“Golden Opportunity” Enhancing Missile Defense & Space Operations and Training Through Modeling and Simulation

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List of Terms

Golden Dome for America	A proposed national missile defense initiative designed to create a layered and robust shield against a broad spectrum of missile threats, encompassing both ballistic and hypersonic projectiles, to protect the U.S.
Iterative Process	A cyclical method of problem-solving and development involves repeating steps until a desired outcome is achieved.
Modeling and Simulation	Computer simulations replicate the system's performance to assess the capabilities and limitations of how elements function under a wider variety of conditions than can be achieved through the limited number of flight tests conducted.
State of the Art	Technically superior technologies, techniques, or tactics, also referred to as advanced or sophisticated techniques, are not readily available or exploited by state-sponsored or non-state-sponsored entities.
State of the World	Technologies, techniques, or tactics readily available or exploited by state-sponsored or non-state-sponsored entities

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Executive Summary

Title: “Golden Opportunity” Enhancing Missile Defense & Space Operations and Training through Modeling and Simulation

Institution: University of Southern California (USC) in conjunction with the Missile Defense Advocacy Alliance (MDAA)

Program: USC SHIELD Executive Program in Global Space and Deterrence

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To effectively counter sophisticated threats, the U.S. Department of Defense must efficiently develop advanced missile defense (MD) and space capabilities. Modern acquisition approaches, including the Adaptive Acquisition Framework (AAF) and the mandated Digital Engineering (DE) strategy, depend fundamentally on Modeling and Simulation (M&S) for designing, testing, training, and sustaining these complex systems, particularly where live testing is limited. However, a critical gap persists: inconsistent requirements and funding for concurrent M&S development, validation, and sustainment impede the realization of AAF and DE objectives and negatively impact readiness. This research advocates for a critical policy refinement mandating a comprehensive, funded M&S Support Plan, integrated from initial requirements documentation through the entire capability lifecycle. Implementing this change is crucial to fully leverage M&S, fostering more affordable, adaptable, and rapidly delivered MD and space capabilities with enhanced training fidelity; this significantly improves force readiness and effectiveness, directly enabling the successful realization of complex, integrated defense initiatives such as the envisioned 'Golden Dome for America'.

Scene Setter

The crimson stain on the Red Sea reflected more than just the setting sun, it signified the rising stakes of a new naval conflict. In an instant, U.S. Navy destroyers became targets of relentless assaults from Houthi rebels, who employed drones, missiles, and even weaponized fishing vessels.

Within the ship's Combat Information Center, focus from the Sailors inside intensified as sensors hummed and operators tracked incoming threats. The missile defense system roared to life, launching interceptors that streaked across the sky. This conflict was about more than survival; every hostile act and successful interception generated crucial data.

Data on missile paths, weapon signatures, and enemy tactics flowed to a central analytical hub, where analysts refined threat models for simulations and wargames. These models supported the Navy in adapting tactics and techniques that were swiftly shared across the fleet. Sailors in training practiced in virtual environments reflecting the ongoing conflict, while ships in the Red Sea and beyond received timely intelligence updates to adjust their strategies.

What began as a perilous zone changed into a proving ground, with each engagement enhancing intelligence-sharing networks, tactics and techniques, and training. The lessons learned in battle translated into actionable knowledge, keeping the Navy one step ahead in this maritime contest.

Introduction

Mission success against peer and near-peer adversaries necessitates near-perfect execution by all capabilities from competition through conflict. While live-fire training and combat offer the most definitive measures of performance, combat represents the least desirable method for identifying capability or training deficiencies. Furthermore, large-scale combat simulations and live-fire exercises are frequently cost-prohibitive, time-consuming, politically sensitive, and, for highly complex systems like missile defense (MD) and space capabilities, potentially technically infeasible. Modeling and Simulation (M&S) provides a critical bridge, offering computational representations that simulate system performance to evaluate capabilities and limitations across a broader spectrum of conditions than achievable through limited physical testing. Consequently, M&S is indispensable for the effective development, testing, training, and sustainment of advanced MD and space capabilities. The U.S. military's ability to maintain its relative advantage is critically dependent on technological superiority and readiness. Therefore, enhancing the effectiveness and integration of M&S within capability development and training is an essential condition for achieving combat-credible forces and mission success. M&S capabilities must evolve in parallel with adversary threats and become fundamentally integrated into the development and sustainment processes for future Department of Defense (DOD) MD and space systems, leveraging the structures afforded by contemporary DOD acquisition frameworks.

Background to the Problem

The historical foundations of modern military M&S extend back to World War II-era operations research (OR), the strategic importance of which was reinforced during the Cold War (Huber, 2018). Following decades oriented towards counter-insurgency operations, the DOD has

redirected its focus towards preparing for strategic competition across multiple domains (GAO, 2016). This strategic realignment necessitates forces equipped with highly advanced capabilities maintained at peak readiness, posing significant challenges to traditional development and sustainment paradigms in terms of efficiency and effectiveness (Straus et al., 2019). The MD and space communities face particular pressure, needing to innovate rapidly against evolving adversary capabilities while ensuring robust force readiness through sophisticated training methodologies.

MD and space capabilities inherently depend on M&S for system development, enhancement, rigorous evaluation, and efficient personnel training. Despite this recognized dependence and the existence of enabling policies, the DOD continues to face challenges in implementing and utilizing M&S technologies consistently and effectively across its diverse portfolio (GAO, 2016, 2024e). Persistent difficulties include defining accurate M&S requirements at program inception, integrating multidisciplinary expertise throughout the lifecycle, managing vast datasets, ensuring model credibility via Verification, Validation, and Accreditation (VV&A), and overcoming institutional resistance to model-based approaches (Taylor, 2021; DOD, 2024).

Problem Statement

This research explores two interconnected problems situated within the contemporary DOD acquisition landscape. The primary issue concerns DOD capability development processes which, notwithstanding the implementation of frameworks like the Adaptive Acquisition Framework (AAF) designed for agility and integration, frequently fail to mandate and adequately fund the concurrent design, development, and sustainment of M&S capabilities alongside the primary MD or space system acquisition. This systemic disconnect can result in costly systems

potentially misaligned with dynamic threats, outdated operational doctrine, delayed capability fielding, and inadequate post-production training environments lacking necessary fidelity and contemporary relevance. The persistent latency in integrating validated threat and friendly system models into operational and training tools significantly degrades operator proficiency and readiness. The secondary problem addressed is the absence of clearly defined, consistently enforced baseline M&S requirements specifically tailored to the unique characteristics and complexities of MD and space capabilities across the various acquisition pathways these programs might employ.

Thesis

A refinement of policy within DOD capability development processes, reinforcing existing directives such as the Digital Engineering strategy, is required. Such refinement must necessitate a foundational set of M&S requirements for MD and space capabilities, articulated within initial capability requirements documentation. Furthermore, it must mandate a comprehensive, adequately funded M&S support plan integrated with final system specifications and sustained throughout the capability's lifecycle. This approach, predicated on the data-driven analysis and model-based techniques central to modern acquisition paradigms, facilitates iterative capability enhancement on accelerated timelines while providing essential tools to improve force readiness and inform critical decision-making.

Literature Review

MD and space systems represent critical components of military operations and national defense, necessitating robust, adaptable capabilities supported by realistic training paradigms. M&S offers a potent means to achieve these ends; however, its integration with capability development has historically been fragmented, signaling the need for process refinement. This review examines key facets of DOD capability development (Figure 1), the specific role and requirements for M&S within the current acquisition environment (particularly for MD and space), and its direct contributions to force readiness.

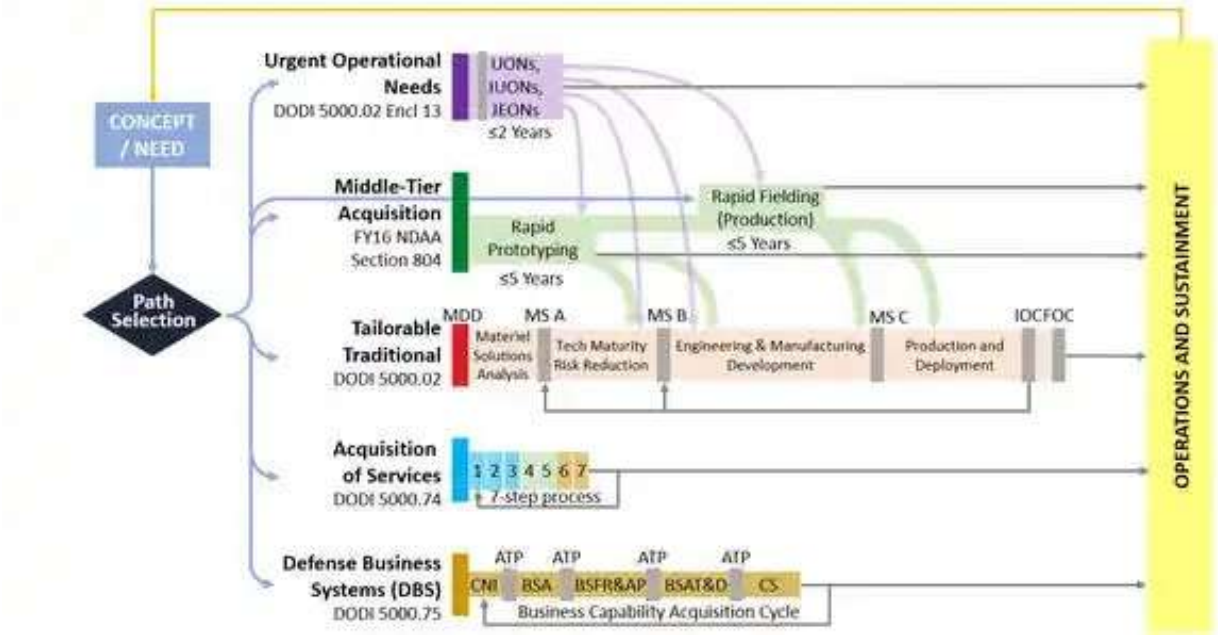

Figure 1. Adaptive Acquisition Framework

The Adaptive Acquisition Framework (AAF) Context

Contemporary DOD acquisition primarily functions under the Adaptive Acquisition Framework (AAF), implemented via DOD Instruction 5000.02 (2022a). The AAF endeavors to deliver effective, sustainable solutions with increased velocity by establishing a flexible structure

comprising multiple, distinct acquisition pathways, including Urgent Capability, Middle Tier of Acquisition (MTA), Major Capability Acquisition (MCA), Software Acquisition, Defense Business Systems, and Acquisition of Services. This framework delegates significant authority to Program Managers (PMs) and Milestone Decision Authorities (MDAs) to tailor acquisition strategies according to specific program attributes such as technical complexity, risk profile, and operational urgency. Core AAF tenets promote policy simplification, PM empowerment, data-driven decision-making, proactive risk management, competition, modular open systems architectures, early sustainment planning, and integrated cybersecurity. M&S, particularly when implemented through a comprehensive Digital Engineering (DE) approach, serves as a fundamental enabler for achieving the AAF's objectives of speed, flexibility, and informed decisions across its varied pathways. Nevertheless, the consistent and effective integration of M&S remains a significant implementation challenge affecting the realization of the AAF's intended benefits.

Mandated and Expected Integration of M&S

While a singular, universal mandate for M&S applicable to every acquisition scenario may not exist, its use is substantially driven by interconnected policies and overarching strategic direction, rendering it an expected, often functionally required, element of modern capability development. A primary driver is the Digital Engineering (DE) Mandate, which directs programs to utilize DE methodologies reliant on digital models as authoritative data sources throughout the lifecycle, inherently necessitating M&S for design, analysis, testing, and sustainment (DOD, 2024). Programs are required to address DE implementation in foundational documents like the Acquisition Strategy and Systems Engineering Plan (DOD, 2024). Furthermore, Test & Evaluation (T&E) policies designate M&S as integral to modern evaluation strategies,

compelling its use for assessing performance under diverse conditions, reducing dependence on costly live tests, and informing comprehensive test planning; planned M&S usage must be formally documented in the Test and Evaluation Master Plan or T&E Strategy (DOD, 2023b). Critically, when M&S supports acquisition decisions or T&E, Verification, Validation, and Accreditation (VV&A) processes are mandated to establish the credibility and suitability of models and data for their specific intended use, with accreditation serving as the official certification (DOD, 2020a). Collectively, these policies support core Systems Engineering principles and AAF tenets (DOD, 2022b) emphasizing data-driven analysis, rigorous risk management, and comprehensive lifecycle support, all areas where M&S serves as a key enabling capability.

Importance of M&S in MD and Space Capabilities within the AAF

Due to their complexity and high stakes, robust M&S is essential across all acquisition pathways for MD and space systems. Whether utilizing Major Capability Acquisition, rapid prototyping, software-intensive development, or urgent acquisition processes, M&S provides critical support for system analysis, testing, vulnerability assessment, and lifecycle sustainment. Proactively integrating M&S requirements early within the capability process is particularly beneficial, enabling the early identification of capability gaps and ultimately leading to the development of more effective and resilient MD and space capabilities prepared for diverse operational environments.

Improving Force Readiness through M&S

M&S substantially enhances force readiness by providing realistic, repeatable, low-risk training environments. This is particularly valuable for complex MD and space scenarios involving numerous threat permutations that are impractical or impossible to replicate in live

settings (GAO, 2024c). Synthetic training environments enable personnel to develop and maintain proficiency without the need to expend limited live ordnance or operate systems in potentially hazardous conditions. Moreover, M&S provides a powerful tool for refining tactics, techniques, procedures (TTPs), and operational doctrine by allowing exploration of diverse scenarios. It directly addresses readiness challenges identified by oversight bodies, including training limitations in specific theaters, integrating multi-domain operations concepts, and optimizing weapon system sustainment strategies (GAO, 2023b, 2024b).

Government Accountability Office Reports

Findings from the GAO consistently underscore persistent challenges in the DOD's application of M&S within acquisition programs. Additionally, the GAO has found that the DOD’s acquisition of weapons systems faces persistent challenges in stakeholder engagement and communication regarding M&S. The reports highlight limited input from service members and the defense intelligence community, which hinders the development of models that accurately reflect real-world conditions and address evolving threats (GAO, 2024e). The lack of input creates risks of delivering MD and space capabilities outpaced by the threat and failing to meet operational needs (GAO, 2024e). Furthermore, GAO found inadequate communication of M&S limitations to senior-level decision-makers, potentially leading to unrealistic expectations and hindering informed decisions about MD programs (GAO, 2018). The findings underscore the need for the DOD to improve communication channels, require stakeholder engagement, establish processes and products to align MD and space capabilities in early development with service member touchpoints, and enhance transparency regarding M&S limitations (GAO, 2015, 2019, 2020b, 2021, 2024e).

Figure 2. Ground-Based Interceptor Launch

Summary

MD (Figure 2) and space capabilities constitute vital national security assets. This analysis, framed within the context of the AAF and DE initiatives, identifies a persistent deficiency in DOD acquisition: the inconsistent integration and dedicated funding of M&S concurrently with the development of the primary capability. This gap endures despite policies advocating for model-based approaches. Shortcomings repeatedly documented by the GAO—such as insufficient stakeholder input, inadequate communication of model limitations, VV&A execution challenges, and lack of standardized tools—contribute to the development of systems potentially lagging evolving threats and supported by inadequate training resources. Rectifying these issues necessitates reinforcing policy within the extant acquisition framework. Specifically, a change is required to mandate a funded, comprehensive M&S support plan, incorporating baseline requirements early in the requirements definition phase (initial capability documents)

and maturing throughout the lifecycle, intrinsically linked to final system specifications and sustainment strategies, thereby fully realizing DE principles.

Methodology

A qualitative research methodology was selected to investigate the enhancement of M&S for MD and space systems operations and training, thereby justifying the requirement for a mandated M&S support plan within DOD capability development processes. The analysis involved reviewing pertinent DOD instructions, capability development guidance documents, relevant GAO reports, academic literature on M&S and systems engineering, and illustrative case studies. As described in the NASA Systems Engineering Handbook, the system lifecycle was the primary analytical framework for defining initial M&S base MD and space capability development requirements (e.g., formulation/design, implementation/production, operations/sustainment) (NASA, 2016). This approach enables a detailed analysis of how M&S requirements can be integrated effectively within the flexible structure of the AAF and ongoing DE implementation efforts.

Analysis and Findings

M&S is not merely a tool for early design but an integral component spanning the entire capability acquisition lifecycle, from concept exploration through disposal, possessing critical applications in MD and space training (DOD 2023a, DOD, 2022a). The early and continuous application of M&S, a central tenet of DE, supports the creation of representative simulations applicable to diverse testing, analysis, and training needs, often integrating physical hardware-in-the-loop with digital models. This holistic approach aims to mitigate operational and programmatic risks while reducing total lifecycle costs, directly aligning with stated AAF objectives (GAO, 2020b). The following analysis examines key stakeholders operating within the modern acquisition environment, outlines a structured M&S plan approach compatible with DE precepts, and explores illustrative MD and space capability case studies.

Stakeholder Analysis

Effective M&S programs consider diverse perspectives and drive to balance competing interests while improving capabilities, training, and operations for MD and space. A comprehensive stakeholder analysis of military M&S reveals various actors with diverse interests and levels of influence. Key stakeholders include Congress, DOD, service members, the intelligence community, industry, and academia.

Congress. Congressional oversight of DOD's MD and space programs is essential to ensure the responsible allocation of taxpayer funds and alignment with national security priorities. Understanding the effectiveness, affordability, and potential risks of MD and space systems is critical for informed decision-making regarding program funding and policy directives. Congressional inquiries, hearings, and legislative actions can significantly influence

the direction of DOD's programs, underscoring the importance of transparency, accountability, and responsiveness to stakeholder concerns.

DOD. Multiple decision makers and governing bodies in the DOD play crucial roles in M&S for MD and space capabilities and include: the Secretary of Defense, Office of the Under Secretary of Defense for Research and Engineering (OUSD(R&E)), Director of the Department of Defense Test Resource Management Center (TRMC), the Under Secretary of Defense for Acquisition and Sustainment, the Director of Operational Test and Evaluation, the DOD Chief Information Officer, the Chief Digital and Artificial Intelligence Officer, and relevant DOD Component Heads with Acquisition Authority, DOD agencies i.e. Missile Defense Agency (MDA), and requirements validation bodies (e.g., JROC). The DOD, tasked with maintaining national security, ensures the MD and space capabilities align with overarching strategic objectives and resource allocation priorities. The DOD shapes MD and space investments through requirements, guidance, and oversight of funding and acquisition. Successfully balancing these investments with other defense needs demands careful evaluation of policy, costs, technology, and current threats. Ultimately, key stakeholders collaboratively define policy, manage resources, guide implementation, and confirm capability needs.

Service Members. Service members encompass a broad spectrum from individual service members to senior military leaders. Service members are the ultimate end-users of MD and space systems and are vested in ensuring these systems are operationally effective and capable of mitigating realistic threats. Service members directly utilize M&S tools for training, enhancing mission readiness, and mitigating risks in real-world operations. On the other hand, commanders leverage M&S to make informed decisions on capabilities, ensure capabilities operate effectively, provide the necessary range of options, and deliver combat-credible forces. Service

member input regarding evolving threat perceptions and desired capabilities is critical for shaping system requirements and informing development priorities. However, operational demands and specialized technical knowledge can limit their influence on M&S efforts, necessitating the establishment of streamlined communication channels and collaborative engagement.

Intelligence Community. The intelligence community provides timely and accurate threat assessments for M&S. Their expertise in adversary capabilities and intentions directly influences the fidelity of threat representation within models, ultimately influencing the design and evaluation of systems. Effective collaboration between the intelligence community and those developing these systems is essential for ensuring that models accurately reflect the latest understanding of adversary threats, enabling the development of robust and adaptable MD and space systems.

Industry. Industry stakeholders significantly influence the M&S landscape. Defense contractors strive to develop and deliver cutting-edge M&S technologies, while technology providers focus on advancing state-of-the-art hardware and software solutions. Driven by a desire for funding, profit, and to contribute to the ongoing evolution of M&S's capabilities both sectors advance M&S technologies.

Academia. Academia advances M&S through research, educating future experts, and fostering effective collaboration. Universities spearhead groundbreaking research, developing new methodologies and addressing critical challenges such as predicting emerging threats and improving human-computer interactions. They cultivate a skilled workforce by offering interdisciplinary programs and providing continuing education opportunities. Furthermore, academia facilitates knowledge sharing through partnerships with the military and industry,

hosting conferences, and publishing research findings, ensuring the continual advancement of M&S capabilities.

Key considerations. Balancing competing interests among diverse stakeholders involves negotiation and collaboration to ensure that the needs and priorities of all parties are adequately addressed (Kivitz, 2011). Maintaining high readiness in the military demands frequent and realistic training exercises, necessitating a significant expenditure of resources, specifically personnel and equipment. Integrating advancing technologies, such as advanced sensors and artificial intelligence, into training is crucial for maintaining relevance in a rapidly evolving threat environment.

This stakeholder analysis built a framework for understanding the interplay of interests and influences within the M&S for MD and space capabilities. Congressional oversight is essential to ensure the responsible allocation of taxpayer funds and alignment with national security priorities for MD and space systems. This oversight ensures transparency, accountability, and responsiveness to stakeholder concerns regarding the effectiveness, affordability, and potential risks to personnel and agencies, focusing on national security, cost-effectiveness, and program oversight. The DOD executes the policy and ensures capabilities are funded. Service members support the identification of shortfalls in capabilities and can reduce risk of capabilities failing to meet required operational needs. The intelligence community's timely and accurate threat assessments are crucial for developing robust and adaptable MD and space systems, as their expertise directly impacts the fidelity of threat representation in models, influencing system design and evaluation. Industry stakeholders, including defense contractors and technology providers, aim to advance M&S technologies, secure contracts, and drive

innovation. Academia contributes through research, education, and workforce development. By addressing these various stakeholders, M&S solutions are available.

M&S Plan

Developing and implementing a successful M&S demands a structured engineering approach. One systems engineering approach is the system lifecycle as described in the NASA Systems Engineering Handbook (NASA, 2016). This lifecycle provides a systematic framework for progressing from identifying a need to realizing a fully functional capability (NASA, 2016). Within this framework, a defined line of effort encompasses distinct phases, broadly categorized as formulation and implementation (NASA, 2016). The formulation phase similar to the design phase in other modes, emphasizes early understanding and definition. The formulation phase prioritizes a comprehensive elicitation and articulation of stakeholder needs, expectations, and derived technical requirements that will serve as the foundation for the subsequent implementation phase (NASA, 2016). While modeling most of this approach, this capstone emphasizes thorough objectives, instead of requirement, definition and design. Ultimately, resulting in a system with M&S that effectively addresses the identified stakeholder needs and fulfills its intended purpose within the broader system context (NASA, 2016).

Need and Expectations. The driving force behind this capstone stems from a critical DOD requirement for a highly adaptable and responsive M&S system to support complex systems, such as MD and space operations as laid out in Table 1. The overarching objective is to develop M&S capability that provides value throughout the entire capability development process, spanning initial capability development, training, and mission execution. Incorporating M&S early provides improved capability development, training outcomes, and a higher degree of mission success (RAND, 2023).

Need: M&S for MD and Space capabilities that is more capable, flexible, agile, and responsive for improving training and ensuring mission success.	
Goals	Objectives
1. Build MD and space capabilities for the force in 2030 and beyond.	1.1 Capability is developed to defeat the adversary of 2030 and beyond. 1.2 Capability development utilizes all M&S tools available to build a capability. 1.3 A digital twin is created concurrently with capability. 1.4 Capability allows for software upgrades with minimal hardware upgrades to improve performance
2. Provide the operator a seamless transition from a training suite to capability.	2.1 Training suite emulates the physical characteristics of the capability. 2.2 Training suite emulates capability within real-world parameters.
3. Provide simulation training of real-world scenarios.	3.1 Provide real-time capability visualization and reporting. 3.2 Simulation emulates required threat models based on mission area. 3.3 Simulation incorporates World Weapons Equipment Guide threat models and updates threat models within 30 days (threshold), 7 days (obj.) 3.4 Provide simulation of real-world scenarios employing State of the World (SoW) and State of the Art (SoA) tactics, techniques, and procedures (TTPs). 3.5 Provide dynamic scenairos based on threat TTPs. 3.6 Allow ingestion of new friendly and threat TTPs. 3.7 Provide real-time visualization of impacts to simulated targets.
4. Improve operator performance on capability	4.1 Improve operator performance above 90% (against TE&Os) with no major errors recorded 3.2 Provide operator agile and responsive training scenarios.
5. Provide Immediate assessment feedback	5.1 Provide certification (90% or better with no major errors) with feedback in 5 minutes (threshold), <1 minute (objective)
6. Reduce the amount of Humans-in-the-loop (HITL), training coordinators, required to conduct training and evaluations	6.1 reduce the number of HITLs to the minimum required to conduct training to standard
7 Collect data on operator performance.	
8. Collect data on scenarios	

Table 1. MD and Space M&S Minimum Mission Need, Goals, and Objectives.

Practical MD and Space M&S Examples

Ground-Based Interceptor / Next Generation Interceptor. The challenges facing the Ground-based Midcourse Defense (GMD) system (Figure 3) underscore the critical need for improved M&S within capability development and training. The difficulties in maintaining GMD M&S capabilities that effectively address evolving operational enhancements and emerging threat advancements underscore several key areas for improvement applicable across a broader range of defense systems. Given that the Missile Defense System (MDS), a system of systems directly contributing to GMD, cannot be fully assessed via flight tests due to cost and safety constraints, the reliance on M&S to create realistic operational environments for

performance evaluation, improvement development, and tactical modifications is essential (GAO, 2024e).

Figure 3. GMD System

Firstly, the Office of the Director of Operational Test and Evaluation (DOT&E) consistently emphasizes the critical need for robust and accredited M&S to support the evaluation of complex defense systems. In its Fiscal Year 2024 Missile Defense Systems Annual Report, DOT&E emphasizes the importance of early and continuous integration of M&S within the capability development process. DOT&E notes ongoing challenges in obtaining sufficient data for comprehensive M&S validation and accreditation, which can limit the ability to conduct thorough end-to-end performance evaluations of MDS, including programs like the GMD system (DOT&E, 2024), The latency in developing and accrediting M&S capabilities for GMD has

resulted in delayed fielding of needed defensive tools and a potential mismatch between simulation fidelity and real-world operational demands. This issue is not unique to GMD. It is however, illustrative of a systemic problem where M&S is often treated as an afterthought rather than an integral component of system development and operator training. The MDS Operational Test Agency (OTA) has been advocating for the validation and accreditation of models used during operational testing since 2018, publishing findings that MDS M&S often fails to meet various DOD and MDA instructions, as well as DOT&E guidance regarding verification, validation, and accreditation (GAO, 2018).

Secondly, the GMD case emphasizes the necessity of accurate and timely threat modeling. The complexities of simulating realistic intercontinental ballistic missile (ICBM) threats, including evolving countermeasures, necessitate robust input from the intelligence community and a flexible M&S development process. MDA threat modeling is exempt from traditional DOD requirements, allowing for flexibility in addressing emerging threats (GAO, 2024e). While intended to enhance agility, this non-standard approach to threat acquisition, which provides threat models without full intelligence community details, introduces potential risks to the accuracy of the models. MDA utilizes these advanced threat models to verify the capability of each MDS element to detect and defend its threat space (GAO, 2024e). Despite collaboration between MDS OTA, MDA, and the intelligence community to develop a threat accreditation plan, this process omits critical intelligence parameters traditionally used for validation in the standard DOD process (DOD, 2020b). Given the increasing sophistication of adversary threats, maintaining pace in threat modeling accuracy is important for providing decision-makers with reliable data.

Thirdly, the GMD example underscores the importance of M&S across the entire system lifecycle. From initial design and testing to operator training and ongoing system upgrades (e.g., "Golden Dome for America" initiatives), M&S plays a crucial role. The need for continuous M&S development to support the Next Generation Interceptor (NGI) development and the integration of space-based sensors, such as the Hypersonic and Ballistic Tracking Space Sensor, exemplifies this system lifecycle requirement. For instance, Northrop Grumman, a key defense contractor for GMD, emphasizes the role of M&S in analyzing sensor performance and advancing layered missile defense. The Missile Defense Integration and Operations Center (MDIOC) in Colorado Springs is a central hub for MDS M&S and wargaming. The MDIOC supports GMD operations and evaluations for warfighter requirements. Furthermore, gamified training systems are being developed to enhance warfighter proficiency in operating complex systems, such as the Command and Control, Battle Management, and Communications system, which is integral to the GMD system.

In conclusion, the challenges and proposed solutions surrounding GMD M&S provide valuable insights into broader efforts to enhance the effectiveness of M&S as part of the acquisition, operations, and training segments. The emphasis on early integration within the capability development process, realistic and timely threat modeling with robust intelligence input, comprehensive system lifecycle support through continuous M&S development, and strong stakeholder collaboration offer a roadmap for improving M&S across complex weapon systems and operational environments.

Aegis. The Aegis Combat System (ACS) (Figure 4), a cornerstone of the U.S. Navy surface fleet defense, presents a strong and positive case study for the critical and adaptive application of M&S in response to evolving threats and operational demands. Recent experiences

in the Red Sea, where U.S. Navy destroyers equipped with ACS have engaged Houthi rebel missiles and drones of various types, underscore the imperative for continuous refinement of M&S capabilities to maintain tactical advantage and ensure the survivability of U.S. naval assets, allies, and partners, as well as merchant shipping.

Figure 4. Aegis Combat System

The ability to rapidly analyze real-world engagement data and translate those insights into actionable improvements highlights a crucial aspect of effective M&S for the Aegis. A dedicated team of experts, led by the Naval Surface and Mine Warfighting Development Center (SMWDC), has been analyzing data from shootdown events since October 2023, with a focus on U.S. engagements in the Middle East and the specific threats posed by Yemeni militants (Eckstein, 2024). This analysis directly informs the development and refinement of operational

strategies and the identification of necessary self-defense capabilities for the fleet. This iterative process, driven by real-world data, aligns with the GAO's ongoing emphasis on robust testing and data analysis to inform the development of MD systems (GAO, 2023c). The GAO has consistently reported on the challenges the MDA faces in meeting its testing goals, highlighting the critical role of M&S in evaluating system performance when live testing is limited. This reliance on M&S, as corroborated by the recent Aegis software updates, underscores the need for these models to be accurate and adaptable to emergent threats (GAO, 2021).

This situation highlights several key areas where enhanced and adaptive M&S plays a vital role in the Aegis program. Firstly, the swift development and deployment of software updates necessitate agile M&S environments that can rapidly prototype, test, and validate these changes against realistic threat representations. These simulations must incorporate the specific characteristics of Houthi missiles and drones, including their flight profiles, electromagnetic warfare capabilities, and potential countermeasures. The ability to conduct "what-if" scenarios within these M&S environments allows the Navy and industry partners to proactively identify vulnerabilities and optimize engagement tactics before testing in live-fire situations. GAO reports have highlighted the increasing complexity of weapon systems and the necessity for iterative development approaches, where M&S plays a vital role in expediting the delivery of effective capabilities (GAO, 2024f).

Secondly, the analysis of combat engagements emphasizes the importance of high-fidelity post-mission analysis tools rooted in robust M&S. By feeding real-world, engagement data back into simulation environments, engineers and tacticians can gain a deeper understanding of system performance, identify areas for improvement in sensor processing, fire control algorithms, and weapon effectiveness, and refine operator training scenarios. In the past, USN

ships would send tape recordings back to the Naval Surface Warfare Center Dahlgren Division for analysis. The findings would then take months to years to be incorporated into the operational fleet for surface warfare tactics, techniques, and procedures. However, since the development of SMWDC in 2015, a streamlined process has been implemented and analysis from data recordings and potential technical and tactical improvements returns to the fleet within days (Wade & Baker, 2019). This continuous feedback loop, where real-world data informs and validates M&S, is crucial for maintaining the Aegis system's effectiveness against an adaptive adversary. SMWDC adapted its Surface Warfare Advanced Tactical Training exercise to incorporate invaluable lessons learned through real-world events experienced in the Red Sea. As a result, USN ships deploying in and around the Red Sea are now receiving advanced combat simulations in training environments designed to replicate the complex conditions of the Red Sea maritime environment (Wade & Baker, 2019). GAO has previously noted that assessments of the Aegis Ballistic MD (BMD) system's suitability and effectiveness have been accomplished with limitations, partly due to the challenges in verifying, validating, and accrediting the underlying models and simulations (GAO, 2011). The current situation in the Red Sea further underscores the need to address these limitations and ensure accurate performance evaluations.

Thirdly, the need to improve operational strategies and identify necessary self-defense capabilities highlights the role of M&S in supporting tactical development and resource allocation. By simulating various engagement scenarios with different threat types, numbers, tactics, and environmental conditions, the Navy can evaluate the effectiveness of current doctrine, identify gaps in capabilities, and inform decisions regarding future upgrades to the Aegis combat system and the development of complementary defensive measures. This proactive use of M&S enables informed decision-making regarding resource allocation and the

prioritization of development efforts, ensuring the fleet remains adequately equipped to face emerging threats. GAO reports have emphasized the importance of acquisition approaches and the need for MDA to strike a balance between pursuing new technologies and maintaining existing systems, where M&S plays a crucial role in assessing effectiveness and sustainability (GAO, 2020a, 2021, 2024a, 2024f).

In conclusion, the recent experiences with Aegis in the Red Sea serve as a powerful case study for the critical role of adaptive and responsive M&S. The ability to rapidly analyze real-world engagement data, translate it into software updates and tactical adjustments, and proactively assess future threats through sophisticated simulations is paramount to maintaining the effectiveness of the Aegis Combat System. This case, corroborated by the GAO's ongoing oversight of MD programs, underscores the need for continuous investment in agile, high-fidelity M&S capabilities to keep pace with the evolving threat landscape and ensure the continued protection of naval assets and maritime commerce.

Army Space Control. The U.S. Army's Space Control Companies (SCCs), including those within the 1st Space Brigade and Multi-Domain Task Force (MDTF), face a significant challenge: fielding space control (SC) systems (Figure 5) without robust M&S fully incorporated into their acquisition lifecycle. This oversight has resulted in deploying capabilities where the necessary M&S tools for practical training, operational planning, and threat evaluation are absent, inadequate, or developed as an afterthought. This situation resonates with broader concerns raised by the GAO regarding the DOD's acquisition of MD and other complex weapon systems. Specifically, where insufficient attention to testing and evaluation, including using M&S, can lead to performance shortfalls and increased costs (GAO, 2023a, 2023c).

Figure 5. Expeditionary Space Control System

The Army Space Vision (2024) articulates the critical need to counter adversary space systems. However, the acquisition of the very tools these SCCs use has often proceeded without a commensurate emphasis on delivering accompanying validated M&S. This disconnect means that Soldiers are receiving advanced hardware and software without the synthetic environments required to understand their capabilities, limitations, and optimal employment against realistic threats. Consequently, the readiness and effectiveness of these units are potentially hampered by a lack of integrated M&S. GAO reports on space acquisitions have highlighted challenges in ensuring the timely delivery of critical capabilities and the need for improved planning and oversight (GAO, 2017). The absence of integrated M&S in the fielding of Army SC systems directly contributes to these challenges by delaying effective utilization and assessment.

One significant consequence of this shortfall in acquisition is the limited ability to conduct high-fidelity training on newly fielded systems. Without embedded M&S, Soldiers lack the synthetic environments necessary to practice complex SC electromagnetic spectrum (EMS) maneuvers, respond to simulated adversary actions, and develop proficiency in operating

systems under various conditions. This reliance on limited real-world exercises, which are costly and often insufficient to replicate the full spectrum of threats, leaves a critical training gap. GAO findings on military readiness have consistently underscored the importance of realistic training enabled by simulation (GAO, 2024d).

The challenge is further exacerbated by the difficulty in conducting thorough threat evaluations of fielded systems without corresponding M&S. SCCs need the ability to simulate how their systems will perform against advanced adversary counterspace capabilities. However, units are left without the means to rigorously assess their vulnerabilities and the effectiveness of their defensive measures in a synthetic environment. The lack of integrated M&S also hinders developing and validating Tactics, Techniques, and Procedures (TTPs). Refining practical employment concepts for these new systems becomes a slow and potentially error-prone process without the ability to experiment and analyze outcomes in a simulated environment. Additionally, without a built in method for training, build a bench of trained and certified operators becomes difficult to maintain if the system is deployed. This situation can result in readiness deficiencies across the SCCs.

In conclusion, fielding Army SC capabilities without concurrent and comprehensive incorporation of M&S into their acquisition has created a significant challenge. These units are often equipped with advanced systems but lack the essential synthetic environments for practical training, TTP development, operational planning, and threat evaluation. Addressing this deficiency by making M&S a fundamental and integrated deliverable in future SC system acquisitions is crucial to ensuring the readiness and effectiveness of the Army's SCCs in a rapidly evolving and increasingly contested domain.

Recommendations

To address the identified shortcomings, this capstone recommends that the DOD reinforce and refine existing acquisition policies to mandate concurrent M&S development, integration, and funding for MD and space capabilities. First, specific AAF pathway guidance documents should be updated to include more explicit language detailing required M&S applications, deliverables, and VV&A expectations pertinent to each pathway's objectives and timelines, ensuring direct support for the DOD DE Strategy. Second, policy should mandate a funded "M&S Support Plan" as a formal program artifact; baseline M&S requirements (see Table 2) must be defined in initial capability documentation, with the comprehensive plan—addressing M&S development, data management, VV&A strategy, infrastructure needs, and lifecycle sustainment—finalized concurrently with system specifications and maintained within the program's authoritative data environment as envisioned by DE. Third, standardized M&S planning elements should be required within existing key AAF documents. Fourth, a stronger linkage must be established between program milestone decisions, as defined within AAF pathway guidance, and the successful completion and formal approval of VV&A activities for M&S capabilities critical to supporting those decisions. Finally, these changes should be implemented through established formal mechanisms, such as a DOTmLPF-P Change Recommendation (DCR) process or direct updates to relevant DOD instructions, targeting the appropriate policy documents for revision.

Requirements	Description
Digital Twin	The capability shall include a digital twin for capability improvements.
Modeling	The capability shall be capable of ingesting the most up-to-date target modeling based on verified data.
Simulation	The capability shall be capable of emulating real-world scenarios based on the capability parameters of the system and threat models in a closed loop environment.
Visualization	The visualization within the capability shall provide a real-time simulation of the operating environment.
Interoperability	The capability shall be able to exchange data with other simulations and systems.
Training Suite Fidelity	The capability shall include three types of fidelity for a training suite (simulation, physical, and functional), allowing operators to train in real-world tasks, equipment, and environments, capture the visualization and feel of a system or environment, and how the capability behaves.
Training Scenarios	Training scenarios shall prompt cognitive, behavioral, and affective responses relevant to performance in a particular setting and be dynamic, responsive, and based on threat modeling that includes SoW and SoA TTPs.
Feedback	The capability and training suite shall have real-time visualization and reporting to include playback capability for After Action Reviews (AARs) and automated, objective feedback about trainees' performance during training events.
Data Management	Data management shall allow for the capability to efficiently store, retrieve, and analyze large amounts of data, including capability and operator performance. The training suite shall provide scenario performance to operators and evaluators, which will be sent to a centralized data collection and management site.
Software	The capabilities software and accompanying training tools shall be upgradable with limited hardware changes.

Table 2. M&S Baseline Requirements

Building in Baseline Requirements into the M&S Plan.

The systematic incorporation of M&S, guided by DE principles, significantly strengthens military system acquisition processes. A structured M&S support plan, predicated on clearly articulated baseline requirements (Table 2) and tailored to the program's specific AAF pathway, is foundational for operational effectiveness. These requirements serve as the basis for informed decision-making throughout the lifecycle, facilitate comprehensive risk mitigation strategies, and ensure the effective allocation of programmatic resources. Furthermore, well-defined M&S requirements promote system interoperability, enhance the realism and effectiveness of training initiatives, and provide a traceable framework for continuous improvement and capability evolution consistent with the digital thread concept. Establishing these comprehensive baseline

requirements early in the acquisition process, specifically within initial requirements documentation, is central to effectively leveraging M&S capabilities. These initial requirements form the load-bearing structure upon which successful M&S integration is built, guiding development, VV&A, implementation, and utilization throughout the system's operational life. As the program matures towards final system specifications, these baseline M&S requirements are refined and solidified within the detailed M&S Support Plan. By embedding clearly defined baseline M&S requirements within both initial and final capability documentation artifacts, the DOD can cultivate a more strategic, efficient, and effective approach to employing this critical technology.

Implementation Plan

Integrating a mandated, comprehensive M&S plan within DOD's capability development processes necessitates a structured, phased implementation strategy carefully aligned with existing AAF structures and ongoing DE initiatives. The initial phase, Policy Change Initiation, involves OUSD(R&E), in coordination with key stakeholders like OUSD(A&S), DOT&E, the Services, and relevant agencies (e.g., MDA), establishing a working group to draft necessary policy updates. These updates would mandate the funded, concurrent M&S plan for MD and space capabilities, define baseline requirements tied to DE strategy, and specify full plan elements. Subsequently, the Policy Approval and Dissemination phase focuses on securing formal approval through established DOD channels and effectively communicating the revised policy, developing clear guidance documents and training materials framed within the AAF/DE context. The third phase, Pilot Program Implementation, transitions policy into practice by applying the updated requirements to selected new-start or major modification MD and space programs across different AAF pathways. This phase requires close monitoring of M&S plan development, VV&A execution, DE environment integration, and overall program impact, carefully documenting challenges and successes. Informed by pilot outcomes, the Policy Evaluation and Refinement phase involves systematically assessing the policy's impact, incorporating stakeholder feedback, and revising policy, guidance, and training materials based on lessons learned to ensure practical applicability. The final phase, Full Policy Implementation and Sustainment, represents the full-scale rollout across all applicable new MD and space programs. This phase includes updating all relevant documentation, providing continuous training and support (addressing M&S and DE workforce development), and establishing

mechanisms for ongoing monitoring and adaptation to ensure long-term success and alignment with evolving AAF and DE best practices.

Potential Challenges to Implementing an M&S Plan within Capability Development Processes.

While the phased implementation plan provides a robust framework, successful integration of mandated M&S plans faces considerable potential challenges inherent in large-scale organizational change within the DOD. Resistance to change and bureaucratic inertia within established acquisition cultures may impede adoption of truly model-based approaches across diverse programs; overcoming this requires sustained leadership commitment – particularly from OUSD(R&E) officials and DOD Component Heads – and a clear articulation of benefits linked to AAF goals like speed and efficiency.

Resource & Investment Considerations. Resource constraints present a significant hurdle, as comprehensive M&S requires dedicated funding for personnel, tools, infrastructure, and rigorous Verification, Validation, and Accreditation (VV&A). The difficulty in reliably quantifying M&S cost savings or return on investment complicates resource justification, making successful pilot program demonstrations essential, and exploring alternative funding mechanisms like cross-service collaboration could prove beneficial.

Workforce Development & Expertise Gaps. A shortage of personnel possessing the requisite expertise in advanced M&S techniques, Digital Engineering (DE) tools and practices, and disciplined VV&A execution constitutes a critical workforce development challenge. This demands focused training, certification programs, and potentially new career path specializations.

Data & Cybersecurity Complexities. Effective M&S and DE also depend heavily on data management, interoperability, and security; challenges include establishing common data standards, facilitating data sharing across security domains and organizational boundaries, ensuring interoperability among diverse modeling tools and digital environments, and implementing robust cybersecurity measures for these complex digital ecosystems.

VV&A Bottlenecks & Technological Advancement. The execution of timely and credible VV&A for increasingly sophisticated models remains a persistent bottleneck that can delay critical decisions and capability fielding. Finally, the rapid pace of technological advancement in M&S, artificial intelligence, machine learning, and high-performance computing necessitates continuous adaptation, ongoing investment in modern tools and infrastructure, and fostering a culture of innovation and continuous improvement within the M&S domain.

By acknowledging and proactively addressing these multifaceted challenges through a holistic approach encompassing policy adjustments, resource allocation strategies, workforce initiatives, technological investment, and process oversight, the DOD can significantly increase the likelihood of successfully implementing comprehensive M&S plans within the AAF, leading to more effective and efficient development, training, and deployment of MD and space capabilities, ultimately enhancing national security.

Mechanisms to Support M&S Implementation

Successfully integrating and sustaining M&S as a foundational component of MD and space capability development requires more than a policy mandate alone. Effective implementation necessitates a multi-faceted approach with supporting mechanisms across policy, resources, personnel, technology, incentives, and oversight. These mechanisms must work

synergistically to embed M&S and DE principles (DOD, 2023a) deeply within the DOD acquisition process, enabling the goals of the AAF (DOD, 2022a).

Policy and Guidance Refinement. Operationalizing the mandate within existing structures requires refining specific policies and guidance. This includes updating AAF pathway instructions to detail required M&S applications and deliverables pertinent to each pathway. Key acquisition documents central to program execution must incorporate standardized M&S planning elements, consistent with overarching AAF operations and T&E policy. Critically, the linkage between successful VV&A of key models and the approval criteria for major program milestones and technical reviews must be strengthened and enforced by Milestone Decision Authorities within the AAF structure (DOD, 2022a).

Dedicated Funding and Resourcing. Overcoming resource constraints necessitates dedicated funding strategies. Specific budget lines within MD and space programs should be allocated for M&S tool development, authoritative data procurement, infrastructure, and robust VV&A efforts (DOD, 2020a). Funding structures should incentivize significant M&S investment early in the capability lifecycle where it yields the greatest impact on design and risk. Furthermore, exploring enterprise-level funding for common-use, accredited models (e.g., threat, environment) can promote reuse and reduce costs for individual programs, aligning with efficient resource management principles within the Defense Acquisition System.

Workforce Development and Expertise. Addressing the workforce gap is paramount for successful DE and M&S adoption (DOD, 2023a). Mandatory training via institutions like the Defense Acquisition University covering M&S, DE, data analytics, and VV&A is crucial for personnel across key acquisition functions. Developing specialized M&S and DE career paths and ensuring consistent emphasis from senior leadership on the value of model-based approaches

are necessary to cultivate needed expertise and drive cultural change. This investment in human capital is fundamental to leveraging the technical capabilities M&S provides.

Enabling Tools, Infrastructure, and Data. The technical backbone for M&S implementation requires accessible and effective tools, infrastructure, and data governance. Promoting common or interoperable DE environments and M&S toolsets enhances collaboration and supports the DE strategy's goals (DOD, 2023a). Investment in robust, searchable repositories for models, simulations, and VV&A artifacts fosters reuse and transparency. Clear processes for accessing validated, authoritative data sources are critical, alongside robust cybersecurity measures integrated within these digital ecosystems to protect sensitive program information.

Incentives and Contractual Accountability. Motivating adoption and ensuring compliance requires appropriate incentives and accountability structures. Effective M&S and DE implementation should be incorporated into performance metrics for program leaders. Contractual mechanisms must explicitly require M&S deliverables (e.g., validated models, digital twins) in Statements of Work and Contract Data Requirements Lists, potentially using incentive fees or award terms to encourage contractor innovation and data rights sharing. Furthermore, the maturity and VV&A status of key models and simulations (DOD, 2020a) should serve as explicit criteria for major technical reviews and AAF milestone decisions (DOD, 2022a).

Integrated Oversight and Review Processes. Ensuring M&S is integral to program execution demands dedicated oversight. Program reviews, both technical and programmatic under the AAF structure, must specifically assess the M&S strategy, execution, resource adequacy, VV&A status, and integration within the DE approach (DOD, 2022a; DOD, 2023a). Independent technical assessments can provide objective feedback. Continuous reinforcement of

the "digital thread" concept—ensuring models and data flow seamlessly across lifecycle phases—is essential for realizing the full benefits of model-based capability development.

Implementing these supporting mechanisms holistically is fundamental to successfully embedding the proposed M&S Support Plan requirement and achieving more effective, agile, and affordable development and sustainment of critical MD and space capabilities within the DOD acquisition system.

Conclusion

In conclusion, the escalating technological sophistication of potential adversaries demands a fundamental evolution in how the DOD develops and fields its critical MD and space capabilities. Future large-scale defense initiatives, such as the envisioned 'Golden Dome for America,' will necessitate the integration of diverse, cutting-edge technologies, demanding a more integrated and digitally-grounded approach to capability development than previously employed. Therefore, this capstone advocates for a significant elevation of M&S within the DOD's acquisition processes, positioning it not as an supplementary activity but as a foundational component fundamentally intertwined with the DOD's DE strategy and essential for effective execution within the AAF.

The capstone identified a critical deficiency in current practices: the lack of consistent requirements for concurrent M&S plan development, funding, and sustainment throughout a capabilitie's lifecycle. This omission impedes the realization of benefits promised by both the AAF and DE initiatives, potentially leading to costly systems with delayed fielding and inadequate training support against dynamic threats. The proposed policy refinement—mandating a comprehensive, funded M&S plan for all new MD and space capabilities, integrated from initial requirements definition through sustainment—directly addresses this deficiency. This proactive integration ensures M&S is intrinsically woven into the fabric of capability development, fostering more cost-effective system design, enabling realistic and adaptive training environments, and ultimately yielding more agile, responsive, and effective MD and space capabilities.

Within the broader context of global strategic competition, where opportunities for extensive live-fire testing of complex systems are often limited by cost, safety, and security

constraints, M&S emerges as an indispensable instrument for maintaining technological superiority and assuring national security. By fully embracing a comprehensive, M&S-driven approach to capability development—rigorously aligned with DE principles and effectively implemented within the AAF structure—the DOD can significantly enhance the effectiveness of its future forces, strengthen strategic deterrence, successfully navigate the complexities of a rapidly evolving global threat landscape, and achieve its critical national defense objectives like ‘Golden Dome for America’.

References

Chairman of the Joint Chiefs of Staff. (2020). *Charter of the Joint Requirements Oversight Council and Implementation of the Joint Capabilities Integration and Development System* (CJCSI 5123.01H). https://www.jcs.mil/Portals/36/Documents/Library/Instructions/CJCSI%205123.01H.pdf?ver=2020-02-10-113031-810

Department of Defense. (2020a). *DOD Instruction 5000.61: DOD Modeling and Simulation Verification, Validation, and Accreditation.* https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/500061p.pdf

Department of Defense. (2020b). *DOD Instruction 5000.86: Acquisition Intelligence.* https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/500086p.PD

Department of Defense. (2022a). *DOD Instruction 5000.02: Operation of the Adaptive Acquisition Framework*. https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/500002p.PDF

Department of Defense. (2022b). *DOD Instruction 5000.85: Major Capability Acquisition*. https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/500085p.PDF

Department of Defense. (2023a). *DOD Instruction 5000.97: Digital Engineering*. https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/500097p.PDF?ver=bePIqKXaLUTK_Iu5iTNREw%3d%3d

Department of Defense. (2023b). *DOD Instruction 5000.98: Operational Test and Evaluation and Live Fire Test and Evaluation.* https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/500098p.PDF

Department of Defense. (2024). *DOD Instruction 5000.61: DOD Modeling and Simulation Verification, Validation, And Accreditation*. https://www.esd.whs.mil/Portals/54/

Documents/DD/issuances/dodi/500061p.pdf

Director, Operational Test and Evaluation. (2024). *FY 2024 Missile Defense Systems Annual Report*. Office of the Secretary of Defense. https://www.dote.osd.mil/Portals/97/pub/reports/FY2024/other/2024mds.pdf?ver=PYojIXXQ9ay4-gGl1BWtUw%3d%3d

Eckstein, M. (2024). *U.S. Navy making Aegis updates, training changes based on Houthi attacks*. Defense News. https://www.defensenews.com/naval/2024/03/21/us-navy-making-aegis-updates-training-changes-based-on-houthi-attacks/

Government Accountability Office (GAO). (2011). *Missile defense: Actions needed to improve transparency and accountability* [GAO-11-555T]. United States Government Accountability Office.

Government Accountability Office (GAO). (2015). *Defense acquisitions: Joint action needed by DOD and Congress to improve outcomes* [GAO-16-187T]. United States Government Accountability Office.

Government Accountability Office (GAO). (2016). *Army training: Efforts to adjust training requirements should consider using virtual training devices* [GAO-16-636]. United States Government Accountability Office.

Government Accountability Office (GAO). (2017). *Space acquisitions: DOD continues to face challenges of delayed delivery of critical space capabilities and fragmented leadership* [GAO-17-619T]. United States Government Accountability Office.

Government Accountability Office (GAO). (2018). *Missile defense: The Warfighter and Decision Makers Would Benefit from Better Communication about the System's Capabilities and Limitations* [GAO-18-324]. United States Government Accountability Office.

Government Accountability Office (GAO). (2019). *Missile defense: Delivery delays provide opportunity for increased testing to better understand capability* [GAO-19-387]. United States Government Accountability Office.

Government Accountability Office (GAO). (2020a). *Missile defense: Assessment of testing approach needed as delays and changes persist* [GAO-20-432]. United States Government Accountability Office.

Government Accountability Office (GAO). (2020b). *Missile defense: Lessons learned from acquisition efforts* [GAO-20-490T]. United States Government Accountability Office.

Government Accountability Office (GAO). (2021). *Missile defense: Recent acquisition policy changes balance risk and flexibility, but actions needed to refine requirements process* [GAO-22-563]. United States Government Accountability Office.

Government Accountability Office (GAO). (2023a). *Leading practices: Iterative cycles enable rapid delivery of complex, innovative products* [GAO-23-106222]. United States Government Accountability Office.

Government Accountability Office (GAO). (2023b). *Marine Corps Indo-Pacific posture: Actions needed to address training challenges* [GAO-23-105783C]. United States Government Accountability Office.

Government Accountability Office (GAO). (2023c). *Missile defense: Annual goals unmet for deliveries and testing* [GAO-23-106011]. United States Government Accountability Office.

Government Accountability Office (GAO). (2023d). *Space command and control: Improved tracking and reporting would clarify progress amid persistent delays* [GAO-23-105920]. United States Government Accountability Office.

Government Accountability Office (GAO). (2024a). *DOD acquisition reform: Military departments should take steps to facilitate speed and innovation* [GAO-25-107003]. United States Government Accountability Office.

Government Accountability Office (GAO). (2024b). *F-35 sustainment: Costs continue to rise while planned use and availability has decreased* [GAO-24-106703]. United States Government Accountability Office.

Government Accountability Office (GAO). (2024c). *Force structure: Army and Marine Corps face challenges developing new multidomain units* [GAO-24-106266C]. United States Government Accountability Office.

Government Accountability Office (GAO). (2024d). *Military readiness: Actions needed for DOD to address challenges across the air, sea, ground, and space domains* [GAO-24-107463]. United States Government Accountability Office.

Government Accountability Office (GAO). (2024e). *Missile defense: Next generation interceptor program should take steps to reduce risk and improve efficiency* [GAO-24-106315]. United States Government Accountability Office.

Government Accountability Office (GAO). (2024f). *Weapon systems annual assessment: DOD is not yet well-positioned to field systems with speed* [GAO-24-106831]. United States Government Accountability Office.

Huber, R. K. (2018). Military Modelling and Simulation - A Recollection and Perspective. *2018 Winter Simulation Conference (WSC)*, 1–1. https://doi.org/10.1109/WSC.2018.8632263

Kivits, R. A. (2011). Three component stakeholder analysis. *International Journal of Multiple Research Approaches*, *5*(3), 318–333.

NASA. (2016). NASA Systems Engineering Handbook. National Aeronautics and Space Administration. https://www.nasa.gov/sites/default/files/atoms/files/nasa_systems_engineering_handbook_rev2.pdf

Office of the Deputy Under Secretary of Defense for Acquisition and Technology (OUSD A&T). (2008). *Modeling And Simulation Guidance for the Acquisition Workforce*. AcqNotes. https://www.acqnotes.com/Attachments/Modeling & Simulation Guidance for the Acquisition Workforce.pdf

Taylor, C. (2021). *Implementation Strategies for Modeling and Simulation in Military Organizations.* ProQuest Dissertations & Theses.

RAND Corporation. (2023). *A Modernized Enterprise Army Modeling and Simulation Concept* (RAND RRA3261-1).

Stone, G. (2023). *Making Simulations Future Proof.* Journal of Defense Modeling and Simulation, 20(4), 429–430. https://doi.org/10.1177/15485129221097725

Straus, S., Lewis, M., Conor, K., Eden, R., Boyer, M., Marler, T., Carson, C., Grimm, G., & Smigowski, H. (2019). *Collective Simulation-Based Training in the U.S. Army: User Interface Fidelity, costs, and training effectiveness*. RAND. https://www.rand.org/pubs/research_reports/RR2250.html

Wade, J., & Baker, T. (2019). *Red Sea Combat Generates High-Velocity Learning. U.S. Naval Institute. https://www.usni.org/magazines/proceedings/2017/september/red-sea-combat-generates-high-velocity-learning*

U.S. Army. (2024). *Army Space Vision Supporting Multidomain Operations. https://www.armyupress.army.mil/Journals/Military-Review/English-Edition-Archives/March-2024/Army-Space-Vision/*