Source
Modular architecture	A system architecture in which the system has been partitioned into architectural components that exhibit good abstraction, have high internal cohesion, have low coupling to other components and external systems, and encapsulate their internal implementation behind visible interfaces.	Firesmith and Donohoe 2015
Modular system	A modular system is made of independent units which can be easily assembled and which behave in a certain way in a whole system.	Baldwin and Clark 1997
Modularity	Modularity is a very general set of principles for managing complexity. By breaking up a complex system into discrete pieces, which can then communicate with one another only through standardized interfaces within a standardized architecture, what would otherwise be an unmanageable spaghetti tangle of systematic interconnections can be eliminated.	Lanlois 2002
Module	A complex group that allocates a function to the product and which could be changed and replaced in a loose way and be produced independently.	Wilhelm 1997
Product architecture	The scheme by which the function of the product is allocated to physical components, i.e., the arrangement of functional elements, the mapping from functional elements to physical components, and the specification of the interfaces among interaction physical components.	Sako and Murray 1999

2.4.2 Steps for Implementing a Modular Approach

Modular building blocks can be structured and arranged in an architecture by adhering to the following steps:

- **Step 1: Modularize** by decomposing system capabilities into functional modules. Below are some characteristics of modules to consider:
    - Single Abstraction – module represents the key aspects of a single capability or concept.
    - High Cohesion – module contains all parts necessary to implement its abstraction (sufficiency) and only parts related to its abstraction (necessity).
    - Low Coupling – module minimizes (or optimizes) the number, scope, and complexity of interfaces required.
    - Encapsulation – module boundaries hide implementation details behind specified visible interfaces and these interfaces are the only way to interact with internal module functions.
    - *Note:* Modules may also be "components."
- **Step 2: Specify (or Configure Interfaces)** by identifying connections between system building blocks.
    - Interfaces "connect" modular components within the architecture. In addition, there are multiple ways in which functional modules can be organized. Some configuration may be optimal, some not, and the modularity of the functional interfaces will impact the overall modularity.
- **Step 3: Define Interface Specifications** by capturing how functional modules interact.
    - Interface specifications define "how" functional modules behave.
    - Interface specifications should address both syntactic and semantic considerations for data flowing through the interface.
- **Step 4: Standardize Interface Specifications** to allow for opportunities of future modernization.
    - Standardization of interface specifications enables technology developers to access, manage, and build to well-defined interfaces, thus allowing interoperability across new solutions (i.e., designs must "conform" to interface specifications).
    - Well-defined interface specifications will significantly reduce the effort required for integration of modules from disparate sources.
    - For standardized interfaces, programs should have a method for verifying compliance with the standard.

3 MOSA Reference Framework

A MOSA reference framework identifies, defines, and documents the recommended elements for facilitating the implementation of MOSA consistently among similar programs. Although using MOSA successfully includes relying on standards, specifying a particular standard is not sufficient to ensure a MOSA implementation will be successful. Standards, along with architectures, must be implemented properly to be effective.

A sample MOSA reference framework providing architecture and standards guidance for Services and Agencies across the Department will be stored in the newly formed Modular and Open Systems Standards and Specifications (MOSS) Lead Standardization Area located in ASSIST, the web-enabled database for standardization documents available to DoD. OUSD(R&E) initiated the ASSIST MOSS Standardization Area in August 2018 to cover "specifications and standards that support MOSA in defense systems" (DSP 2019). The MOSS also includes "specifications used to define system interfaces and system architectures that allow severable components; and standard formats for data exchanges, physical (electrical, mechanical, etc.) and practices for implementing MOSA frameworks and architectures, as well as compliance testing for implementations of standards in support to the MOSA practice" (DSP 2019).

3.1 Application of MOSA in a Framework

Programs should consider MOSA during architecture development; MOSA cannot be only the result of design or implementation. In addition, programs should gather lessons learned from design, implementation, and integration to improve the architecture.

DoD is developing further guidance regarding how to implement MOSA in a strategic manner to ensure business and technical drivers are achievable, which may vary by organization; however, the following principles are common among organizations:

- There must be (1) modularity of functionality, (2) modularity of hardware components (including computing hardware), and (3) modularity of software components.
- Open interfaces are required at the boundaries of each module, including (1) open software interfaces (including syntactic and semantic data constraints), (2) open hardware interfaces, and (3) well-defined functions to accompany open interfaces. These shared boundaries may be
    - Between a major system platform and a major system component;
    - Between major system components; or

      Between major system platforms that are: (1) defined by various physical, logical, and functional characteristics, such as electrical, mechanical, fluidic, optical, radio frequency, data, networking, or software elements; and (2) characterized clearly in terms of form, function, and the content that flows across the interface in order to enable technological innovation, incremental improvements, integration, and interoperability.

3.1.1 Technical Architecture

Every program, system, and process has a technical architecture, but it may be documented in varying ways. To successfully implement MOSA, the technical architecture is a component of the design that should consider external interface definition, support growing scale and functionality, and accommodate technology insertion opportunities. The technical approach for implementing MOSA should capture not only architectures but also the architectural patterns used to implement MOSA when addressing hardware, software, data, and functional areas of concern.

Architecture and design documents should capture the diverse or dissimilar mix of other systems (hardware, software, and human) with which the system needs to exchange information. Implementing MOSA requires (1) the right documentation and (2) the right data. As such, MOSA supports the creation of modular, layered architectures, and MOSA should be used at major system interfaces. Describing and documenting the physical, logical, and functional characteristics of these architectures is imperative. Finally, data management strategies should define data models, descriptions, and plans for data/asset management.

3.1.2 Business and Stakeholder Considerations

As part of the MOSA reference framework, each program must develop not only the technical guidance but also MOSA business guidance, including data and asset management, compliance guidance, and contracting guidance (Figure 3-1).

Technical CONSIDERATIONS

- Technical Reference Framework
  - ❑ Reference architecture and technology configuration to include system layout and structure
  - ❑ Depicts the modular components that define common architectures for families of related warfighting systems
  - ❑ Data and application architecture
- Technical Standard
  - ❑ Standardization and specs that can be used individually or combined within an architecture
- Physical Architecture Model
  - ❑ Describes system elements, physical and logical interfaces
    - HW elements (electrical, mechanical, etc.) and cabling
    - System and SW logical interfaces
    - Space, Weight and Power (SWAP)
- Data Management
  - ❑ Data Interfaces, Asset Management
  - ❑ Data Rights/Intellectual Property

Business CONSIDERATIONS

- Contracting Guidance
  - ❑ RFP language and contract considerations for data rights
  - ❑ Acquisition & Open Systems Management Considerations
  - ❑ Evaluation criteria
- Business & Stakeholder Guidance
  - ❑ Business Context
    - ❑ Reuse strategies and commonality approaches
      - ❑ Acquisition Strategies and Management of core assets
    - ❑ Relevant Policies and Regulations
    - ❑ Architecture Governance
  - ❑ Stakeholder Considerations
    - People, processes, and organizational use
- Compliance Guidance
  - ❑ Criteria, process, and tools

Figure 3-1. MOSA Reference Framework Considerations

Following are examples of information programs should include in the MOSA business guidance:

- Guidance for achieving MOSA-related benefits, to include: enhanced competition and innovation, significant cost savings or avoidance, schedule reduction, opportunities for technical upgrades, increased interoperability, including system of systems interoperability and mission integration, and other benefits during the sustainment phase of a major weapon system
- Strategy for acquiring system components and platforms that can be separated, competed, and independently evolved throughout the life cycle
- Technical data rights for (major) system interfaces:
  - Outline the strategy for acquiring system components and platforms that can be separated, competed, and independently evolved throughout the life cycle
  - Address technical data rights for (major) system interfaces
  - Include data rights strategies that are defined to address specific data rights, for example: need for components, interfaces, and data rights options
- Contracting guidance and evaluation factors:
  - May include tying incentive fees or item acceptance to verified MOSA enabling standard conformance, linking a sustainment logistics support option to delivery of sufficient technical data rights, etc.

Other areas to consider include:

- Reuse strategy and commonality approaches
  - Relate to core asset management plan
  - Include acquisition strategies and approaches
- Policies and regulations
- Collaborative international marketplace
- Governance of architecture
- Organizational approach – charters and roles for various portions of the organization

3.2 Standardization and Conformance Guidance

Appropriate selection and application of standards at modular interfaces can contribute to healthy competition among suppliers throughout the acquisition life cycle. Many standards are available for the government programs to choose. Accessing and selecting appropriate standards can be challenging as most were originally developed to solve a specific problem set. Therefore, Program Managers should be careful to use the appropriate standards within contracts, tailored as appropriate for each system.

System designs implementing MOSA, with sufficient standardization at interfaces, allow greater flexibility and agility to reconfigure components to address evolving threats and emerging technology. Contract developers of DoD systems require appropriate business knowledge regarding intended use, stakeholder context, data rights, and intellectual property to select the best standards. Standards implemented at interfaces may contain options and default settings for which multiple combinations are possible, but once selected may not interoperate with other implementations of the same standard. In addition, standards may serve as methods or processes for meeting a business or technical objective, and some process standards may influence the architecture process and support business implementation.

Multiple options, as well as inconsistent availability of information to verify standard implementation, can lead to interoperability problems. Therefore, standards guidance should provide details on implementation and conformance, including which organizations provide verification. Programs should provide a test plan, procedures, and verification methods across the life cycle to ensure compliance.

4 Example MOSA Reference Frameworks

The 2018 DoD MOSA Frameworks Tiger Team conducted a study to identify efforts in DoD that are already implementing a full MOSA framework. The team reviewed many MOSA implementations and selected two that best illustrated the DoD reference framework proposed in this paper: (1) U.S. Army Modular Active Protection Systems (MAPS) and (2) Defense Intelligence Information Enterprise (DI2E) Framework. Both efforts incorporate implementation and conformance guidance as well as plans and procedures for ensuring compliance. The Appendix includes additional examples of MOSA efforts the team considered.

4.1 U.S. Army Modular Active Protection System

The U.S. Army MAPS (Figure 4-1) enables safe, secure, layered protection for modifying vehicle protection needs across ground vehicle platforms with the government-owned MAPS Base Kit. The program leverages a stable software code base in MAPS Controller for use with many different sensors and effectors.

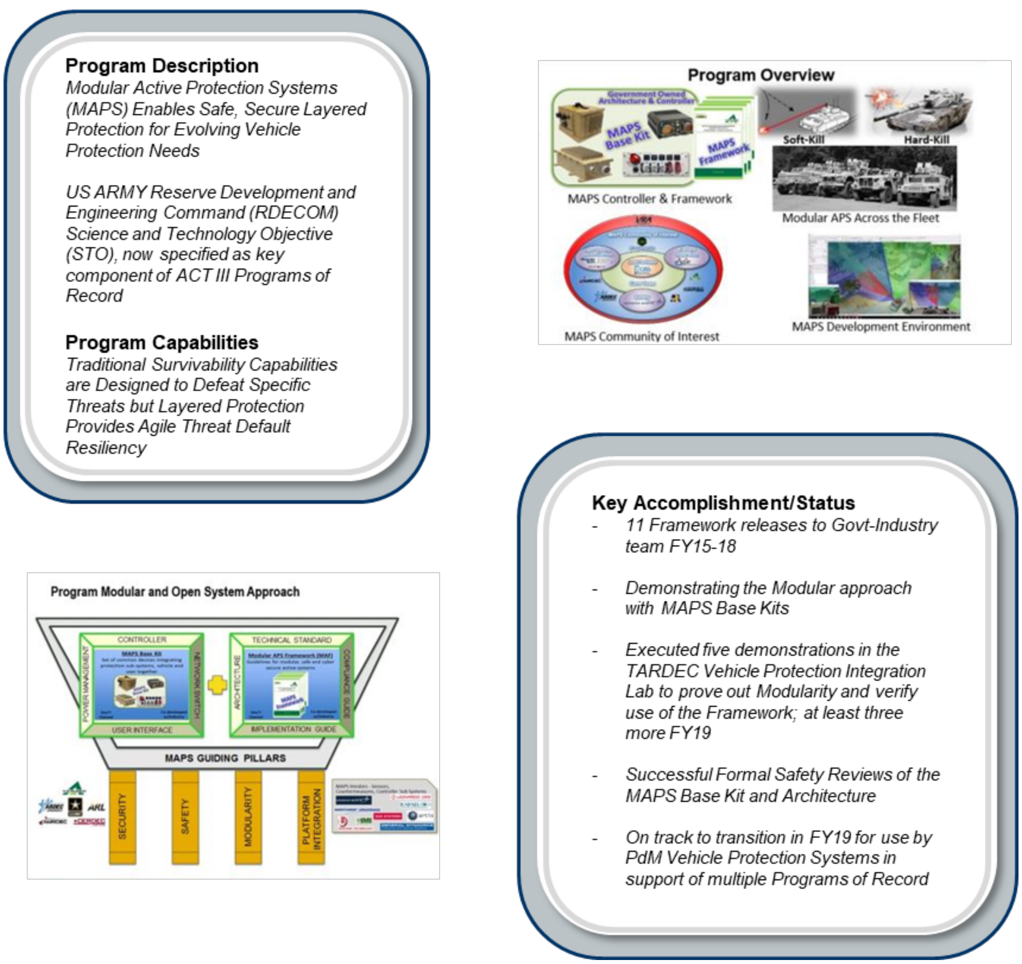

Figure 4-1. Modular Active Protection System (MAPS)

MAPS enables reuse and commonality of ruggedized base kit components by multiple ground vehicle platforms. The MAPS MOSA framework permits ease of understanding new or updated requirements and interfaces for those compliant to an earlier level of architecture, due to ongoing architecture and baseline release process. MAPS supports reduced time for new sensor and effector pairing. It uses a modular design and open system architecture approach that:

- Addresses Active Protection System development aspects previously overlooked
- Gains more insight than past efforts, which were performance-focused demonstrations
- Defines modular, interoperable, scalable, and reconfigurable standards
- Permits configuration and integration to any target platform
- Parses functionality into modules that can be replaced to adapt to changing threats
- Permits DoD to maintain system design ownership
- Avoids proprietary, "blackbox," unique design solutions
- Facilitates a more orderly upgrade process

MAPS' implementation of MOSA (Figure 4-2) provides:

- Comprehensive functional decomposition at core of architecture
    - SysML model; logical architecture, interconnect diagrams, interface types and requirements, sequence and activity diagrams
- Ability to derive multiple system design solutions constrained by safety and cybersecurity needs
- Capacity to work with varying performance levels, variable threats, or multiple ground vehicles
- Framework – Reference Implementation Guide (RIG): describes how to leverage the architecture to derive a modular APS design, applicable for
    - Existing active protection systems and subsystems
    - Yet to be developed subsystems
- Ability to grow a library of design models for compliant subsystems
- Framework – Data Modeling:
    - Includes core data model and describes signals that define the interfaces between the reference architecture's functions
    - Functions are sequenced to describe APS behaviors
- Framework – Reference Architecture Interface Control Document, Compliance Guide, and Technical Standard:
    - Identifies compliance requirements for signals and interfaces

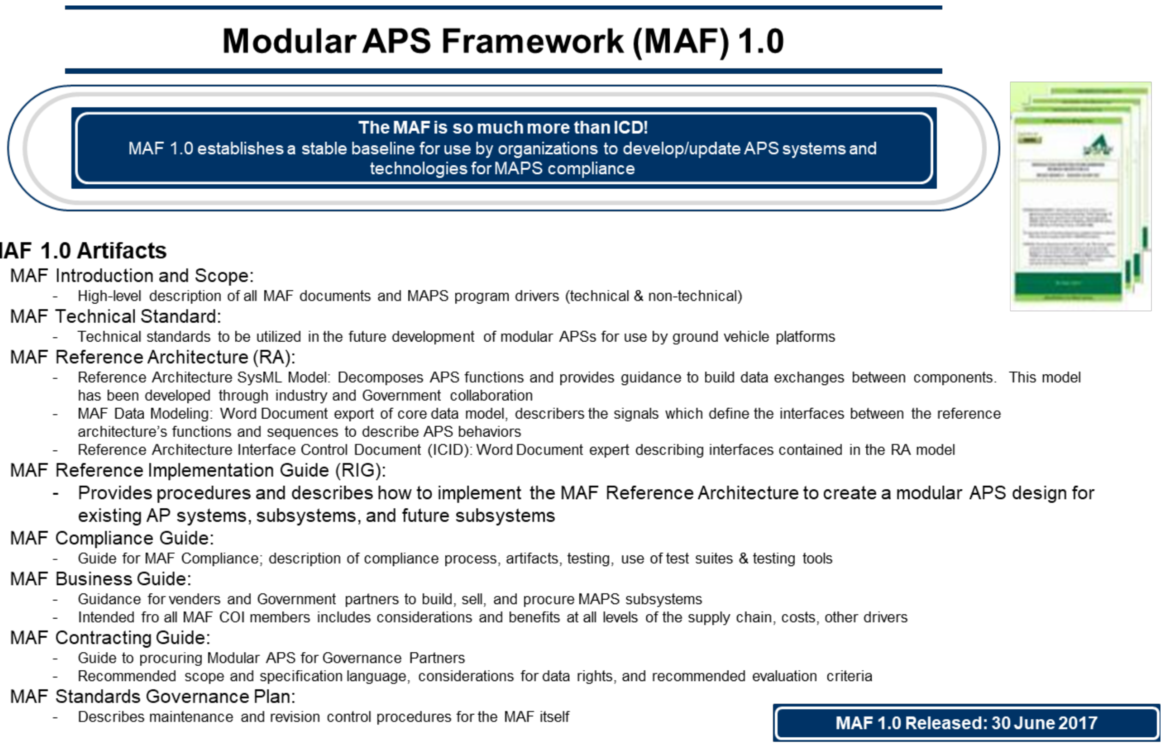

Figure 4-2. MAPS Framework Artifacts

4.2 Defense Intelligence Information Enterprise (DI2E) Framework

The DI2E framework (Figure 4-3) lays the foundation for embracing and implementing software, services, and capabilities reuse across DoD and the Intelligence Community to achieve effective and efficient global intelligence, surveillance, and reconnaissance (ISR) pairing.

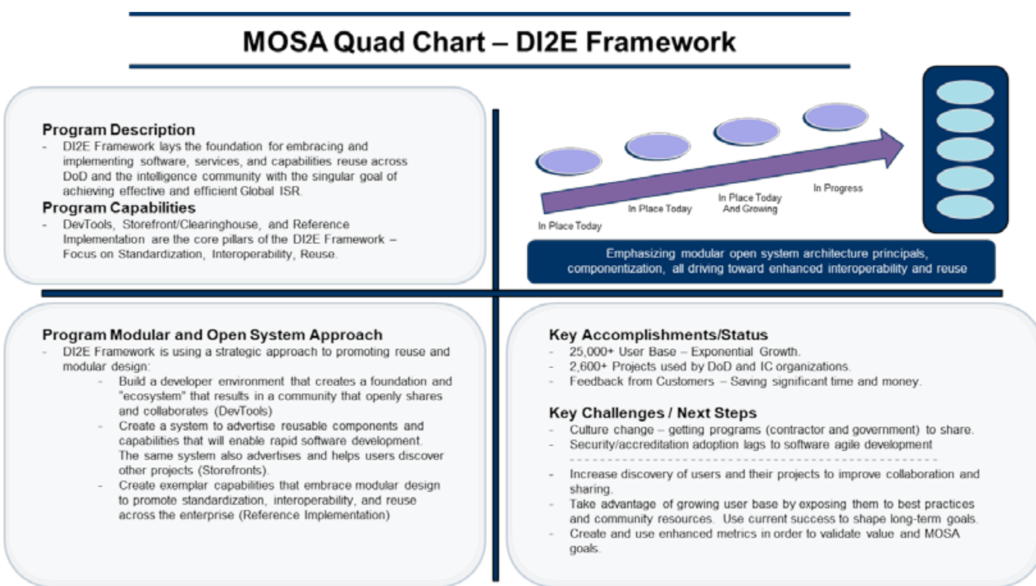

Figure 4-3. Defense Intelligence Information Enterprise (DI2E) Framework

The DI2E Framework provides a software development environment; however, there are some internal development efforts including the following:

- DevTools (developer environment; enables MOSA)
- Reference Implementation (RI) (Some internal development)
- Storefront (internally built system; follows MOSA tenets)
- Clearinghouse (significant focus on MOSA through evaluation process)

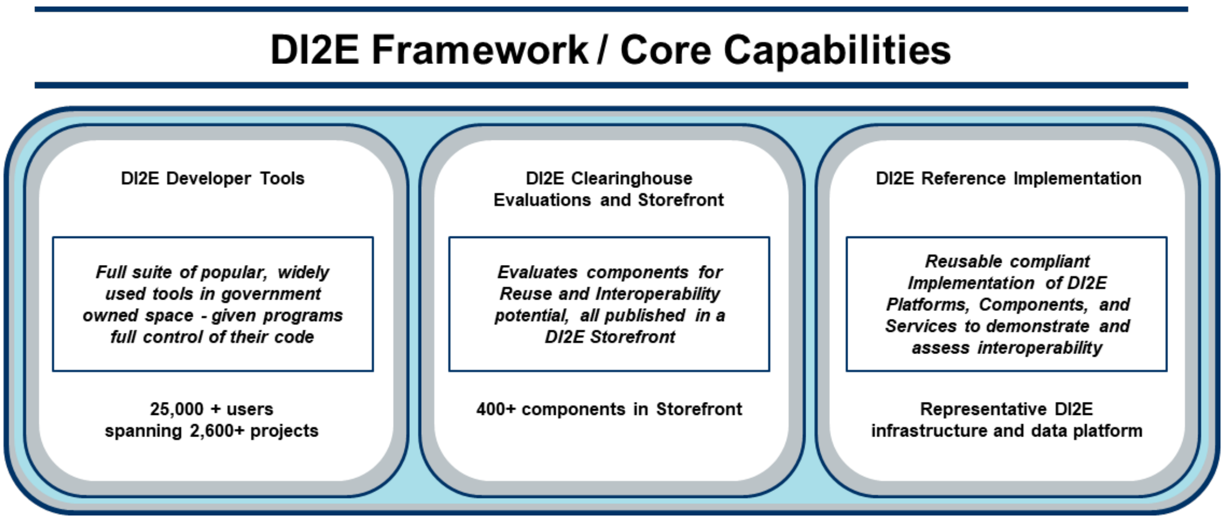

Figure 4-4. DI2E Capabilities

Although the DI2E framework (Figure 4-4) is mostly a developer environment, MOSA tenets and principles are reflected in the tools and resources provided to the community. In areas in which DI2E framework develops software/capabilities, MOSA tenets and principles are implemented. DI2E framework has been successful in enabling MOSA to occur; however, it is difficult to accurately validate that the community is fully embracing MOSA tenets. The DI2E framework is designed to increase reuse due to its large user base and widely used developer environment across the Intelligence Community and DoD.

Appendix A: Survey of MOSA Implementations across DoD

Air Force Open Architecture Distributed Common Ground System (OA DCGS)

The Air Force OA DCGS (Figure A-1) asserts it has been transformed through MOSA. The program used MOSA principles to renew internal processes, embracing agile software constructs. MOSA and agility go together as the best agile teams use open interfaces, operate with service contracts, and leverage already existing modular code. Through MOSA and agile principles, OA DCGS seeks to achieve a vision of delivering capability at the "speed of relevance" (Mattis 2018).

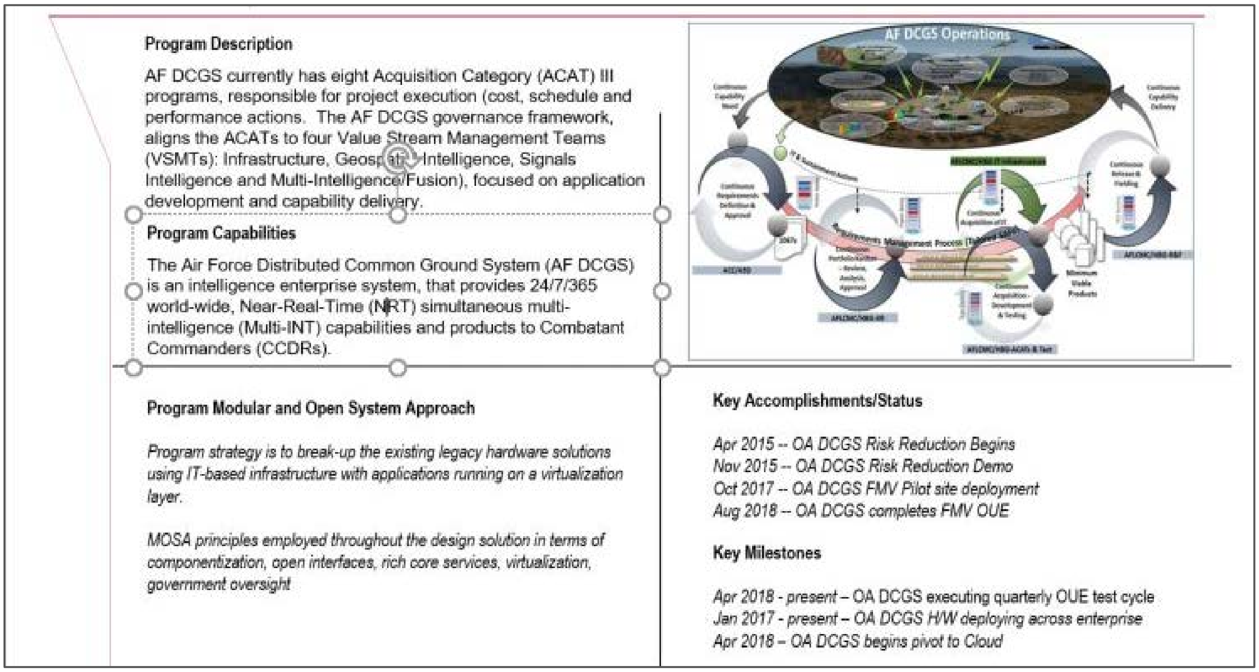

Figure A-1. Air Force Open Architecture Distributed Common Ground System (OA DCGS)

OA DCGS seeks to deliver a robust and cyber-secure enterprise, using commercial and Intelligence Community standards and best practices. The program addressed the following in implementing OA DCGS:

- Accelerate the transition to an open architecture.
- Achieve cybersecurity for the DCGS enterprise.
- Modernize, sustain, test, and field capabilities
- Implement SAFe, agile, and ITIL (Information Technology Infrastructure Library) principles, practices and framework to deliver ISR capabilities

The AF DCGS weapon system is implementing OA DCGS to:

- Transition from prototype to fielded capability faster
- Seamlessly integrate development and operational testing

- Leverage and quickly integrate best-of-breed Intelligence Community and industry practices
- Integrate test and evaluation (T&E) practices, hold a shorter cycle
- Implement Intelligence Community, DoD, and commercial standards
- Manage data and data sources
- Own the Technical Baseline (OTB)
- Mitigate cybersecurity vulnerabilities
- Implement rigorous cybersecurity testing
- Integrate system designs that are open versus closed
- Deliver software releases, patches and enhancements on cadence

The OA DCGS team has been forward leaning; migrating to the cloud, as in C2S or SC2S, will be straightforward. As code is refactored the program is requiring task orders “12 factor app” compliant software, which makes the deliverable cloud compliant. OA DCGS is making the OA DCGS of the future a totally composable system that can be built through automation, thereby allowing the program to integrate changes in minutes rather than months or years.

RAS-G IOP (Figure A-2) implementations of MOSA use IOP versions designed with industry to develop standardized interfaces and supporting documentation to perform specific operational functions. In addition, IOP provides government Program Managers (and others) with a master library of standardized interfaces, tools, and supporting documentation for use in defining an “instantiation” for a given unmanned ground vehicle (UGV), class of UGVs, or program.

The vendor builds subsystem design to “instantiations” (Figure A-3) to provide an Engineering Change Proposal if a design is more optimal to meet system requirements. The vendor system/subsystem’s IOP solution is then validated to conformance to “instantiation,” ensuring interoperability.

Robotic Autonomous Systems Ground Interoperability Profile (RAS-G IOP)

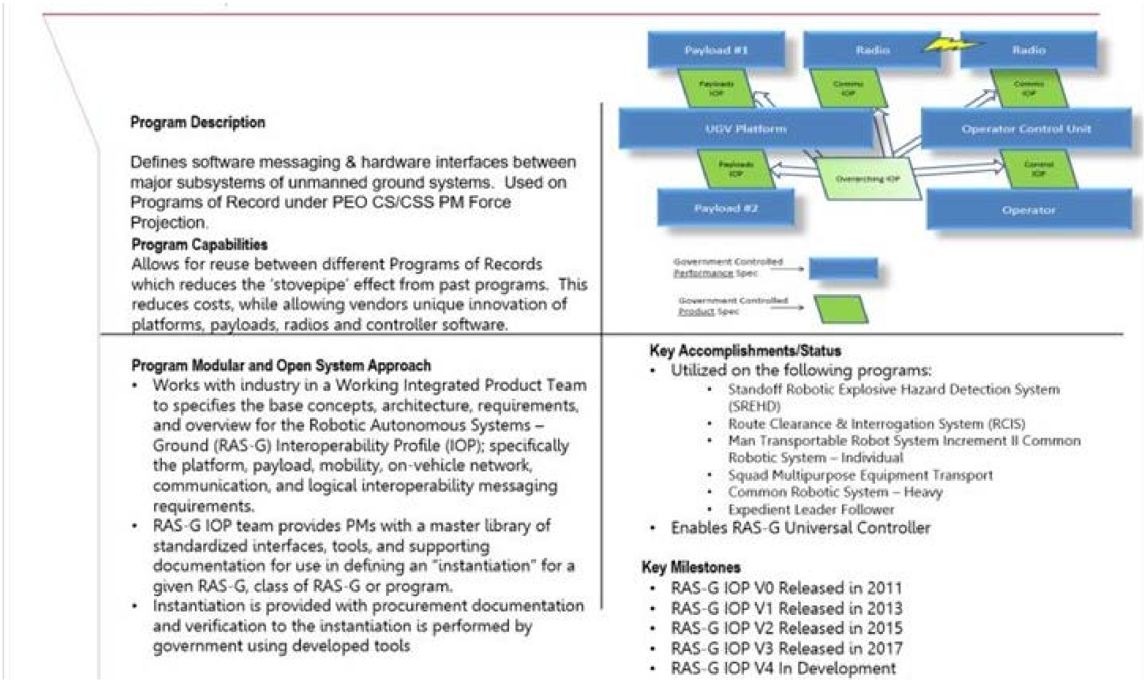

Figure A-2. RAS-G Interoperability Profile Quad Chart

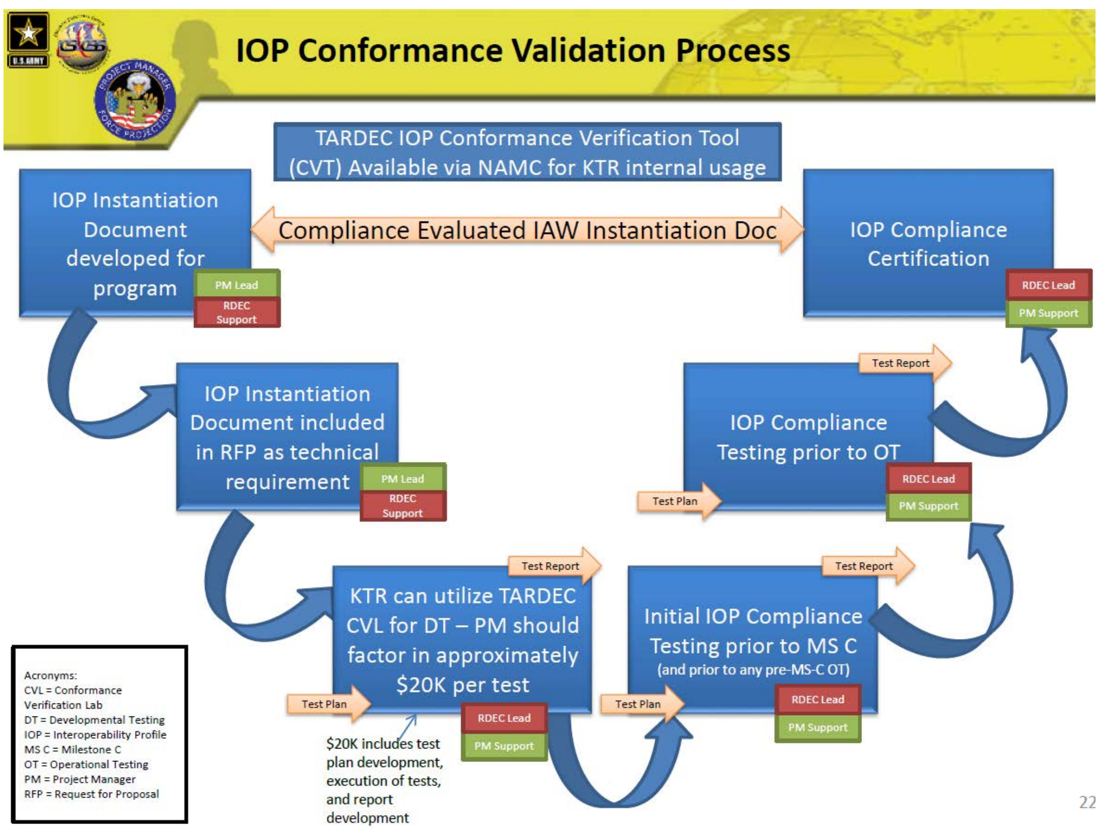

Figure A-3. Interoperability Profile Conformance

For the RAS-G IOP, MOSA provides the following benefits:

- Allows for use of a universal robotic controller
- Allows for faster, easier, and less expensive replacements or upgrades to a program
- Allows for use of a common radio solution
- Allows for the capability to exchange payloads between systems
- Allows for the ability to place existing chemical, biological, radiological, nuclear, and explosive (CBRNE) sensors on RAS-G and control and monitor from the Universal Control Unit
- Allows for common interfaces with the Navy Advanced Explosive Ordnance Disposal Robotic System (AEODRS)
- Allows common autonomy kits to be used with vehicle-specific drive-by-wire kits
- Reduces dependence on operators for manned-unmanned teaming
- NATO benefits through a Standardization Agreement (STANAG)

TAS-G IOP uses legacy standards to save time and money while improving interoperability by removing ambiguity in implementation. Vendors are able to interface IOP-compliant subsystems (Figure A-4) rapidly to provide enhanced capabilities. Vendors can replace obsolete subsystems with little to no changes to the other subsystems, and subsequently, the universal control unit allows for more efficient air/ground teaming.

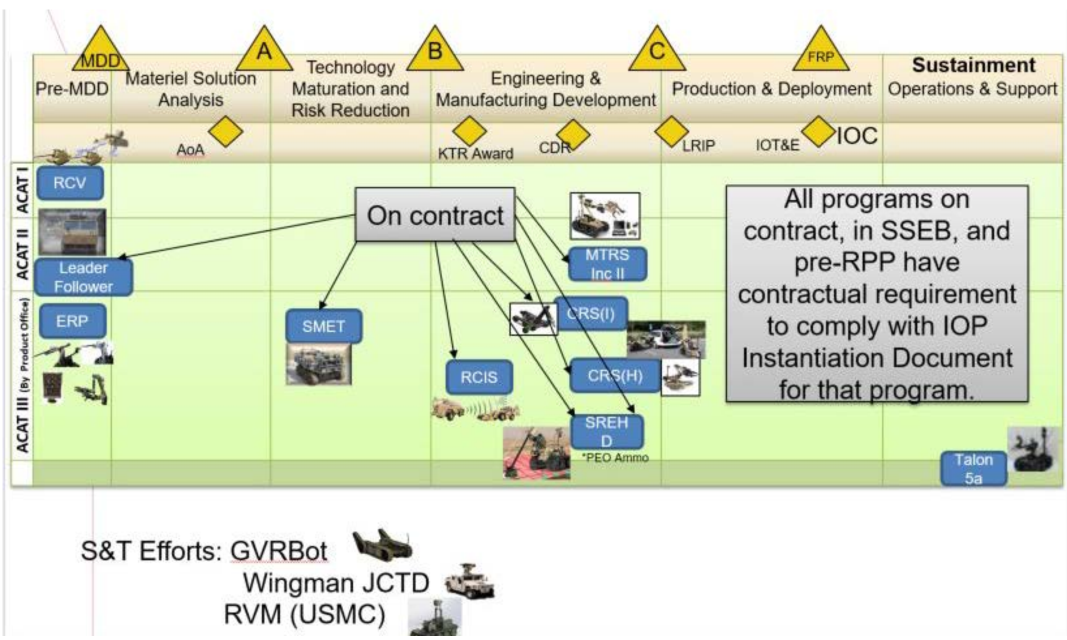

Figure A-4. Interoperability Profile Projects

The IOP facilitates enhanced competition, allowing for more subsystem vendors to have their products evaluated for replacements or upgrades to a system. Industry and government are able to work together to provide more capabilities to the Warfighter.

The IOP allows reduced fielding time, integration costs, and training burden. The strategy reduces the number of different subsystem variants and total number that need to be fielded for spares. A reduced number of subsystems and common interfaces allows for testing efficiencies as system software becomes more complex. In addition, the program could reduce its dependence on operators for manned-unmanned teaming. The universal control unit allows for more efficient air/ground teaming.

Upgrade UH-60L BLACK HAWK – Ground Interoperability Profile (UH-60V)

UH-60V (Figure A-5) was motivated to implement MOSA to build a platform upon which software capability anticipated to be available in the future could be added with minimal impact to the fielded system. The program sought to ensure the use of non-proprietary interfaces, standards, and protocols. It also sought to ensure agility in the design, such that modifications to specific performance requirements would be reasonably isolated only to the components related to that requirement, and thus improve responsiveness to changing requirements both during development and after the system was fielded. UH-60V was motivated to ensure delivery of a Technical Data Package that maximizes the Program Manager's competitive options throughout the life of the program, including unlimited data rights where feasible. UH-60V MOSA implementation enabled future integration efficiencies and enabled future reductions in repeated integration costs. In addition, the program integrated two COTS applications.

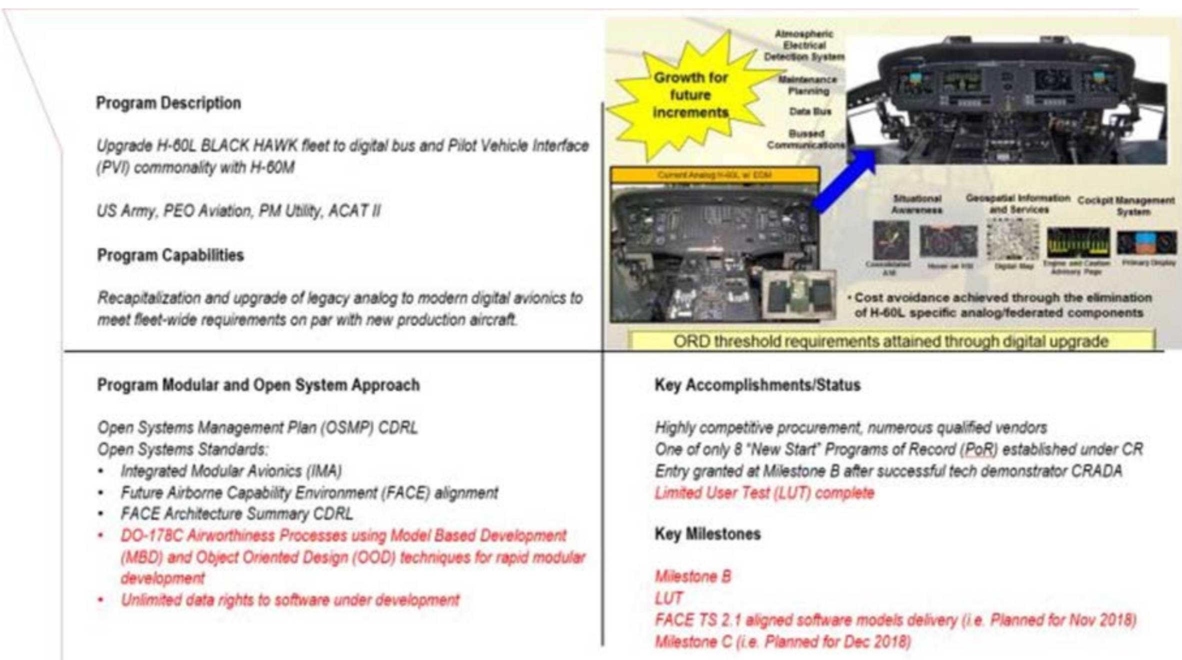

Figure A-5. UH-60V Quad Chart

Acronyms and Abbreviations

AD	Architecture Description
AEODRS	Advanced Explosive Ordnance Disposal Robotic System
APS	Advanced Protection System
C4I	Command, Control, Communications, and Computers
C4ILE	Command, Control, Communications, Computers, & Intelligence Learning Environment
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CANES	Consolidated Afloat Networks and Enterprise Services
CBRNE	Chemical, Biological, Radiological, Nuclear, and Explosive
CIO	Chief Information Officer
COTS	Commercial Off-the-Shelf
CS/CSS	Computer Software/Computer Software System
DAU	Defense Acquisition University
DCGS	Distributed Common Ground System
DI2E	Defense Intelligence Information Enterprise
DoD	Department of Defense
DoDAF	Department of Defense Architecture Framework
DSC	Defense Standardization Council
DSP	Defense Standardization Program
ECP	Engineering Change Proposal
FACE™	Future Airborne Capability Environment™
HW	Hardware
ICD	Interface Control Document
INCOSE	International Council on Systems Engineering
IOP	Interoperability Profile
ISO/IEC	International Organization for Standardization – International Electrotechnical Commission
ISR	Intelligence, Surveillance, and Reconnaissance
ITIL	Information Technology Infrastructure Library
IWS	Integrated Warfare System
JTNC	Joint Tactical Networking Center
MAF	Modular Active Protection System Framework
MAPS	Modular Active Protection System
MOSA	Modular Open Systems Approach
MOSS	Modular Open Standards and Specifications

M&S	Modeling and Simulation
NAMC	National Advanced Mobility Consortium
NATO	North Atlantic Treaty Organization
NDS	National Defense Strategy
OA	Open Architecture
OASIS	Organization for the Advancement of Structured Information Standards
OMS	Open Mission Systems
OSD	Office of the Secretary of Defense
OSTJF	Open Systems Joint Task Force
OTB	Own the Technical Baseline
OUSD(R&E)	Office of the Under Secretary of Defense for Research and Engineering
PEO	Program Executive Office
PM	Program Manager
RA	Reference Architecture
RAS-G	Robotics Autonomous System–Ground
RI	Reference Implementation
RIG	Reference Implementation Guidance
SAFe	Scaled Agile Framework
SC2S	Strategic Command and Control Software
STANAG	Standardization Agreement (NATO)
SUB	Submarine
SW	Software
SWFTS	Submarine Warfare Federated Tactical System (U.S. Navy)
SySML	Systems Modeling Language (Unified Modeling Language)
TARDEC	U.S. Army Tank Automotive Research, Development, and Engineering Center
T&E	Test and Evaluation
TRF	Technical Reference Framework
UCI	Universal Command and Control Interface
UGV	Unmanned Ground Vehicle
USA	United States Army
USAF	United States Air Force
USN	United States Navy
VICTORY	Vehicular Integration for (C4ISR) Command, Control, Communication, Computers, Intelligence, Surveillance, Reconnaissance /(EW) Electronic Warfare (EW) Interoperability (U.S. Army)

References

Alberto, Jose, and Michel Tollenaere. 2005. “Modular and Platform Methods for Product Family Design: Literature Analysis.” *Journal of Intelligent Manufacturing* 3 (371-390): 16.

Baldwin, C. Y. 2006. “Modularity in the Design of Complex Engineering Systems.” *In Complex Engineered Systems* (Berlin, Heidelberg): 175-205.

Baldwin, C. Y., and Kim B. Clark. 1997. “Managing in the Age of Modularity.” *Harvard Business Review*, September-October.

Clinger-Cohen Act. 1996. *National Defense Authorization Act (NDA) for Fiscal Year 1996 (S. 1124; Pub.L. 104–106).* Washington, D.C.: 104th Congress.

Cloutier et al. 2010. “The Concept of Reference Architectures.” *Systems Engineering* 13 (1): 14-27.

DAU. 2020. *Acquipedia.* Fort Belvoir, VA: Defense Acquisition University (DAU).

DAU Glossary. 2020. *DAU Acquisition Glossary*. Fort Belvoir, Va.: Defense Acquisition University (DAU). https://www.dau.edu/glossary/Pages/Glossary.aspx.

DiMario, Michael, Robert Cloutier, and Dinesh Verma. 2008. “Applying Frameworks to Manage SoS Architectures.” *Engineering Management Journal* 20 (4): 18-23.

DoD CIO. 2010. *DoD Architecture Framework (DoDAF) Version 2.02*. Washington, D.C.: Department of Defense (DoD) Chief Information Officer (CIO).

DoD CIO. 2012. *DoD CIO Reference Architecture Description.* Washington, D.C.: Department of Defense (DoD) Chief Information Officer (CIO).

DoD MOSA TSWG. 2016. *Modular Open Systems Approach (MOSA) in Defense Acquisition Programs.* Washington, D.C.: Department of Defense (DoD) Modular Open Systems Approach (MOSA) Technical Standards Working Group (TSWG).

DoDM 4120.24. 2018. *Department of Defense (DoD) Manual 4120.24, Defense Standardization Program (DSP) Procedures.* 2014 incorporating Change 2 effective October 15, 2018, Washington, D.C.: DoD.

DSP. 2019. *Defense Standardization Program Standardization Directory (SD-1).* Washington, D.C.: Department of Defense.

Firesmith, Donald, and Pat Donohoe. 2015. *Model Open System Architecture (OSA) Requirements.* Special Report, Pittsburgh: Software Engineering Institute, Carnegie Mellon University.

Fuchs, Christopher, and Franziska J. Golenhofen. 2019. *Mastering Disruption and Innovation in Product Management: Connecting the Dots.* Munich, Germany: Springer.

Guertin, Nickolas H., H. R. Sweeney, and Doug Schmidt. 2015. “How the Navy Is Using Open Systems Architecture to Revolutionize Capability Acquisition: The Navy OSAA Strategy Can Yield Multiple Benefits.” *Proceedings of the 12th Annual Acquisition Research Symposium.* Tampa, FL: National Defense Industrial Association . https://www.dre.vanderbilt.edu/~schmidt/PDF/NDIA-2014.pdf.

Haskins, Cecilia, Kevin Forsberg, and Michael Krueger. 2006. *INCOSE Systems Engineering (SE) Handbook.* Handbook, Seattle: International Council on Systems Engineering (INCOSE).

ISO/IEC 42010. 2011. *ISO/IEC 42010:2011 Systems and Software Engineering Architecture Description.* New York: ISO/IEC.

Lanlois, Richard N. 2002. "Modularity in Technology and Organization." *Journal of Economic Behavior & Organization* 19-37.

Mattis, Jim. 2018. *Summary of the 2018 National Defense Strategy of the United States of America: Sharpening the American Military Competitive Edge.* Washington, D.C.: Department of Defense.

OASIS Open. 2012. *Reference Architecture Foundation for Service-Oriented Architecture, Version 1.0.* Standards Track Work Product, OASIS Open. http://docs.oasis-open.org/soa-rm/soa-ra/v1.0/soa-ra.html.

OSJTF. 2004. *An Open Systems Approach to Weapon System Acquisition, Version 1.0.* Published Draft, Washington, D.C.: Department of Defense (DoD) Open Systems Joint Task Force (OSJTF).

P.L. 114-328. 2017. *U.S. Code Title 10. Subtitle A, Part IV, Chapter 144B, Subchapter I: Modular Open Systems Approach in Development of Weapon Systems.* Washington United States: 114th Congress.

Pereira, Carla Marques, and Pedro Sousa. 2004. "A Method to Define an Enterprise Architecture Using the Zachman Framework." In *Proceedings of the 2004 ACM Symposium on Applied Computing*, 1366-1371. ACM.

Sako, Mari, and Fiona Murray. 1999. "Modules in Design, Production and Use: Implications for the Global Auto Industry." *IMVP Annual Sponsors Meeting.*

Ulrich, Carl. 1995. "The Role of Product Architecture in the Manufacturing Firm." *Research Policy* 24 (3): 419-440.

Wilhelm, Bernd. 1997. "Platform and Modular Concepts at Volkswagen: Their Effects on the Assembly Process." In *Transforming Automobile Assembly—Experience in Automation and Work Organization*, by K. Shimokawa,, U. Juergens and T. Fujimoto, 146. Berlin: Springer.

Wilkes, Lawrence. 2012. *Establishing a Reference Framework: An Overview.* Fairfax, Va.: Everware-CBDI, Inc.

Zimmerman et al. 2018. "Considerations and Examples of a Modular Open Systems Approach in Defense Systems." *Journal of Defense Modeling and Simulation.*

Modular Open Systems Approach (MOSA) Reference Frameworks in Defense Acquisition Programs

Office of the Under Secretary of Defense
Research and Engineering
3030 Defense Pentagon
Washington, DC 20301-3030