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Investigating Potential Improvements to MBSE Software to Support DoDAF

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Investigating Potential Improvements of MBSE Software Tools to Support DoDAF

by

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Abstract

Title: Investigating Potential Improvements to MBSE Software Tools to Support DoDAF

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The integration of models created through model-based systems engineering methods with DoDAF is not a new concept. By creating DoDAF-aligned models, DoD program managers are following DoD guidelines to hopefully achieve more effective communication with stakeholders and improve efficiency of their programs. With the use of MBSE tools to create these models, DoD program managers are able to take further advantage of the benefits of MBSE methods. However, even with the use of MBSE tools, there continue to be issues throughout DoD programs. The literature has shown that a continuous improvement approach regarding the use of MBSE tools with DoDAF and within DoD programs may result in significant improvements to DOD processes in terms of comminucation, efficiency, and integration. This study provides an investigation on the current status of these tools and their functions that are most commonly used by people in the defense industry. The research aims to suggest potential improvements to these tools based on reviewed literature and interviews from industry professionals for future development to further modernize DoD program management. Keywords: model-based systems engineering, architecture framework, program management

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Dedication

To John, thank you for being by my side throughout this process. Your support and encouragement were essential and I am forever grateful. I never would have gotten here without you.

Chapter 1
Introduction

Introduction

Over the last 20 years, the use of digital engineering (DE) and model-based systems engineering (MBSE) has taken off in the defense industry, both within the United States and outside [1]. The benefits of DE and MBSE include improved communication between project members and stakeholders, clearer understanding of the project, traceability, and risk reduction [2]. In order to take full advantage of these benefits, the defense industry applied the already-existing Department of Defense Architecture Framework (DoDAF). This framework in general enables effective communication, informed decision making, and easier management of complex systems. In addition, the framework creates consistency, interoperability, and alignment of systems and processes across different departments and organizations within the DoD.

Over time, the process of fitting MBSE models into DoDAF structure evolved to be more efficient, shifting from manual conversion to using integrated software tools. These software tools serve a variety of purposes that range from converting file formats to full modeling environments with DoDAF or other framework integration. Because of this innovation, it is easier than ever to convey complex project information from a defense standpoint. By enabling faster integration of models and DoDAF structure, DoD program managers can improve efficiency and use the time that would otherwise be spent converting models manually to further the goals of their program and team.

While the use of MBSE tools has greatly improved modeling within the DoD, there is always a need for continuous improvement. The DoD is constantly evolving and must ensure that it is capable to staying ahead of adversaries. This need is aligned with the DoD Digital Engineering Strategy that was published in 2018 [3]. In addition, the needs of systems engineering (SE) users are constantly evolving and the future of SE must be more iterative and responsive to user needs [4]. By identifying potential improvements in MBSE tools that are used by defense industry professionals on a regular basis, we can push forward the modernization of these tools to keep up with changing industry needs.

In this thesis, we address the benefits of MBSE tools and how they integrate with DoDAF. This will lead us to suggest improvements to better fit the needs of DoD program managers. This information is intended to improve DoD program management in efficiency and effectiveness. In this section, a background of the research is provided as well as further defining the research objectives. The proposed methodology is a systematic literature review that is complemented by an interview of industry professionals that use these MBSE tools. This is further detailed in Chapter 2. Chapter 3 analyzes the resulting information obtained from the research methods. Chapter 4 presents the conclusions from this study and recommendations for future research on the topic.

Background and Problem Statement

DoDAF is an architecture framework that was created by the DoD to replace the Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) Architecture Framework in 2003 [5]. These frameworks were originally created to enable DoD managers to make key decisions more effectively. Key features of these frameworks, specifically DoDAF V2.0, include DoDAF-described models and fit-for-purpose views. DoDAF-described models are created based on a subset of data for the application while fit-for-purpose views are "user-defined views of a subset of architctural data" [6]. These different features allow DoD managers to convey a variety of information in a way that is more flexible than the C4ISR Architecture Framework.

The architecture frameworks were originally created in response to the need of a standardized framework to present information across departments and organizations. For example, the United States Department of Defense has DoDAF, and the United Kingdom created the Ministry of Defense Architecture Framework (MODAF). After the publication of DoDAF V2.0, the Object Management Group (OMG), creator of the Unified Modeling

Language (UML) and the Systems Modeling Language (SysML), published the Unified Profile for DoDAF and MODAF, also known as UPDM [7]. This profile was intended to work with DoDAF as it provides a comprehensive structure for modeling that could be utilized by more than the United States DoD.

After UPDM was developed, the Unified Architecture Framework (UAF) was published to incorporate DoDAF, MODAF, and the North Atlantic Treaty Organization (NATO) Architecture Framework (NAF) [8]. With each new framework, expansion took place to encompass more organizations to further enable interoperability. The goal of the different developments was to keep up with the ever-growing demand for modernization in the defense industry.

Within the architecture frameworks are guides to developing viewpoints and models, meaning the use of MBSE tools comes naturally with the integration of DoDAF. MBSE tools are used for a variety of reasons that includes creating models of systems and systems of systems (SoS). There are multiple benefits associated with the integration of DoDAF with MBSE that have been previously studied at length. These include the capability of communicating across a broad audience, effectively making key decisions, replacing text-based documents with models for easier visual understanding, and many more [9].

While the defense architecture frameworks were being developed, modeling tools for MBSE methods were evolving as well. Modeling tools such as Core, now replaced by GENESYS, by Vitech or Cameo Enterprise Architecture by Dassault Systemes were created for the purpose of modeling systems. Each tool operated as a platform that was integrated with aspects of the system development lifecycle (SDLC) to enable creation of systems and systems-of-systems. The developers of these tools are constantly updating them to ensure they are meeting industry needs and staying competitive in the marketplace. Examples of these modeling tools include Cameo Systems Modeler and Sparx Enterprise Architect.

With the growth of primary MBSE tools and capability maximization, additional tools were created to work in conjunction and fulfill any gaps that may exist between softwares. Each tool is designed to fit specific customer needs while incorporating aspects of other tools for cohesion. For example, the SODIUS Publisher family of modeling tools operate as a plugin for other modeling tools such as IBM Rhapsody, IBM Ration Software Architect, or UNICOM System Architect [10]. When used together, it is possible to convert the applicable modeling file format into a Cameo MagicDraw file format. The MagicDraw file format is preferred because it allows for easier sharing, version control, and interoperability compared to others. Additionally, some DoD contracts require delivery of MagicDraw of Cameo model files meaning this conversion from other modeling tools is essential.

Even though the use of MBSE is still growing in the defense industry, the use of modeling tools is essential to convey important system information. By using the tools in conjunction with available architecture frameworks, communication across a variety of audiences is possible, and efficiencies of programs and projects are improving. With this capability comes the need to keep up with evolving technology and processes, which is the purpose of this research. Continuous improvement in the use of MBSE tools with DoDAF means that DoD processes will become more efficient with improved communication and addressing perceived drawbacks of integration such as increased cost and worsened capability [11].

Additionally, the DoD has a long history of program cancellations without any or few operational results. Between 1997 and 2016, the DoD had spent an additional $62 billion on programs that were eventually cancelled [12]. Studies done have analyzed the critical factors to DoD acquisition program terminations. This resulted in identifying that there is a need for the DoD to continue investment in understanding system requirements as well as investing in program manager training and equipping those managers with the appropriate tools. Equipped with this information, there is a path to follow on the investigation of improving DoD program management that emphasizes the use of MBSE and DoDAF.

The rapidly evolving world and MBSE's growing part in the defense industry means it is important to preemptively identify and address the needs of the warfighter. Current MBSE tools have grown to incorporate the aspects of DoDAF and studies have presented key benefits that can be gained by the incorporation of the two. To capitalize on these benefits by identifying potential areas for improvement is to ensure the continuous improvement of DoD processes and constant support of the warfighter.

By analyzing historical information about the use and evolution of architecture frameworks, it is possible to understand the need for these frameworks and anticipate future evolution that may impact the use of MBSE within the defense industry. In studying the capabilities of the currently available tools, needs of users can be identified and addressed to improve effectiveness and efficiency within DoD programs. This research is essential as it is the start to identifying improvements that can benefit users of MBSE tools and especially DoD program management.

Research Objectives

While the goal of the research has previously been identified, there are objectives that are relevant to help guide the research. We can use these research objectives to focus on our goal of innovations in MBSE tools with respect to DoDAF or equivalent framework integration. The primary research objectives are:

1. Trace the evolution of defense architecture frameworks and their role in advancing MBSE within DoD programs.

2. Assess how systems engineers currently employ MBSE tools alongside these frameworks in the defense industry.

3. Propose advancements for MBSE tools aiming to modernize DoD program management, including implementation strategies.

4. Describe the anticipated impact of these innovations and propose future research directions for continuous modernization of DoD program management.

These research objectives are important to keep in mind while following the research methodology and analyzing the compiled information as they help narrow the search for information that aligns more closely with the goal. By tracing the evolution of the defense architecture frameworks, we can clearly define the current state of integration of MBSE tools with these frameworks. In assessing how systems engineers currently utilize MBSE tools with the frameworks in the defense industry, we can identify the needs of the consumers and propose advancements for these tools. An important note is that any advancements of tools would typically be expected to come from the tool vendor being used, which could impact any implementation strategites that are suggested. Another research objective that helps fulfill the research goal is to describe the anticipated impact of these innovations and possible future research to pursue.

These objectives provide a solid base to build the research on. Each strives to answer the question of how to modernize DoD program management by integrating MBSE with DoDAF or equivalent frameworks. Having clear research objectives helps provide guidelines for conducting and effectively communicating the progression of the research. Throughout this paper, the stated research objectives will be referenced to ensure alignment with the intended purpose of the research.

Chapter 2
Methodology

Literature Review

The methodology that was used in this research was a systematic literature review. By performing such a review, we gain a comprehensive understanding of the topic and its applicability as well as understanding of the literature that has already been done. Additionally, systematic literature reviews are able to reveal information through the analysis of existing studies and identify gaps that may be worth researching further. The comprehensive list of literature that was reviewed is included in the References section of this thesis.

The first portion of the literature review includes the evolution of defense architecture frameworks to the present day. This portion reviews the relevance of the topic as these frameworks are continuously evolving to fit the world around them. The second portion of the literature review targets the integration of MBSE with DoDAF in DoD programs and other organizations in general, and its overall qualitative impact. A small addition to the literature will also include a brief discussion on the quantification of the benefits and impact of MBSE practices. This portion is not comprehensive, but it presents ideas that were identified during the course of the research that are relevant to the topic.

DoD websites and publications were primarily used to collect information on the evolution of architecture frameworks in the defense industry. This is due to the fact that the defense architecture frameworks were originally created within the department itself. However, these frameworks have evolved to include other organizations, such as UAF which was published by the OMG. For information on the current frameworks being used, information was obtained from the OMG website as well as the INCOSE website.

To obtain the most applicable articles for MBSE-DoDAF integration research, a search of papers including specific keywords was conducted. The primary keywords for the search included “model-based systems engineering” or “MBSE”, “Department of Defense Architecture Framework” or “DoDAF”, “integration”, and “software” or “tools”. These keywords were identified based on the research question and objectives, and phrasing was adjusted to find niche peer-reviewed documentation.

The search was performed using *Google Scholar* as well as the Florida Institute of Technology’s (FIT’s) Evans Library online system. First, a search using phrases that included the keywords was conducted in the *Google Scholar* search engine. Upon identifying literature that appeared applicable based on the article title and abstract, the title was entered into the search function of the FIT library online system and access to the full document was gained for review. Additionally, there are DoD-specific sources such as the DoD Document Archives as well as the Defense Information Systems Agency (DISA) that are not publicly available and therefore further documentation on the use of MBSE within DoD programs is limited to what was researched through *Google Scholar* and the FIT Evans Library databases.

While finding literature review, case studies regarding the use of MBSE tools were also researched to provide context. In addition to these case studies, product brochures from MBSE tool developer websites were compiled to create a list of tools used in industry. These sources provide information on MBSE tool capabilities that will be analyzed as part of the literature review process. While these sources are not peer-reviewed, they are directly from the tool developers and are the most accurate when analyzing the capabilities of tools that systems engineering professionals are using in the defense industry. Additionally, the vendor’s websites were scoured for available information on the quantitative impacts of their modeling tools and no information was discovered.

Interview

While the literature review is intended to be the primary source of information in this study, interviews were also conducted with industry experts. The interviews act as a complement to the literature review and provide real-world context for applications and information that are observed through the literature. The ultimate goal of these interviews was to determine how relevant DoDAF-integration MBSE tools are in everyday defense industry work.

The interview questions were determined based on the research topic. Each question was thoughtfully curated to ensure the interview process and intentions was clear to all parties involved. The interview participants were asked to provide their background and experience in the industry. From there, interviewees were asked questions that were aimed at determining applicable MBSE tools, how these tools are used, and how much time they spend using these tools versus how much time they spend typically applying DoDAF or equivalent architectures to their models. A copy of the interview questions is located in Appendix A.

Chapter 3
Results

Literature Review Findings

For this literature review, over 50 pieces of literature were idenfied and reviewed to provide context and understanding for this research. The review is also broken into portions that discuss an important aspect of the research. The first portion of the literature review presents the evolution defense architecture frameworks across decades. The second portion of the literature review delves into the integration of MBSE with DoDAF, consisting of integration on an organizational level as well as what tools are used for this integration.

Tracing the evolution of defense architecture frameworks

Understanding the evolution of defense architecture frameworks directly supports the research objective to create a foundation of knowledge on the current state of defense architecture frameworks. In order to suggest effective innovations on the integration of MBSE with these architecture frameworks, we must know where the frameworks started, what developments have been made, and any current progress already being made. By studying the background of defense architecture frameworks and having a solid foundation, we can ensure that the suggested innovations are applicable and would be beneficial to DoD program management.

TAFIM was the original DoD architecture framework that began development in 1986. This framework provided guidance for the evolution of DOD technical infrastructure [13] However, TAFIM took a few years to reach publication and was ultimately cancelled after nearly 16 years of development. TAFIM was cancelled in 2000 due to the extensive amount of resources required for support [14]. In addition, TAFIM was seen as extremely inefficient, and ill-prepared to be used for communication across a wide audience [15].

Before TAFIM was cancelled however, the C4ISR Architecture Framework was published. When the C4ISR Architecture Framework was initiated in 1996, the intent was to develop and establish an architectural guidance that would be comprehensive for all of the DoD. It was identified by Sowell & Mclean [16] that the evolution of the C4ISR consisted of a widened scope to include more DoD-wide applications as well as improving previous versions in accordance with lessons learned and new tools and technologies of the day.

DoDAF was published in 2003, replacing the C4ISR Architecture Framework [17]. The original DoDAF only had four basic views and it was intended to improve the C4ISR framework by restructuring in a way that broaded the applicability of the architecture. DoDAF in its current state has 7 viewpoints as well as over 30 different models [6]. This broadening allows for a variety of applications and the freedom of choice for decision-makers and process owners to determine what is best used for their objectives.

UPDM was developed in 2008 as a profile that combines DoDAF and MoDAF. The creation of UPDM was a collaborative effort between members of International Counsel on Systems Engineering (INCOSE) and the OMG. This indicates initial moves from the development of architecture frameworks and related applications to outside the DoD and the expansion of the reach of DoD-defined architectures across national boundaries. As Hause [18] detailed, UPDM is not a replacement for either DoDAF or MoDAF but rather it specifically provides an integration of DoDAF 1.5 and MoDAF 1.2 architectures within UML-based tools to promote interoperability. Additionally, UPDM was updated to version 2.0 to include NAF 3.1 and updated DodAF 2.0, as shown in Figure **3-1**.

The UAF was developed by the OMG in 2015 and further incorporates DoDAF and MoDAF with NAF. The primary drive behind this update to a new architecture framework was because the nuances between DoDAF, MoDAF, and NAF continued to interfere with interoperability [5]. In addition to the creation of UAF, a profile for UAF was developed similar to UPDM, notably called UAFP. An important note is that UAF was intended to provide a model that can be used by non-UML/SysML tool developers. This would expand the use of UAF to beyond the typical users. UAF also aligns with current OMG standards and allows for enterprise lifecycle interoperability, as well as supporting mission engineering activities [19][20].

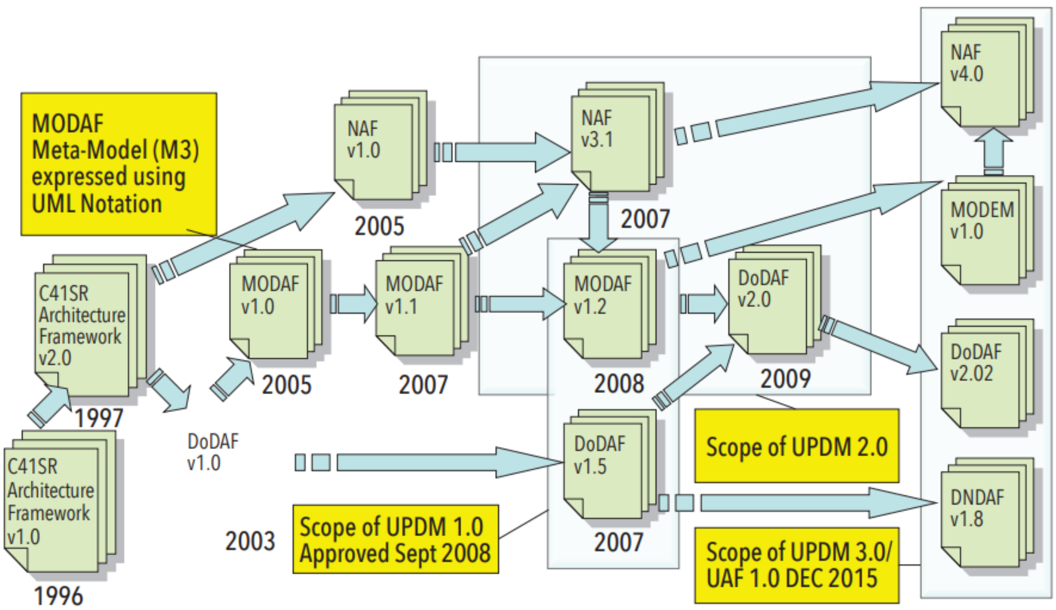

Figure 3-1: Simplified evolution of defense architecture frameworks [5]

Figure **3-1** as visualized by Hause *et al.* provides a simplified evolution of defense architecture frameworks [5]. This provides a visual representation of the previously discussed architecture frameworks, including the specific version and its development and publication year. Overall, the development of these frameworks has been fairly straightforward. The primary reason for development is to keep up with the changing industry as well as provide a more comprehensive and interoperable space for defense industry organizations.

Integration of MBSE with DoDAF

In addition to understanding the evolution of architecture frameworks, researching the literature for information on the integration of MBSE with DoDAF can provide context for possible innovation suggestions. As shown, the use of architecture frameworks even outside the U.S. is a relevant topic when modeling defense systems [21]. Some aspects of the literature that was reviewed focused on the challenges of implementation and integration within companies as well as with these architecture frameworks. Additionally, the primary integration of MBSE with DoDAF relies heavily on the use of modeling tools. By reviewing the literature and compiling the tools that are currently available to defense industry professionals, it may be possible to identify gaps in capabilities of integration and use of these tools.

A large part of the integration of MBSE with DoDAF starts with the deployment of MBSE on an industry and organizational level. A thesis published in 2023 by Pandolf [22] introduced an investigation of challenges in MBSE integration in companies and proposed improvements to the process. This research examined companies within and outside the defense industry and determined that the most key integration challenges were related to technical development as well as MBSE language conflict and management of the applicable data. Additional challenges included resource allocation, employee skills, project schedule, project deliverables, and associated risks. Additional literature by Torok contributes that users of the frameworks and modeling software must have a deeper understanding to ensure a system is captured properly, which aligns with the need to improve employee skills regarding the use of MSBE and modeling [23]. In addition, Henderson *et. al.* and other studies stated that the integration of MBSE is significantly impacted by the interoperability between tools themselves as well as across organizations [24][25][26].

Hause *et al.*, among other literature, also found that the interoperability between modeling tools is difficult to manage [5][27][28], which aligns with the conclusions from Pandolf. Even in 2011, Ramos *et al.* contributed that the integration of common modeling languages, such as SysML, to create "an effective collaborative development environment" would be a key challenge for the future of MBSE [29]. Additionally, Heidary *et al.* identifies from their research that two initiatives with regards to implementing Reliability and Maintainability (R&M) through UAF. These initiatives include improving the skills of reliability and safety engineerings on the application and use of MBSE as well as improved collaboration between MBSE tool vendors and R&M tool vendors to increase interoperability and expand software usage [30]. Martin also found in 2023 that when modeling with UAF and SysML, there are issues with mapping the different elements and can make navigation in the model increasingly difficult [31].

Best practices identified by Henderson *et. al.* and others included the notion that the integration of MBSE within the industry should be taking place at the organizational level as well as the technical level [32][33]. Additionally, Carroll & Malis found that there was significant performance success could be maximized when a systems engineer was assigned as the leadership over engineering processes. [34]. Along with the previously identified challenges to integrating MBSE with DoDAF and on an organizational level as a whole, these identified inefficiencies have the potential to be mitigated by thoughtful innovations suggested by the literature as well as within this study.

In understanding the challenges associated with integrating and implementing MBSE strategies within organizations, discussion of current tools being used within industry becomes relevant as well. The challenges mentioned in the literature included the interoperability between these tools as well as between organizations. A review of the currently available MBSE tools took place. These specific tools are found throughout the literature and are used within the defense industry. While this list is not comprehensive, it indicates the most referenced within the literature and available online. There are many tools, which can make identifying the most appropriate tool for the desired MBSE approach challenging [35] but when the proper tools are used, benefits of using MBSE can be observed.

There are multiple types of available tools that can be divided in different categories. The first category is whole modeling environments that encompass the entire system design, development, and management phases. These tools are broad and can be used throughout the entire SDLC. The second category of tool identified through the research is MBSE-aspect tools that are designed to be utilized for a single portion of the system lifecycle. This has the potential to then be later integrated into the whole system model. The use of this type of tool allows for teams to work on specific aspects of a project, such as requirements management, without wading through the entire system. The final type of tool that is available are the conversion tools that are used to convert working models into more desirable formats to support interoperability. This stems from the need to ensure interoperability between models and potentially even across organizations.

Despite having different purposes and overall abilities, there are common tool capabilities that are available across the MBSE tools identified in Table 3-1 [10][36][37][38][39][40][41][42][43][44]. The first and most relevant capability is that all of these tools have some degree of architecture framework integration. Each vendor's webside identifies the different architecture frameworks that are integrationed within the software. Some tools include one one or two different frameworks while others are integrated with nearly all current frameworks, both in defense and conmercial industries. Another capability that is common across the tools is the use of a standardized modeling language, such as UML or SysML. While some tools directly use UML and SysML, others created their own modeling language but they are explicitly based on the latter. The third common capability is cross-platform accessibility to some degree. Some tools are able to work with Microsoft Office while other tools directly enable interoperability by converting file formats. The fourth capability that is identified is the use of collaboration between project team members or even stakeholders. Most of these tool vendors advertise the capability of collaborative efforts within their tools. The final tool capability is the generation of reports, which is essential in industry for documentation purposes. Majority of these tools offer automated and manual report generation capabilities.

Table 3-1: Commercially available MBSE tools

MBSE Tool	*Description*
IBM®	
Rational DOORS	Comprehensive requirements management tool that includes the capture, tracing, analyzing, and managing defined requirements for a system. It allows for collaboration, linking of requirements, and integation with other IBM products and other third-party tools.
Rational Rhapsody	Modeling tool that includes system management, collaborative design development, and test environment. It also supports various architecture frameworks and conforms to industry standards.
No Magic Inc./Dassault Systèmes	
MagicDraw	Development tool to support analysis and design of Object-Oriented (OO) systems and databases that includes capabilities such as support for Java, C++, database schema modeling, DDL generation and reverse engineering.
Magic System of Systems Architect	Modeling tool designed for modeling and analyzing systems of systems (S0S). It allows for managing complex interconnected systems and interactions, and includes features such as dependency management, traceability, and simulation. Can be used together with MagicDraw.
Cameo Systems Modeler	Cross-platform collaborative MBSE environment that allows systems engineers to model all aspects of systems using SysML, allows for requirements management, traceability and gap analysis, report generation, and supports parallel development.
Cameo Enterprise Architecture	Enterprise architecture modeling tool that supports organizing and analyzing enterprise architecture information. It allows organizations to create detailed models using industry-standard frameworks such as UAF, UPDM, DoDAF, and others.
SODIUS MagicDraw™ Publisher family	Software extension that enables the exporting or migrationg of system models from other modeling tools and Cameo Systems Modeler/MagicDraw. Different Publisher products include conversions from IBM Rhapsody, Unicom System Architect, and IBM Rational Software Architect.
Vitech Core/GENESYS	Core (now discontinued) is followed by GENESYS is a modeling tool that is built on the Systems Definition Language (SDL) but still conforms to SysML standard. It allows for real-time collaboration, system lifecycle management, and alignment with DoDAF.
Sparx Systems Enterprise Architect	Ulitmate and Unified editions support SysML modeling, model simulation, and executable code generation. It also supports different architecture frameworks and provides a collaborative platform for MBSE applications that enables testing and quality control, reporting, and automation scripting.
Unicom System Architect	Enterprise architecture tool that enables the building and generation of data-driven views, specific to the organization. It supports various architecture frameworks, integration with other organizational tools, analysis for simulation and optimization, and reverse-engineering capabilities.

Quantification of MBSE benefits and impact in the defense industry

Through the course of the literature review, there was a consistent message across the recommendations for future research. This message was that there are very few studies that have taken place regarding the quantification of MBSE benefits and impact in the defense industry [45][46]. There are a few pieces of literature that do assess the quantification of versions aspects of MBSE methods as well as introduce frameworks for analyzing and quantifying the data [47][48][49]. For example, the research study performed by Whitehead *et. al.* was used to determine a framework for cost-benefit analysis of DE and MBSE benefits [50]. These researchers also performed a systematic literature review and were only able to identify six papers that included empirical evidence of benefits of MBSE.

Additionally, from surveys and interviews in a 2019 study from Huldt and Stenius, it was observed that there were no established methods that existed to measure menefits and efforts of using MBSE on an organizational scale [51]. Since its publication in 2019, along with the information given in Whitehead *et. al.*, there has been more progress of the quanitification of MBSE benefits and impacts on DoD programs and organizations, but the knowledge base is still limited in publicly available literature [27][52]. Additional research into MBSE impacts on DoD programs is taking place in a variety of disciplines, such as DoD contractors creating quadrupedal unmanned ground vehicles (Q-UGV) [53], refueling satellites [54], comparing MBSE to traditional SE approaches in architecting robotic space system through automatic information transfer [55], using configuration management in modeling aircraft landing gears [56], and in modeling Air Force Launch and Test Range System (LRTS) [57][58].

Interview Response Analysis

The interview process was used to determine how defense industry professionals use these MBSE tools within their work. The interview questions that were asked were targeted at determining participant experience in the industry with using defense architecture frameworks along side MBSE tools. A full list of interview questions is available in Appendix A. These interview questions and their answers from participants complements the literature review by providing context for the real-world integration of MBSE with defense architecture frameworks.

The interviews included three industry professionals, each currently employed in critical roles within the defense sector, specifically targeting those who operate daily with MBSE tools on aerospace and defense software projects. The range of their professional experience varied significantly, from as little as two years to over a decade. This diversity in experience enriched the data collected, providing a broad spectrum of insights into the application of MBSE tools. These participants also shared their frequency of using architectural frameworks, which varied from rare to monthly usage. An intriguing observation from the discussions was that managerial staff are often the primary users of these frameworks. According to one participant, managers are primarily responsible for the adherence to these frameworks, ensuring that all project communications align with the strategic directives set forth by both leadership and external industry partners.

The time invested by these professionals in aligning diagrams to fit specific frameworks varied widely, ranging from as little as 30 minutes to as much as three hours per session. This variation highlights the complexity and depth of work required to integrate MBSE tools with defense frameworks effectively. The predominant tool used among the participants was Cameo Enterprise Architecture, noted for its robustness and accuracy in delivering dependable outputs. However, a critical issue highlighted was the disparity in tool access and training within organizations, which hinders effective utilization. This point was particularly underscored by one participant who lamented that non-tool users often lack access to essential tools due to organizational policies that do not prioritize these investments, nor provide the requisite training for their use.

Additional participant insights included framework drawbacks such as generation of excessive documentation, extra labor hours required, concrete understanding of the frameworks, and understanding organizational priorities for the frameworks. These insights align with the previously identified challenges of MBSE modeling and DoDAF integration. While using the tools that integrate models with DoDAF may be less time consuming, the associated challenges with learning to use the tools, ensuring employees have the appropriate resources, and understanding proper application of the tools or frameworks morphe processes from simple tasks to massive undertakings. Combining these factors with lack of organizational interoperability results in an extremely inefficient use of employee time.

One particularly revealing insight from the interviews concerned the strategic direction in the development of defense frameworks. A participant noted that the DoD is stepping back from developing its own architecture frameworks. Instead, this role has shifted to the OMG, with the DoD providing support alongside international agencies. This transition aims to foster the development of more comprehensive frameworks that are suitable for both defense and commercial applications. However, this evolution poses new challenges, particularly regarding how the DoD ensures that the frameworks developed externally align with and fulfill specific defense requirements. This strategic shift highlights the ongoing evolution within the defense sector and raises important questions about future directions and the implications for national and international security protocols.

The interviews conducted offer significant insights into the current state of MBSE tool integration within the defense industry. The findings suggest a clear need for improved training, better resource distribution, and more effective organizational policies. Addressing these issues could mitigate many of the challenges currently faced by defense industry professionals, ultimately leading to more efficient and successful project outcomes.

Chapter 4
Findings and Recommendations for Future Research

Summary of Findings

The findings from the literature review, supported by an interview effort with industry professionals, reveal a variety of avenues for innovation. Through the literature, a solid foundation of the evolution of defense architecture frameworks was developed. With this, an understanding of the purpose of the evolution was uncovered and analyzed. When applying MBSE to these architecture frameworks and integrating them within the DoD and other organizationsl, several pieces of literature introduced challenges and recommended strategies for implementation. Currently available MBSE tools were then analyzed for their capabilities and compared to determine commonalities.

With regards to the evolution of defense architecture frameworks, they have continuously evolved since the original TAFIM was developed in 1986. An important observation from the most recent framework developments is that the creation and maintaining of these defense frameworks has moved from being developed directly by the primary users to development by external subject matter experts (SMEs). This change in development poses the question of how can the DoD ensure that their needs are still being met with these frameworks, despite not being the direct developer any longer?

From the literature, it is identified that the integration of MBSE and DoDAF within organizations has continued challenges that are worth researching. It was identified that there are certain integration challenges that are consistent across organizations. This finding was also supported by interview responses. These challenges included resource allocation, employee skills, project schedule, project deliverables, associated risks, and most notably the difficulties regarding interoperability between tools as well as between organizations. Additionally, from these challenges defined in the literature, clear communication between leadership, program managers, and team members is essential when it comes to large organizational changes. This finding also aligns with the interview response given that leadership is involved in the implementation process and provides employees with the resources needed to complete tasks efficiently. In order for DoD programs to be successful, there must be clear definition of expectations and priorities determined by leadership that is communicated from the top-down.

When reviewing the available MBSE tools and their capabilities, it was identified that there are quite a few commonalities. However, each tool has a specific application with regards to MBSE methods. It is important for tool users to understand the needs of their program to identified which tool would be best suited for their application. Additionally, there are indications from the literature that the current tool capabilities might not be enough to satisfy users. These findings are supplemented in the interview responses by industry professionals.

While studying the application of MBSE within DoDAF and DoD programs, it was identified that there may be an area of research regarding the quantification of MBSE impact in the defense industry. There are some resources available that attempt to quantify the impact, and there are additional studies that create framework for quantifying the information, however it would be beneficial to expand the knowledge base and perform additional research to contribute to this limited topic. Multiple studies completed within the last 5 years indicate the need for future research in this area, as it can provide empirical data for the use of MBSE and further drive research to streamline the integration of MBSE with DoDAF and within organizations.

Interview responses were obtained as a supplement to the literature. The responses that were gathered were intended to provide insight into real-world industry applications. The interview questions that participants answered related to their experience in industry, how they use defense architecture frameworks, and how they use MBSE tools to complete their work. Their responses supported aspects of the literature that were part of the research objectives, which helps reinforce the idea of the need for future research.

Implications

The implications of the literature review findings and interview responses include suggestions for MBSE tool improvement and subsequently identification of areas of future research as well as suggestions for DoD program MBSE integration. Through the literature, multiple areas were identified as needing improvement such as interoperability between tools as well as between organizations, integration on an organizational level as well as technical, and the need for clear communication on expectations and priorities from leadership. The suggestions provided from this research are not comprehensive but provide a good basis and understanding for the current state of MBSE integration with DoDAF and within organizations as well as the tools available for use by systems engineering professionals.

Based on the integration challenges presented by the literature and the interview response, it would be beneficial for DoD leadership to identify their goals and intent for use of DE and MBSE practices to provide clear expectations to program managers. From there, DoD program managers should be provided with additional training on architecture frameworks and MBSE methods and tools that align with these goals. By having proactive leadership, employees can be empowered to have a deeper understanding of their work and improve efficiency of their respective programs. This additional training would provide leadership with the results they originally anticipated by implementing MBSE practices.

There are also recommendations to enable employees to learn the use of MBSE tools and DoDAF integration themselves. MBSE tools could be developed to include highlight features for available frameworks within the software. This feature would be similar to the Microsoft Office suite where there are occasional “Tip” pop-ups that highlight new or applicable functionality, with the option to be disabled. However, these highlights would be based on the architecture framework usage within the MBSE tool and what result the user is intending to achieve. This innovation could also drive additional research and analysis to identify the most commonly used framework aspects. This functionality would help tool users understand the frameworks that they are applying better as well as potentially improve efficiency if employees are guided through the software while creating models.

The literature identified the need for more comprehensive integration across MBSE tools for exchange of information between different companies and organizations or introduce a standardized tool usage for use between organizations. While there are modeling tools that can convert between systems, these may not be comprehensive enough to meet user needs. MBSE tool vendors should complete a survey of their user base to ensure the customer needs are met and if not, how the current integration functionality should be improved upon. Additionally, users may not be informed of the existence of tools that can convert between modeling formats. However, use of these tools typically incurs additional costs and assumes any inefficiencies associated with their use. Additionally, there may be varying tool preferences across organizations and projects. This difference can result in extra labor hours and inefficient use of employee time, which can impact project delivery and other potential issues. Because of this, it may be beneficial to attempt at standardization of modeling tools to benefit the customer. Alternatively, modeling tool vendors could improve their internal processes to allow for deeper interoperability than what is already available.

Recommendations for Future Research

The research effort presented in this thesis work provides important insights that lead to future research areas. The literature that was studied provided essential knowledge that can be built upon further to ensure the knowledge base continues to grow. The following recommendations for future research questions were identified based on findings over the course of this research. The idenfied areas can help deepen the understanding and application of MBSE tools and defense architecture frameworks within the defense industry.

Enhanced integration techniques

There is a need for integration techniques which stems from discussions on the interoperability challenges and inefficiencies noted with current tools, as mentioned in Chapter 3 regarding the integration challenges and inefficiencies due to lack of interoperability. Researching the development of new methods or improvements in existing techniques for integration MBSE tools with defense architecture frameworks should continue to be expanded upon. The focus should be on reducing the complexity and time required for aligning MBSE models with frameworks like DoDAF, potentially through the development of automated integration tools.

Training and adoption strategies

This research identified that there is a disparity in tool access and training within organizations, which hinders effective utilization. To combat this, future research should investigate effective training programs and adoption strategies for MBSE tools, especially focusing on the organizational barriers to adoption. This research could also explore how different levels of experience among defense industry professionals impact the adoption and efficacy of these tools.

Impact of MBSE tool interoperability on project outcomes

The research identified that there are consisten challenges with interoperability of tools and their impact on organizational efficiency, which highlights the relationship between tool interoperability and project efficiency. To investigate this, studies should be conducted that measure how the interoperability of MBSE tools or lack thereof, affects project efficiency, risk management, and overall success of defense projects. This could include exploring the relationship between tool interoperability and project delays or cost overruns.

User-friendly design improvements in MBSE tools

This research highlighted the difficulties that participants noted regarding the complexity of tools. This suggests the need for more user-friendly designs to facilitate easier and more effective use of MBSE tools. Future research should explore the development of more user-friendly MBSE tools that require less intensive training. This could involve user experience research to identify common usability issues and subsequent design changes to enhance ease of use.

Long-term impact of MBSE tools

There is a need for continuous improvement on MBSE tools, as identified by this research, which implies a need to study their long-term impacts on defense projects. This future research should investigate any long-term impacts on defense projects, such as how they effect the lifecycle costs of defense systems and the long-term sustainability of defense projects.

Quantification of MBSE benefits

This research showed that there is a lack of comprehensive studies that quantify the benefits of MBSE. This highlights a gap in empirical data in this area of study. Further research should be done into quantifying the benefits of MBSE in the defense industry and focus on empirical evidence and metrics that can validate the effectiveness and efficiency gains from using MBSE tools.

Security aspects of MBSE tools

While not explicitly mentioned, there is an underlying importance of securing technological tools in defense applications that is a logical extension of the discussions on tool usage and integration. Future research should be conducted on the security aspects of MBSE tools. In particular, how can these tools be secured against cyber threats within the defense sector?

Conclusion

The push for DE and model-based methods within the DoD has made the need for additional research even more apparent. The DoD must stay on the cutting edge of innovation and requires more ways to do so [59]. By researching the use of MBSE with

DoDAF and other defense frameworks, it is identified that there are ways to improve current processes to strive for further modernization. While the use of MBSE within DoD programs has been studied extensively for these purposes, further research opportunities are presented by questions identified in currently available literature.

Based on the information in the literature review regarding the evolution of defense architecture frameworks, there is a need to identify how the DoD will continue to contribute to the development of these frameworks to ensure department needs are met. In doing so, the DoD can ensure continuous process improvement to stay ahead of adversaries. There are also several recommendations for improving the integration of MBSE with relevant architecture frameworks in the defense industry. This includes ensuring that MBSE tools are more user-friendly. This means they would require less intensive training prior to employees being fully capable of generating results, or leadership should be willing to accommodate the additional training needed by their members. Tools could also include features to guide users, similar to Microsoft products, such as optional “Tip” pop-ups or built-in infographics for applying architecture frameworks. Doing so would guide users and cut down on inefficient use of employee time.

With the suggestion of making architecture frameworks more user friendly within the software, there could also be user-friendly architecture framework guides developed by the publishers, likely the OMG. User-friendly architecture framework guides would enable employees to gain a deeper understanding of the topic while cutting out nonessential information that could be distracting for novice modelers. Improvements in the integration of MBSE organization-wide would include clear communication from leadership as well as setting expectations regarding implementation and organizational priorities.

Overall, this research helped investigate a crucial part of the defense industry’s modernization efforts. The research provided a background on an aspect of the industry that is constantly changing and evolving, suggested potential innovations to improve the use of MBSE tools to foster the integration with DoDAF and equivalent frameworks, and identified multiple areas of research that could be expanded upon. Several additional research questions were posed that would provide valuable insight should the future research be pursued. This research supports the modernization of DoD program management, meaning the DoD can keep up with emergent scenarios and the modernization of the warfighter. This also enables us to keep up with and outmaneuver our adversaries. Additionally, this research contributes to the knowledge base on the applications of MBSE applications with regards to architecture frameworks.

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Appendix A

Interview Questions

Title: MBSE Tools Usage Interview in DoD/SE Environments

Introduction:

Welcome to this interview on the usage of Model-Based Systems Engineering (MBSE) tools within the Department of Defense (DoD) and Systems Engineering (SE) domains. Your expertise and insights are invaluable in understanding current practices, challenges, and needs regarding the conversion of SysML diagrams into standardized architecture frameworks like DoDAF or UAF. Your participation is voluntary, and all responses will be kept confidential. Thank you for contributing to this important research.

Section 1: Demographics and General Information

1. What is your current role within your organization?

2. How many years of experience do you have in Systems Engineering?
   (Less than 1 year; 1-5 years; 6-10 years; More than 10 years)

3. Which sector best describes your primary area of work?
   (Defense, Aerospace, Software Development, Other - please specify)

Section 2: Framework Usage

4. How often do you use DoDAF, UAF, or equivalent frameworks in your projects?
   (Daily, Weekly, Monthly, Rarely, Never)

5. On average, how much time per project do you spend converting SysML diagrams to fit these frameworks? ________________ hours

Section 3: Tool Usage

6. Do you use specific tools or software to convert SysML diagrams into DoDAF, UAF, or equivalent frameworks? (Yes, No)

Note: Examples of MBSE software tools:

- DOORS by IBM
- Cameo Enterprise Architecture
- Magic Systems of Systems Architect (SoSA)
- MagicDraw
- MagicDraw Publisher by SODIUS
- CORE/GENESYS by Vitech
- Enterprise Architect by Sparx Systems

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Figure A-1: Page 1 of interview questions

a. If yes, please list the tools/software you use.

b. If no, skip to question 8.

Section 4: Evaluation of Tool Usage

7. If you use these tools:
    a. On a scale of 1 to 5, how confident are you in the results provided by these tools? (1: Not confident at all, 5: Extremely confident)

    b. What do you perceive as the main shortcomings of these tools?

    c. What additional functionality do you wish these tools had? (Open text field)

Section 5: Non-Tool Users

8. If you do not use these tools:
    a. Why have you chosen not to use them?

    b. Do you follow any specific procedures or guidelines for manually creating DoDAF-compliant SysML diagrams? (Yes, No)

        i. If yes, please describe them.

Section 6: Additional Insights

9. Do you have any other comments or insights regarding the use of MBSE tools for creating standardized architecture frameworks?

Conclusion:

Thank you for taking the time to complete this interview. Your feedback is crucial to understanding the current landscape of MBSE tool usage and improving practices within the DoD/SE community.

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Figure A-2: Page 2 of interview questions