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ACQUISITION RESEARCH PROGRAM SPONSORED REPORT SERIES

Plug and Play Acquisition (Implementing MOSA)

December 2024

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Thesis Advisors: Lt Col Jamie M. Porchia, Assistant Professor
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ABSTRACT

The intent of this research was to observe Modular Open Systems Approach (MOSA) equivalent concepts performed by commercial industries, gathering best practices, benefits, and failures, and then correlating it to the Department of Defense (DoD) MOSA framework. The use of secondary sources, such as public data and reports, was used to assess and perform an analysis through desktop investigation and case studies, addressing the gaps in the usefulness of the DoD's implementation of MOSA. With DoD programs from the F-35 and the Large Unmanned Surface Vehicle (LUSV) demonstrating struggles incorporating MOSA, except for V-280, the DoD's use and understanding of MOSA is behind the industry's use and applications. From Cloud Network Architecture, AUTOSAR, and Medical Capsule Robots, the industry's early applications and collaboration among other vendors demonstrate proper use of MOSA and continue to grow and expand its application. Our findings conclude that the DoD should avoid restricting MOSA to one acquisition category and reduce requirements for MOSA use. We suggest the DoD expand its information database on MOSA for a more comprehensive database, create a tool to evaluate the openness of a system, and start collaboration efforts for cross-service MOSA applications to encourage interoperability and streamline innovation.

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LIST OF ACRONYMS AND ABBREVIATIONS

ACAT	Acquisition Category
AUTOSAR	Automotive Open System Architecture
CAE	Component Acquisition Executive
CDP	Concept Development Program
CNA	Cloud Network Architecture
DA	Decision Authority
DAU	Defense Acquisition University
DoD	Department of Defense
EV	Electric Vehicle
EMD	Engineering and Manufacture Development
FLRAA	Future Long Range Assault Aircraft
FY	Fiscal Year
GAO	Government Accountability Office
IP	Intellectual Property
JSIST	Joint Strike Integrated Subsystem Technology
LUSV	Large Unmanned Surface Vehicle
MCA	Major Capability Acquisition
MCR	Medical Capsule Robot
MDA	Milestone Decision Authority
MDAP	Major Defense Acquisition Program
MEB	Modularer E-Antriebsbaukasten/Modular Electric Drive Matrix
MOSA	Modular Open System Architecture
MOSWG	Modular Open Systems Working Group
MQB	Modularer Querbaukasten/Modular Transverse Matrix
MTA	Middle Tier Acquisition
NDAA	National Defense Authorization Act
OUSD(A&S)	Office of the Under Secretary of Defense for Acquisition and Sustainment
OUSD(R&E)	Office of the Under Secretary of Defense for Research and Engineering
OSA	Open Systems Architecture
PEO	Program Executive Officer
PM	Program Manager
RDT&E	Research, Development, Test, and Evaluation

RFP	Request For Proposal
SLS	Space Launch System
SMAC	Stormlab Modular Architecture for Capsules
SME	Subject Matter Expert
SOA	Service Open Architecture
TMRR	Technology Maturation and Risk Reduction
UCA	Urgent Capability Acquisition
U.S.C.	United States Code
VTOL	Vertical Takeoff and Landing

EXECUTIVE SUMMARY

This thesis is an evaluation of the Modular Open Systems Approach (MOSA), that the Department of Defense (DoD) has implemented to reduce costs and improve efficiency, innovation, and accelerate acquisition timelines. MOSA was introduced in the commercial sector by incorporating similar approaches, such as Systems Open Architecture (SOA) and microservices before being introduced to the DoD, where it would be required by law to incorporate into Major Defense Acquisition Programs (MDAPs) after 2019.

The study examines three major acquisitions in the DoD across the Air Force's F-35A, the Army's V-280 Valor, and Navy's Large Unmanned Surface Vehicle (LUSV) and compares them to commercial industry examples like AUTOSAR, Volkswagen's Modular Transverse Matrix (MQB), Cloud Native Architecture, and Medical Capsule Robots (MCRs). The cases selected highlight the MOSA architecture used while displaying the benefits, such as efficiency, upgradability and flexibility, as well as the challenges that exist in the use of MOSA.

The analysis shows that while the DoD's implementation of MOSA have shown potential, it has also revealed obstacles such as technical data rights and vendor lock-ins, as well as limited legal requirements of requiring MOSA in acquisition design philosophy. It is recommended to expand the legal requirement of MOSA to cover all acquisition pathways, develop inter-service cooperation, and develop standardized tools to evaluate the level of openness in product designs, as well as creating an organization to oversee and manage the use of MOSA across DoD acquisitions.

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I. INTRODUCTION

A. PURPOSE

Modular Open Systems Approach (MOSA) was implemented into USC Title 10 in 2019, to ensure cost savings and improve development across Department of Defense (DoD) (Justia Law, 2023). MOSA is not an original DoD approach. MOSA is a process that is derived from similar processes such as Open Systems Architecture (OSA) and microservices, and software focused processes. MOSA was adopted by the DoD in 2008 after recognition of the benefits “modular” and “open architecture approaches” being used by industry (Williams, 2021). Even after the 2008 introduction, it was still not required in the DoD acquisition process until 10 years later. Now, as major acquisition efforts begin to adopt MOSA, there is an opportunity to evaluate how well it is being implemented.

Originating in the 1990s, the concept was developed for software. Companies such as IBM were integrating Service Oriented-Architecture (SOA) into their systems, SOA would be the precursor to “microservices” which would be coined by Dr. Peter Rodgers, who, wanted to improve coding and enact efficient large-scale changes to programs (Foote, 2021). During this point in time, software was still breaking out of its infancy. The World Wide Web was still a new development, and its capabilities were still being explored. Massive machines require components working in tandem to just generate a single webpage. Rodgers was focused on abstract method software development, looking at the machine holistically and moving towards decentralization of its components. He coined the term “micro web-services” in 2005, prior to being adopted as “microservices.” These methods would be, and are still being, used to develop cloud-based services for Google, Amazon, and Apple today (GeekforGeeks, 2023).

The purpose of microservices is to have independent systems working together but not dependent on each other, to allow accessible upgrades and interchangeable parts. This allows flexibility in development and maintenance, as well as bringing cost savings and longevity (Amazon Web Services, 2021). The key to the process is to scale down the components to smaller, manageable services. When each service becomes an independent source, systems can function on larger scales without creating a linear chain of dependency. Instead, it creates a horizontal expansion of components, maintaining an independent function. Google and Amazon have adopted a modular approach to create their well-used and advanced cloud-based services. These bases of cloud services work on a large scale due to microservices. However, the modular approach also applies to hardware, as Volkswagen utilizes this framework for its Modularer Querbaukasten (MQB) vehicle framework. The MQB can be molded to match components without sacrificing its stability.

The DoD has begun implementing MOSA into its acquisitions with programs like the F-35, V-280 Valor and LUSV to adapt MOSA into using both software and hardware approaches. These programs are the most successful attempts for the DoD and are the biggest promoters of the MOSA method. Each project displays varying degrees of success in its implementation, which will be addressed in this paper. We discussed the DoD's hurdles when using MOSA in high dollar value acquisitions, as well as the limitations of vendor lock and Intellectual Property (IP)/data rights that allow vendors to dictate the modular capabilities for the DoD. Examples being F-35 delays from software compatibility (Losey, 2024) and proprietary standards are creating hurdles for Lockheed Martin and the DoD. However, current standards may prevent DoD from gaining the maximum potential benefits that MOSA provides.

The industry's use of MOSA highlights its significant benefits, particularly due to their profit-driven objectives. For industry, MOSA enables adaptability in developing software and hardware and fostering innovation. This flexibility has allowed massive cloud services to flourish without dependence on a single provider. For example, Volkswagen's MQB can be modified to suit multiple vehicle models and incorporate various software systems. Similarly, medical capsule robots (MCRs) utilize the SMAC approach, enabling custom software insertion from software libraries and hardware customization to address various scenarios. However, industry successes are not universal, as seen with challenges faced by SpaceX and Boeing's spacesuits. Compared to industry, the DoD faces additional challenges due to regulations and standards that hinder progress and innovation. MOSA is intended to help overcome such obstacles rather than add to them.

As for the DoD's use of MOSA, this research aims to enhance understanding and guide future major acquisition efforts. Since MOSA is still a relatively new method in acquisitions, the goal is to show how it can be better utilized. The lessons learned from this research can help the DoD achieve MOSA's original goals, such as cost savings, accelerated innovation for major acquisitions, and improved timelines for the acquisition process.

B. BACKGROUND

MOSA, or Modular Open Systems Approach, is a concept specific to the DoD, crafted for its own use in implementing modular techniques. In May 2003, the DoD published Department of Defense Directive (DoDI) 5000.1, which states that, "Acquisition programs shall be managed through the application of a systems engineering approach that optimizes total system performance and minimizes total ownership costs. A modular, open-systems approach shall be employed, where feasible" (USD(AT&L), 2003, p. 11).

In June 2010, the Navy issued a memorandum instructing Program Executive Officers (PEOs), Program Managers (PMs) and Contracting Officers to use the Naval Open Architecture Contract Guidebook.

> All PEO, IWS, PMs and KOs are directed to become familiar with reference (a) and employ its principles in all future contractual program development. This includes, but is not limited to, using its recommended contract language in requests for information, requests for proposal, and all contracts. The Milestone Decision Authority (MDA) will use the PEO and Program Manager (PM) questions contained in Appendices 2 and 3 of the Guidebook to determine OA-compliance at major milestones. (Naval Open Architecture Enterprise Team, 2010, p. 3)

The guidebook provided PEOs with tools and resources for acquisitions and required them to meet certain milestones based on OA-compliance.

In 2016, the Office of the Under Secretary of Defense for Research and Engineering (OUSD(R&E)) established the Modular Open Systems Working Group (MOSWG) to address standards and architectures, as mandated by the Fiscal Year (FY) 15 National Defense Authorization Act (NDAA) Section 801 (Geier, 2022). The goal was to create a system architecture that "allows components to be added, modified, replaced, removed, or supported by different vendors throughout the life cycle of the system to afford opportunities for enhanced competition and innovation while yielding—(i) significant cost and schedule savings; and (ii) increased interoperability" (National Defense Authorization Act For Fiscal Year 2015, 2014). In 2017, a congressional requirement was established under the FY17 NDAA Section 805, mandating that all Major Defense Acquisition Programs (MDAPs) receive Milestones A and B approvals after January 1, 2019, be designed and developed using MOSA, to the greatest extent possible. This would enable incremental development, foster innovation, and enhance competition (National Defense Authorization Act for fiscal Year 2017, 2016).

In 2019, Congress provided further direction through the FY20 NDAA Section 840 to deliver MOSA implementation guidance, codifying the FY17 NDAA. By 2021, a congressional requirement under the FY21 NDAA Section 804 called for the establishment of a MOSA-enabled interface repository to access interfaces and relevant documentation. This guidance explained how the DoD was implementing MOSA, including the type of systems it applied to. The scope included weapon systems and allowed for extension to software-based non-weapon systems, like business and cybersecurity systems. Furthermore, it specified that components meeting certain criteria would be treated as modular systems (National Defense Authorization Act for fiscal Year 2020, 2019). "A modular system component is defined as one "able to execute without requiring coincident execution of other weapon systems or components and can communicate across component boundaries and through interfaces" (National Defense Authorization Act for fiscal Year 2020, 2019, p. 351) and one that "can be separated from and recombined with other weapon systems or components to achieve various effects, missions, or capabilities" (116th Congress, 2021, p. 350).

The purpose of MOSA for the DoD is to drive competition by reducing barriers to entry for businesses working with the government and addressing obsolescence risks through increased accessibility (Office of Law Revision Counsel of the U.S. House of Representatives, 2021). When the Navy implemented the Open Architecture Guidebook, it aimed to incorporate both business and technical practices to develop modular systems capable of interacting with externally developed systems. This approach was intended to expand the potential for innovation, competition, and product reusability while reducing life cycle costs (Naval Open Architecture Enterprise Team, 2010).

At the 17th Annual National Defense Industrial Association Systems Engineering Conference in Springfield, VA, Mr. Stephen Welby emphasized that MOSA "Enables Open, Competitive Business Model – allowing components to be added, modified, replaced, removed or supported by different vendors throughout the life cycle – driving opportunities to enhance competition and innovation" (Welby, 2014, p. 3). MOSA is designed to be resilient, addressing evolving threats, rapid technological advancements, innovation at both tactical and strategic levels, improved use of commercial systems in the DoD, and resource uncertainty. At the 2022 National Defense Industrial Association Systems and Mission Engineering Conference, Ms. Nadine Geier from the Office of the Under Secretary of Defense for Research and Engineering presented the MOSA vision. She stated that the goal is to, "Acquire systems that can be upgraded or modified to incorporate new technologies and respond to emerging threats" (Geier, 2022, p. 5). Geier further highlighted the importance of identifying standards that, "facilitate modularity and openness to enable consistent component replacement and interoperability" (Geier, 2022, p. 5) and utilizing technology forecasts to, "field systems using tailorable modular and open system approaches for technology insertion that contribute to system success" (Geier, 2022, p. 5).

One example of a situation that could have been prevented, through the incorporation of MOSA, was the incident involving the Boeing Space Launch System (SLS) which left two astronauts stranded in space. The issue, however, is not directly with the spacecraft, but with the spacesuit Boeing developed. NASA utilized the Commercial Crew Program with both Boeing and SpaceX to develop their own rockets, the Starliner, and Dragon respectively, in which NASA could purchase astronaut transportation (Petras et al., 2024). Boeing and SpaceX designed different spacecraft, per NASA's request, with NASA's request for these companies consisting of general requirements and safety standards, there was no mention of collaboration in the design with equipment already developed and successfully in use between the companies. This resulted in both companies developing space suits that consisted of different fittings, restraints, life support, and communication connections (Petras et al., 2024). This lack of interoperability between Boeing and SpaceX meant that although SpaceX could complete a mission to retrieve the astronauts, they could not safely be returned to Earth without first delivering spacesuits that could operate onboard their spacecraft, requiring a separate mission for suit delivery months after the initial incident. By requiring the use of standardized parts, it could have mitigated this incident. Figure 1 illustrates the differences between the Boeing and SpaceX spacesuits.

Figure 1. Starliner IVA v. Dragon IVA. Source: Petras et al. (2024).

C. RESEARCH OBJECTIVES AND QUESTIONS

There are several objectives that this thesis aims to meet. The first objective is to understand what MOSA was through its history within the United States Government, specifically the DoD, and how industries outside the government are utilizing it. The second objective was to analyze how commercial businesses through three industries are incorporating MOSA, or MOSA adjacent concepts in their respective fields. The third objective was to identify shortcomings within the DoD regarding how it has, and is currently, using MOSA. The fourth and last objective is to gather lessons learned from industry, successes and failures, to identify how the DoD can better utilize MOSA.

The researchers in this thesis provide answers to two questions, as well as recommendations for future studies.

1. How does industry apply MOSA and MOSA equivalent methods?
2. What lessons can the DoD learn from industry, and how can the DoD leverage this to improve its use of MOSA?

D. SCOPE

The scope of this thesis is concerned with providing a better understanding of MOSA, evaluating how it is being used within both the DoD and industry, and providing lessons already learned to address any DoD shortcomings. It also aims to enable better implementation of MOSA. Although modularity has been a topic of much discussion within the DoD, MOSA is not a judgement of how modular a system is, but instead, how interoperable a system is with external systems. This thesis does not offer an alternative to MOSA, but rather highlights current and potential issues and uses of MOSA within the DoD.

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II. LITERATURE REVIEW

A. ACQUISITION CATEGORIES

Acquisition categories are assigned to acquisition programs based on the expected cost or interest the program will incur. The category selected will inform the level of review, who the decision authority is, and any applicable procedures that the program is required to follow. The areas that determine the acquisition category are the expected program cost and/or level of interest (Defense Acquisition University [DAU], 2020). MOSA is only required, by law, in acquisitions classified as a Major Defense Acquisition Program (MDAP) (National Defense Authorization Act for fiscal Year 2017, 2016) which are limited to ACAT I programs. An ACAT I MDAP is a category used when designated by the Secretary of Defense, or when the RDT&E is expected to exceed $525M, or if the procurement is expected to exceed $3.065B (DAU, 2020).

B. ACQUISITION PATHWAYS

Defense Acquisitions are broken up into four pathways that are determined by the type of acquisition being conducted. These acquisition pathways provide the freedom for MDAs/Decision Authorities (DAs), as well as PMs, to create strategies and implement processes to the acquisitions that align with the characteristics of the systems being acquired (Defense University Acquisition [DAU], n.d.-a).

1. Urgent Capability Acquisition

The first pathway is Urgent Capability Acquisition (UCA), with the intended use, as described in the DoDD 5000.17 as, “DoD’s highest priority to provide war fighters involved in conflict or preparing for imminent contingency operations with the capabilities needed to overcome unforeseen threats, achieve mission success, and reduce risk of casualties” (Defense Acquisition University [DAU], n.d.-e). The threshold for the pathway is that each capability must not exceed $525M with research, development, and test and evaluation (RDT&E), or $3.065B fiscal year dollars with the aim of fielding in 2 years or less. Figure 2 provides an illustration of the UCA pathway, highlighting the timelines and phase.

Figure 2. Urgent Capability Pathway. Source: DAU (n.d.-e)

On DAU's website (DAU, n.d.-e) it states that UCAs are broken down into four phases, with the first phase in the UCA pathway is the Pre-development phase, which is used to determine the course(s) needed to quickly field a capability and develop and acquisition approach. The next phase is the development phase, which includes performance assessment, safety, suitability, survivability, and the ability to further support, including the software, and lethality of the capability being acquired. Not all deficiencies, including safety, need to be resolved prior to production or deployment. The third phase is Production and Deployment, which is the acquiring organization provides the capabilities needed. This includes any training, spares, or technical data such as: hazards, risks, and software. Additionally, this also includes temporary or permanent facilities, equipment, support, maintenance or any other logistic support necessary for operation. The last phase used in the UCA pathways is the Operations and Sustainment phase. DAU explains that this is where the PM executes the supportability strategy to meet both material and performance requirements needed over the life cycle of the program. Upon completion of the previous phases, the continuation of the acquisition will be determined at the Component Acquisition Executive (CAE) level on whether to continue the acquisition, or terminate (DAU, n.d.-e).

Due to the limitations of the funding allowed for RDT&E and total procurement cost, UCAs cannot be considered ACAT I nor MDAPs under current legal requirements. However, there is still value in implementing MOSA into UCAs. According to Deputy Director for Engineering, the OUSD(R&E), "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" (Deputy Director for Engineering, 2020, p. 16). In the example provided by Defense Acquisition University (DAU) the DoD attempted to overcome drone threats by using UCA. In the video, Marine Corps Lt Col David Sousa (Branch Head of Integrated Air and Missile Defense) says, "These pieces and parts have to be interchangeable in order to evolve with that threat. If they are not, you're beholden to the system that you have, and you'll never be able to keep pace with that threat" (Kaltura, 2019). And lastly, MOSA should be considered for incorporation to account for future upgrades and replacements. Stephen Welby, Deputy Assistant Secretary of Defense for Systems Engineering (DASD(SE)), states, "Open Systems Architectures offer great opportunities to leverage sub-system level competition to future-proof systems, provide a pathway for innovation and drive down cost over time" (Welby, 2014, p. 16).

2. Middle Tier Acquisition

The DAU website (Defense Acquisition University [DAU], n.d.-c) states that the Middle Tier Acquisition (MTA) pathway is meant to fill a gap in the Defense Acquisition System capabilities. Specifically for programs with a level of maturity that allow for them to be rapidly prototyped in an acquisition program or field. The timeline for this pathway is less than five years. Additionally, DAU claims the pathway can also accelerate capability maturation or to do minimal development for rapid fielding. Figure 3 shows the timeline and sub-paths involved in MTAs.

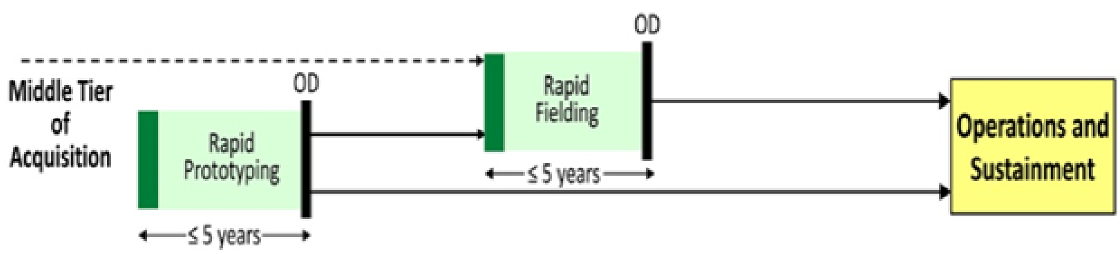

Figure 3. Middle Tier Acquisition Pathway. Source: DAU (n.d.-c).

DAU identifies two sub paths that can be utilized by PMs when completing an MTA, on its website (DAU, n.d.-c). The first sub path is Rapid Prototyping which allows for the use of modern technologies, allowing for the rapid development of fieldable prototypes with the intent to demonstrate emerging capabilities and meeting military needs. The next sub path is Rapid Fielding, which involves using existing, proven, technologies to field new, or upgraded, systems that require little to no development (DAU, n.d.-c).

Like UCAs, MTAs are also not to be considered MDAPs, as per FY17 NDAA. "In FY17, the definition of a Major Defense Acquisition Program was updated to specifically not include MTA programs" (DAU, n.d.-c). Therefore, MTAs are also not required by law to implement MOSA. However, MTAs could benefit from the implementation of MOSA, Government Accountability Office (GAO) report 23–105008 recommended four product development principles used by leading companies. The key principle recommended, that applies to MOSA, is the use of an iterative design approach. By incorporating MOSA during the prototype phase, it would allow effective incorporation of iterative design, as the lessons learned, and innovation developed can be stacked upon each other, opposed to restarting every time (GAO, 2023c).

3. Major Capability Acquisition

The Major Capability Acquisition (MCA) pathway is the focus of the MOSA mandate, and is the pathway designed for MDAPs in the DoD. MCAs are determined from the dollar threshold and DoD Mission objectives (Defense Acquisition University [DAU], n.d.-b). For this research, we focus on MCAs that fall under ACAT I thresholds as that is when MOSA is required to be implemented by law. MCA is further broken down into Milestones, which decided whether the program being acquired will proceed to the next phase of the procurement. Figure 4 illustrates the sequence of events throughout the course of an MCA program.

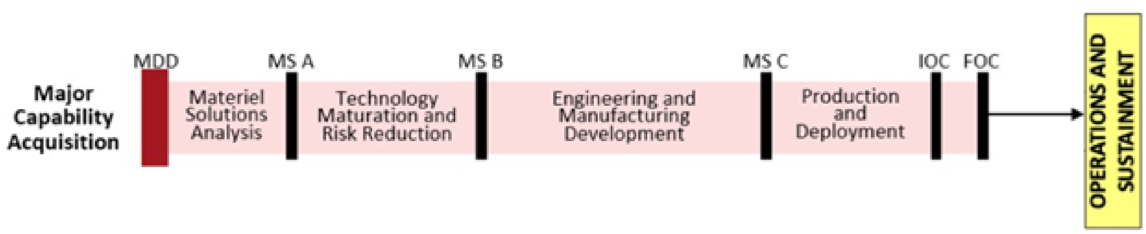

Figure 4. Major Capability Acquisition Pathway. Source: DAU (n.d.-b).

The NDAA only requires that MOSA be implemented, to the maximum extent possible, at Milestones A and B (National Defense Authorization Act for fiscal Year 2017, 2016). The responsibility of Milestone A is to approve entry into the Technology

Maturation and Risk Reduction (TMRR) phase. Milestone A also approves the acquisition strategy and release of the final Request for Proposals (RFP) for TMRR. "Milestone A approves program entry into the technology maturation and risk reduction (TMRR) phase, approval of the program acquisition strategy, and release of the final request for proposals (RFPs) for TMRR activities" (DAU, n.d.-b). This milestone is crucial in detailing the cost, schedule and technical plans. MOSA's implementation would be considered here before moving forward and become integral to the analysis of the project. Milestone B authorizes programs to enter the Engineering and Manufacture Development (EMD) Phase, which is where a material solution is developed, built, and tested to ensure all requirements are met. Milestone B is also where risks, such as technology, security, engineering, integration, manufacturing, and sustainment are assessed (DAU, n.d.-b).

4. Software Acquisition

"This pathway is designed for software-intensive systems. The pathway objective is to facilitate rapid and iterative delivery of software capability to the user" (Defense Acquisition University [DAU], n.d.-d). Speed and improvement is the focus of the software acquisition, to maintain the pace and turnout, MOSA comprises two phases, planning and execution. Starting from the planning phase: "The purpose of this phase is to better understand the users' needs and plan the approach to deliver software capabilities to meet those needs" (DAU, n.d.-d). This phase requires constant engagement with the end users regarding the feature, interoperability requirements, and any legacy interfaces. IP rights are established in the planning phase as well, to facilitate cooperation and provide clear expectation with return on government investment.

The execution phase is intended to rapidly and iteratively develop, test, and operate a software capability that is both resilient and reliable, that meets the needs of the intended users (DAU, n.d.-d). Programs will maximize the iterative nature of this pathway by continuously implementing new capabilities through user feedback and engagement. This is accomplished through a cyclical flow that allows for corrections and adaptation while also benefiting from oversight by both the users and developers.

The other unique factor when it comes to the software pathway is software is not considered MDAP, regardless of the RDT&E or total acquisition cost. Section 2430 Title 10 highlights this by stating, “Programs executing the software acquisition pathway will not be treated as major defense acquisition programs even if exceeding thresholds in Section 2430 of Title 10, United States Code. See Section 800 of Public Law 116-92” (DAU, n.d.-d). This effectively reduces many checks that other MDAP projects would go through, further benefiting the software acquisition pathway.

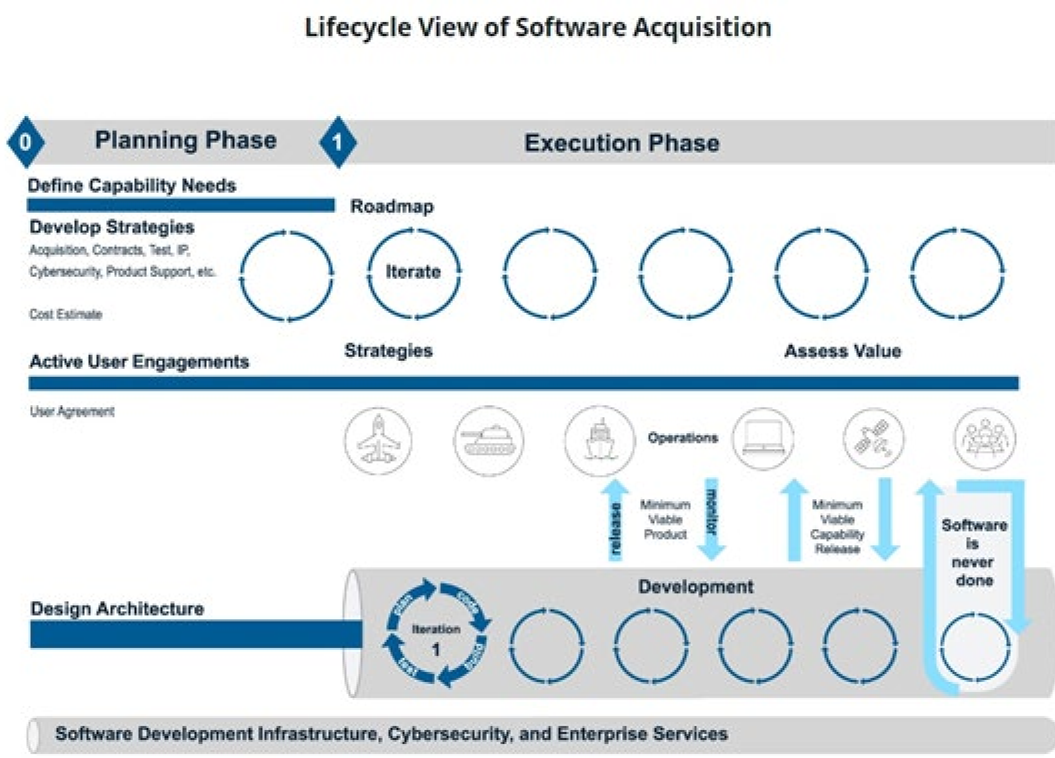

Figure 5. Software Acquisition Pathway. Source: DAU (n.d.-d)

MOSA could best be utilized in the software acquisition pathway, with continuous improvement and iterative design in both the planning and execution phases. MOSA should be leveraged in this pathway due to the necessity of operating with existing systems. Unlike the previously mentioned acquisition pathways, the software acquisition pathway requires constant iteration throughout the use of the capability required. The software is continuously upgraded throughout its life cycle to meet changing mission requirements, cybersecurity needs, interoperability, interface, and intelligence (DAU, n.d.-d). Figure 5 demonstrates the iterative approach used in software acquisitions. The intent of this is for the DoD to maintain pace with the progression of technology through continuous improvement of software quality (DAU, n.d.-d). The software pathway accomplishes the goals of MOSA but needs to adapt this system beyond just software, and into other acquisition pathways.

C. MOSA ALTERNATIVES

Industry has been leading the charge with MOSA like methods, alternatives that would inspire the DoD's implementation of MOSA. Industry has the freedom to experiment and adapt quicker than the DoD is currently allowed under existing regulatory restrictions regarding acquisitions. What is critical about these alternatives is how they have been expanded upon, since their conception, and are still used today to progress and innovate industry standards. What will be discussed are the two parallel concepts to MOSA that are seen throughout industry.

1. Systems Open Architecture

System Open Architecture (SOA) or Service Oriented Architecture, has no definition, as described. Still true to this day, even in Industry, each has its own definition of what SOA does "There is not an agreed upon definition for SOA in the commercial sector. In a complementary thesis, the researcher found that definitions for SOA varied from company to company" (Cole, 2011, p. 14). But each definition shared a similar theme of services being able to locate other services on a network. The MOSA strategy is to take the system and divide between the hardware and software components. Once division is created, the focus for hardware upgrades and the application software are developed independently from the processors using transportable middleware. The separation of processes grants the ability to interchange parts of the system while leaving the rest intact, which allows for faster development and deployment (Boudreau, 2006).

> There were risks involved with the MOSA approach, as system development for different components proceeded independently of each other and introduced interoperability risks into the process. Extra time and expense were needed for tracking and version control of key software interfaces, standards, and protocols amongst the different development teams. (Cole, 2011, pg. 51)

Open Systems Approaches (OSA) were introduced in 1994 to the DoD. This was led by the Under Secretary of Defense for Acquisition, Technology, and Logistics when they required the use of open systems standards and specifications for all weapons systems, acquired by the various components and agencies. (Schmidt and Sledge, 2016). The goal from the start with the initiative was to incorporate open systems standards to improve acquisition process and major weapon systems. "Therefore, although OSA is the right thing to do--and we will gut our way through some of it—it is not an easy thing to go off and accomplish. We have cultural dimension problems on the government buying side and we have business relationship friction on the industry side" (Schmidt and Sledge, 2016).

2. Microservices

Microservices were developed from SOA methodologies. Credit is given to Dr. Peter Rodgers for the term in 2005, as mentioned earlier, but there was not adopted commercially until 2011 through introductions at workshops "The term "microservices" was first introduced in 2011 at an architectural workshop to describe the participants' common ideas in software architecture patterns" (Dragoni et al., 2017, p. 7). The "microservices" are what many large tech companies build their systems on today, this is due to the benefits of making larger platforms run efficiently and reducing the burden of upgrading independent platforms through modular techniques "Microservices manage growing complexity by functionally decomposing large systems into a set of independent services. By making services completely independent in development and deployment, microservices emphasize loose coupling and high cohesion by taking modularity to the next level" (Dragoni et al., 2017, p. 7).

Microservices is focused on providing the ability for continuous and consistent maintenance "This approach delivers all sorts of benefits in terms of maintainability, scalability and so on" (Dragoni et al., 2017, p. 7). Flexibility is one of the strongest benefits, providing the capability to maintain and improve without falling behind technological trends and evolutions. "A system is able to keep up with the ever-changing business environment and is able to support all modifications that is necessary for an organization to stay competitive on the market" (Dragoni et al., 2017, p. 7).

Microservices involves modular methods to be the flexible and dynamic system. It is “A system is composed of isolated components where each component contributes to the overall system behavior rather than having a single component that offers full functionality” (Dragoni et al., 2017, p. 7). Involving various “services” within an application, like Netflix streaming, Amazon Prime, and Google Apps (Docs, Drive, Mail, etc.) each are compartmentalized as in containers, working as independent systems within the application. The independence of each system gives the application freedom to operate without dependency on each service, decentralized service capable of updating and maintaining without sacrificing service. “A system should stay maintainable while constantly evolving and adding new features” (Dragoni et al., 2017, p. 7).

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III. METHODOLOGY

A. RESEARCH DESIGN

For this research, we employed two methodologies. The first method was gathering information through desktop research. The second method was the use of case study to analyze the information discovered. The combined approach of these methods was to find information regarding the applicability of MOSA/MOSA adjacent concepts used in the categories identified in both cases.

Desktop research was part of the research design that was chosen for this thesis, as it is a type of research where information is gathered from established sources.

> Desktop research (also known as secondary research) involves the use of existing sources of information to gather data and insights on a topic of interest. This type of research relies on information that has already been collected and published by others, such as academic articles, government reports, market research studies or existing project documentation. It is often used to gather background information, support primary research, or to inform decision-making processes. (Queensland Government, 2023)

This methodology was selected due to the infancy of MOSA's use in the DoD. Additionally, the availability of information, especially from industry, allowed us to easily obtain published sources for our research. Lastly, since MOSA is used for major/complex acquisitions, there was no meaningful way to conduct experimentation.

The use of a case study was chosen to analyze the current use of MOSA, through current DoD acquisition and industry programs. The case study method aids us in the exploration and understanding of MOSA through our qualitative means of research, comparing the practices of both entities (Zucker, 2009). As MOSA can be a complex topic, using case studies would be the proper vehicle for readers.

B. DATA COLLECTION METHODS

Since desktop research was conducted, we utilized the following data resources to gather information to form our case studies for analysis and findings.

- Academic publications
- DoD Regulations

- U.S. Law
- Conference Resources
- News Articles
- Books
- Websites

C. SELECTION CRITERIA

For this paper, seven total cases were selected to be reviewed. The first category comprised ongoing major DoD acquisitions utilizing MOSA, from the Air Force, Army, and Navy. The next set of cases focused on MOSA/MOSA similar methods being utilized through various industries in the commercial sector, to include automobile hardware, automobile software, telecommunications, and medical robotics.

These projects have been chosen not only for their notoriety but also the integral use of MOSA in the designs. The F-35, being a joint aircraft, is using integrated proprietary systems and subsystem integration, which have modular features in their design. Meaning the various subsystems involved working in tandem without needing to do a complete redesign to compensate. Although the F-35 program is not officially designated as MOSA, there are significant characteristics that align with MOSA, which will be expanded upon later in the case study.

The Bell V-280 Valor was chosen due to its Army perspective and the focus on flexibility in the development. Using modularity in its approach, their mission capabilities are given the ability to switch out payloads and a propulsion system allowing for incremental upgrades. The V-280 also heavily incorporates Commercial Off-The-Shelf (COTS) products in its development.

The Navy's LUSV case was picked for its emphasis on open architecture design, which is set to be modular, adapting to different mission requirements and interoperable. This design allows a variety of capabilities to be implemented, upgraded and replaced ranging from sensors, communication, and navigation systems. Various vendors working on this design follow the MOSA philosophy of preventing vendor lock-in, but a critical factor in the LUSV design is that MOSA is not required for software projects. But the MCA pathway requires MOSA to be implemented at milestones A&B. The disconnect between the processes prevents LUSV from continuing its development and affects the objective of LUSV's modular intent.

The following cases, in industry, that were selected to be researched were decided based on their implementation of MOSA or similar methodology. The first cases selected were in the field of automobile production. AUTOSAR, which is a collaborative effort between several automotive manufactures, utilizes a standardized framework for the software found in most vehicles. By using this framework, it allows for collaboration which reduces the time and cost to develop components and software for intelligent cars. Also, regarding automobile manufacturing, there is the Volkswagen's MQB platform, which utilizes a standard frame and drivetrain that is shared with all brands under Volkswagen. By standardizing the most critical and complex components of the vehicle manufacturing process, Volkswagen saves both time and money when developing new cars.

The next case selected is in the field of telecommunications as Cloud Network Architecture, which employs the use of microservices, and is utilized by some of the biggest companies in the cloud service environment, such as Google and Amazon. Cloud Network Architecture is an open architecture framework that allows the service to operate autonomously while also allowing for independently operated systems to be upgraded and replaced without degrading the overall service. This allows for faster innovation without discontinuing the level of service in place.

The last case, which was selected, comes from the healthcare/medical field as the Medical Capsule Robot (MCR) which implements Modular Open Architecture in both its use of software and hardware. The MCR is capable of being integrated into multiple operating systems, as well as outfitted with variations of hardware that can be adjusted according to the medical operation being conducted. The design of this robot allows for use throughout various hospitals regardless of the operating systems they use, as well as tailored to the procedures it will be used for.

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IV. ANALYSIS AND FINDINGS

Two cases were developed to illustrate the DoD's application of MOSA within its acquisition programs and compared it to commercial industry's approach to applying modular concepts. We took three public MDAPs to best display this attempt at implementing MOSA. In contrast, we also chose four public examples of industry using MOSA/MOSA equivalents in their development through various fields and categories. The examples chosen will demonstrate the successes, issues and lessons learned of industry and what DoD can take away.

A. DOD CASES

The DoD case analyzed three acquisitions across the Air Force, Army, and Navy. We researched the purposes, developmental histories of the project, and outcomes by reviewing acquisition documents and issues brought up by entities, such as the GAO.

We found from the applications selected that when MOSA was not implemented early enough, programs were hindered by vendor lock-in and restrictive data rights. Also, when programs started outside of MDAP ACAT I there was no legal requirement for incorporating MOSA but, when implemented successfully, the use of iterative and collaborative efforts in design could lead to smooth and rapid development.

1. Air Force F35 Joint Strike Fighter

The first application examined was the Multi-role Joint Strike Fighter, otherwise known as the F-35, which has been using the MCA acquisition pathway since 2000 (Lockheed Martin, 2020). The purpose of the F-35A is to fulfill the role of the latest fifth generation fighter, with the intent of replacing both the F-16 and A-10, bringing an improved capability to survive in an environment full of advanced threats. It provides new levels of stealth, improved situational awareness, and reduces visibility (Air Force, 2014).

Despite being a Joint Strike Fighter, it was decided to treat it as an Air Force Requirement due to being led by Air Force PEOs (F-35 Joint Program Office, n.d.). Figure 6 shows the number of complex systems in use throughout the F-35 that require technical expertise that is being safeguarded by Lockheed Martin through technical data rights.

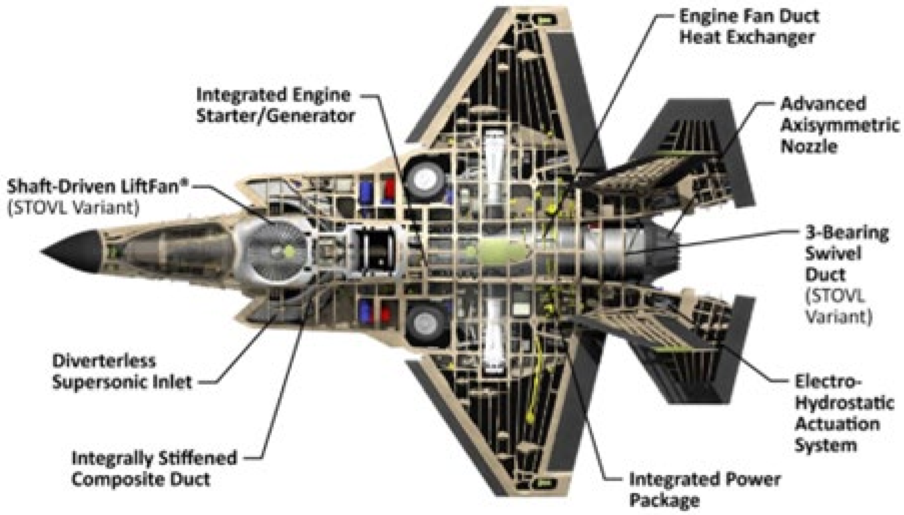

Figure 6. F-35 Schematic. Source: Wiegand (2018).

The F-35 has been a DoD project since 1996 and entered Milestone C in 2024. Below is a timeline showing the various steps the F-35 has undergone throughout its acquisition life cycle.

- Concept Demonstration: November 1996 (US Navy, 2022, p. 7)
- Milestone B: October 2001 (US Navy, 2022, p. 7)
- Milestone B Re-approval: March 2012 (US Navy, 2022, p. 7)
- Milestone C: 12 March 2024 (DoD, 2024)

Since 1996, it was decided that the DoD would need to consider affordability for its Joint Strike Fighter. Although MOSA was not required, as it was not invented yet, this acquisition leveraged many of the core concepts of MOSA "Specifically, both Boeing and Lockheed Martin will demonstrate commonality and modularity" (OSD, 1996, p. 3). There are two successful uses of MOSA during the F-35 program. The first example of use is through the open integration framework through the LYNX MOSA.ic™:

> will enable the TR3 subsystems to be cleanly architected from reusable software components that avoid proprietary dependencies, providing the program with more commercial options to manage supplier and manufacturing costs. LYNX MOSA.ic™ provides additional flexibility to integrate components of varying degrees of complexity and quality, including open-source components, without undermining architectural assurance properties. Finally, in providing a simpler foundation for

hosting safety-critical applications, LYNX MOSA.ic ™lowers the cost, effort, and risk of multicore certification compared with traditional SMP RTOS approaches. ("LYNX MOSA.ic™," 2020)

The second successful use in which the F-35 implemented MOSA concepts was through the Joint Strike Integrated Subsystem Technology (JSIST). This subsystem occurred parallel with the Concept Development Program (CDP) which saw competitors, during the developmental phase, create a cooperative environment, sharing data and results. By doing this, risk was mitigated by allowing the integrated vehicle system to progress without encumbering the concept demonstrator aircraft schedule. This enables the results of the CDP, JSIST, and all lessons learned to be implemented in the F-35 (Wiegand et al., 2018).

There were also a few instances where issues arose during the F-35 program due to late implementation of MOSA, as the program began before MOSA was established. A major area identified through research was the restriction of technical data from the prime and subcontractors. This is reported in GAO report 23–105341, where government maintainers were prevented from performing repairs on the aircraft. This was caused by using proprietary information being withheld by the contractors, who did not want to expose information that could reduce their competitiveness as private companies (GAO, 2023a). This was also seen in the training of government maintainers, from the contractors, due to the high level of technical data that was considered proprietary and withheld from the military services. Due to this, the military services cannot develop effective internal training programs for their maintainers, leading to reliance on the contractors (GAO, 2023a).

Due to MOSA not being introduced into the DoD until 2008, the F-35 was too far into development to fully incorporate MOSA's concepts into its design. This has limited the ability to incorporate MOSA on the hardware and training side of the program, however, the software being incorporated into the F-35 utilizes reusable and iterative components, which are key aspects of MOSA. This was seen in the TR3 upgrade, but this is still running into hurdles due to the hardware implemented not being able to match the pace of software actively being developed, and not being able to interoperate with external systems. This is a result of the low manufacturing of parts necessary for the aircrafts production. Which has led to using software to overcome hardware design challenges from aging equipment. An independent review of the software architecture found there is solid architecture, but until the underlying hardware is outdated, due to this, "the F-35 program will continue to struggle with software integration efficiency" ("F-35 Tech," 2024). With the late introduction of MOSA, the F-35 is limited in its use of MOSA by DoD standards, caused by proprietary standards early on in its development, we can see results of failing to consider MOSA applications early in the development process.

2. Army V-280 Future Long Range Assault Aircraft

The next application examined is the Army's V-280 Valor, otherwise known as the Future Long Range Assault Aircraft (FLRAA) which is using the MTA pathway to acquire it. The role of V-280 will be to assault enemy forces outside the range of their long-range fires by utilizing increases speed, range, and ability to maneuver, while also integrating with other Future Vertical Lift (VFL) systems (Future Long Range Assault Aircraft (FLRAA), n.d.). Figure 7 references the V-280 prototype from Bell Textron Incorporated.

Figure 7. Bell V-280 Valor Prototype. Source: Bell Flight (2019)

The V-280 has seen initial success in meeting its schedules per the MTA pathway. Below is a timeline showing the various steps the V-280 has undergone throughout its acquisition life cycle.

- First Flight: 18 December 2017 (Bell Flight, 2019)

- Contract Award: 05 December 2022 (PEO Aviation, 2024)
- Milestone B: 02 August 2024 (PEO Aviation, 2024)

From the beginning, both the Army and Bell had MOSA in mind when developing the V-280. Bell displays this on their website when describing the V-280, listing the benefits as being affordable, innovative, and adaptable (Bell Flight, 2024). The Army Contracting Officer stated in their Justification and Approval for other than full and open competition.

> These efforts, combined with FLRAA PM engagements at the Association of the United States Army, virtual Army Aviation Association of America events, and various Vertical Lift Society symposiums have helped determine the availability of commercial off-the-shelf (COTS) or other production system that will or could (if modified) meet the defined requirements for the FLRAA. (Weeks, 2020, p. 11)

Furthermore, the PMs listed MOSA in their lines of effort for the FLRAA program "FLRAA and Future Attack Reconnaissance Aircraft (FARA) PMs presented information on the lines of effort, program strategy, and current schedule. In addition, they presented common requirements, including MOSA, and mission systems across both projects" (Weeks, 2020, p. 13).

The GAO highlighted the V-280's successful implementation of MOSA in its report 23–105554 where it said that the VFL portfolio uses MOSA and its officials anticipate faster upgrades to the software, hardware, and down to the subsystem level (GAO, 2023b). However, unlike the F-35, the V-280 is still early in its acquisition life cycle but has yet to show any significant issues regarding the three main categories of cost, schedule, and performance. Thus far, the V-280 implementation program is exhibiting signs of successful implementation because it meets the goals of MOSA, such as its use of COTS which leads to a platform with existing interoperable products, as well as reduced R&D time and costs. This is seen through the expedited timeline the V-280 has experienced in comparison to other MDAPs.

"The Army's Future Vertical Lift program took a major step forward as the Future Long Range Assault Aircraft, or FLRAA, program entered the next major phase of development when the Army announced the approval of the FLRAA Milestone B Acquisition Decision Memorandum on August 2, 2024" (PEO Aviation, 2024). The V-

280 Valor is proving to be the best example of MOSA use in the DoD, showing little to no issues in its development.

3. Navy Large Unmanned Surface Vehicle

The last application studied is the Navy's Large Unmanned Surface Vehicle (LUSV). The LUSV is planned to be used as a long-range uncrewed vessel used for conducting operations in conjunction with crewed ships while utilizing varying levels of autonomy. The Navy intends for the LUSV to be a low-cost ship, capable of being reconfigured to carry various capacity of modular payloads. Figure 8 displays an operational prototype, by Bollinger Shipyards Lockport LLC, which was one of six companies awarded the contract for design of the LUSV.

Figure 8. Bollinger LUSV Prototype. Source: O'Rourke (2024)

Of the three DoD acquisitions that we researched, the LUSV is the newest and earliest within its acquisition life cycle, resulting in little information being readily available. Below is a timeline of significant events:

- Initial Design: September 2020 (GAO, 2023d)
- Milestone A: 29 July 2022 (O'Rourke, 2024)
- Milestone B: Projected July – September 2025 (GAO, 2023d)
- Milestone C: Projected FY28 (O'Rourke, 2024)

The LUSV was mandated in a Congressional Research Service report from 2024 requiring the utilization of MOSA.

> The committee recommends a provision that would require the Secretary of the Navy, not later than 180 days after the date of the enactment of this Act, to provide a forum on unmanned maritime autonomy architecture (UMAA) that would facilitate industry participation in the creation and management of modular open systems architecture and associated standards for maritime unmanned systems (O’Rourke, 2024, p. 27).

At the time of this research, there are no examples of how the Navy intends to incorporate MOSA, specifically, in the design. The closest the LUSV appears to achieve, through our research, to MOSA capabilities is in the Modular Payload Delivery. However, as previously discussed, the modularity of a system does not equate to be considered MOSA. “The Navy wants LUSVs to be low-cost, high-endurance, reconfigurable ships with ample capacity for carrying various modular payloads—particularly anti-surface warfare (ASuW) and strike payloads, meaning principally anti-ship and land attack missiles” (O’Rourke, 2024, p. 2).

Considering how early in development the LUSV, it may be too soon to determine if the Navy is appropriately applying MOSA concepts in this design. As of the time this research was conducted, the Navy is still competing the design of the LUSV with six vendors. The Navy intends to award sole source contract modifications to Austal USA, LLC, Bollinger Shipyards Lockport, L.L.C, Marinette Marine Corporation, Gibbs & Cox, Inc., Huntington Ingalls Incorporated, and Lockheed Martin Corporation in accordance with FAR 6.302-1, for a continuation of design studies on the LUSV under the following contracts: N0002420C6315, N0002420C6316, N0002420C6317, N0002420C6318, N0002420C6319, and N0002420C6320 (Brese, 2021).

Due to the lack of publicly available information, it is not readily apparent on how the Navy intends on incorporating MOSA in the acquisition of the LUSV, aside from the congressional report mandating its use.

B. INDUSTRY CASES

For industry, the use of MOSA and MOSA equivalent methods have had the benefit of time and leniency in their development, when compared to DoD acquisitions. From creating adaptive automobile framework, large scale app services and advanced medical robotics, industry is willing to choose collaboration over competition to achieve innovation and reduce R&D time and cost. Their use of MOSA allows for an environment to create larger services that will provide iterative systems with rapid upgrades without sacrificing time and facilitating iterative and cooperative practices to achieve advancement and expansion of existing capabilities.

1. Automobiles

The automobile industry was chosen as a parallel to DoD acquisitions, as it involves a great deal of investment in the research and development of both hardware and software that will be integrated into one product. AUTOSAR is an example of MOSA being applied to the software involved in manufacturing vehicles, as well as the collaborative nature it facilitates by bringing together multiple, competing, automobile manufacturers to share technical data and findings to accelerate innovation, reduce costs in research and development, and increase software scalability (Bunzel, 2011). The next example is the Volkswagen MQB, which involves the hardware aspect of automobile manufacturing. The MQB incorporates MOSA in the philosophy of developing a standardized chassis, which comprises the frame and transversal equipment, as it is one of the most expensive aspects of the car Volkswagen benefits from standardizing this across all its brands, thus reducing cost, engineering hours, weight, and emissions (Volkswagen AG, 2011).

a. AUTOSAR

Worldwide Development partnership developed in 2003, major owners include, but are not limited to: Bosch, Toyota, GM, BMW, Volkswagen and Mercedes. This partnership brought about the production of standardized software architecture for the major automotive industries labeled AUTOSAR, Automotive OSA.

The use of AUTOSAR was to have an automotive software architecture standard in the field. "Accordingly, the AUTOSAR standard comprises a set of specifications describing software architecture components and defining their interfaces as well as the definition of a standardized development methodology" (Bunzel, 2011). The intended users are the manufacturers and producers of the automotive industry to perform in an open industry. The purpose of this partnership is to create the software standard and allow independent software components to be interchangeable between different make and models, allowing a level of scalability among various models and platforms aiming to increase the reusability of software components, particularly in different vehicle platforms. By implementing AUTOSAR, the ability to scale software into different vehicle platforms via a network of manufacturers to seamlessly apply modules from a variety of suppliers. (Bunzel, 2011). Figure 9 illustrates how AUTOSAR is used to integrate independent hardware with standardized application software.

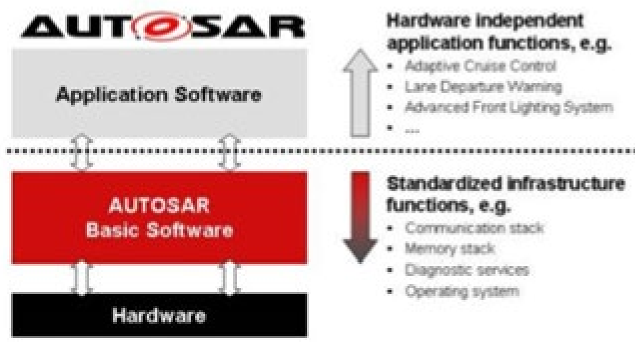

Figure 9. AUTOSAR Use and Structure. Source: Bunzel (2011)

We considered this as MOSA through AUTOSAR's focus on independent software component use, which allows for scalability and interoperability among various models and platform variants to create an industry standard among various producers and manufacturers in the automotive industry. The implementation of the AUTOSAR is a strong example of software scalability and interoperability. MOSA is about independence and flexibility, AUTOSAR follows through with its development of software:

> The development of the application software components with the definition of the internal behavior, coding, and implementation are independent of hardware and can be done separately for each component. In particular many model-based design tools on the market already can handle e.g., the SWC description and thus address the AUTOSAR methodology (Bunzel, 2011).

Current issues of AUTOSAR are with the new electronic architecture for current EV's. AUTOSAR struggles keeping pace with the advanced architecture involved with new EVs. Knowledge required and resource intensity prove a challenge even with the current scalability AUTOSAR has been operating for over two decades now.

> AUTOSAR will only be providing some of the software layers within the systems. Whilst they have somewhat of a monopoly on vehicle networking, the Adaptive Platform might not be the major choice for implementing complex autonomous features and there are many other software system (Howle and Dunoyer, 2022).

AUTOSAR is still the backbone of integration and progression but there is a limit to its capabilities in the current state.

AUTOSAR is a leading example in how MOSA can be utilized. Software architecture standard implemented across an industry allowing independent software to be interoperable and scalable to different models or variety of platforms. IP rights do not prevent the software from being implemented or integrated into other frameworks. The standard set by the AUTOSAR is made to allow the connection and flexibility of software and to advance the manufacturing of the automobile.

b. MQB

The design of the MQB is owned by the Volkswagen group and is applied to various brands such as: BMW, Bentley, Bugatti, and Volkswagen. Like AUTOSAR, Volkswagen was interested in developing a standard for their automotive brands, but instead of the software focus, they went with standardized chassis called the MQB, Modularer Querbauksten or Modular Traversal Toolkit.

The intended users of the MQB are for Volkswagen production facilities. The MQB allows a singular frame to be adapted to make various models across their brands. "As an extension of the modular strategy, this toolkit can be deployed in vehicles whose architecture permits a transverse arrangement of the engine components. The MQB enables us to meet customers' expectations for a growing variety of vehicle models, equipment features and design, reducing the complexity, costs incurred, and time required for development at the same time" (Volkswagen AG, 2011).

The purpose of the MQB is to save on cost and on time. Using a system of adaptable frames, Volkswagen can achieve a modular standard that cuts down on time and grants flexibility across manufacturing. "This stuff is among the most expensive portions of a car to develop, and the production line also must be built around it.

Standardizing it saves fortunes and allows the plants to build whatever demand dictates. The steel platform can be built in a range of wheelbases and there are various levels of suspension system, several suites of driver aids, different levels of entertainment/ navigation. The important fact is they all use common physical mounting points and electrical architecture" (Horrell, 2014).

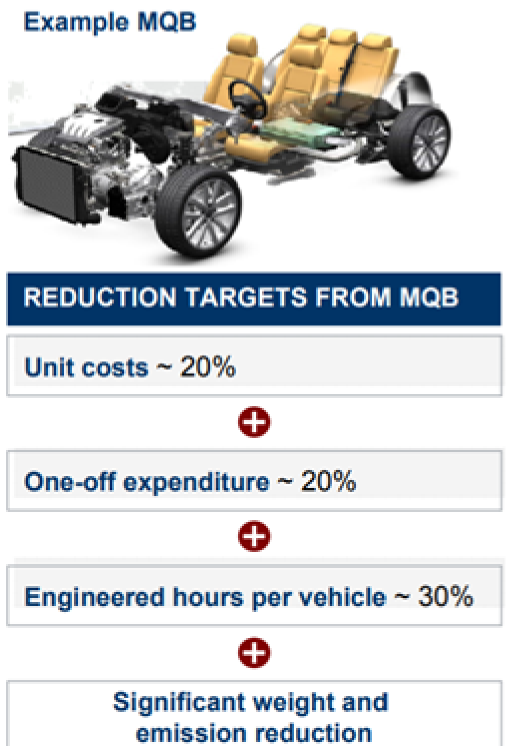

Figure 10. MQB Chassis and Benefits. Source: Horrell (2019)

The MQB is a good example of MOSA through its adaptive modular system. Across multiple platforms, the MQB gives Volkswagen the ability to shift production when needed to achieve desired objectives. The frame can adjust to achieve standardization without sacrificing diversity. The combination of standardization and diversity are displayed in the MQB's use in more than 42 vehicles in the global Volkswagen Group umbrella (Biermann, 2020). The MQB is another example where a modular design is being used to create multiple models without sacrificing quality and decreasing manufacturing cost and time.

Though many models can be built off of the MQB system and provide consistent quality, there will be a limitation to what it can extend for Electric Vehicles (EV), which is why the next adaption is the Modular Electric Drive Matrix (MEB) “Based on experiences with the MQB, Volkswagen has developed the modular electric drive matrix (MEB) for the all-electric models of the ID. product line. Like the MQB, the MEB provides a clearly defined and yet versatile matrix for the high-volume Group brands” (Volkswagen AG, 2022).

Volkswagen has benefited from the implementation of the MQB platform, but through this MOSA adopted framework, it is limited to its application for EV vehicles. Because of this, Volkswagen must adopt the Modular Electric Drive Matrix (MEB)

The MQB is another standard use of MOSA. With its focus on flexibility and cost savings, it achieves the goals of MOSA and maintains a level of quality and consistency that the DoD strives to achieve with its major acquisitions.

2. Cloud Native Architecture

Cloud Native Architecture (CNA) is a system used by many major tech companies, such as Google, Amazon, Oracle, and many others. CNA takes what microservices do within applications and extends it to servers, creating the large cloud services that are offered today.

> Created with the express purpose of maximizing the cloud computing model. It combines software development ideas with DevOps techniques and processes from cloud services. From servers, networking, data centers, operating systems, and firewalls, it abstracts all IT levels. The ability to create applications as loosely linked services using microservices architecture and operate them on platforms with dynamic orchestration allows for the creation of these applications by businesses. (GeekforGeeks, 2023)

This architecture has been developed overtime using various industry practices, which eventually became the standard used by tech corporations across the world. Amazon, for example, introduced its Amazon Web Services (AWS) in 2006 and became one of the largest cloud-based services using CNA. Developers create independent applications that are already commercially available, opposed to using a specialized infrastructure. This allows developers to make quick changes, such as updating an app numerous times a day without having to take it offline (GeekforGeeks, 2023). Tech developers are using CNA for stability and dependability, for the assurance of building and deploying apps in the cloud, in the form of an operating environment. The developers no longer have the burden of managing hardware compatibility issues that arise from the cloud provider. Now developers can focus on maximizing value to the app, because they no longer have to additionally build the necessary infrastructure (GeekforGeeks, 2023).

CNAs use microservices to create several small software programs that can operate independently. This is an improvement in traditional software development, which relied on monolithic applications which utilized one block structure containing all necessary functions. CNA allows developers to section off the overall application into several microservices that require minimal computing resources to operate, and can be upgraded and scaled independently, while allowing for the overall application to remain functional (Google Cloud, n.d.). Figure 11 shows how Google utilizes microservices in its CNA.

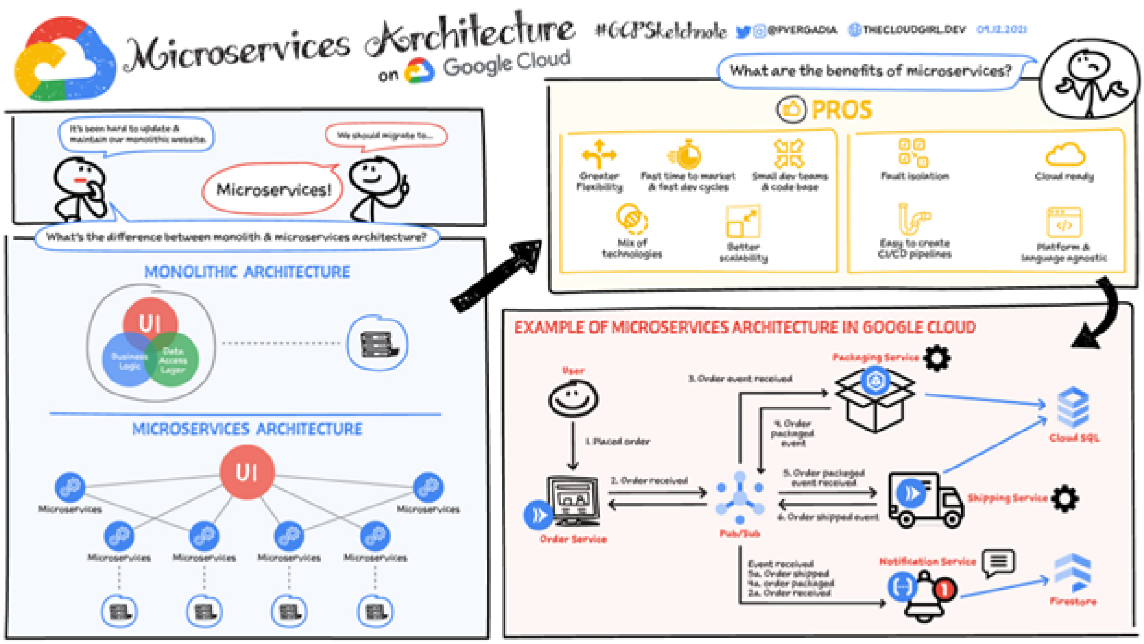

Figure 11. Process Chart from Google's Cloud Network Architecture. Source: Vergadia (2021)

Amazon Cloud Architecture is also using multiple services within its applications to achieve a horizontal hierarchy within their system. This organization of microservices creates less burden for the hardware. Creating a decentralized system through microservices that can work independently, as well as being capable of being upgraded, scaled or replaced without affecting the system (Amazon Web Services, 2022).

Google operates like the way Amazon uses CNA, Google uses the decentralized system of microservices to operate cloud applications. Using this system allows for updates and scalability for many applications and online based services. CNA has become a standard to operate these large online services at the current scale of operation. This system is a grand example of an effective MOSA application, not only in its use of independent multiple services but in its continuous improvement. Open Architecture has allowed these services to adapt over the years and keep pace with many software and hardware advances, establishing a longevity that MOSA aims to bring to DoD Acquisition.

3. Medical Capsule Robot

The I-Corps Team developed a unique device for healthcare professionals to minimize the invasiveness of endoscopic and surgical procedures. The Medical Capsule Robot (MCR) is a capsule robot aimed at serving the purpose of improving surgical methods, "Capsule robots are meso-scale devices that leverage extreme miniaturization to access and operate in environments that are out of reach for larger robots. In medicine, capsule robots can be designed to enter the human body through natural orifices or small incisions, and to perform endoscopy and surgery while minimizing the invasiveness of the procedure" (Marco et al., 2014). Figure 12 highlights the communication between the MCR and computer hardware/software. Since there is no standard hospital operating system, the MCR needs the ability to be utilized, regardless of the system the operators are using.

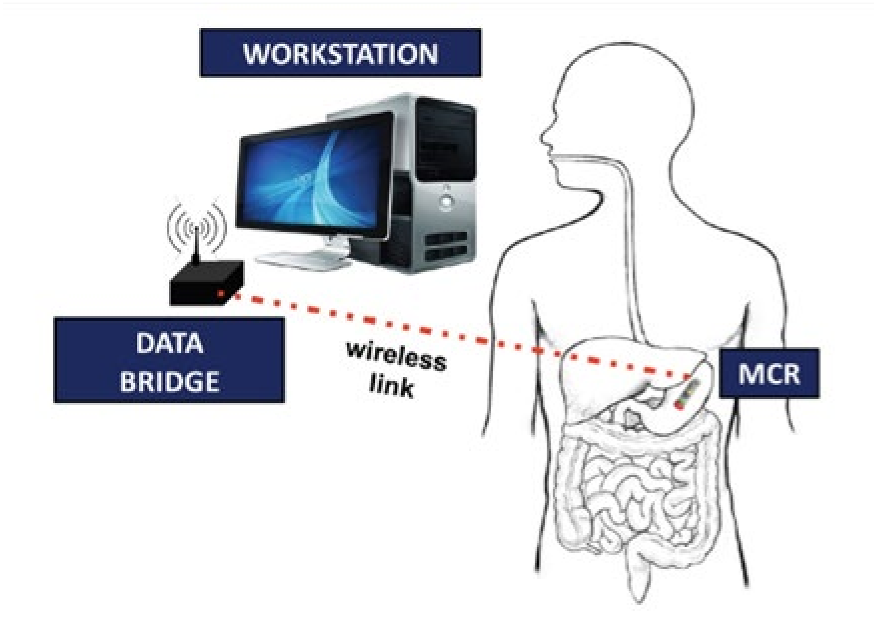

Figure 12. Basic Concept of MCR Function. Source: Marco et al. (2014)

The MCR is made with the intent of adapting to procedures. To achieve this adaptability, the MCR requires a flexible architecture with reduced development. “This laid the groundwork for the implementation of several devices based on one-time hardware prototyping with the support of reconfigurable firmware architecture. By adopting this approach, the firmware development time can be reduced drastically by software layering” (Marco et al., 2014). The prototype can apply different software for the chosen procedure. This captures the core objective of MOSA, an open system architecture that allows for wide use and versatility in its software and hardware. Additionally, the modularity and reusability of both its hardware and software make the field more accessible to the research community (Marco et al., 2014).

The open architecture of the MCR allows for the potential of expanded research, allowing other researchers to experiment and benefit from the prototyping process, but not only for the medical field but also other STEM fields of study as well. By having a platform that utilizes both modular hardware and software, the entry barrier is lowered, allowing for more design space exploration, granting accelerated progress in prototyping (Marco et al., 2014). STORM labs further break down the primary benefits from the modular approach, The paper from Marco proposes that the Stormlab Modular Architecture for Capsules (SMAC) is a MOSA platform based on the module’s reusability, reconfigurable software library, and support from the free open-source community (Marco et al., 2014).

The potential to open a free source library, with reconfigurable software and module reusability, grants freedom in design and implementation without risking IP rights or vendor lock-in. Right now, the MCR does have specific design requirements to meet its surgical needs. The first requirement is that it, "must fit the internal diameter of a surgical port, typically from 3 mm to 12 mm" (Marco et al., 2014). The second requirement is that it must, "have been designed with a round-shaped Printed Circuit Board (PCB) having a maximum external diameter of 9.8 mm" (Marco et al., 2014).

Though that is expected for an initial prototype, the system itself is what will lead to greater strides in innovation. SMAC utilizes software modularity by providing the users with interfacing layers to the existing hardware modules (Marco et al., 2014). The SMAC benefits from having MOSA inspired software to take advantage of the rapid innovation that is occurring, and the hardware in use needs to be able to accommodate future software requirements. "Concerning the hardware, a SMAC-based MCR embeds miniature modules connected together by the developer to accomplish the desired task. Each miniature module provides a distinct functionality, such as wireless communication, powering, digital or analogue sensing, actuation, vision, and illumination" (Marco et al., 2014).

The MCR is an exciting use of open architecture and exhibits MOSA qualities, but the downside to the MCR comes from the modular approach itself. To be able to be versatile and adaptable to a multitude of procedures, it cannot be specialized for any of those procedures. "The main downside of a modular approach, however, is that a system made of modules is not optimized for the particular application, and it usually requires more space compared to a custom device" (Marco et al., 2014, p. 3). To achieve an open system, the sacrifice that must be made is the ability for the robot to be specialized. Overall, the MCR will be good at many things, but never perfect for a specific task.

Further efforts to improve the MCR are still being made and fill the gaps using this modular approach. By creating and establishing an open library of software, future proofing takes place by expanding the material available to modify the MCR. "Future work will aim to extend the SMAC libraries to include additional microprocessors, sensor and actuator modules, and wireless transceivers implementing different communication protocols and carrier frequencies" (Marco et al., 2014). MOSA is present in the MCR as it effectively incorporates MOSA concepts in its design and execution. The MCR is a great example of not only the innovation and applicability a modular approach can do for innovation, but also accurately depicts limitations in its use of MOSA, due to lack of special design for specific purposes.

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V. SUMMARY

From the research conducted and the analysis of our findings, we will address the limitations of our research, such as: the format of data collection, availability of resources, and the lack of history regarding the topic. We will also suggest recommendations the DoD can make, based on the results of our findings. We will conclude with our recommendations for future researchers to further examine this topic for the generation of new data.

A. LIMITATIONS

The first limitation for our analysis comes from the desktop research format. With the use of desktop research, we were able to gather a wide variety of publicly available sources that covered the general material of the cases we developed. However, the use of interviews could have been beneficial in gathering further insight into the determination and application of MOSA in the acquisition and developmental process. The next limitation is the availability of source material. For the DoD case, many of the details needed to elaborate on our findings were limited due to the classification of these programs for national security. Like the DoD, commercial companies safeguard their IP data, such as their design information, to maintain their competitive edge in their respective markets. Finally, MOSA is a recent platform used in the DoD. MOSA was codified by congress in FY19 and mandated for use in FY21. Due to the recent implementation of MOSA, the availability of resources was limited to a few references that have recently covered this topic.

B. RECOMMENDATION FOR THE DOD

The first recommendation we have for the DoD, based on our findings, is to avoid restricting MOSA into one acquisition category, which is ACAT I MCA MDAPs. Based on the information in our literature review, MOSA can be applied into additional acquisition pathways to expand its use, as well as prevent design failures in acquisitions prior to their transition to MDAPs. For example, UCAs rely on rapidly filling capability gaps to meet the evolving needs of the warfighter in a short timeframe but are vulnerable to accepting proprietary systems that do not allow for efficient adaptability/upgradability.

Additionally, MTAs focus on rapid prototyping and fielding to meet capability requirements in five years or less. Like UCAs, MTAs are vulnerable to accepting proprietary systems, due to its rapid acquisition cycle. This could limit the DoD's ability to expedite innovation that could come from collaboration in the rapid prototyping/ fielding phases. While UCAs and MTAs aim to expedite acquisition timelines, Software Acquisitions aim to make the capabilities acquired iterative, allowing for continuous improvement. The iterative nature of software acquisitions mirrors the concepts of MOSA through iterative design and continuous improvements that should be incorporated into additional pathways.

The second recommendation for the DoD is to avoid labelling more acquisitions as ACAT I MCA MDAPs to require the use of MOSA. Requiring this designation of acquisition programs would mitigate the benefits of the previously mentioned acquisition pathways such as rapid development/fielding and iterative design philosophy. By avoiding this, the DoD can benefit from the efficiencies that MOSA allows, such as: reducing the cost and time during the R&D phases, diversifying the vendor pool which would increase competition, accelerate innovation, and future-proofing programs to reduce life cycle costs by incorporating commercially accepted standards. Rather, the DoD should focus its efforts implementing the first recommendation and capitalize on MOSA's benefits across all acquisition pathways.

The third recommendation is to develop a tool that could be used to assess the implementation of MOSA in a system. When reviewing the DoD cases, there was no documentation to support the claim assessing the level MOSA applied to the design philosophy of these platforms. For example, the F-35 was intended to be designed with the concepts of MOSA at the core, however it would eventually be plagued by the use of proprietary information and tooling that drastically hindered the government in performing maintenance and upgrades. The tool could be used to generate a numerical score of a system's application of MOSA concepts. This could be accomplished by assessing the program's use of the following objectives: commercial standards, open business practices, and treatment of proprietary elements. Efforts towards this recommendation have already been made in the form of the "Opens Architecture Assessment Tool" (Rendon, 2007, p. 9-18) which uses an Excel-based approach to assess the previously mentioned objectives. The DoD should treat this tool as a baseline that should be refined and standardized across all services, for the use of evaluating openness of a program's initial design proposal. The tool should also be used to reassess the level of openness upon the completion of each design phase, to ensure consistent application of MOSA concepts.

The last recommendation for the DoD is to institute an approach to interservice collaboration between programs that are developing similar capabilities. Just as AUTOSAR fosters collaboration among different automobile manufacturers to reduce research and development time and costs, so can the DoD. AUTOSAR is the standardized software infrastructure for the automotive industry, which uses collaboration among competing companies to establish a joint effort. We recommend a concept that mimics that of AUTOSAR, which would involve a collaboration amongst the different services in the DoD. The Air Force, Navy, Army, Space Force and the Marines should collaborate on procurements for overlapping capabilities and establish standardization to reduce redundancy, encourage interoperability, and streamline innovation. Standardized guidance and personnel, from each service, will be required to successfully implement this strategy. Regarding guidance, all services would need to establish a common operational picture to guarantee the mission objectives and required capabilities of each service are met. Additionally, we recommend that each service provides acquisition personnel to form an organization that focuses on the implementation of MOSA and meeting these objectives.

C. RECOMMENDATION FOR FUTURE STUDIES

As research into MOSA is limited, we recommend pathways to further progress knowledge and efforts to better educate and guide others on the topic. We suggest conducting follow-up research on the DoD applications to assess how well their development has progressed, and the levels of interoperability they possess. This will determine the degree of MOSA. Following continued research of our stated applications, we would also suggest expanded research on incorporating, assessing and incentivizing the use of MOSA. Our final suggestion would be to continue building the MOSA database based on this thesis and following the parallels between DoD acquisitions and industry. With the recent introduction of MOSA in FY20, information is limited, and we encourage future research to track the progress and catalog new data to create continuity for personnel to witness. This will generate valuable data for lessons learned, which can be extended to the DoD acquisition community and researchers.

D. CONCLUSION

In conclusion, MOSA has the potential to enhance the DoD's acquisition efficiency and technological innovation, provided it addresses the challenges identified in this research, such as: expanding regulatory limits, technical data rights, late implementation, and interservice coordination are properly addressed. The DoD should apply the lessons learned from the commercial sector, such as: AUTOSAR's external cooperation, MQB's common standards integration, CNA's independent software capabilities, and MCR's dedicated research pool. By implementing these lessons learned, the DoD can reduce costs, accelerate innovations, and promote system scalability in response to evolving demands. However, the DoD has the unique issue of proprietary systems and restrictive vendors that limit system interoperability and efficient upgradability.

By incorporating MOSA across all acquisition pathways and adopting an open and collaborative framework, per the commercial sector, the DoD could gain greater flexibility and reduce redundancies. Moving forward, the DoD should expand MOSA policies across all acquisition domains to increase efficiency.

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