Landscape Analysis: Integrated DON Understanding of Mission Engineering Efforts & Digital Tools

Phase A Deliverable Report

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Executive Summary

Project Background

The Department of Navy (DON) aims to improve and formalize the application of Mission Engineering (ME) to transform the DON into a strategically agile organization that makes data-informed decisions to achieve priorities laid out in strategic naval priorities and objectives. Currently, however, the DON requires an enterprise approach to ME and enabling digital engineering (DE) disciplines for improved decision-making processes. The DON Office of Strategic Assessment (OSA) assigned Applied Research Laboratory for Intelligence and Security (ARLIS) and VT-ARC to explore foundational elements for an enterprise-wide ME approach. This initiative aims to ensure consistency, effectiveness, and scalability, leveraging DE for data-driven decision-making. The goal is to enhance strategic agility and portfolio management. The team will develop, apply, and gather recommendations surrounding an Applied Mission Engineering Process, capturing future-state needs along the foundational layers depicted in figure 1, moving the DON toward an enterprise approach to ME.

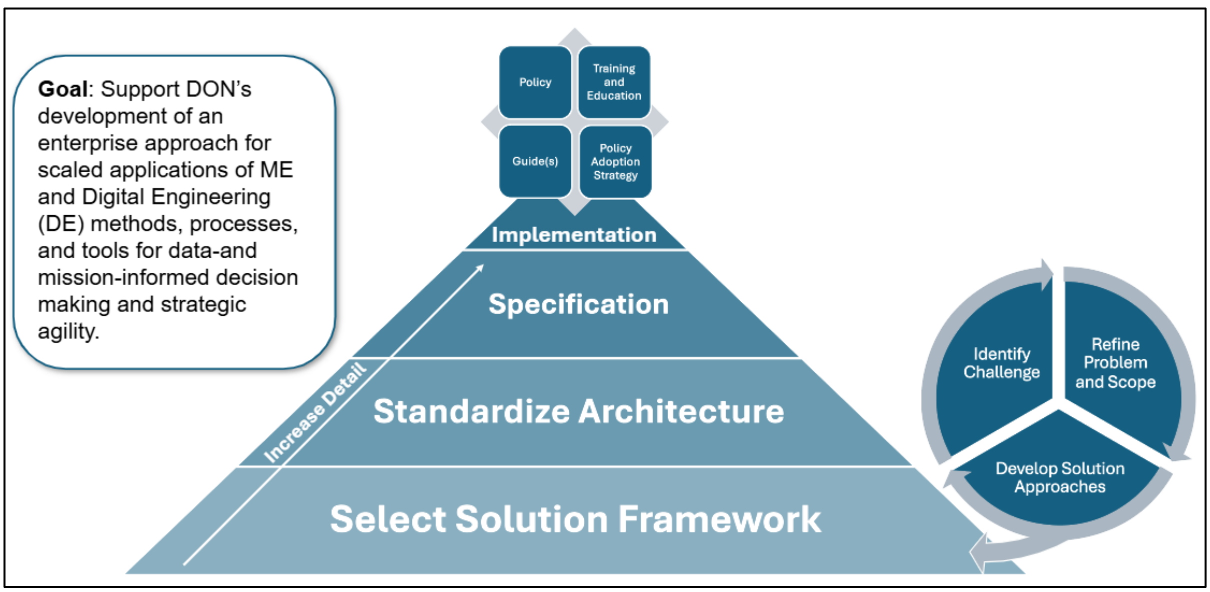

Figure 1 Macro Foundations for Developing an Applied ME Process

Report Objective

The landscape analysis presented here provides an integrated macro and micro-level understanding of the ME efforts and the enabling DE methods and tools leveraged across the DoD for strategic decision-making. It illuminates key areas that the DON should consider in an enterprise-wide approach. The team built upon an adjacent landscape analysis conducted for DON OSA, led by Ryan Loehrlein (Digital Mission Engineering Chief Engineer at Naval Surface Warfare Center (NSWC), Crane Division) and Jasmine Webb (Computer Scientist at NSWC Crane Division). Augmenting the NSWC Crane report, this present landscape analysis focuses on the following overarching objectives:

1. Baseline macro and DON-specific policies, organizations, methods, and resources surrounding ME and DE implementations for strategic decision making.
2. Capture common lexicon needs and important distinctions (e.g., ME versus DE)
3. Capture current DON ME and DE capability and policy/guidance gaps.

Keywords: Department Of Navy; DON; Mission Engineering; ME; Digital Engineering; Data-Driven Decision Making; Mission-Informed Decision Making; Decision Science; Strategic Agility; Portfolio Management; Strategic Decision Making; Enterprise Approach; Applied Mission Engineering

Summary of Key Findings

An integrated analysis of the ME and DE landscape is provided below. Leveraging a combination of policy analysis, technical data, and knowledge graph methodologies, this work builds upon previous ME and DE landscape reports. Findings identify key enablers, challenges, and strategic gaps in ME and DE implementation, aligning with broader DoD transformation initiatives such as the 2018 DoD Digital Engineering Strategy, strategic naval priorities and objectives, and the 2020 DON Digital Systems Engineering Transformation Strategy.

Key Findings:

1. ***Value of Applied ME –*** ME can be applied to a broad decision space including the development of new operational concepts, enhanced capabilities, the identification of infrastructure investments, resilient security architecture builds, and the facilitation of elasticity and readiness. To realize value, ME implementation requires a multi-pronged approach: comprehensive policy, guidebooks, standardized training and education, and a policy adoption strategy.
2. ***Evolving ME and DE Knowledge Graph Approach*** – The team applied a structured, data-centric methodology to identify ME and DE discipline adoption trends, critical toolsets, and technological dependencies across DON and the broader DoD. This approach could provide the DON a scaled, enduring capability to maintain a living representation of the ME and DE landscape, as it evolves in practice across the DON, DoD, and commercial sectors.
3. ***Stark Contrast Between ME and DE Implementation Approaches*** – There is a stark contrast between the structured, policy-driven implementation of DE and the relatively fragmented, community-driven adoption of ME.[1]
4. ***Institutional Barriers to ME Adoption Persist*** – This research validates previous ME and DE landscape assessment results that organizations likely do not manage ME at a mission level, reflecting governance, policy, and procedural gaps that hinder effective and consistent implementation.
5. ***Inconsistent ME and DE Process & Data Standardization*** – Tool adoption and training remain fragmented across DON components, necessitating a unified approach to interoperability, data governance, and workforce development. There is a lack of understanding of the minimum essential authoritative data to execute ME. Data is scattered across the enterprise without transparency regarding where it resides and who oversees it.
6. ***Need Strategic Alignment with Naval Priorities & Objectives*** – AI-driven mission planning, digital twin technology, and advanced simulation techniques are key emerging priorities for enhancing mission success and optimizing naval operations. These key priorities, along with DE initiatives, are key enablers to enhance and scale ME in practice.
7. ***Operational and Policy Implications*** – The absence of an authoritative lexicon and common digital infrastructure exacerbates interoperability challenges, emphasizing the need for clearer governance frameworks and increased investments in secure, scalable ME and DE platforms.
8. ***ME Implementation Executed as a Coalition of the Willing*** – The DON relies heavily on Warfare Centers to define and execute ME. ME in practice across the DoD is a "Coalition of the Willing" with different approaches, techniques, and tools, lacking formal policies and discrete charters to drive cohesive direction and implementation of ME.

To ensure that ME and DE remain core enablers of the DON's future operational and acquisition strategies, the team recommends the following actions as part of a DON enterprise approach:

1. ***Develop an Authoritative ME and DE Lexicon*** – Establish a standardized terminology framework across the DON to improve cross-organizational collaboration and cohesive implementation.
2. ***Enhance Digital Infrastructure and Data Governance*** – Invest in enterprise-level DE environments and infrastructure that enable secure, seamless data sharing across stakeholders.
3. ***Determine & Codify the Minimum Essential Data Required*** – Create a minimum essential data framework to support ME process execution, enabled by DE environments.
4. ***Formalize Cross-SYSCOM Standardization Efforts*** – Establish common ME and DE frameworks to align methodologies, tools, and training programs across NAVAIR, NAVSEA, NAVWAR, and NUWC.
5. ***Accelerate AI-Driven ME and DE Integration*** – Leverage predictive analytics, AI-assisted mission planning, and digital twin models as part of ME applications to improve decision-making and operational effectiveness.
6. ***Expand ME and DE Training and Workforce Development*** – Establish a unified training pipeline that ensures personnel at all levels can effectively utilize standardized ME and DE methodologies and tools.

This snapshot landscape analysis underscores the critical role of ME and DE in enabling a more agile, data-driven, and interoperable DON. The team will build on these recommendations through the execution of applied ME case studies, the output of which will provide further detailed recommendations surrounding lexicon, process, workforce/training, and authoritative data/information as part of this effort's goal of supporting the DON in the development of an enterprise approach to ME applications, enabled by DE.

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1 Background & Historic Context of ME

This section provides a macro and DON-specific historical overview of mission engineering (ME). It discusses the decision spaces that benefit from ME applications, with digital engineering (DE) as a key enabler, and the challenges associated with leading change organizationally to drive and formalize ME and DE adoption across the DON and greater DoD.

1.1 Introduction

ME is a relatively recent innovation, originating in 2010 within the Navy Systems Command's Integration and Interoperability Activity.[2] The I&I activity team developed the discipline in response to Chief of Naval Operations (CNO), ADM Roughead's concerns about Fleet mission thread execution and a desire to shift from the sub-optimization of individual programs to a mission capability approach. A complex system of systems (SoS), mission-centric approach required a better understanding of the interactions and dependencies between the multitude of systems required to execute complex, multi-domain operational missions. Successful transition required the refinement of a structured approach to support strategic decision-making across the defense ecosystem.

The ME discipline, developed in response to these needs, links engineering rigor to operational insights necessary to identify requirements and material solutions in alignment with the Department of Defense (DoD) mission. The DoD Mission Engineering Guide, Version 2.0 (MEG 2.0) defines ME as "an interdisciplinary process encompassing the entire technical effort to analyze, design, and integrate current and emerging operational needs and capabilities to achieve desired mission outcomes."[3] In practice, Mission Engineers plan, analyze, organize and integrate operational concepts for the purpose of evolving the end-to-end operational architecture and capability attributes, across the Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, Facilities, and Policy (DOTMLPF-P) spectrum, including anticipated Blue Force (BLUFOR) and Opposition Force (OPFOR) behaviors. ME analysis integrates authoritative data and a common framework to produce SoS architectures and capability attributes that inform requirements and establish data-driven technical architecture baselines. The ME outputs inform stakeholders and decision makers across the defense ecosystem.

ME can be applied to a broad decision space including to develop new operational concepts, enhance capabilities, increase access and identify infrastructure investments in key geographical areas, build a resilient security architecture, and facilitate elasticity and readiness in the defense ecosystem—specifically within the acquisition process. It can accelerate acquisition speed, ensure appropriate acquisition of systems designed to address the most critical current challenges, and support the design of open systems able to integrate cutting edge technology and overcome challenges with obsolescence, interoperability, and cost effectiveness. As shown in Figure 2, a macro view of the applied ME process, shows natural feedback loops between ME consumers and the ME process to ensure consumers integrate emergent requirements and technological innovations appropriately and both system performance and impact to mission assessment data is accessible for decision makers.

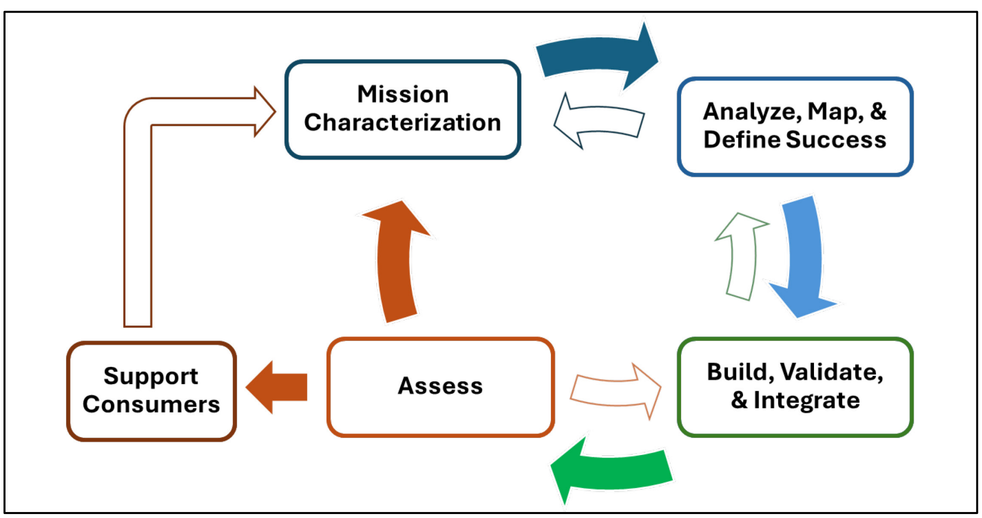

Figure 2 Macro Applied ME Process Overview

Effective ME application requires evaluation of large-scope complex missions with multifaceted system interdependencies which cross multiple portfolios and organizations. Integrated analysis requires mission, system, interface, interactions (organizational, functional, and technical), and interdependency data to successfully bridge engineering and mission effects. Relying on validated mission threads, ME practitioners must navigate barriers across the defense ecosystem's organizational geography. DE is a key enabler and supporting function for ME application. DE combines model-based techniques, digital practices, and computing infrastructure which can mitigate the complexity of applied ME, specifically those associated with scope and complexity, cross-organizational engagement, integrated analysis capability, data, and testing and assessment.

DE leverages authoritative digital models, real-time data integration, and predictive analytics to inform engineering decisions across a system's lifecycle, ensuring that system designs remain adaptable to evolving mission requirements.[4] DE enables developers to design and integrate more frequently and test earlier, more often, and more thoroughly. DE can automate the design, development, and integration of systems which can readily inform highly complex mission threads, in a wide range of operating conditions, and support data-informed decision-making. When integrated into practice, ME and DE provide a structured framework for designing, analyzing, and improving complex, multi-domain operations, enhancing adaptability, efficiency, and mission success.[5] While ME as a discipline is model agnostic, the increasing operational complexity and rapid technology innovation suggests that DE will be a critical enabler for effective ME application. Recognizing this, the 2025 Mission Architecture Style Guide (MASG) specifically details the use of model-based systems engineering and digital engineering as integral to mission architecture development.[6] While not integrated as a community, these disciplines must act in concert to ensure effective implementation.

Today, the ME discipline strongly aligns to the DoD's overall mission, including specific defense priorities noted in the 2022 National Security Strategy: [7]

1. Defending the homeland, paced to the growing multi-domain threat posed by the PRC.
2. Deterring strategic attacks against the United States, Allies, and partners.
3. Deterring aggression, while being prepared to prevail in conflict when necessary, prioritizing the PRC challenge in the Indo-Pacific, then the Russia challenge in Europe.
4. Building a resilient Joint Force and defense ecosystem.

Within the DoD, ME and DE have both become indispensable in theory or individualized practice for force modernization, operational readiness, and technological superiority.[8] However, their adoption increasingly appears reliant on communities of interest, or communities of the willing, rather than a centrally enforced or structured approach.[9] The DoD Digital Engineering Strategy and various service-specific initiatives aim to streamline acquisition processes, increase interoperability, and improve mission effectiveness through digital transformation and application of disciplines such as ME and DE. However, despite these efforts, challenges persist in defining governance structures, ensuring seamless integration across disciplines, and interoperable implementations.[10]

Evolving disciplines such as ME and DE face the same adoption challenges as emerging technology. As a result, policies and guidance alone cannot overcome critical barriers. Effective ME and DE implementation must include considerations for both adoption and resistance challenges. Academic literature identifies four key factors that influence innovation resistance: employee-management relationship, personality traits, employee participation in the decision-making process, and job security.[11] Adoption will only occur after resistance is removed. Once resistance is removed, adopters will assess the innovation against five commonly accepted innovation attributes (relative advantage, compatibility, complexity, trialability, and observability). Across the adoption theories, it is the end-user's perception of the innovation and the structural environment that makes the largest impact on adoption rates. Leading change that ensures the DoD can realize the value of ME, particularly when supported by DE, requires a multi-pronged approach: the

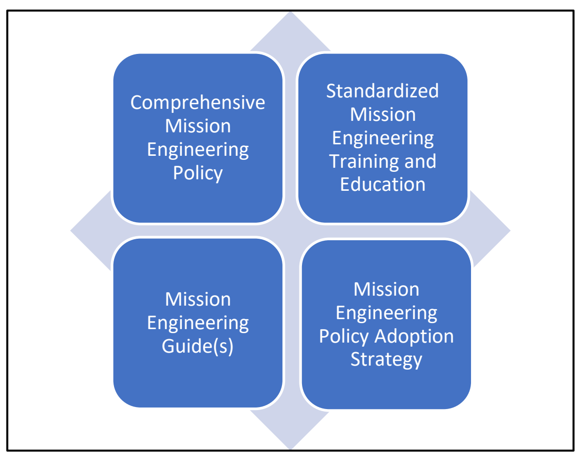

Figure 3 Recommended ME Implementation Approach

development of comprehensive policy, ME guidebooks, standardized ME training and education, and a policy adoption strategy (Figure 3).[i]

In 2024, the DoD established the Deputy Assistant Secretary of Defense for Mission Integration (DASD(MI)) within the office of the Assistant Secretary of Defense for Mission Capabilities. DASD(MI) published the MEG 2.0 and the 2025 MASG to guide the ME community towards standardized practice. Despite guidebook publication, there remains a lack of cohesive ME policy. Without such policy, a tailored policy adoption strategy, and standardized ME training and education the DoD may foster cylinders of excellence but will fail to realize the depth of ME impact.

With the multipronged adoption approach in mind, a key barrier to effective ME adoption within the DON and broader defense community is a misunderstanding of what ME truly entails and how it differs from other disciplines – often key enablers or supporting ME – such as modeling and DE.[12] While DE focuses on creating authoritative digital representations of systems and their interactions, and modeling enables simulation-driven analysis, ME is fundamentally about understanding and structuring the mission itself—ensuring that mission objectives, mission threads, and mission success factors are clearly defined and directly aligned with system design and capability development. Without a mission-driven engineering framework, even the most advanced digital models and simulations risk optimizing individual platforms without fully considering how they integrate into larger warfighting concepts and operational scenarios.[13] ME serves as the critical link between mission needs and system capabilities, ensuring that warfighters are equipped with not just cutting-edge technology, but the right operational solutions to achieve mission success.[14] It is not just an analytical exercise but a strategic imperative, particularly as warfighting becomes more complex, multi-domain, and dependent on synchronized capabilities across air, land, sea, space, and cyber.

1.2 Evolution of Mission Engineering & Digital Engineering

1.2.1 Definition & Formalization of Mission Engineering

Unlike DE, which has benefited from a well-structured policy framework and governance model, ME has largely developed through practical necessity, grassroots initiatives, and communities of interest operationally driven to diagnose system-of-systems failures in real-world missions rather than an academic or policy-driven framework.

The original definition for DoD Mission Engineering began with the CNO's Integration and Interoperability (I&I) Initiative as, "planning, analyzing, organizing, and integrating current and emerging operational concepts for the purpose of evolving the end-to-end operational architecture and capability attributes, across the DOTMPLF-P Spectrum, including anticipated BLUFOR and OPFOR behaviors, that are needed to inform the communities of interest involved in fulfilling mission needs statements." [15] This activity had a kickoff meeting in 2010 but became formal with the signing of the Vice-CNO Charter in 2012. This charter established the roles, responsibilities, authorities, and deliverables associated with executing I&I within existing Naval processes. At that time, it was envisioned according to the Charter that I&I would provide a disciplined assessment of I&I gaps from a mission area kill/effects chain perspective and develop solution recommendations to inform investment decisions. I&I leveraged existing end-to-end kill/effects chain gap analysis efforts and required cooperation between CNO, U.S. Fleet Forces Command, and SYSCOM Subject Matter Experts. I&I was established as a formal activity under the pretense not to duplicate or circumvent existing Planning, Programming, Budgeting and Execution, and Joint Capability Integration and Development System processes; rather it would provide more informed inputs to these processes.

Kill/Effects Chain Analysis (KEC) is a systematic process used in military operations to understand and optimize the sequence of actions required to achieve a desired effect on a target. It involves identifying the necessary sensors, decision-making processes, and weapon systems to successfully detect, track, engage, and neutralize a target.

The ME methodology followed under the I&I Initiative is depicted in figure 4. The current definition of ME stated earlier in this report has evolved from the original definition while still placing a major emphasis on mission execution by focusing on end-to-end effectiveness of mission essential tasks (mission thread) with defined mission success criteria (i.e., Measures of Success, Measures of Effectiveness, Measures of Performance).

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[i] The Kotter 8-stage model is a common resource for leading change: 1) Establish a sense of urgency, 2) Create a guiding coalition, 3) Develop a vision and strategy, 4) Communicate the change vision, 5) Empower broad-based action, 6) Generating short term wins, 7) Consolidating gains, 8) Anchor new approaches in the culture to enable a policy adoption strategy to prepare, transform, and sustain (Kotter, 1995).

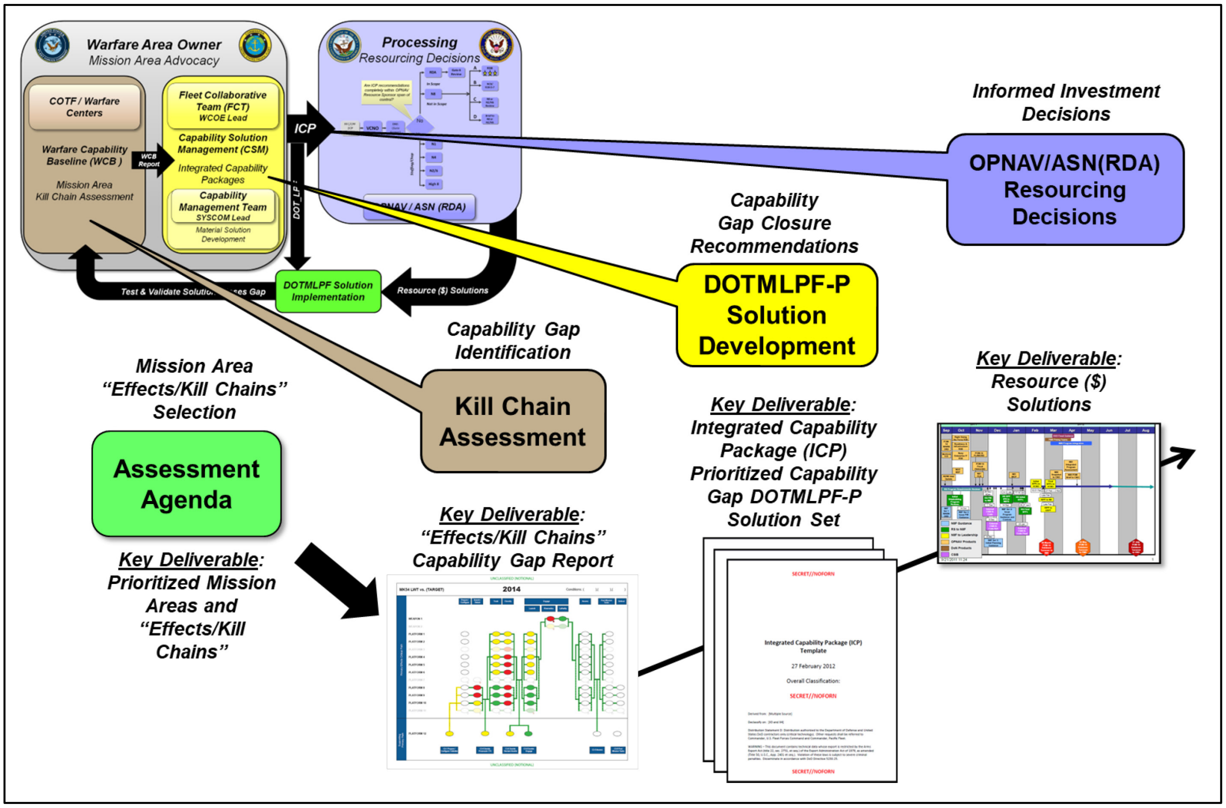

Figure 4 Navy I&I Initiative Methodology [16]

ME was developed and introduced into the DoD in September 2014 under the leadership of the Undersecretary of Defense for Acquisition, Technology, and Logistics with Dr. James Moreland, Jr. serving as the pioneer, thought leader, and implementer of this innovative discipline. It took numerous years to introduce this innovative approach across the military services to educate and gain momentum on a path forward. This activity was performed as an additional duty until formalized with the introduction of Mission Integration Management (MIM) in the National Defense Authorization Act of 2017 (NDAA 2017), Section 855. From this point forward, other policies have followed to guide the implementation of ME as outlined below and further visualized in figure 5. Appendix A also contains an expanded policy analysis of digital modernization and data strategies across the DoD, which is important when considering digital transformation as a key enabler to ME. These details on policies, statutes, and establishment of technical authority boards augment the NSWC Crane landscape report.

- **NDAA 2017, Section 855:** Focused on enhancing MIM using advanced data, modeling, and simulation capabilities following an ME approach. It emphasizes improving the DoD's ability to integrate and align resources, strategies, and operations across various missions. By leveraging these tools, the DoD aims to strengthen coordination and decision-making processes, ensuring that mission objectives are achieved efficiently and effectively. The section also requires periodic assessments and reporting to Congress, fostering accountability and ensuring that MIM remains adaptive to evolving defense needs and technological advancements.
- **DoD Directive (DoDD) 5000.01:** Provides the foundational framework for the Defense Acquisition System, emphasizing the efficient and effective development, procurement, and sustainment of defense capabilities. In the context of ME, the directive highlights the importance of a systems-of-systems (SoS) approach, integrating engineering disciplines to design, analyze, and optimize mission-level solutions. It prioritizes interoperability, scalability, and the alignment of capabilities with operational objectives, ensuring that systems work cohesively to achieve mission success. By embedding ME principles throughout the lifecycle of defense acquisition, DoDD 5000.01 fosters a holistic approach to addressing complex operational challenges and delivering resilient, adaptable, and mission-ready solutions.
- **DoD Instruction (DoDI) 5000.88, Engineering of Defense Systems:** Establishes policy and guidance for the application of systems engineering across the lifecycle of defense acquisition programs. In the context of ME, this instruction emphasizes the importance of designing and managing systems to achieve integrated mission outcomes. It highlights the role of ME in analyzing complex mission threads, identifying interdependencies, and ensuring

interoperability across SoS. DoDI 5000.88 promotes the use of rigorous technical processes, digital engineering tools, and data-driven analysis to optimize mission effectiveness, reduce risk, and support decision-making. By embedding ME into systems engineering practices, it ensures that capabilities are developed and delivered in alignment with overarching mission objectives and operational needs.

- **DoD Directive (DoDD) 7045.20, Capability Portfolio Management (CPM):** Establishes policies for managing groups of related capabilities to ensure they align with strategic priorities and deliver maximum value. In the context of ME, this directive supports the integration and coordination of capabilities across systems and portfolios to achieve mission-level objectives. It emphasizes the importance of a holistic, SoS approach to analyze interdependencies, reduce redundancies, and ensure that capabilities are interoperable and effective within mission environments. By aligning capability investments with operational requirements, DoDD 7045.20 enables ME to drive informed decision-making, resource optimization, and the delivery of cohesive, mission-ready solutions across the DoD.
- **DoD Directive (DoDD) 5135.02, Under Secretary of Defense for Acquisition and Sustainment (USD(A&S)):** Defines the roles and responsibilities of the USD(A&S) in managing the acquisition and sustainment of defense capabilities. In the context of ME, this directive supports the integration of engineering and acquisition efforts to ensure that systems and capabilities align with mission requirements. It emphasizes the application of ME principles, such as a SoS approach, to ensure interoperability, lifecycle management, and operational readiness. By fostering collaboration between engineering, acquisition, and sustainment activities, DoDD 5135.02 enables the delivery of cohesive, mission-focused solutions that address the DoD's complex operational challenges.
- **DoD Directive (DoDD) 5137.02, Under Secretary of Defense for Research and Engineering (USD(R&E)) Charter:** Outlines the responsibilities and authority of the USD(R&E) in overseeing the research, development, and engineering of advanced technologies to maintain the DoD’s technological advantage. In the context of ME, this directive assigns the USD(R&E) a central role in fostering the integration of innovative technologies and engineering practices to address mission-level challenges. It emphasizes advancing SoS engineering, enhancing interoperability, and ensuring that emerging technologies are aligned with mission requirements. By promoting collaboration across domains and leveraging ME principles, DoDD 5137.02 ensures the effective design, development, and deployment of capabilities that support complex and evolving operational needs.
- **Chairman of the Joint Chiefs of Staff Instruction (CJCSI) 5123.01J, Charter of the Joint Requirements Oversight Council (JROC) and Implementation of the Joint Capabilities Integration and Development System (JCIDS):** Establishes guidance for identifying, prioritizing, and validating joint military capability requirements. In the context of ME, this instruction emphasizes the importance of aligning capabilities with mission objectives through a SoS approach. It integrates ME principles by ensuring that capability development considers mission-level performance, interoperability, and operational effectiveness across joint and coalition environments. CJCSI 5123.01J supports rigorous analysis and collaboration to identify gaps, evaluate alternatives, and ensure that developed capabilities are fully integrated and optimized to meet the demands of complex missions.

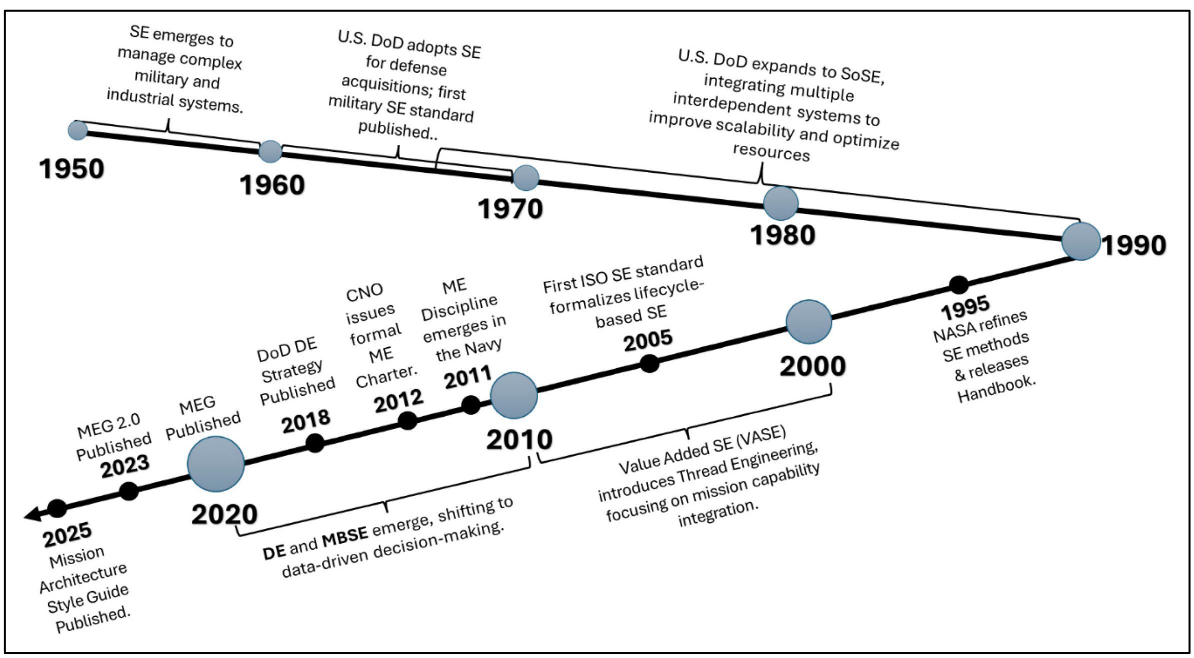

Figure 5 Timeline of ME and DE Evolution

The current methodology for ME as captured in MEG v2.0 is shown in Figure 6. This methodology has moved away from the detailed approach outlined in the original Mission Engineering and Integration Guidebook in November 2019 produced by Dr. Moreland consisting of 10 steps and the use of an effects/kill web framework.[17] However, it is very similar to the methodology presented in MEG v1.0. The main differences between MEG v2.0 and MEG v1.0 are the following:

- Front matter revised to focus on benefits and scalability of the interdisciplinary ME process.
- ME methodology revised to show applicability beyond studies; to inform acquisition, research and development, systems and SoS integration, and evolving concepts of operation.
- Refocused MEG v1.0 content on Government Reference Architectures to the critical elements of mission thread and mission engineering thread development; supporting broader application of the ME process.
- ME terminology definitions revised and expanded to reflect current state-of-practice.
- References updated to show alignment with current DoDD and DoDI series.
- Design of analysis content revised to better depict lessons learned and best practices in planning, resourcing, execution, and curation of findings from ME activities—i.e., types of data and products.

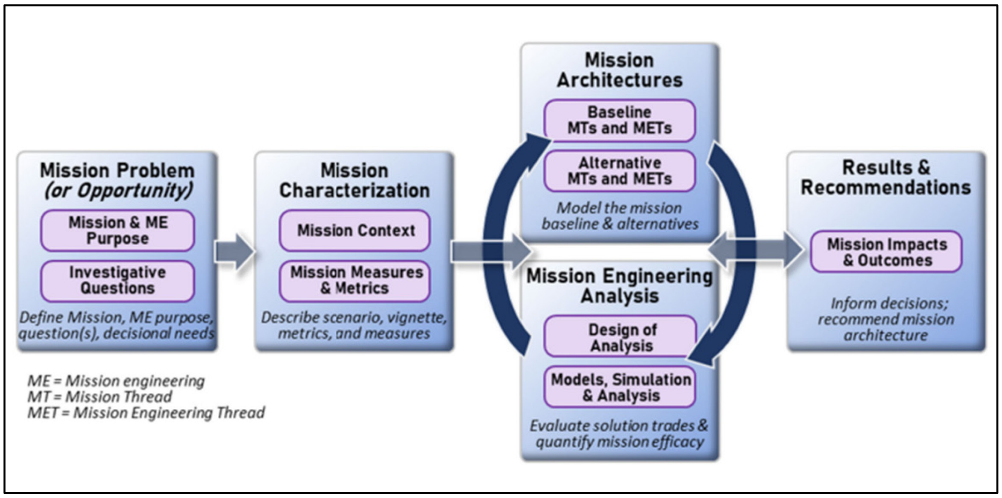

Figure 6 DoD OUSD(R&E) ME Methodology [18]

1.2.2 Formalization of Digital Engineering

DE is a discipline that has benefited from a structured and policy-driven approach, accelerating its integration across defense acquisition, systems development, and lifecycle management. The DoD Digital Engineering Strategy, first introduced in 2018, provided a clear framework for transforming traditional document-based engineering processes into a data-driven, model-based enterprise focused on the application of science and mathematics in a computational manner. Unlike ME, which evolved out of necessity to address integration and interoperability challenges, DE was deliberately developed as a cross-cutting modernization initiative, designed to bring greater efficiency, traceability, and analytical rigor to engineering practices cross functions and across organizational boundaries. The structured adoption of DE was largely driven by:

- Top-down policy mandates, such as DoD Instruction 5000.97, which reinforced the requirement for model-based, digital-first approaches in engineering and acquisition.
- Establishment of Digital Engineering Ecosystems, such as digital twins, authoritative source-of-truth data repositories, and cloud-based engineering platforms, which have enabled cross-organizational collaboration and real-time decision support.
- Well-defined toolchain and infrastructure, including Model-Based Systems Engineering (MBSE), system-of-systems modeling, and advanced simulation techniques, which have made DE an integral part of modern capability development

Despite these advancements, DE adoption within the DON has not been without its challenges. One of the most significant barriers has been the difficulty of fully integrating digital workflows across the acquisition lifecycle, particularly in programs that still rely on legacy systems, traditional systems engineering methodologies, and document-heavy approval processes. Additionally, while DE has been heavily promoted within the acquisition and engineering communities, its application at the operational level remains limited, meaning that warfighters, operational planners, and decision-makers often do not have direct access to or understanding digital engineering insights.

A key lesson from DE's adoption is that top-down policy alone is not enough—successful implementation requires organizational buy-in, workforce training, and a clear cohesive strategy and roadmap for integrating DE with real-world mission execution. As the DON continues to refine its DE implementation efforts as a critical enabler to ME, ensuring stronger alignment between DE and ME will be essential, allowing digital tools and mission-driven engineering methodologies to work in tandem to drive future force development.

1.2.3 Broader Application Space for ME and DE

Across industry and government sectors, ME and DE are transforming how organizations manage complexity, enhance decision-making, and optimize system performance.[19] Industries such as aerospace, automotive, energy, and telecommunications increasingly rely on ME and DE methodologies to drive innovation, improve efficiency, and reduce risk.[20] Companies like SpaceX, Boeing, Raytheon Technologies, and Lockheed Martin have adopted DE to integrate digital twins, model-based systems engineering (MBSE), and AI-driven simulations into product development, enhancing design optimization, performance prediction, and lifecycle management.[21] Similarly, mission-critical sectors such as global logistics, emergency response, and space exploration apply ME principles to synchronize operations, optimize resource allocation, and enhance resilience in dynamic environments.[22]

1.2.4 Navy-Specific Actions for ME

The effectiveness of ME and DE is ultimately measured by the impact of these disciplines on decision-making, mission success, and operational agility. While ME provides a structured, systems-based approach to designing and executing missions, DE enables the real-time integration of authoritative data, modeling, and simulation to improve strategic, operational, and tactical decisions.

Despite the potential benefits of ME and DE, their role in shaping decisions within the DON remains uneven, with varying levels of adoption across different programs and organizational levels.[23] This is due to, at the DON-specific level, no formal policies to drive the direction or enterprise-wide implementation of ME. However, the DON has taken proactive steps in advancing ME and DE through initiatives such as the Digital Systems Engineering Transformation (DSET) Strategy, establishment of the Office of Naval Operations (OPNAV) N9,[ii] Deputy Chief of Naval Operations for Warfighting Requirements and Capabilities to be the central office for ME-related activities, and establishment of the ME Technical Authority Board (ME TAB) under the Navy's Chief Engineer located within the Assistant Secretary of the Navy for Research, Development, and Acquisition's Office. Of note, the DON established the ME Technical Authority Board (ME TAB) to examine current processes and has created a path forward for the implementation of ME within the Navy. In addition, the Naval Sea Systems Command (NAVSEA) is investigating the establishment of a PMA 296 Office at NAVSEA Headquarters, similar to PMA 298 at the Naval Air Systems Command (NAVAIR), to handle the leadership and future direction of ME.

The DON relies heavily on Warfare Centers to define and execute ME for both NAVSEA, NAVAIR, and Naval Information Warfare Systems Command (NAVWARSYSCOM). However, ME is currently executed as a "Coalition of the Willing" with different approaches, techniques, and tools used across groups of practitioners. This challenges the DON's ability to implement potential solutions across warfighting domains when there are inconsistencies in the approaches as well as a potential breakdown in tool set and artifact interoperability. Ambiguities in policy, role definitions, and community management have led to inconsistencies in execution. Stakeholders across DON face difficulties in aligning ME and DE efforts, standardizing processes, and integrating digital tools at the enterprise level.[24] Addressing these challenges is critical to fully harnessing the potential of ME and DE, improving decision-making processes, and optimizing mission effectiveness in an increasingly contested battlespace.[25] The Naval Surface Warfare Center Crane Division landscape report discussed some of the activities occurring at the Warfare Centers; however, there was no discussion about OPNAV N9 and the activities at

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[ii] In the last couple of years, there appears to be some movement away from the OPNAV N9 original responsibilities regarding ME.

the SYSCOM level. The team intends to engage OPNAV N9 through a case study as part of this work, which will illuminate further the current policies, practices, and tooling leveraged by that group for ME applications.

This study represents a snapshot of available data and information. The ME and DE fields continue to evolve and experience adoption across government, industry, and research domains, driving a shift toward data-centric, model-based, and digitally integrated engineering practices. Within defense, aerospace, and critical infrastructure sectors, organizations are actively refining ME and DE methodologies to improve mission assurance, lifecycle efficiency, and operational resilience. Organizations are, often independently, attempting to integrate the practices but with varying degrees of rigor. Leading change, particularly change that is critical to the success of the Joint Force, is a wicked problem. Building a cohesive DON approach to ME, particularly in concert with DE, will be essential to ensure that ME is no longer dependent on informal communities of practice or individual program champions. A cohesive approach will enable more standardized application and the realization of the benefits of both disciplines. The DON must embed a formalized framework for ME within force design and development, acquisition, operational analysis, and capability development processes, providing consistent, repeatable, and scalable methodologies that inform decision-making at all levels.

2 Validating & Augmenting NSWC Crane Landscape Report Findings

2.1 Commonalities & Validation of Findings

Several findings from the NSWC Crane Landscape Report align with the VT-ARC/ARLIS team's assessment in this report, outlined below, and reinforce the DON's understanding of long-standing challenges in ME/DE implementation.

1. ***Lack of Governance and Policy Enforcement*** – The NSWC Crane Landscape Report identified a lack of authoritative guidance and formalized governance for ME, making implementation fragmented and overly reliant on "communities of the willing." The VT-ARC/ARLIS team's landscape analysis findings confirm that, unlike DE—which benefits from structured policies such as the DoD Digital Engineering Strategy (2018) and DoDI 5000.97 (2023)—ME remains loosely governed, lacking standardized frameworks, funding pathways, and cross-organizational alignment. The DON established the ME TAB to address gaps.

2. ***Disjointed ME and DE Adoption Across DON*** – The NSWC Crane Landscape Report highlighted a lack of interoperability and coordination, with varying levels of ME and DE maturity at DON components. The VT-ARC/ARLIS team's landscape analysis confirms that ME adoption remains inconsistent across the enterprise, with some organizations integrating ME successfully, while others lack structured methodologies.

3. ***Challenges in Aligning ME with Digital Engineering*** – The NSWC Crane Landscape Report emphasized that ME is not consistently embedded within DE frameworks, leading to inefficiencies in SoS assessments and trade-space analysis. Our findings reinforce this, showing that while digital twins, MBSE, and AI-driven decision-support tools are widely used within the DE implementation space, these models are often focused on system performance rather than mission effectiveness. The lack of ME-driven design processes in DE frameworks limits the ability to validate mission success factors at the engineering level.

While ME and DE adoption are advancing, persistent organizational and structural challenges hinder full institutionalization.[26] Addressing these challenges will require a coordinated effort to establish enterprise-wide governance policies, standardize ME/DE toolsets, and invest in workforce training initiatives to build technical expertise in mission-driven engineering. A coordinated effort is one major step of Kotter's Leading Change model – covered in Section 1 – to drive long lasting transformation and adoption.[27]

2.2 Complementary Findings to Augment

The NSWC Crane Report captured foundational insights into the ME and DE landscape, many of which were validated by this present landscape analysis. The VT-ARC/ARLIS team captured the following findings intended to augment the NSWC Crane Report:

1. ***Role of Mission Engineering in Emerging Naval Warfare Concepts*** – The NSWC Crane Landscape Report focused heavily on ME and DE's integration within acquisition and system design, but did not fully address their role in

modern naval warfare strategies such as Distributed Maritime Operations (DMO) and Joint All-Domain Command and Control (JADC2). The VT-ARC/ARLIS landscape analysis expands on ME's role in force-level integration, kill chain effectiveness, and cross-domain operational planning, identifying gaps in ME's ability to support these mission sets due to fragmented policy enforcement.

2. ***Gaps in Workforce Development and ME Training Pipelines*** – While the NSWC Crane Landscape Report noted that ME expertise is concentrated among a small number of specialists, it did not provide a detailed roadmap for scaling ME workforce development. The VT-ARC/ARLIS landscape analysis builds on this by recommending the creation of formal ME training curricula at DAU, NPS, and within SYSCOM training programs, ensuring that ME principles are more broadly institutionalized.

3. ***Funding and Resourcing Disparities Between ME and DE*** – The NSWC Crane Landscape Report acknowledged funding challenges for ME but did not quantify the disparity between ME and DE investment priorities. The VT-ARC/ARLIS landscape findings highlight that while DE benefits from dedicated funding within acquisition and sustainment budgets, ME projects often rely on ad hoc funding and discretionary program support, limiting their scalability. Without sustained financial investment, ME remains an informal practice rather than an institutionalized discipline.

4. ***Data Standardization, Discoverability, & Access Critical to ME*** – The NSWC Crane Landscape Report covered data strategy, standards, utilization, and storage in the context of the DoD DE strategy and in relation to authoritative sources of system data throughout the development of a system. The VT-ARC/ARLIS landscape expands the scope of a critical need for data standardization as a critical enabler to ME in practice and at scale. Necessary data to support the execution of ME is scattered across the DoD at various organizational levels and across many different platforms. Appendix A provides further information into the data strategy landscape across the DoD.

2.3 Points of Clarification or Divergence

The NSWC Crane Landscape Report identified ME and DE gaps critical to address in shaping the DON's enterprise approach to ME and DE. Much of this present landscape analysis validates and compliments these findings. However, the VT-ARC/ARLIS team found a few areas where findings diverge or where the team sought to refine through an adjusted scope, outlined below.

1. ***Definition and Scope of Mission Engineering*** – The NSWC Crane Landscape Report focused on ME primarily as a technical discipline supporting acquisition and system-of-systems integration. The VT-ARC/ARLIS team broadens this scope, emphasizing that ME is more than a subset of systems engineering; it is a mission-driven discipline shaping capability development from the outset. Rather than viewing ME as a supporting function within acquisition, this shift in perspective positions ME as a foundational element of force design and operational planning, integral to the acquisition process both up front and iteratively throughout to inform decision making.

2. ***Effectiveness of ME/DE Oversight Structures*** **–** The NSWC Crane Landscape Report suggested that the ME TAB and other oversight bodies could provide the necessary governance framework for ME/DE alignment. The VT-ARC/ARLIS team's findings indicate that, while these structures exist, they lack enforcement mechanisms, funding authority, and standardized adoption across the DON. Without clearer policy mandates, these boards will struggle to drive meaningful change.

3. ***Interoperability of ME/DE Data and Toolsets*** – The NSWC Crane Landscape Report emphasized the importance of developing standardized toolchains for ME and DE but focused primarily on existing digital engineering tools such as MBSE and simulation frameworks. The VT-ARC/ARLIS findings highlight the lack of mission-thread-based digital architectures that connect operational-level mission analysis to engineering workflows. Current DE tools excel at optimizing system performance but lack the ability to dynamically adapt system-of-systems models based on real-world mission constraints. Appendix A provides an expanded analysis of digital transformation and data analytics platforms across the DoD. Understanding the minimum essential data, and where it lives across the DoD, will be critical to ME implementation.

3 Current ME & DE Landscape

This section builds upon the adjacent NSWC Crane Landscape Report and extends its findings by providing a data-driven holistic assessment of ME and DE adoption within the DON to further validate, contextualize, and refine those findings. Importantly, this landscape analysis extends beyond the DON to examine ME and DE applications across the broader DoD and commercial landscape. These insights help contextualize best practices that could inform future standardization and scaling efforts within the DON. This is a working-understanding of the landscape and is not intended to be exhaustive or definitive; rather, it is a holistic assessment of a snapshot in time designed to validate, contextualize, and refine prior ME and DE analyses, which will be further augmented in future iterative reports as part of this effort. Appendix A and B provide expanded analysis on data strategy and tooling landscapes for further reading.

3.1 A Macro View of ME & DE Adoption Across Literature

Figure 7 highlights the top 50 words from ME and DE literature. To assess the current state of ME and DE adoption, the VT-ARC/ARLIS team conducted an extensive bibliographic and knowledge analysis, mapping key trends, governance structures, technological tools, and adoption barriers. The literature review examined 858 research papers on ME and 2,789 on DE, encompassing all available direct research in these fields.

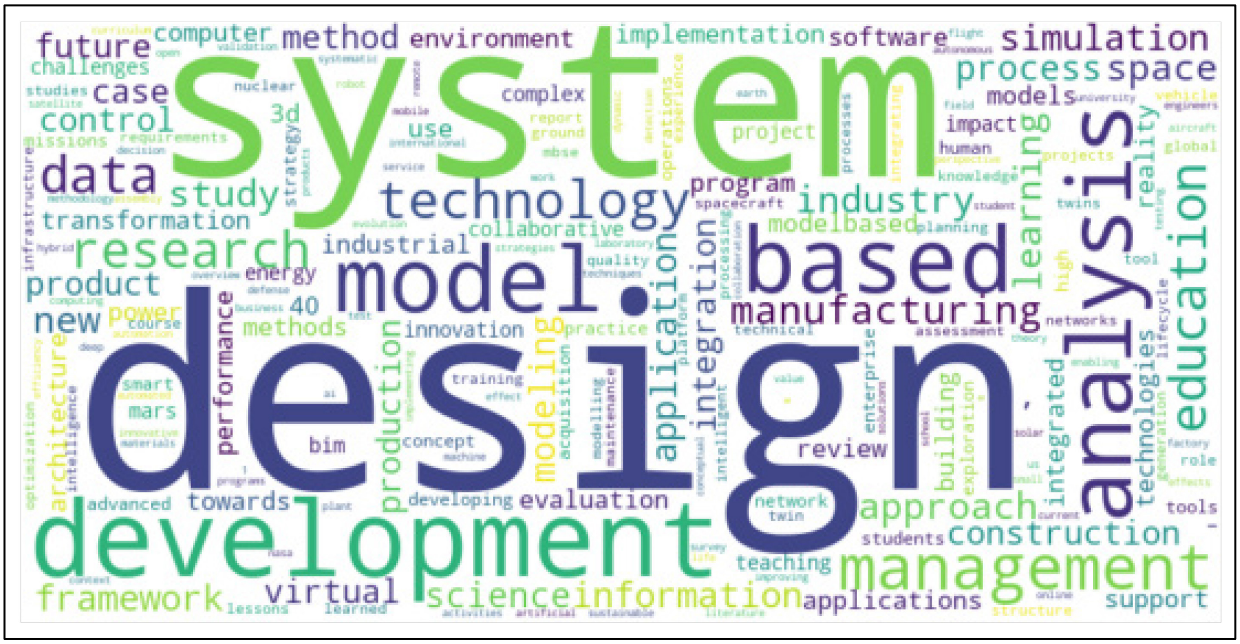

Figure 7 Top 50 Words from ME and DE Literature Examined

Given the identified gaps in ME and DE governance discussed in Section 2, the team examined how leading organizations outside the DoD have successfully implemented these disciplines. NASA Ames Research, Jet Propulsion Laboratory, and Ball Aerospace have been at the forefront of adoption, leveraging blockchain for secure mission data management, AI for decision automation, and augmented reality for immersive mission planning. Their approaches serve as potential benchmarks for the DoD, demonstrating how ME and DE can be effectively integrated into high-complexity, high-risk decision-making environments.

Academic institutions and private-sector companies have also played a critical role in advancing DE standards. Research initiatives focused on integrating DE methodologies into traditional engineering frameworks offer promising pathways for the DoD to enhance its own ME and DE strategies. As these institutions refine best practices, their contributions may serve as critical benchmarks for improving ME and DE interoperability, governance, and execution within the defense sector. The graphs below highlight the top 25 contributing institutions to ME (Figure 8) and DE (Figure 9) from the literature. This is based on the primary contributor list amongst the various literature pertaining to ME and DE, respectively.

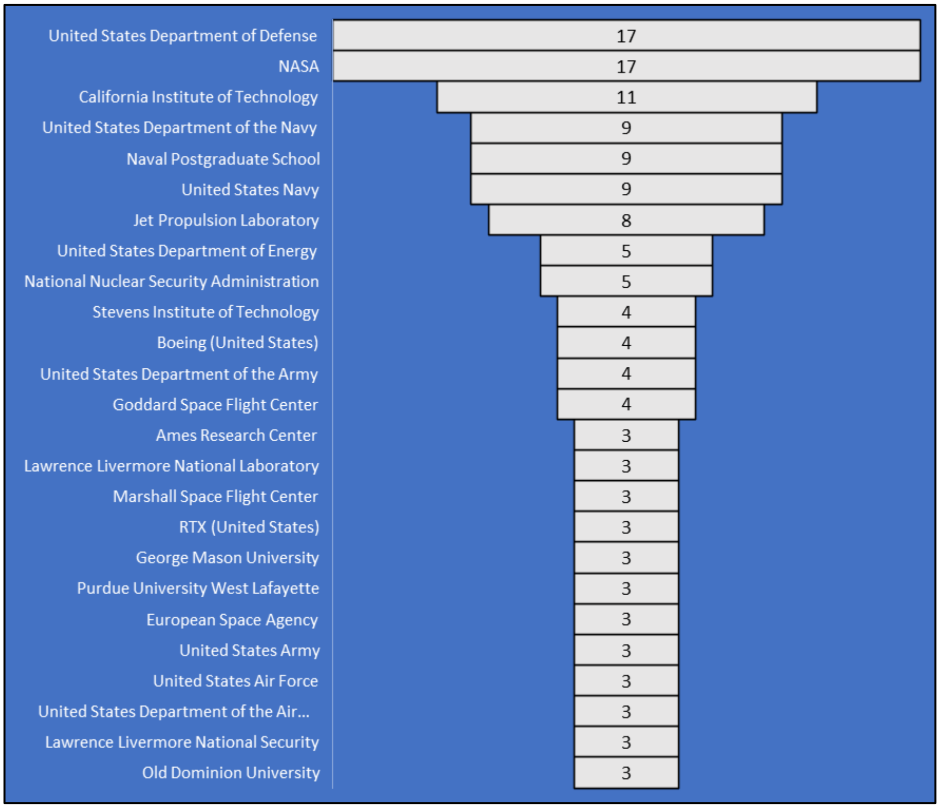

Figure 8 Top 25 Mission Engineering Contributors by Literature Count, N=142 (Remaining 114 Institutions Provided between One and Two Contributions with 137 Additional Unique Contributions)

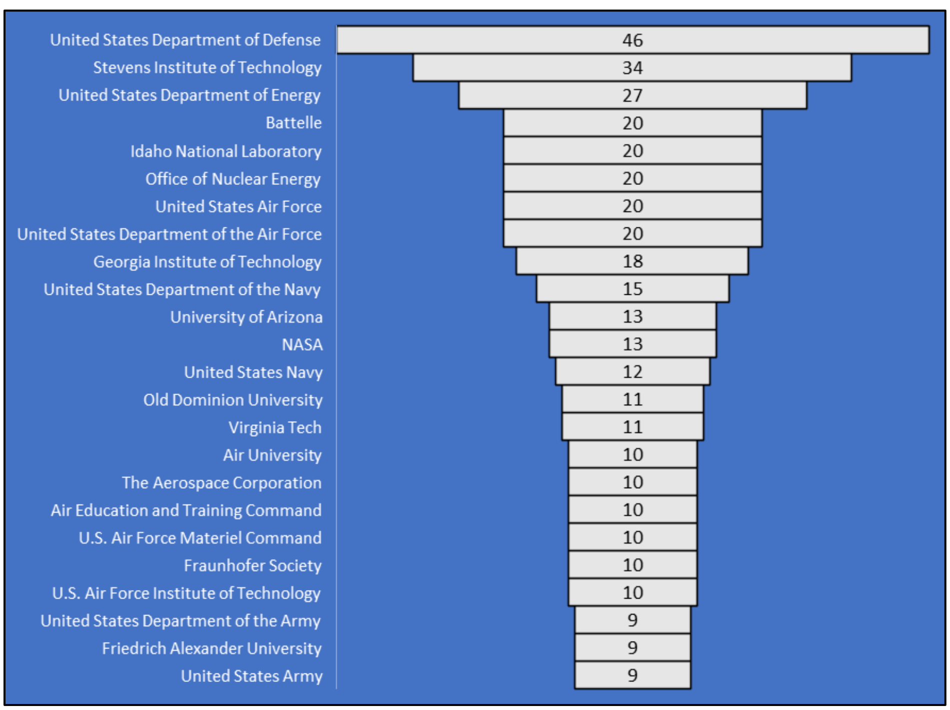

Figure 9 Top 25 Digital Engineering Contributors by Literature Count, N=387 (Remaining 176 Institutions Provided between 1-8 Contributions with 499 Additional Unique Contributions)

To provide a structured representation of and dive deeper into the ME and DE adoption trends across these organizational contributors, the team leveraged a knowledge graph methodology, which enabled the identification of key stakeholders, technological tools, and strategic adoption patterns.

3.2 Knowledge Graph Approach to Landscape Analysis

In an effort to systematically assess and interpret the key trends across the ME and DE landscape, the team employed a knowledge graph methodology to organize and structure relevant data, interdependencies, and adoption trends. Given the complexity of ME and DE implementation across the DON, the broader DoD, and industry, a traditional linear data analysis approach would have been insufficient in capturing the intricate relationships between stakeholders, technologies, and processes. Instead, a knowledge graph provides a relational structure, allowing for both high granularity and broader strategic insights—a necessity for understanding the varied applications and evolution of ME and DE across defense and commercial ecosystems.

At its core, a knowledge graph functions as a networked representation of data, where nodes represent entities such as organizations, technologies, and processes, and edges define their interconnections.[28] This approach was particularly well-suited for ME and DE landscape analysis, as it enabled the visualization of key relevant entities (such as organizations, stakeholders, standards), the mapping of tool integrations, and the tracking of ME and DE evolution over time. The team used a Neo4J graph database as the primary implementation tool, given its high-performance query capabilities and robust visualization functions for analyzing complex networks in defense applications.

Knowledge graphs provide a structured yet adaptable means of organizing data, offering a scalable framework for tracking ME/DE integration across the defense ecosystem. While this approach primarily served as a means to gather, organize, and analyze complex information for this present landscape analysis, this approach could provide the DON a scaled, enduring capability to capture and iteratively update a living representation of the ME and DE landscape, as ME and DE disciplines continue to evolve in practice and formalization across the DON, greater DoD, and non-DoD sectors. Unlike rigid hierarchical data structures, knowledge graphs dynamically evolve, allowing for continuous updates and refinement as new information emerges[29].

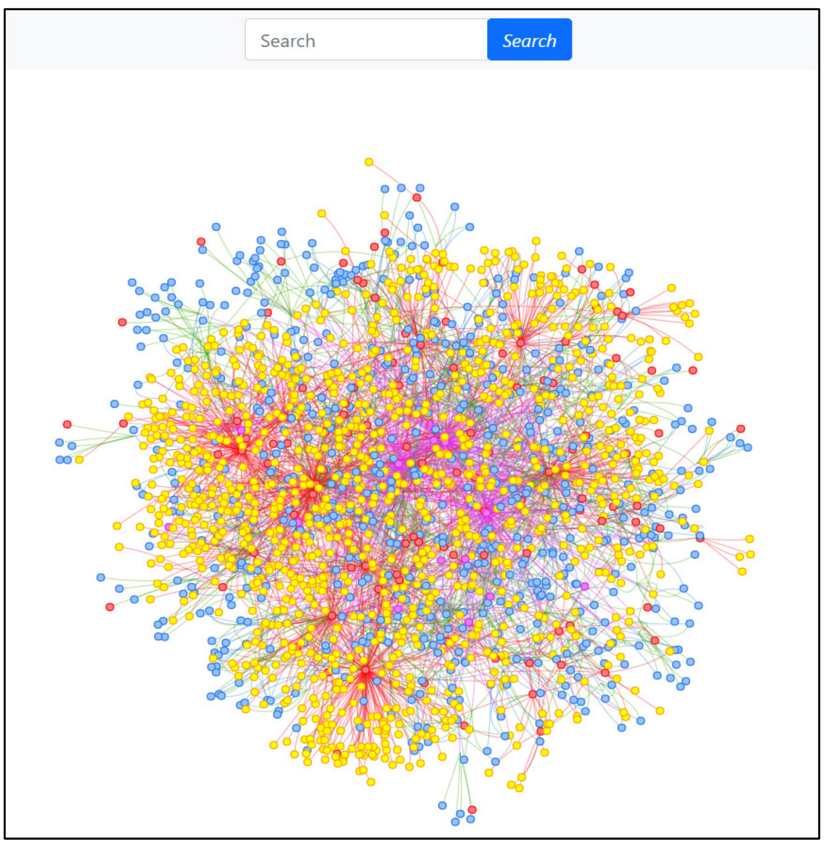

Figure 10 Knowledge Graph of ME & DE Landscape 2025 Snapshot (Neo4J Implementation)

3.3 Knowledge Graph Centrality Analysis: Insights & Implications

The VT-ARC/ARLIS team conducted a node centrality analysis to explore more deeply the relationships between the ME and DE landscape stakeholders, technologies, and processes within the knowledge graph. In network analysis, closeness centrality (or closeness) serves as a key measure of a node's relative accessibility within a connected graph. Thus, the more central a node is, the closer it is to all other nodes. Mathematically, closeness centrality C(x) is the inverse of the sum of shortest path distances from a node xxx to all other nodes in the graph:

$$C(x) = \frac{N-1}{\sum_y d(y,x)}$$

where:
$N = represents\ the\ total\ number\ of\ nodes\ in\ the\ graph, and$
$d(y,x) = denotes\ the\ shortest\ parth\ length\ between\ nodes\ x\ and\ y$

The team leveraged closeness centrality to determine the most influential nodes within the knowledge graph. These nodes represent pivotal research topics, methodologies, or frameworks that have the greatest connectivity across ME and DE literature. The team identified and analyzed key nodes, gaining a clearer understanding of which research areas drive progress, where gaps exist, and how to enhance connectivity for more effective knowledge dissemination. The five most central and relevant publications – key central nodes – identified through this analysis were titled:

1. "Transforming Systems Engineering through Digital Engineering" (Closeness: 4.639)
2. "Towards Developing Metrics to Evaluate Digital Engineering" (Closeness: 4.619)
3. "Transforming System Engineering" (Closeness: 4.282)
4. "Application of Model-Based Systems Engineering Concepts" (Closeness: 4.192)
5. "Analyzing Mission Impact of Military Installations" (Closeness: 4.216)

We see that scores range from 4.2 to 4.6, indicating strong connectivity.

The most central nodes highlighted foundational research topics—systems engineering transformation, digital engineering metrics, and model-based systems engineering— which serve as the conceptual backbone of the fields. The shape and distribution of the knowledge graph also provided confirmatory insights into the fragmentary adoption of the DE and particularly ME, noted in Section 2. Specifically, the team found notable disparities in closeness centrality across the knowledge graph, pointing to fragmentation in the adoption of ME and DE across organizational and theoretical domains (illustrative example shown in figure 11). Specifically, this analysis revealed:

- ***Anchoring from a Few Nodes*** – Those with high closeness centrality exhibit strong interconnectivity and serve as core references, resulting in a relative few entities acting as foundational texts or methodologies that shape the ME/DE landscape.
- ***Large Number of Peripheral Nodes*** – Nodes with closeness values closer to 1 are comparatively isolated, representing niche research areas or emerging topics that have yet to integrate into the broader discourse, which points to the relative newness of adoption of ME and DE principles.
- ***Emergence of Core-Periphery Structure*** – Having a relatively small number of highly central nodes dominate the connectivity while many peripheral nodes remain weakly integrated suggests that certain research efforts are instrumental in unifying the field, whereas others operate in more specialized or fragmented subdomains.

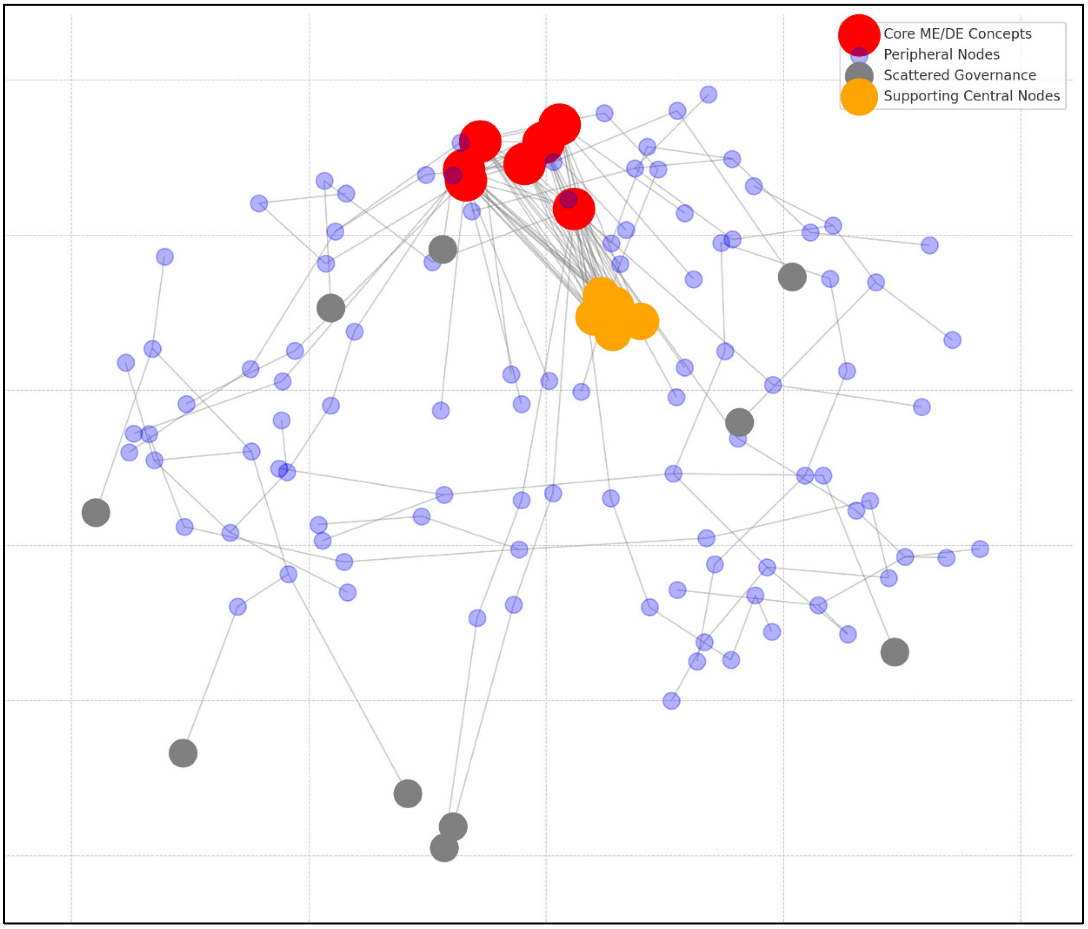

Figure 11 Illustrative Example of Core-Periphery Structure Found in ME & DE Disciplines

The closeness centrality analysis highlights the most well-connected research areas within the ME and DE knowledge graph. By further categorizing papers based on their thematic focus, the team extracted four primary categories of top nodes (outlined below) providing additional strategic and actionable insights for the DON's ME and DE adoption. These categorized nodes demonstrate significant influence within the knowledge graph, suggesting that they act as central hubs in the broader discourse of ME and DE. Their high closeness scores indicate that they are well-integrated into the network, providing critical connections between disparate areas of research. The team compiled the following actionable insights synthesized from content represented in each category of nodes (in the context of extensible approaches to the DON decision space) and suggested next steps the DON could pursue:

1. ***Mandate MBSE adoption to modernize engineering workflows and standardize ME processes.*** The analysis shows that research on MBSE integration into mission engineering has high centrality, highlighting its critical role in standardizing ME processes.[30]
   - **Actionable Insights**:
     - Standardization of ME Processes: Transition from fragmented, manual approaches to digitally connected engineering environments where MBSE models serve as the authoritative source of truth.[31]
     - Interoperability Across Platforms: ME and DE efforts ensure consistent modeling standards (e.g., SysML, UML, and DODAF) to enable cross-domain collaboration between stakeholders, including contractors, fleet operators, and allied forces.[32]
     - Efficiency Gains in Engineering Workflows: MBSE adoption would allow automated validation of system architectures, reducing development time and cost while enhancing risk assessment and mitigation capabilities.[33]
   - **Recommended Next Steps:**

- Implement a Navy-wide MBSE standards for all future weapon system acquisitions and mission planning processes.
- Establish a centralized MBSE repository to house authoritative models and ensure consistent reuse across projects.
- Require contractors and vendors to comply with MBSE-based requirements modeling for all new ships, aircraft, and weapon system designs.

2. ***Prioritize Digital Twin and AI integration to enhance cyber-physical mission planning.*** Digital Twin technology is a core enabler of ME by allowing real-time synchronization between physical assets and virtual models.[34] The high closeness centrality of research on Digital Twin integration in model-based engineering indicates its increasing importance for naval mission planning. AI-powered analytics further enhance Digital Twin capabilities by providing predictive insights, anomaly detection, and mission adaptation in real time. Together, Digital Twins and AI create a self-learning system that can simulate, predict, and optimize operations for mission-critical assets.[35]
   - **Actionable Insights:**
     - Real-Time Situational Awareness: Digital Twins enable live mission monitoring for fleet readiness, predictive maintenance, and battlefield adaptability.
     - AI-Driven Decision Support: AI enhances mission planning by providing automated risk analysis, logistics forecasting, and adaptive mission execution strategies.
     - Cybersecurity Hardening of Naval Systems: The integration of AI-driven cyber resilience into Digital Twin architectures ensures proactive defense against cyber threats.
   - **Recommended Next Steps:**
     - Develop a Navy-wide Digital Twin framework to support ship and aircraft lifecycle management, fleet readiness, and logistics tracking.
     - Leverage AI-driven predictive analytics to automate wargaming, mission rehearsal, and cyberattack mitigation.
     - Establish a joint AI & Digital Twin research initiative with DARPA, CDAO, Navy R&D, and defense contractors to align and accelerate prototype testing.

3. ***Leverage aerospace mission engineering principles for naval operational resilience.*** High-closeness centrality research in space mission engineering, autonomous spacecraft navigation, and interplanetary operations offers direct applications for naval mission resilience. Concepts such as autonomous asset coordination, fault-tolerant systems, and adaptive mission execution developed for deep-space missions can enhance distributed naval operations in contested environments.
   - **Actionable Insights:**
     - Apply Deep-Space Navigation Algorithms to Autonomous Naval Systems: Space-based formation-flying and multi-agent coordination techniques can improve the command-and-control (C2) resilience of naval unmanned systems.
     - Enhance Redundancy in System Architectures: Lessons from aerospace fault-tolerant avionics can be applied to naval mission-critical electronics, ensuring greater survivability during combat operations.
     - Use Orbital Mission Planning Techniques for Distributed Maritime Operations: The trajectory optimization methods used in Mars rover landing site selection can be repurposed to enhance naval convoy routing and multi-domain fleet coordination.
   - **Recommended Next Steps:**
     - Establish a collaborative mission engineering task force between the Navy and Space Force to cross-pollinate resilient mission planning strategies.
     - Develop autonomous naval operations doctrine that integrates aerospace mission autonomy for unmanned underwater vehicles (UUVs) and aerial drones.
     - Adapt orbital mechanics-based optimization techniques to improve naval fleet movement planning in contested waters.

4. ***Modernize lifecycle management and logistics through predictive analytics and Industry 4.0 tools.*** High-closeness centrality research highlights Industry 4.0 technologies, such as predictive maintenance, blockchain-based logistics tracking, and digital supply chains, as critical to modernizing lifecycle management. Given the Navy's large, distributed asset base, improving data-driven decision-making will significantly enhance readiness and cost efficiency.
   - **Actionable Insights:**

        - AI-Driven Predictive Maintenance for Fleet Readiness: Predictive analytics can preemptively detect component failures in ships, aircraft, and ground vehicles, reducing downtime and operational risks.
        - Digital Supply Chain Visibility: Implementing blockchain and smart contracts will enhance transparency, traceability, and security across DoD logistics pipelines.
        - Industry 4.0 Smart Warehousing: Autonomous robotic inventory management and automated replenishment tracking will improve logistics efficiency and deployment readiness.
    - **Recommended Next Steps:**
        - Deploy AI-powered fleet maintenance dashboards for real-time asset health monitoring.
        - Implement blockchain-based tracking for high-value military equipment logistics and spare parts management.
        - Establish digital twins for Navy depots to optimize spare part availability and repair cycle efficiency.

Summarizing these insights and next steps, the closeness centrality analysis provides a clear roadmap for ME and DE adoption, and, in summary, provides the basis for the following strategic recommendations:

1. Mandate MBSE adoption to modernize engineering workflows and standardize ME processes.
2. Prioritize Digital Twin and AI integration to enhance cyber-physical mission planning.
3. Leverage aerospace mission engineering principles for naval operational resilience.
4. Modernize lifecycle management and logistics through predictive analytics and Industry 4.0 tools.

By understanding how information propagates through the full knowledge graph, the DON can optimize their research investments, policy frameworks, and workforce training programs to align with the most influential concepts. A deliberate effort to strengthen weakly connected nodes—such as emerging methodologies or experimental frameworks—could lead to a more resilient and innovative knowledge network in the future. The presence of a core-periphery structure indicates an opportunity to enhance integration between high-centrality and low-centrality nodes. Bridging gaps between these groups through cross-referencing, collaborative research initiatives, and standardization efforts could accelerate knowledge diffusion and improve alignment across ME and DE applications.

By acting on these insights, the DON can accelerate its adoption of ME and overall digital transformation through DE enablers, improving mission effectiveness, interoperability, and operational agility in complex environments.

3.4 ME & DE Tooling Analysis: Insights & Implications

The landscape of ME and DE tooling continues to evolve, including within the DON and wider DoD, driven by advancements in computational power, software methodologies, and operational needs. Recent refinements in tool adoption trends have provided a clearer understanding of the structure of these engineering disciplines, the enabling technologies that support them, and the challenges of achieving standardization and interoperability.[36] The team's comprehensive data analysis (representing a snapshot in time) revealed over 1,000 unique and relevant tools for use in both ME and DE. Of these tools, ME-specific applications of these tools were referenced 3,235 times, while DE-specific applications were mentioned 10,993 times, highlighting the broader divide in adoption between ME and DE. DE toolsets are more diverse and widely used, while ME relies on a more structured, model-driven but nascent tooling environment. This disparity reflects fundamental differences in how each discipline approaches engineering problems—ME relies on Model-Based Systems Engineering (MBSE), simulation frameworks, and risk assessment tools, whereas DE incorporates well-established capabilities surrounding DevOps automation, AI/ML, cloud-based workflows, and data analytics.[37]

ME prioritizes structured system modeling, operational feasibility assessments, and risk quantification to ensure that mission objectives align with system capabilities.[38] The most frequently cited tools in ME workflows reflect this emphasis, with Valispace, Cameo, Teamcenter Systems Engineering, and Riskion serving as foundational platforms for system modeling, mission planning, and risk analysis.[39]

Monte Carlo-based simulation frameworks, which were referenced 49 times in the literature dataset, reinforce the importance of probabilistic modeling in mission planning, allowing for the quantification of uncertainties and system performance under varying operational conditions. Riskion's (212 mentions) prominence highlights its strong role in mission risk quantification, ensuring that decision-makers can evaluate trade-offs in mission planning based on data-driven risk assessments.[40] These capabilities are critical for understanding system vulnerabilities, optimizing decision-making under uncertainty, and ensuring mission resilience.[41]

Despite the shift toward data-driven decision-making, legacy tools persist in some areas. Visio (221 mentions) and Mission Planner (62 mentions) continue to appear in mission workflows, despite the availability of more advanced digital modeling and simulation alternatives.[42] The persistence of these tools suggests that organizational inertia, legacy workflow dependencies, and a lack of comprehensive training are barriers to full-scale digital transformation within ME frameworks.[43] Additionally, ME tooling must evolve beyond isolated digital environments to enable seamless interoperability across mission models, risk assessments, and operational simulations. For example, in figures 12 and figure 13 below, approximately 30 tools were categorized as highly significant and related; however, 227 tools remained uncategorized as their overall impact and relevance greatly varied and were largely boutique or highly specialized example.

By standardizing MBSE frameworks, investing in enabling DE technologies, like Digital Twin platforms, consolidating data analytics platforms, and enforcing data interoperability standards, the DoD and DON can develop a fully integrated mission engineering ecosystem that enhances collaboration, data-driven decision-making, and mission resilience.[44] As the DoD advances its engineering methodologies, ME and DE tools will fundamentally shape how mission-critical systems are designed, tested, and sustained. While computational advancements and automation-driven workflows are improving, the primary challenge lies in balancing tool flexibility with interoperability.[45]

To fully harness the potential of ME and DE, strategic priorities include:

- Standardizing MBSE frameworks to enhance interoperability in ME.
- Developing unified guidelines for version control and configuration management in ME and DE implementations.
- Consolidating data analytics tools to enable enterprise-wide insights.
- Investing in Digital Twin technologies to enable predictive modeling and mission forecasting.
- Enforcing data interoperability standards between toolsets.

By addressing these challenges, DoD and DON can build a future-ready engineering ecosystem that is both adaptable and resilient to emerging threats and technological advancements.[46]

Further tooling insights, implications, and potential recommendations – extracted from across the ME and DE literature and tooling review – are included in Appendix B. Over the period of performance, the VT-ARC/ARLIS team will build upon this work through ME application to DON case studies, exploring which tooling types (from a functional perspective) are critical enablers to executing and scaling an Applied ME process.

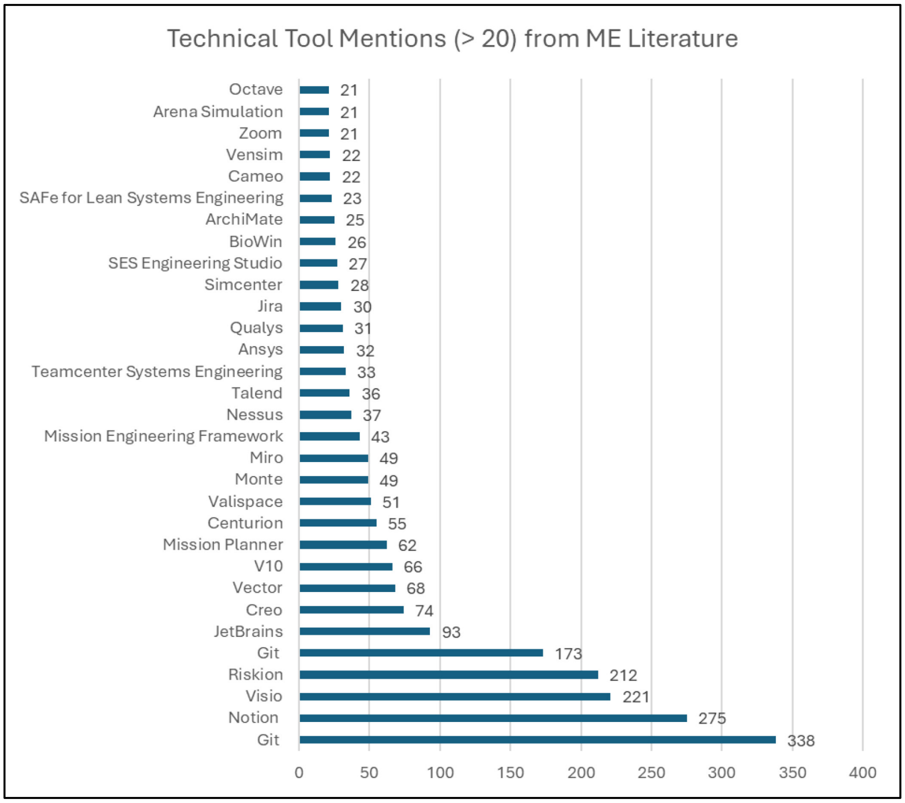

Figure 12: Top Mentions for Tools in Mission Engineering Literature

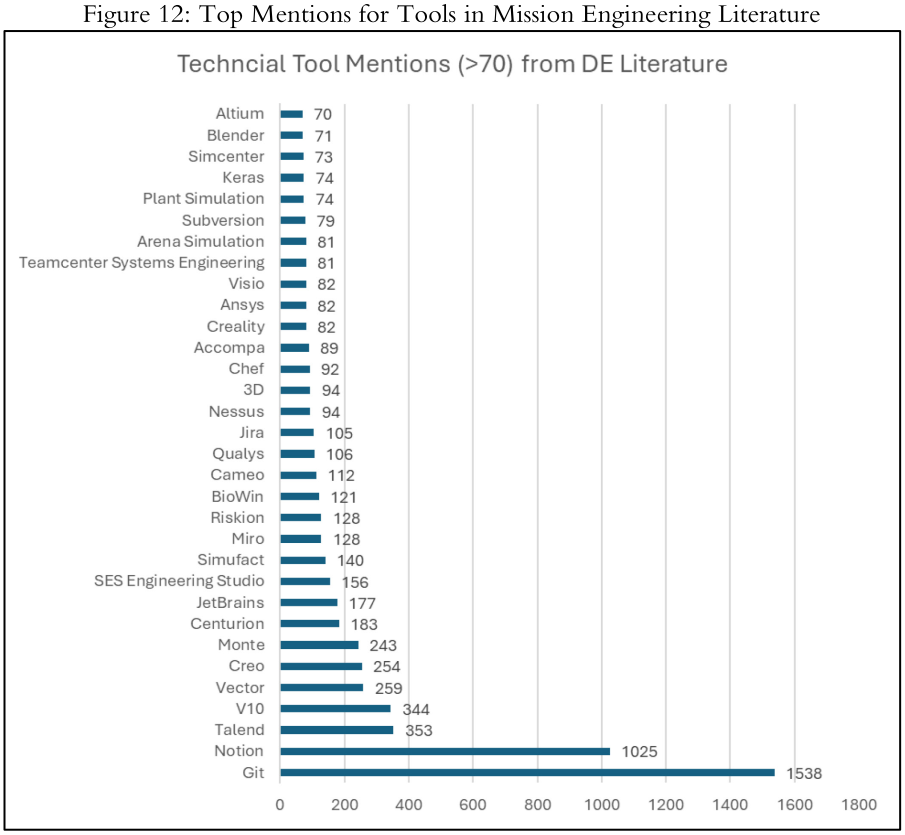

Figure 13: Top Mentions for Tools in Digital Engineering Literature

4 Toward An Enterprise Approach

4.1 The Macro Foundations

ME is inherently complex, requiring a structured approach to integrate systems, operations, and technologies effectively. A key challenge in ME implementation within the DON – as noted throughout this report – is the lack of a standardized framework for aligning mission objectives with engineering processes, data structures, and decision-making criteria. As part of this effort, the VT-ARC/ARLIS team is developing and executing an Applied ME Process, capturing future-state needs and recommendations along the macro layers depicted in figure 14 in efforts to move the DON closer toward its vision of forming an enterprise approach to ME implementation. The team will incorporate findings from this landscape analysis into the future-state needs and recommendations.

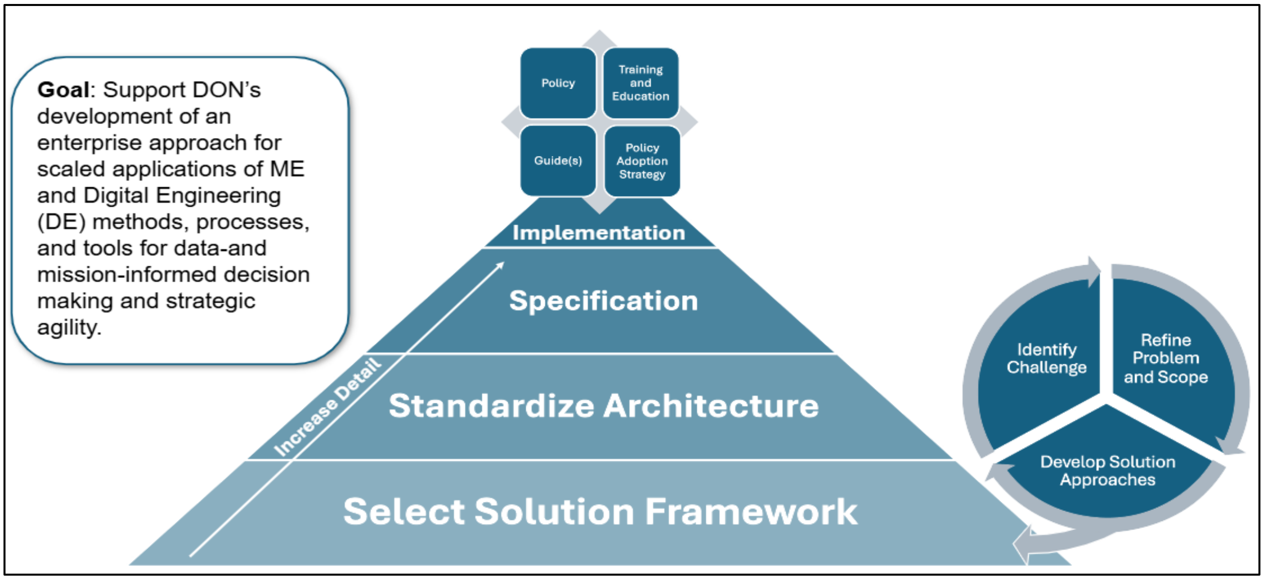

Figure 14: Macro Foundations for Developing an Applied ME Process

4.2 The In-Progress Applied ME Process

The VT-ARC/ARLIS team – which includes subject matter expertise from Dr. Moreland – is developing an Applied ME Process ato operationalize ME theory and guidance. This Applied ME Process, shown in figure 15, is based on the 10-step ME process,[47] originating from Dr. Moreland's efforts in the Navy's I&I initiative[48] and early renditions of the DoD mission engineering guide described in Section 1.

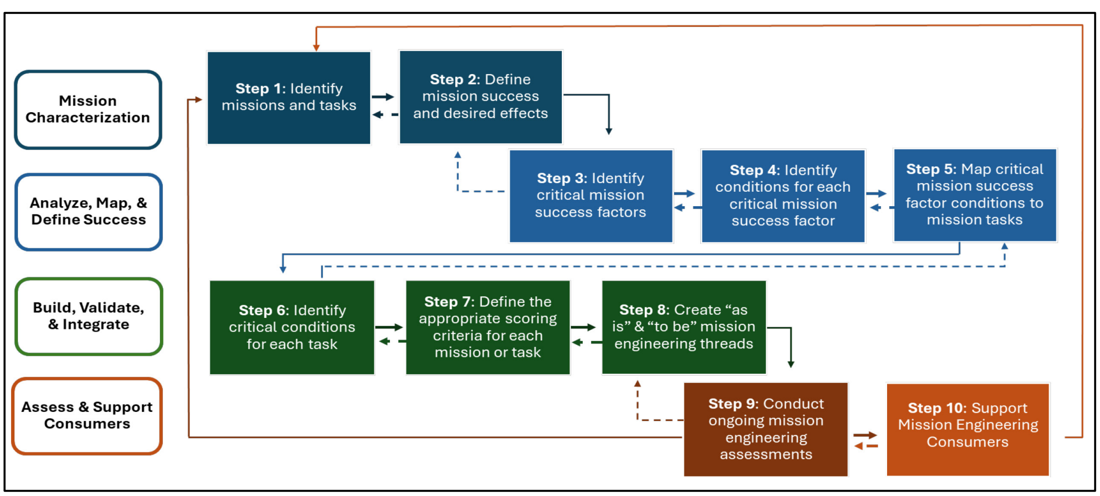

Figure 15 Macro Foundations for Developing an Applied ME Process

4.3 The Zachman Framework for ME Formalization & Implementation

As one piece to approaching the bottom of the pyramid depicted above, the VT-ARC/ARLIS team is exploring the Zachman Framework – a structured method to defining mission-critical information, system interdependencies, and operational workflows across different levels of abstraction. The Zachman Framework provides a formalized method to map mission engineering activities into clearly defined categories, ensuring consistency across DON's strategic, operational, and tactical levels ME process confusion.

The Zachman Framework serves as a conceptual structure that organizes ME information by who, what, when, where, why, and how—enhancing clarity in mission analysis, system design, and operational execution. This approach provides several key benefits when approaching the standardized framework foundations for a DON enterprise approach to ME:

- ***Standardized ME Process Mapping*** – Aligns ME activities with mission objectives using a structured approach to requirements definition, system interactions, and decision-making pathways.
- ***Improved Interoperability*** – Enables cross-SYSCOM alignment by providing a common reference model for integrating digital tools, simulation environments, and engineering workflows.
- ***Enhanced Data-Driven Decision-Making*** – Supports AI-driven analytics, digital twins, and predictive modeling by structuring mission-relevant data in a way that is accessible across DON platforms.
- ***Identification of Authoritative Data Sources***– Supports the systematic assessment of the minimum essential data and information for each major step and facet of the applied ME process.
- ***Scalability & Adaptability*** – Establishes a repeatable framework that can be scaled across different levels of command, ensuring alignment with broader DoD transformation initiatives.

The VT-ARC/ARLIS team is applying the Zachman Framework to ME through a structured breakdown of key mission elements, mapping the 10 Applied ME Process steps to mission tasks, actors, locations, functions, events, and intent. This approach ensures that ME activities remain solution-agnostic, focusing on mission objectives rather than predefined system architectures. By leveraging this structured approach, DON can improve ME adoption, bridge gaps in interoperability and governance, and ensure data-driven mission planning and execution.

To fully capture the complexity of ME implementation, we employ two complementary interpretations of the Zachman Framework: one through a conceptual lens and another through a documentation-driven perspective.

- ***Conceptual Zachman Framework*** – This approach provides a high-level abstraction of the ME process, helping decision-makers and engineers structure mission-critical information based on fundamental questions: Who? What? When? Where? Why? How? It focuses on the strategic alignment of ME activities, ensuring that all elements—mission objectives, system functions, operational environments, and decision timelines—are clearly defined before implementation (Figure 16).
- ***Documentation Zachman Framework*** – While the conceptual framework defines a high-level structure, the documentation lens translates these mission elements into practical, traceable artifacts used for execution, validation, and refinement. This perspective ensures that ME processes are well-documented, repeatable, and aligned with DE tools such as MBSE models, simulation environments, and operational dashboards. It also provides a mechanism for tracking changes, assessing risks, and ensuring compliance with DON and DoD policies.

By integrating both perspectives, the Zachman Framework not only facilitates a structured understanding of ME but also ensures that the process is grounded in actionable, well-documented engineering practices. This dual-lens approach enhances interoperability, data-driven decision-making, and long-term sustainability within the DON ME and DE ecosystem.

Zachman Perspective	What (Inventory/Entities)	How (Process/Function)	Where (Location/Network)	Who (People/Actors)	When (Time/Event)	Why (Motivation/Intent)
Contextual (Planner)	Mission objectives, high-level tasks, and key deliverables (e.g., ISR platforms, logistics hubs). **(Steps: 1, 2)**	Strategic processes for identifying and aligning mission objectives with tasks and resources. **(Steps: 1, 2)**	Operational theaters and AORs relevant to mission goals (e.g., Indo-Pacific Command zones). **(Steps: 1, 2)**	Strategic stakeholders and decision-makers (e.g., Combatant Command planners, coalition partners). **(Steps: 1, 2)**	Campaign planning timelines, including phases for execution and assessment. **(Steps: 1, 2)**	Strategic goals and desired mission effects driving operational objectives. **(Steps: 1, 2)**
Conceptual (Owner)	Mission threads, tasks, and success criteria aligned with operational goals. **(Steps: 2, 3, 4)**	Operational workflows for mission execution, including task decomposition and mapping. **(Steps: 3, 5)**	Operational nodes and logistics hubs critical for task completion (e.g., forward bases). **(Steps: 3, 5)**	Operational planners and force leaders managing mission tasks (e.g., JTF Commanders, Fleet Commanders). **(Steps: 3, 5)**	Mission phases, readiness milestones, and success criteria assessments. **(Steps: 2, 3, 7)**	Operational purpose tied to success criteria and risk management. **(Steps: 3, 5, 7)**
Logical (Designer)	Functional requirements and system dependencies for mission tasks. **(Steps: 3, 5, 8)**	System-task mapping and detailed functional workflows for integration. **(Steps: 5, 8)**	Communication nodes, system interaction points, and integration environments. **(Steps: 5, 8)**	Architects and system engineers designing integrated operational frameworks. **(Steps: 5, 8)**	Development timelines, system integration milestones, and testing phases. **(Steps: 5, 8)**	Ensure functional dependencies align with mission tasks and objectives. **(Steps: 3, 5, 8)**
Physical (Builder)	Detailed technical specifications for mission systems and subsystems (e.g., UAVs, ISR tools). **(Steps: 5, 6, 8)**	Processes for building and integrating mission-critical systems and infrastructure. **(Steps: 5, 6, 8)**	Deployment locations for mission systems and physical assets (e.g., staging areas, operational hubs). **(Steps: 6, 8)**	Engineers and developers implementing systems and ensuring readiness (e.g., System Commands, PEOs). **(Steps: 6, 8)**	Build and validation timelines, including component readiness reviews. **(Steps: 6, 8)**	Ensure technical specifications align with operational and functional requirements. **(Steps: 5, 6, 8)**
As-Built (Subcontractor)	Mission-ready components and systems validated for operational use (e.g., sensors, effectors). **(Steps: 5, 6, 8)**	Installation, validation, and maintenance workflows for task-specific components. **(Steps: 6, 8)**	Locations for component installation and validation in operational environments. **(Steps: 6, 8)**	Technicians and maintainers responsible for deploying and validating components. **(Steps: 6, 8)**	Synchronization points for deployment and operational validation tasks. **(Steps: 6, 8)**	Ensure mission systems meet operational readiness standards and task requirements. **(Steps: 6, 8)**
Operational (User)	Real-time systems and tools used for executing tasks in dynamic mission environments. **(Steps: 6, 8, 9)**	Tactical workflows and adaptive decision-making during task execution. **(Steps: 6, 9)**	Specific areas of operation where tasks are performed (e.g., maritime zones, contested airspace). **(Steps: 6, 9)**	Operators and analysts executing tasks and feeding real-time data back into mission threads. **(Steps: 6, 9)**	Real-time task execution schedules, decision-making cycles, and contingency activation timelines. **(Steps: 6, 9)**	Ensure immediate tactical objectives align with operational and strategic goals. **(Steps: 6, 8, 9)**

Figure 16: Working Conceptual Zachman Framework for Understanding the ME Application Process

5 Conclusion & Future-State Considerations

The team conducted integrated analysis of the ME and DE landscape leveraging a combination of policy analysis, technical data, and analysis methodologies, building upon previous ME and DE landscape assessments. The analysis covered a discussion on historical background and evolution of ME and DE, shortfalls in policy and guidance in the DON for ME implementation, key findings from a comprehensive literature review, graph node centrality analysis, the current state of ME/DE tooling, and considerations for future-state improvements in DON's approach to ME enabled by DE. By leveraging a graph-based approach, the team was able to contextualize the interdependencies between ME and DE stakeholders, identify emerging trends in technology adoption, and provide strategic insights and future state considerations for DON ME applications, summarized below. Moving forward, the knowledge graph could serve as a living framework, continuously updated to reflect new developments in mission engineering, positioning the Navy and DoD at the forefront of digital transformation.

If done effectively, ME can be applied to a broad decision space including the development of new operational concepts and enhanced capabilities; increased access and the identification of appropriate infrastructure investments in key geographical areas; resilient security architectures; and the facilitation of elasticity and readiness in the defense ecosystem. To realize the value of ME across the DON, particularly when supported by DE, requires a multi-pronged macro approach focused on 1) the development of comprehensive policy, 2) ME guidebooks, 3) standardized ME training and education, and 4) a policy adoption strategy.

While DoD and DON leadership recognize the importance of digital transformation and mission-centric engineering, significant gaps remain in the actual execution and scaling of ME and DE. ME within the DON remains fragmented and inconsistently applied. Unlike DE, which is backed by formal governance structures, standard toolchains, and enterprise-wide adoption strategies, ME still relies heavily on individual commands, program offices, and informal communities of interest to drive adoption. The team emphasizes the necessity of aligning these efforts with broader DoD transformation initiatives while addressing the unique challenges facing DON-specific equities. The VT-ARC/ARLIS landscape analysis validated previous ME and DE landscape assessment results that organizations likely do not manage ME at a mission level, reflecting governance, policy, and procedural gaps that hinder effective implementation and contribute to fragmented silos of practice at varying degrees of rigor. The team synthesized several structural, technical, and cultural factors and gaps that contribute to misalignment and limit the art of the possible for ME and DE implementation and scaling:

- The absence of a centralized governance model, leading to variability in ME implementation across different programs and warfare domains.
- The absence of an authoritative lexicon and common digital infrastructure exacerbates interoperability challenges.
- A lack of dedicated policy enforcement, meaning while some groups adopted ME methodologies, others continue to rely on traditional systems engineering approaches that may not fully capture mission-level dependencies.
- A lack of understanding of the minimum essential authoritative data to execute ME. Data is scattered across the enterprise without transparency into where it resides and who is in charge of it.
- Limited cross-organizational collaboration, resulting in redundancies, inefficiencies, and difficulties in scaling ME efforts across the DON enterprise.
- ME and DE are frequently cited in DoD and DON strategic plans, but actual implementation remains uneven, often constrained by policy gaps, funding challenges, and a lack of standardized governance.
- DE implementation areas such as digital twin technology, AI-driven analytics, and MBSE frameworks have gained traction within the DON, but used to validate system performance rather than evaluate mission effectiveness.
- An over-reliance on subject matter experts (SMEs) rather than broad workforce institutionalization creates bottlenecks and siloes in ME/DE adoption.
- Gaps in seams between warfighters, acquisition professionals, science & technology and rapid capability development professionals, and engineers limits cross-functional collaboration in capability development.
- The need for dedicated ME training pipelines, including warfighter-acquisition collaboration models, operationally informed engineering courses, and structured certification programs.
- ME and DE integration has been influenced by broader modernization efforts, particularly initiatives such as Joint All-Domain Command and Control (JADC2), digital transformation roadmaps, and force restructuring efforts. However, ME adoption has not kept pace with DE implementation, creating gaps in how mission priorities are translated into system-of-systems solutions.
- Tool adoption and workforce training efforts remain fragmented across SYSCOMs, PEOs, and Warfare Centers, necessitating a unified approach to interoperability, data governance, and workforce development.

Further cohesive efforts that cross organizational seams within the DON and within the greater DoD are needed to lead change in realizing an enterprise approach. Bridging these gaps will require a deliberate effort to institutionalize ME within DON engineering and acquisition frameworks, ensuring that mission-driven engineering becomes a standard practice across levels and layers of stakeholders rather than an optional approach.

To ensure that ME and DE remain core enablers of DON's future operational and acquisition strategies, the team recommends the following actions as part of a DON enterprise approach formation:

1. ***Develop an Enterprise DON ME Strategy*** – Establish a DON enterprise-wide ME strategy that ensures ME is a required, not optional, component of force design, planning, requirements, and capability development communities.
2. ***Develop an Authoritative ME and DE Lexicon*** – Establish a standardized terminology framework across DON to improve cross-organizational collaboration.
3. ***Enhance Digital Infrastructure and Data Governance*** – Invest in enterprise-level DE environments that enable secure, seamless data sharing across stakeholders.
4. ***Determine & Codify the Minimum Essential Data Required*** – Create a minimum essential data framework to support ME process execution, enabled by DE environments.
5. ***Formalize Cross-SYSCOM Standardization Efforts*** – Establish common ME and DE frameworks to align methodologies, tools, and training programs across NAVAIR, NAVSEA, NAVWAR, and NUWC.
6. ***Accelerate AI-Driven ME and DE Integration*** – Leverage predictive analytics, AI-assisted mission planning, and digital twin models to improve decision-making and operational effectiveness.
7. ***Expand ME and DE Training and Workforce Development*** – Establish a formal unified training pipeline that ensures personnel at all levels can effectively utilize ME and DE methodologies and tools, understand how to implement ME effectively.
8. ***Clear Governance and Funding Mechanisms*** - Establish clear governance and funding mechanisms to prevent ME efforts from being dependent on short-term leadership priorities or discretionary funding.

As the DON continues to evolve its approach to ME, ensuring that it is not just a methodology, but an enduring, institutionalized discipline will be critical to ensuring decision superiority, operational flexibility, and mission success in an increasingly complex warfighting environment.

Building upon this landscape analysis, the VT-ARC/ARLIS team will continue to build out the macro foundations necessary to support the DON's pursuit of an enterprise approach to ME. The team's work will provide the foundational framework through the Applied ME Process and Zachman Framework, gather insights and recommendations through case study applications of the framework, capturing a holistic assessment of the next steps for the DON to work toward the vision of an enterprise approach to ME.

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Appendix A: DoD Digital Transformation & Data Strategy Landscape

This appendix provides key findings from a previous synthesis that VT-ARC conducted[49] surrounding DoD digital data, digital transformation, and digital modernization strategies. As a key enabler to executing the ME process, understanding data and DE environment needs are critical. The DoD, at the OSD level and across each of the services, has many initiatives to digitally transform the processes and systems for how the DoD handles data. Currently, this is fragmented in nature, which will challenge the DoD's ability to define and ensure readily available access to the minimum essential authoritative data necessary for ME execution. Since this work, the DON alone has launched several digital transformation initiatives (i.e., various data and analytics task forces, data strike teams, data cataloguing efforts covered at the 2025 DON IT West Conference), exemplifying the accelerated pace at which DoD is moving.

Key Findings:

- ***Multi-faceted Challenge*** – Digital transformation of acquisition processes is a multi-faceted challenge with many dimensions surrounding data, organizational structures, and factors associated with the acquisition decision landscape. [50]
- ***Existing Strengths*** – There is no shortage of Service and enterprise-level strategies inspiring and driving successful lower-level change efforts across DoD departments, Services and program offices (see Figure 19). Aligned with the first step of Kotter's Leading Change Framework, common themes across these strategies show a shared sense of motivation and urgency for change. These strengths present opportunities that OSD could leverage, amplify, align, and expand to consolidate and expand gains. [51]
- ***Generating Lower-level Progress*** **–** There are several lower-level digital transformation, modernization, and acquisition innovation initiatives underway across the Services and greater DoD (see Figure 20 and 21). These initiatives and platforms share similar goals of improving acquisition processes and streamlining data integration, curation, and use to support decision making; they differ by use case, architecture, and domains of interest.
- ***Needed Vision and Integration*** – Despite individualized progress and strategies, change within the Services and greater DoD remain uncoordinated, impeding DoD's ability to move forward in functions described by two areas of Kotter's framework: consolidating gains and anchoring lasting change enterprise-wide. Lower-level change efforts described above, while effective and transformative at their levels, remain siloes of excellence (see Figure 17). The acquisition community across the DoD needs an overarching vision and implementing coalition focused on a concerted effort to translate and amplify individual progress into scaled, interoperable, and integrated capabilities across the DoD to drive lasting change. [52]
- ***Current State Acquisition Decision Landscape Model*** – The research team created an Acquisition Decision Landscape Model to help understand the current state of acquisition transformation and to identify high-impact areas for OUSD(A&S) and the greater DoD to drive progress toward a common vision. This model portrays core elements and relational aspects of the DoD A&S decision landscape. The model illustrates how various higher-level decisions rely on access to lower-level data generators. [53]
- ***Future State Acquisition Decision Landscape Model*** – Finally, the team created a future state version of the model to describe the state of the possible and portray critical areas that require further alignment and progress to consolidate gains. [54]

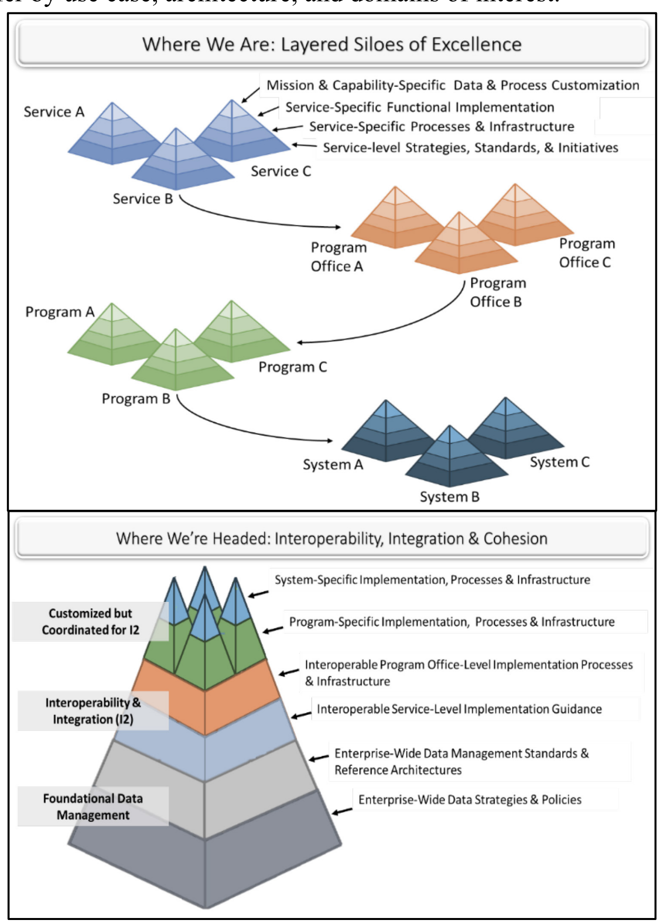

Figure 17 Illustrative Example of the Complex Layers of Data Strategy Implementation & Need for Cohesion

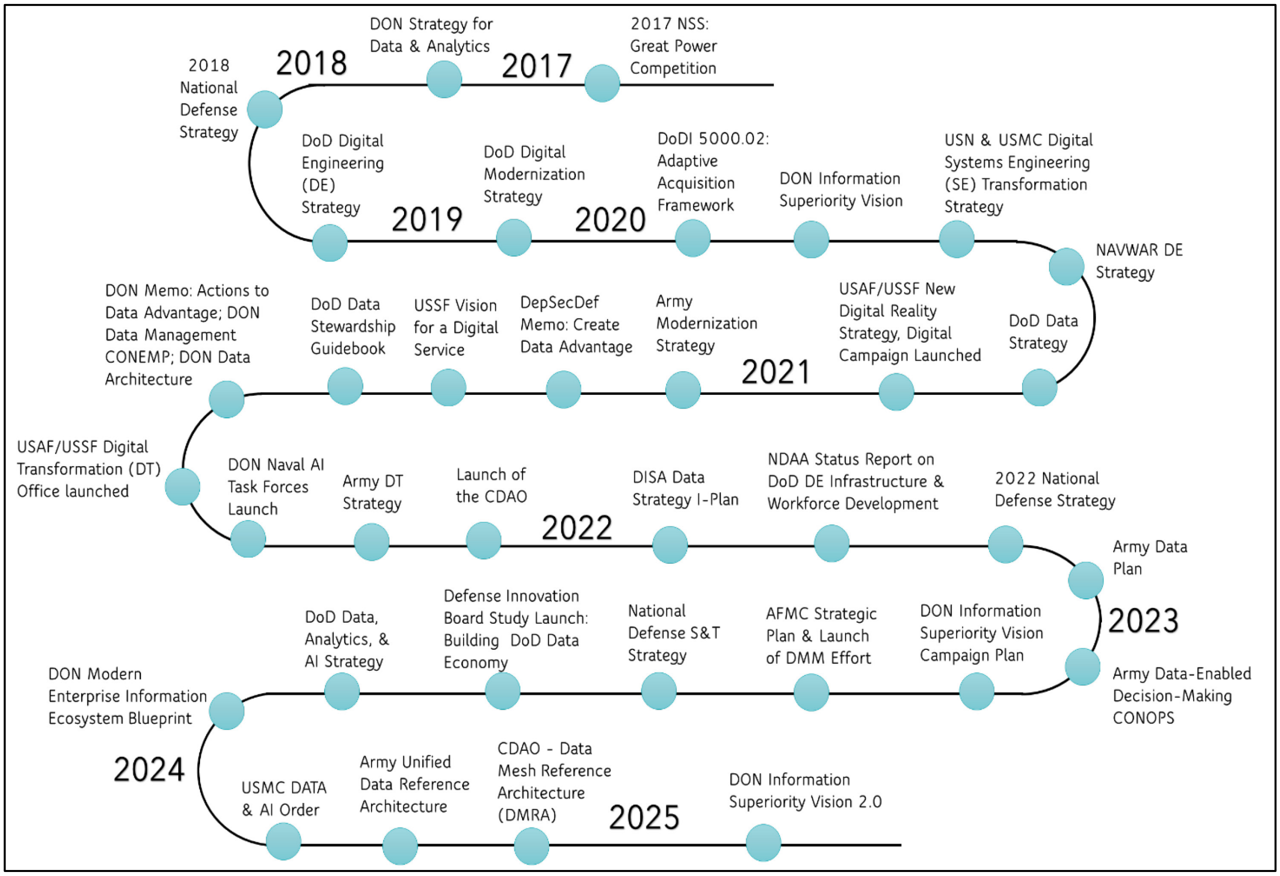

Figure 18 Timeline of DoD & Service Strategies & Efforts for Digital Transformation Efforts (Non-Exhaustive) [55]

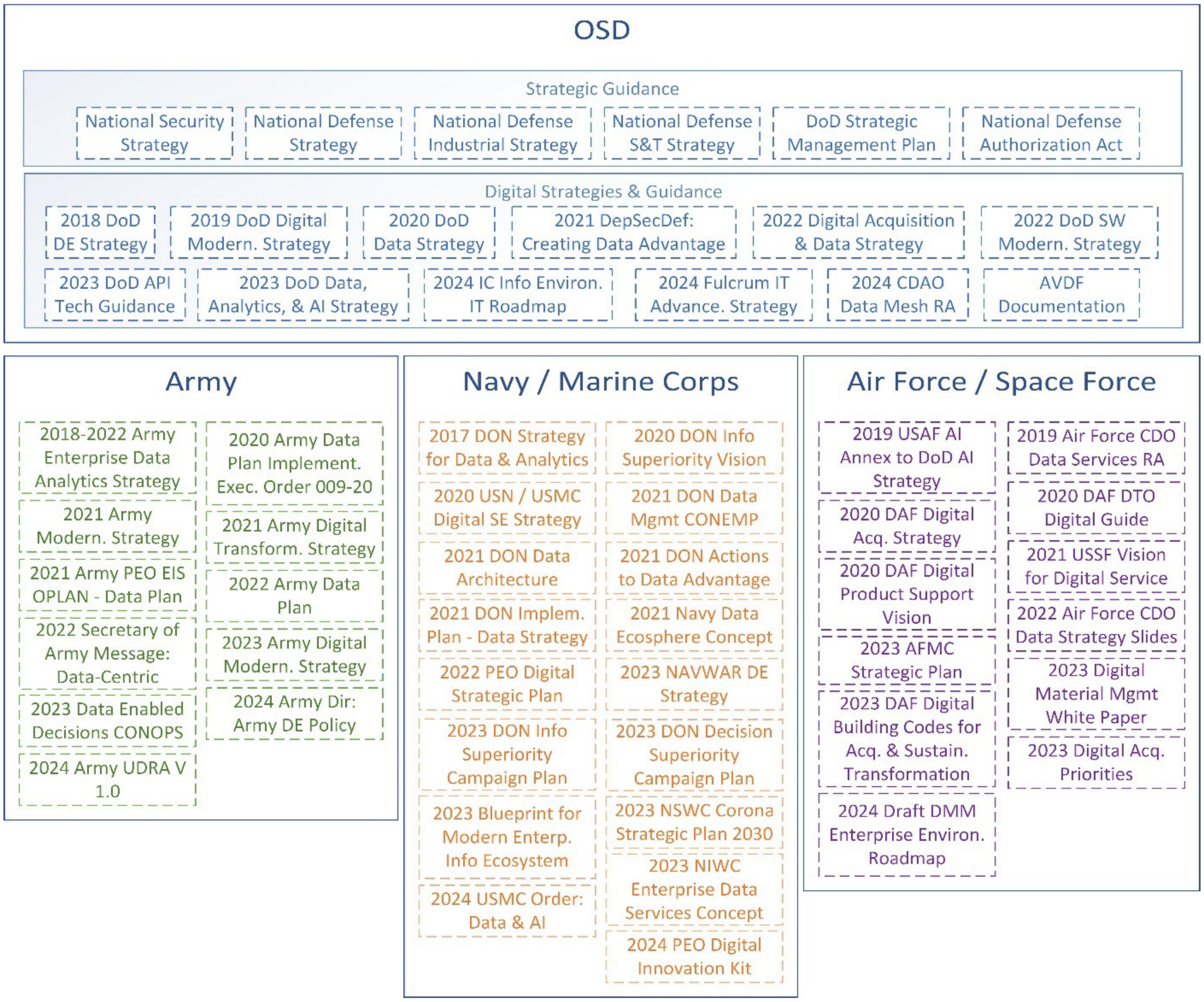

Figure 19 DoD & Service Strategies & Documentation for Digital Transformation Efforts (Non-Exhaustive) [56]

Figure 20 DoD & Service Digital Transformation Initiatives (Non-Exhaustive) [57]

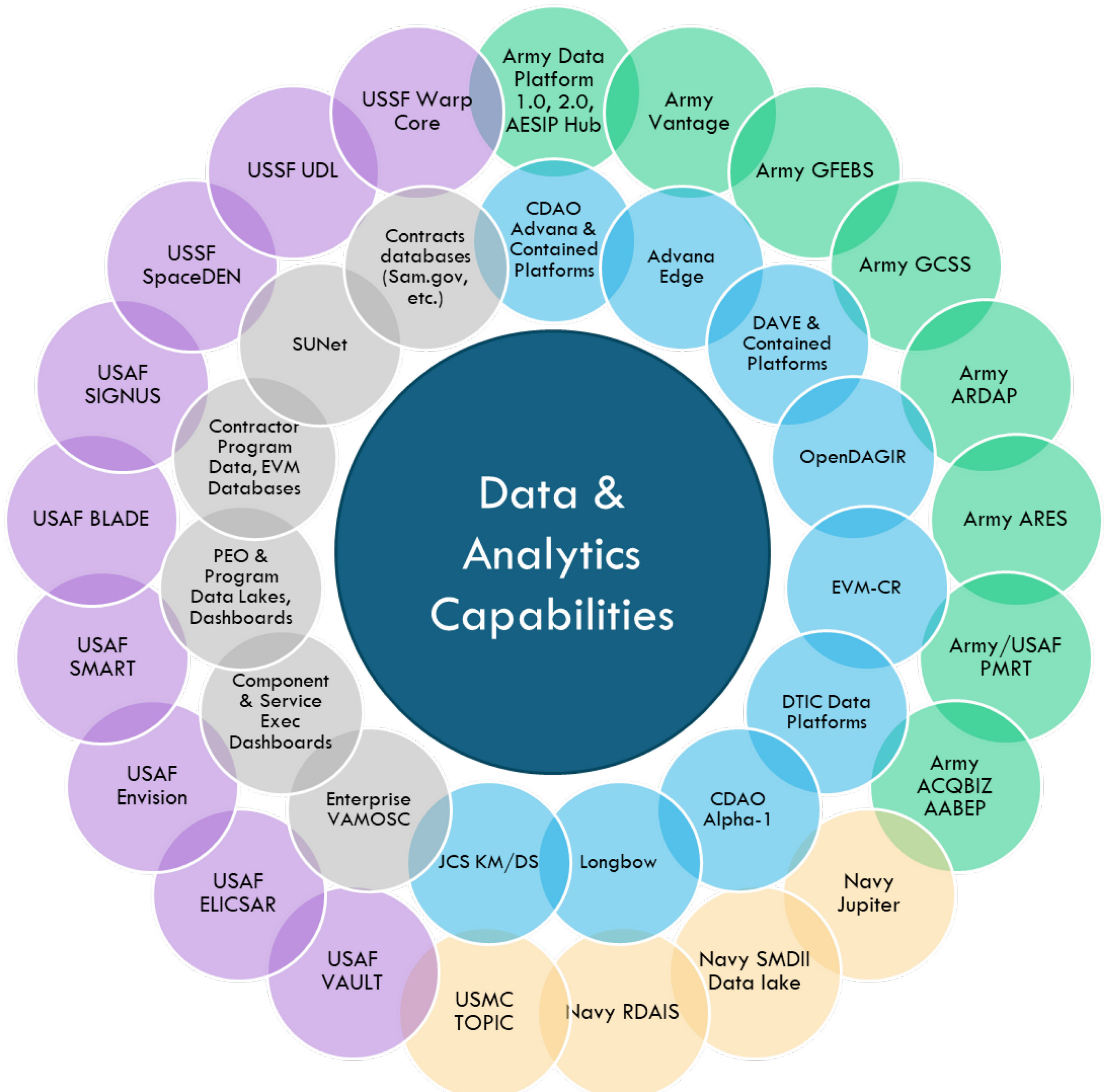

Figure 21 DoD & Service Data & Analytics Platforms (Non-Exhaustive) [58]

Appendix B: Deep Dive into ME & DE Tooling Literature

This appendix provides a synthesis of findings extracted from across the ME and DE literature and tooling publications assessed as part of this landscape analysis surrounding key ME and DE tools, key limitations, and improvements that could be made to ME and DE tool suites.

Improvements and Enhancements to Existing ME Tool Suites

The Need for Multi-Domain Integration in ME Tools

One of the defining features of modern warfare is the integration of multiple domains—air, land, sea, space, and cyber—into a cohesive operational picture. ME tools must support this level of complexity by enabling cross-domain analysis, simulation, and coordination between different service branches (Hernandez, 2022).

- Finding: Existing MBSE platforms, such as Cameo and Teamcenter Systems Engineering, are designed primarily for system-level modeling and engineering integration. However, their ability to model cross-domain mission dependencies is limited, requiring additional data fusion efforts (Pennock et al., 2022).
- Recommendation: Enhancing ME tool capabilities to support multi-domain interoperability, where mission models can represent not only system dependencies but also the broader operational environment (McDermott et al., 2022)
- Supporting Technologies: The integration of Digital Twin architectures and real-time sensor data fusion will be key to enabling a mission-first rather than system-first approach to engineering (Dahmann et al., 2022).

Gaps in Real-Time Decision Support and Mission Adaptation

ME tools today primarily focus on pre-mission planning, but mission success often depends on real-time adaptability and in-mission decision-making (Williams, 2022).

- Finding: Current ME tools (e.g., Riskion, Monte Carlo-based risk assessment platforms) emphasize static mission planning but do not fully support dynamic mission adaptation based on real-time data (McDermott et al., 2022).
- Recommendation: Developing adaptive mission engineering tools that integrate real-time operational intelligence, AI-driven scenario generation, and live mission simulations to provide decision-makers with actionable insights (Bekdache & DeLaurentis, 2024).
- Potential Future Approaches: AI-enhanced risk modeling to continuously update mission parameters based on changing battlefield conditions (Dahmann & Baldwin, 2019); Agent-based simulation modeling to dynamically reconfigure mission objectives when operational disruptions occur (Hernandez, 2022).

Integration of Mission Engineering with DevOps and Agile Workflows

While DE has in several areas successfully integrated DevOps and Agile methodologies, ME still largely relies on sequential, waterfall-style planning approaches (Pennock et al., 2022).

- Finding: The adoption of iterative software development methodologies in mission planning remains limited, leading to rigid mission models that struggle to accommodate evolving operational needs (McDermott et al., 2022).
- Recommendation: ME tools must be adapted to support DevOps-style iteration, where mission models and risk assessments are continuously refined through rapid feedback loops rather than being treated as static, one-time plans (Dahmann & Baldwin, 2019).
- Best Practices from DE: Borrowing techniques such as Model-Based DevSecOps (integrating security into mission software pipelines) and automated mission validation testing to continuously update mission scenarios based on live data feeds (Bekdache & DeLaurentis, 2024).

Strengthening MBSE for Mission-Level Engineering Trade-Offs

MBSE tools currently focus on system requirements and performance modeling, but do not always capture mission-level trade-offs and constraints effectively (Williams, 2022).

- Finding: Cameo and Valispace enable technical trade-space analysis at the system level, but they lack built-in frameworks for weighing mission success factors against engineering constraints (McDermott et al., 2022).
- Recommendations:
    - Extending MBSE platforms to include trade-space visualization for mission objectives—for example, allowing engineers to weigh force posture vs. logistics vs. risk tolerance in real-time (Pennock et al., 2022).
    - Mission-aware MBSE models that allow decision-makers to quantify the impact of design decisions on mission effectiveness (Dahmann & Baldwin, 2019).
    - Expanding Riskion and Monte Carlo-based ME tools to better integrate with MBSE workflows, providing seamless transitions between technical trade-space analyses and mission-level impact assessments.

Enhancing User Experience and Accessibility of Mission Engineering Tools

A persistent challenge for ME tool adoption is that many platforms are too complex for non-technical users, limiting their applicability in operational settings (Dahmann, Baldwin, & Kelley, 2022). The usability gap in ME tools prevents warfighters, planners, and strategists from fully leveraging digital mission modeling capabilities, particularly in time-sensitive decision environments (McDermott, Henderson, & Salado, 2022). The suggested improvements would broaden the accessibility of ME tools, ensuring that warfighters and decision-makers can directly engage with mission modeling platforms without requiring specialized MBSE training (Pennock et al., 2022).

- Finding: Many ME tools require specialized MBSE knowledge, creating barriers to adoption for warfighters, strategists, and planners who lack engineering backgrounds (Hernandez, 2022). This is particularly evident in platforms such as Cameo and Valispace, which offer powerful system modeling capabilities but require formal MBSE training to use effectively (Pennock, Driscoll, Dahmann, & Adams, 2022).
- Recommendation:
    - Developing more intuitive, user-friendly interfaces for ME tools, ensuring they can be used effectively by commanders and operational planners without extensive MBSE training (Dahmann & Baldwin, 2019).
    - Implementing low-code/no-code mission simulation environments, where mission planners can adjust variables and generate scenario analyses without deep technical expertise (Bekdache & DeLaurentis, 2024).
    - Incorporating natural language processing (NLP)-driven mission planning interfaces, enabling users to interact with ME tools using conversational AI rather than complex software inputs (Hernandez, 2022).

Standardization of Mission Engineering Workflows Across DoD

A final challenge is that different service branches and agencies approach ME differently, leading to inconsistent methodologies and limited cross-compatibility of mission models (Dahmann et al., 2022). By establishing a standardized, cross-service Mission Engineering framework, the DoD can ensure greater interoperability, improved efficiency in mission planning, and enhanced collaboration between different military branches and operational units (Williams, 2022).

- Finding: While the DoD has MBSE guidelines, there is no universally enforced ME framework, leading to each organization defining its own approach to mission modeling and execution (Hernandez, 2022). This has resulted in:
    - Variability in mission modeling architectures, making it difficult to integrate mission scenarios across different operational domains (Pennock et al., 2022).
    - Redundant investments in custom ME tool development, as different service branches build isolated mission modeling platforms rather than adopting a unified framework (Williams, 2022).
    - Barriers to data sharing and interoperability, as mission models built using different methodologies cannot be easily exchanged across agencies (Bekdache & DeLaurentis, 2024).
- Recommendation: Developing a DoD-wide Mission Engineering Standard, similar to DoD's Digital Engineering Strategy, that establishes:
    - Common mission modeling architectures to ensure interoperability between different ME tools, preventing redundant software development efforts (Dahmann & Baldwin, 2019).
    - Standardized risk quantification frameworks that allow Riskion-style tools to work across different mission domains, enabling consistent evaluation of mission risks and uncertainties across service branches (McDermott et al., 2022).
    - Mandated training and certification programs for ME practitioners, ensuring that engineers and planners are aligned in their use of ME tools and methodologies (Hernandez, 2022). Without formalized ME training,

practitioners risk applying inconsistent mission modeling techniques, limiting the effectiveness of cross-agency mission analysis (Pennock et al., 2022).

As the DoD and DON continue to refine their engineering ecosystems, these improvements will be critical for ensuring that Mission Engineering is fully aligned with modern warfighting needs, adaptable to dynamic operational conditions, and seamlessly integrated with Digital Engineering best practices.

DE: A Software-Centric, Automation-Driven Discipline

Unlike ME, which is structured around predefined models and risk-based analysis, DE is software-centric, iterative, and built around automation and AI-driven analytics. The continued move toward DE represents a fundamental shift in engineering methodologies, moving from traditional document-based, sequential processes to dynamic, software-driven workflows that integrate continuous iteration, automation, and AI-enhanced analytics. DE is inherently agile, prioritizing DevOps, cloud-native architectures, and AI/ML integration to accelerate system development, testing, and sustainment (Dahmann et al., 2019).

An analysis of DE tooling trends highlights the dominance of automation, cloud-based infrastructure, and AI-driven decision support systems. Git (1,538 mentions) and GitLab (565 mentions) exemplify the importance of version control and Continuous Integration/Continuous Deployment (CI/CD) pipelines in DE workflows, reinforcing an iterative approach to modern software and systems engineering (McDermott et al., 2022). Similarly, high mentions of Terraform (50 mentions), Kubernetes, Jenkins, and Ansible signal a strong DevOps influence, emphasizing infrastructure automation, system orchestration, and scalable deployment strategies.

Beyond DevOps, AI and data-driven engineering workflows have become increasingly prevalent. Monte Carlo-based risk modeling (243 mentions), MATLAB-based computational analysis, and AI/ML frameworks (Keras, TensorFlow, Julia) demonstrate a paradigm shift in engineering decision-making, where real-time data processing, predictive analytics, and algorithmic optimization are foundational to modern DE practices (Hernandez, 2022). This transition allows engineers to incorporate live operational data, self-learning algorithms, and continuous system validation into the design process, significantly improving adaptability and resilience in complex systems.

Despite these advancements, significant challenges remain in tool interoperability, cross-domain integration, and security automation, necessitating key improvements in the DE tool landscape:

Enhancing Interoperability Across Digital Engineering Toolchains

DE tools, while powerful in isolation, often lack seamless integration across different software ecosystems, creating silos in engineering workflows (McDermott et al., 2022).

- Finding: While Kubernetes and Terraform enable automated infrastructure provisioning, they are not always natively integrated with MBSE environments, leading to fragmented toolchains that require manual reconciliation (Pennock et al., 2022).
- Recommendation: Develop standardized API-driven frameworks to facilitate cross-tool interoperability, allowing DevOps platforms to directly interface with system modeling tools like Cameo and Teamcenter.
- Supporting Technologies: AI-powered middleware solutions that automatically translate engineering data between different tool ecosystems, reducing integration overhead and enabling real-time synchronization between DE platforms (Dahmann & Baldwin, 2019).

Advancing AI-Driven Decision Support and Automated Model Validation

AI-enhanced engineering has gained traction, yet many Digital Engineering workflows still rely on human-driven validation processes, limiting the efficiency gains of AI integration (Hernandez, 2022).

- Finding: Despite high mentions of TensorFlow, Keras, and Monte Carlo risk modeling, most AI/ML models are used as advisory tools rather than decision automation engines in Digital Engineering workflows (McDermott et al., 2022).

- Recommendation: Develop self-validating AI models that continuously learn from operational data, refining system performance predictions and enabling automated model-based decision-making (Bekdache & DeLaurentis, 2024).
- Potential Future Approaches:
  - Reinforcement learning-driven engineering workflows, where AI models iteratively refine system designs based on real-world performance feedback (Dahmann & Baldwin, 2019).
  - Automated software verification and validation pipelines, integrating AI-based anomaly detection and predictive failure modeling to preemptively address system vulnerabilities (Hernandez, 2022).

Strengthening Cybersecurity and Zero Trust Architectures in DE Workflows

As DE environments become increasingly cloud-native and software-driven, cybersecurity concerns have emerged as a critical challenge, requiring robust Zero Trust security frameworks (Pennock et al., 2022).

- Finding: While DevSecOps principles have been adopted in select DoD projects, many DE platforms lack automated security enforcement, relying on manual review processes for compliance (McDermott et al., 2022).
- Recommendation: Mandate Zero Trust security integration within all DE toolchains, ensuring continuous threat monitoring, access control, and real-time security validation in CI/CD pipelines (Dahmann & Baldwin, 2019).
- Best Practices from Industry:
  - Automated security compliance testing during software builds to detect vulnerabilities before deployment (Hernandez, 2022).
  - AI-driven threat modeling within DE environments, leveraging behavioral analytics to identify and mitigate emerging cyber risks in real time (Pennock et al., 2022).

Standardizing Cloud-Native Engineering Architectures

The shift to cloud-based engineering has unlocked scalability and flexibility but has also introduced inconsistencies in deployment strategies across DoD entities (Williams, 2022).

- Finding: While Kubernetes and Terraform are widely adopted, there is no standardized approach to cloud infrastructure deployment in DoD Digital Engineering, leading to duplication of effort and inconsistent architectures (McDermott et al., 2022).
- Recommendation: Establish DoD-wide cloud-native engineering standards, ensuring uniform deployment strategies, security compliance, and tool compatibility across different branches and agencies (Dahmann & Baldwin, 2019).
- Key Initiatives:
  - Unified Digital Engineering Cloud Strategy, outlining standardized cloud orchestration models and security configurations.
  - Automated containerization pipelines, ensuring consistent deployment of engineering applications across different operational domains.

Improving User Accessibility and Democratization of Digital Engineering Tools

A persistent challenge in DE is the complexity of tool usage, particularly for non-software engineers, warfighters, and operational decision-makers (Hernandez, 2022).

- Finding: High mentions of Git, GitLab, Kubernetes, and Terraform suggest a steep learning curve for those without software development expertise, limiting broader adoption of Digital Engineering tools (McDermott et al., 2022).
- Recommendation:
  - Develop low-code/no-code DE environments, enabling engineers and operators to leverage automation tools without extensive programming knowledge (Dahmann & Baldwin, 2019).
  - Implement Natural Language Processing (NLP) interfaces for DE tools, allowing users to interact with engineering platforms using conversational commands rather than command-line scripting (Hernandez, 2022).
  - Provide role-based DE toolkits, offering pre-configured workflows for different user personas (e.g., cybersecurity analysts, system architects, mission planners).

Challenges in Standardization and Interoperability

As both the ME and DE ecosystems expand, the lack of standardization and interoperability across DoD engineering toolsets remains a critical challenge and limitation to adoption. Despite advancements in automation, AI-driven workflows, and MBSE frameworks, fragmentation across tools, version control policies, and data management strategies hinders full integration and collaboration (Pennock, Driscoll, Dahmann, & Adams, 2022). This is further evidenced in Appendix B.

While ME and DE operate under distinct paradigms—ME focusing on model-driven system integration and risk assessment, while DE prioritizes software-centric automation and iterative workflows—both disciplines struggle with siloed tool adoption, inconsistent data standards, and the persistence of legacy systems (McDermott et al., 2022). To fully leverage digital transformation, DoD must address these interoperability gaps by implementing unified engineering standards, enterprise-wide collaboration frameworks, and AI-enhanced tool integration solutions (Hernandez, 2022).

MBSE Fragmentation in Mission Engineering

The lack of standardization in Model-Based Systems Engineering (MBSE) platforms impairs cross-organizational collaboration and forces engineers to reconcile models across Cameo, Valispace, Teamcenter, and Genesys, each of which offers overlapping but distinct capabilities.

- Finding: Inconsistent MBSE tool adoption results in redundant data modeling efforts, making it difficult for different DoD branches to share mission models and risk assessments (Pennock et al., 2022).
- Recommendation: Establish a unified MBSE framework that enforces cross-tool interoperability, allowing mission engineers to seamlessly transfer models across different platforms.
- Supporting Technologies: AI-enhanced model translation engines that automatically convert system models across different MBSE tools (Dahmann & Baldwin, 2019).

Version Control Disparities in Digital Engineering

Version control is a cornerstone of modern DE workflows, yet inconsistencies in repository management and CI/CD implementations create challenges in maintaining a unified software development lifecycle across the DoD.

- Finding: While Git is universally used, different teams rely on GitHub, GitLab, or internally hosted repositories, leading to disparate versioning practices (Bekdache & DeLaurentis, 2024).
- Recommendation: Develop a DoD-wide repository governance framework, ensuring uniform version control policies, traceability, and collaborative development standards.
- Best Practices from Industry: Implementing GitOps workflows, where version control and automation pipelines are tightly integrated to enhance consistency across DE toolchains (McDermott et al., 2022).

Persistent Use of Legacy Tools Despite More Advanced Alternatives

The continued reliance on outdated tools in both ME and DE prevents full adoption of modern digital workflows.

- Finding: Visio and Mission Planner remain embedded in ME workflows, despite the superior capabilities of MBSE-driven mission planning platforms (Dahmann & Baldwin, 2019).
- Finding: Manual spreadsheet-based risk assessments persist in some ME environments, reducing the effectiveness of AI-enhanced risk quantification platforms such as Riskion (Williams, 2022).
- Finding: Digital Engineering workflows still feature manually scripted CI/CD pipelines, despite the automation capabilities of Terraform, Kubernetes, and Jenkins (McDermott et al., 2022).
- Recommendation: Increase institutionalized training programs to accelerate the transition to modern ME and DE toolsets, ensuring engineers are proficient in AI-driven risk modeling, MBSE automation, and DevOps workflows.

Data Fragmentation in Digital Engineering

ME and DE tools generate large volumes of mission-critical data, yet without standardized analytics infrastructures, insights remain siloed across different DoD divisions.

- Finding: Power BI, Tableau, Grafana, and Qlik are all widely used, but each system operates independently, making it difficult to integrate real-time engineering insights across the enterprise (Williams, 2022).
- Recommendation: Develop a unified DoD-wide analytics framework that enables cross-platform data sharing and mission-driven AI-enhanced insights.
- Potential Future Approaches:
    - Cloud-native analytics pipelines, where ME and DE insights are automatically aggregated in a centralized data lake for real-time visualization (Bekdache & DeLaurentis, 2024).
    - AI-powered engineering dashboards, dynamically updating ME and DE stakeholders on risk assessments, system performance metrics, and mission readiness indicators (McDermott et al., 2022).

To fully integrate ME and DE, DoD must enforce common tool interoperability standards, streamline version control practices, phase out legacy systems, and establish enterprise-wide data analytics frameworks. Key priorities include:

- Developing a DoD-wide MBSE interoperability standard to unify mission modeling frameworks.
- Implementing GitOps-driven repository governance to ensure version control consistency across ME and DE.
- Mandating AI-enhanced decision support in both ME and DE workflows, reducing reliance on legacy tools.
- Creating a cloud-native data sharing strategy, enabling seamless collaboration across mission and digital engineering teams.

By addressing these challenges, DoD can transform ME and DE into a fully integrated, AI-augmented, and automation-driven engineering ecosystem, ensuring enhanced collaboration, mission resilience, and digital readiness for future warfighting environments (Pennock et al., 2022).

Future Directions: Building an Integrated Digital Engineering Ecosystem

The evolution of ME and DE, especially in the DON and DoD, reflects a broader transformation in how complex and defense systems are conceptualized, developed, and sustained. This research highlights that ME and DE remain distinct disciplines with unique methodologies and objectives; however, their increasing interconnection necessitates improvements in interoperability, standardization, and tool integration, i.e. harmonization. The literature does not suggest that ME and DE should merge into a single framework. Rather, the goal is to enhance interoperability so that the two disciplines can effectively complement one another (Dahmann & Baldwin, 2019; McDermott et al., 2022).

A key challenge remains the lack of standardization between ME and DE tools, leading to inefficiencies in data integration, version control, and model-based decision support. Addressing these challenges will require a coordinated effort to improve tool interoperability, streamline governance structures, and modernize workforce training initiatives.

To maximize the benefits of both ME and DE, the DoD must focus on the following key initiatives:

- Improve Interoperability Between ME and DE Toolchains
    - Establish DoD-wide interoperability standards for MBSE (Cameo, Valispace, Teamcenter) and DE automation workflows (Git, Kubernetes, AI/ML frameworks).
    - Ensure that ME and DE tools can exchange data seamlessly to support cross-functional mission planning and digital sustainment.
- Leverage Digital Twin Technologies for Mission-Level Analysis
    - Implement Digital Twins across mission-critical systems to enable real-time predictive modeling, risk analysis, and operational forecasting.
    - Integrate AI-enhanced analytics to improve scenario modeling, mission adaptability, and automated risk assessment.
- Modernize Lifecycle Management Through Cloud-Native Engineering
    - Transition ME and DE workflows to cloud-based architectures to improve collaboration, data sharing, and automation.
    - Establish standardized DevSecOps pipelines to ensure secure, efficient software deployment across defense agencies.
- Enhance Workforce Readiness and Digital Literacy

- Expand training programs to equip personnel with expertise in MBSE, DevOps, AI/ML, and simulation-based mission planning.
  - Develop joint DoD-industry-academia partnerships to accelerate innovation in ME/DE methodologies and tool integration.
- Strengthen Governance and Standardization Across SYSCOMs
  - Align ME and DE initiatives across NAVWAR, NAVAIR, NAVSEA, and other SYSCOMs to streamline engineering workflows and enhance mission resilience.
  - Develop DoD-wide version control and data integration policies to eliminate inefficiencies caused by fragmented tool adoption.

For the DON workforce, and more broadly DoD community, these advancements necessitate a fundamental shift in technical competencies, engineering methodologies, and workforce development strategies. As DE tools become more integrated into mission planning and sustainment, personnel across ME and DE domains must develop proficiency in AI/ML applications, DevOps workflows, cloud-native architectures, and data-driven decision-making. This transition will require comprehensive training programs, cross-disciplinary skill development, and expanded collaboration between government, industry, and academia. Additionally, ensuring that the workforce remains adaptable to emerging technologies will demand a culture of continuous learning, investments in modern engineering education, and incentives to attract and retain talent with expertise in digital engineering, cybersecurity, and systems integration. By addressing these workforce challenges, the DON can build a technically proficient, agile, and future-ready engineering community capable of sustaining the rapid evolution of ME and DE methodologies.

Acronyms

API	Application Programming Interfaces
ARLIS	Applied Research Laboratory for Intelligence and Security
ASN	Assistant Secretary of the Navy
ASOT	Authoritative Source of Truth
BLUFOR	Blue Force
CHENG	Chief Engineer
CNO	Chief of Naval Operations
COI	Community of Interest
CONOPS	Concepts of Operation
DASD(MI)	Deputy Assistant Secretary of Defense for Mission Integration
DAU	Defense Acquisition University
DE	Digital Engineering
DET	Digital Engineering Transformation
DME	Digital Mission Engineering
DoD	Department of Defense
DODD	Department of Defense Directive
DODI	Department of Defense Instruction
DON	Department of Navy
DOTMPLF-P	Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, Facilities, Policy
I&I	Integration and Interoperability
ICAP	Industrial Committee of Ammunition Producers
ICF	Integrated Capability Framework
JCIDS	Joint Capabilities Integration Development Systems
JCS	Joint Chiefs of Staff
JP	Joint Publication
KPI	Key Performance Indicators
M&S	Modeling and Simulation
MASG	Mission Architecture Style Guide
MBE	Model Based Engineering
MBL	Model Based Logistics
MBLE	Model Based Logistics Engineering
MBSE	Model Based Systems Engineering
ME	Mission Engineering
ME TAB	Mission Engineering Technical Authority Board
MEG	Mission Engineering Guide
MEG	Mission Engineering Guide
MET	Mission Engineering Thread
MIL-HDBK	Military Handbook
MOE	Measure of Effectiveness
MOP	Measure of Performance
MOS	Measure of Success
MT	Mission Thread
NAVAIR	Naval Air Systems Command
NAVINST	Navy Instruction

NAVSEA	Naval Sea Systems Command
NAVWAR	Naval Information Warfare Systems Command
NDS	National Defense Strategy
NPS	Naval Postgraduate School
NSWC	Naval Surface Warfare Center
NUWC	Naval Undersea Warfare Center
NUWC	Naval Undersea Warfare Center
OOP	Object-Oriented Programming
OOSE	Object-Oriented Systems Engineering
OPFOR	Opposing Force
OPNAV	Office of the Chief of Naval Operations
OSA	Office of Strategic Assessments
OUSD(A&S)	Office of the Under Secretary of Defense for Acquisition and Sustainment
OUSD(R&E)	Office of the Under Secretary of Defense for Research and Development
PMBE	Physical Model Based Engineering
PMBE	PPBE Planning, Programming, Budgeting, and Execution
RDT&E	Research, Development, Test, and Evaluation
ROPE	Resources, Operations, Policies and Economics
SECNAV	Secretary of Navy
SERC	Systems Engineering Research Center
SoS	System of Systems
SYSCOM	Systems Command
VT-ARC	Virginia Tech Applied Research Corporation

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The team reviewed a large number of publications and DoD strategies that influenced this work. Those central to findings included in this report are cited below and some are annotated additionally as endnotes throughout this report when directly cited for a key statement or finding.

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