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Accelerating Implementation of Critical Joint Warfighting Concepts and Capabilities

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Abstract

Mission engineering is a relatively new discipline born out of the need to support mission planners and strike authorities with emerging technologies and innovative solutions to achieve mission success in complex, multi-domain operating environments. Mission engineering combines the future operating environment and the strategic intent outlined in the National Defense Strategy with the rigor of system engineering, software engineering, digital engineering, and related disciplines, to identify critical operational gaps and architect the system of emerging materiel and

non-materiel solutions required to reach the desired strategic or tactical objectives. The ultimate objective is to optimize mission accomplishment and outcomes by advancing the existing operation plans, kill-webs, mission threads, and vignettes with innovative technologies and capabilities to deter or defeat any adversary in the most complex engagements. This article discusses the challenges of mission engineering and proposes the integration of operational and live fire test and evaluation within this process to mitigate some of those challenges.

Introduction

> Organizing to secure our advantage is not just a strategic goal; it is an imperative that assures our nation's future defense. No warfighting domain remains uncontested. The complexity of warfighting is growing with technology, so no single Service capability can win alone without truly realized joint force capabilities.

—Admiral Christopher W. Grady, "Sharpening Our Competitive Edge: Honing Our Warfighting Capabilities Through the Joint Warfighting Concept"

Mission engineering that is grounded in test data and accredited modeling and simulation (M&S) results is one of many tools that identify gaps and look for creative, out-of-the-box solutions to respond to the persistent adversary and dominate in such contested environments. Many other never-before-seen technologies and tactics, techniques, and procedures (TTPs) may be delivered because of rigorous mission engineering efforts that could otherwise not have been identified if the problem was viewed purely at a system level, or even at an individual Department of Defense (DoD) component level.

The current practice of mission engineering relies on M&S—high-level campaign analyses—with the capability to run what-if scenarios to identify gaps in achieving mission success for different vignettes. Mission engineering analyses could guide the department's decisions regarding distributed maritime operations and dynamic expeditionary operations in a high-end-fight, employing thousands of attritable, fully autonomous systems to overwhelm the adversary in mass and achieve the desired lethal effect. Mission engineering would consider various alternatives in the context of the ability to establish electromagnetic spectrum superiority and the possibility that the friendly communications' emissions present a significant susceptibility to being targeted by the enemy. It is necessary to account for these synergistic and emergent effects and the array of possibilities, shown in Figure 1, to realistically represent and exploit the highly complex battle space and achieve an enduring advantage. Mission engineering involves forecasting the performance of future capabilities to inform future requirements and acquisition priorities that will in turn drive science and technology investments. Because of its heavy reliance on M&S and its focus on the operational performance and mission success, it is important to integrate mission engineering efforts with the operational and live fire test and evaluation activities. This integration involves not just the operational and live fire testing of individual systems but also such testing of joint warfighting concepts, kill-webs, vignettes, mission threads, and other system-of-systems scenarios. The integration of these two disciplines can enhance the realism of the mission engineering architecture by identifying and supplying relevant operational data critical to verifying and validating the mission engineering outputs. This article illuminates and explores the synergistic benefits of this integration.

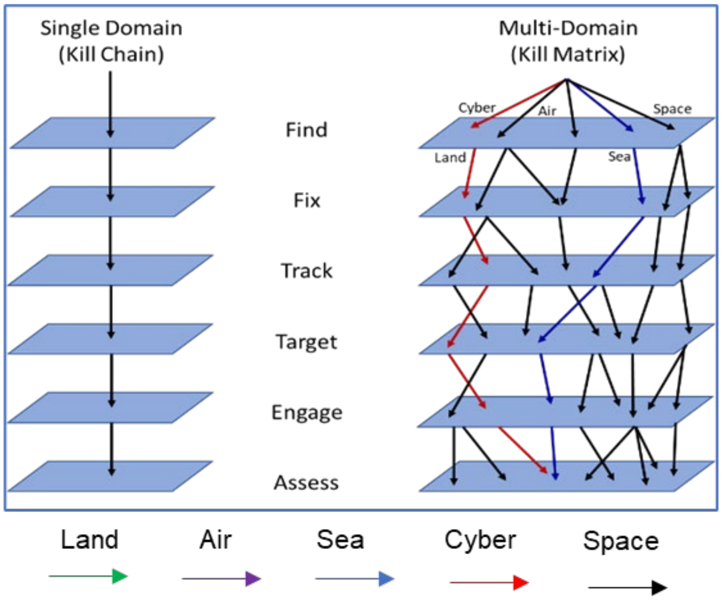

Figure 1. Kill-Web Combinatorics

Mission Engineering

Mission engineering is 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 (Office of the Under Secretary of Defense for Research and Engineering [OUSD(R&E)], 2023). Mission engineering decomposes missions into their constituent parts to

- identify gaps, challenges, and opportunities
- inform decisions regarding requirements, architectures, and technologies needed to achieve the combatant commanders' strategic and tactical mission objectives

The Under Secretary of Defense for Research and Engineering developed a five-part process for mission engineering, shown in Figure 2 (OUSD[R&E], 2023):

1. Frame the mission problem or opportunity.
2. Characterize the mission, including specific scenarios, vignettes, and measures.
3. Model the mission architectures.
4. Perform analysis and evaluate trade-offs.
5. Document results and recommendations.

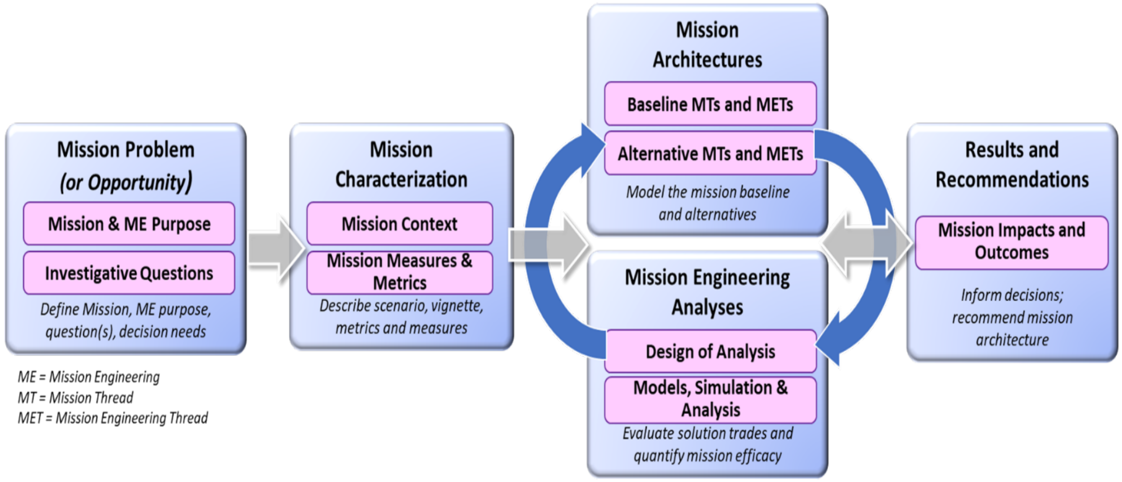

Figure 2. Elements of the Mission Engineering Process

Operational Test and Evaluation in the Context of Mission Engineering

Operational and live fire testing determine the operational effectiveness, suitability, survivability, and lethality of the systems and services that the DoD acquires through the Defense Acquisition System. By Section 139, 4171 and 4172 of Title 10, United States Code, and, more elementarily, by the scientific method that the law is written to reinforce, such determinations cannot be based solely on M&S. They require live data collected in operationally representative conditions using trained operators, maintainers, and defenders. While mission engineering is not intended to determine the operational performance of the to-be fielded systems, it does inform other equally important decisions in support of the warfighter. As the DoD moves into more complex warfighting domains, mission engineering architectures would benefit significantly from being shrewdly rooted in M&S that has undergone rigorous verification and validation using operational and live fire test and evaluation data. This is discussed next in more detail in the context of the five-part process for mission engineering.

Mission Problem

One application of mission engineering is determining the optimal mix of forces to achieve the desired mission effects while expending the least number of resources (Brown et. al., 2023). While operational testing does not typically address this topic, the knowledge gleaned from operational testing may have resource impacts. For example, operational testing may identify operational effectiveness limitations showing that more weapons are required to achieve the desired strategic or tactical effects on the intended targets than originally estimated in mission engineering. Similarly, operational testing may identify operational suitability limitations showing that more systems are required to achieve the same mission effects due to reliability, availability, or maintainability shortfalls than originally estimated using mission engineering. Lastly, live fire testing might identify survivability limitations that again show additional resources are required to account for potential kill removals than originally estimated in mission engineering. One of the chief differences between mission engineering and operational and live fire test and evaluation is that the former focuses on the optimal means to accomplish a mission, while, at least historically, the latter focuses on the mission performance of individual systems. This difference points to an opportunity to use mission engineering to design operational and live fire tests to evaluate future joint warfighting concepts, kill-webs, vignettes, mission threads, and other system-of-systems scenarios—termed in this article **Joint Test**

Concept—to support the collection of definitive data sources underpinning the credibility of mission engineering outcomes.

Mission Characterization

The mission characterization describes the set of variables that provide the context for, among others, the mission objectives, environment, friendly and enemy forces, timeframe, assumptions, constraints, and TTPs. Mission scenarios or vignettes may be derived from joint warfighting concepts, operational plans, concepts of operations, and other mission plans. While mission engineering characterizes the scenarios and mission threads—including the order of battle, threats, and rules of engagement—to identify gaps and solutions and optimize mission outcomes, operational testing characterizes the ability of the system to either execute or contribute to that mission. Mission engineering digital environments enable the evaluation of a broader set of mission contexts, which could inform plans for operational or live fire test and evaluation—especially if future opportunities include the evaluation of the operational performance of vignettes, kill-webs, mission threads, and the like.

Mission Architecture

Mission architecture models the concepts, approaches, and full system of systems to examine the entire mission's process and data flow, interactions and timing, and capabilities and performance required to meet the mission objective. Mission threads are the elements of this architecture that describe the various assets and end-to-end tasks needed to accomplish a specified mission. A mission engineering thread assigns systems, organizations, or assets to perform a task as shown in Figure 3. These mission threads are available from the Joint Staff's Universal Joint Task Lists. Based on the mission thread analysis, operational or live fire test plans could identify the requisite live data and accredited M&S results needed to validate the mission engineering outcomes. The integration of these two disciplines could help ensure that the results of each will provide deeper insight into different aspects of the identified challenges. For example, sharing a common representation of the threat and TTPs could ensure alignment in several areas, including the format and fidelity of threat surrogate digital artifacts.

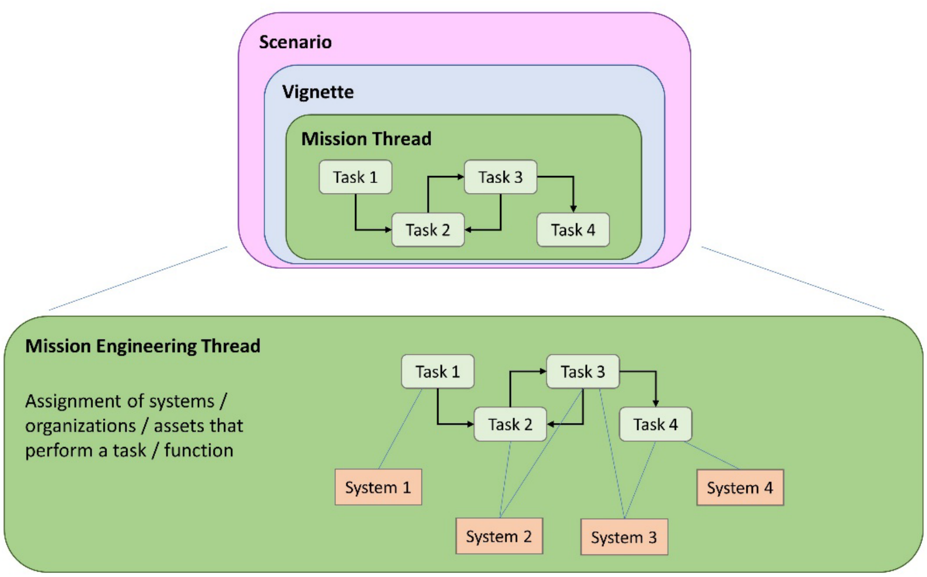

Figure 3. Mission Threads and Systems (Mission Engineering Guide, 2020)

Mission Analysis

Mission engineering and operational test evaluate mission success in different ways. Mission engineering forecasts mission scenario outcomes using M&S and sensitivity analyses to understand how uncertainty propagates across the M&S, while operational testing measures an individual system's contribution to a mission scenario using a combination of live data and accredited M&S results. For example, operational testing measures operational availability and logistics delays, which can play an important role in determining mission outcomes, especially for sustained operations. Both mission engineering and operational testing frequently use force exchange ratios in their evaluation of overall mission effectiveness. The commonality in evaluation areas offers an opportunity for mission engineering to integrate and inform operational system performance measurements collected in operational and live fire test and evaluation. Conversely, mission engineering can extend operational and live fire system performance measurements into a wider range of mission contexts. Mission engineering also often forecasts acquisition and sustainment costs, return on investment, or other cost–benefit–related quantities, whereas operational testing typically does not, although the operational performance demonstrated in test can inform those analyses.

Results and Recommendations

In addition to documenting the analysis results and recommendations, mission engineering also calls for development of a preferred mission architecture and curation of the data, models, and architectures used to produce the results. Operational and live fire test and evaluation reports document the adequacy of the testing that was planned and executed to determine operational performance. They also report on the operational effectiveness, suitability, survivability, and lethality (as applicable) of the system in operationally representative conditions. Lastly, they report on recommendations to address any deficiencies in observed system performance or test limitations that precluded the evaluation of some aspects of the system performance. Both disciplines could leverage each other's reports and data, but this would warrant the development of coordinated data strategies outlining data curation, analysis, and storage needs. These data curation activities are essential to developing a common understanding of mission and system performance and developing realistic assessments of mission success, fully realizing the benefits of each activity.

Opportunities for Leveraging Operational and Live Fire Test Data to Enhance Mission Engineering Outputs

Curiously, the *Mission Engineering Guide* mentions the term *data* more than 60 times but *system testing* just three. The guide does, however, state, "For the purposes of mission engineering, the term "data" means information related to the scenario or vignette, OOB [order of battle], force structure, system parameters or performance, threat, models, and analytical results" (OUSD[R&E], 2023).

This statement implicitly suggests that operational and live fire test data of DoD *systems*—but also of mission *scenarios and vignettes*—should be the basis upon which mission engineering becomes data-driven and more realistic. Focusing operational and live fire testing on only one system may not capture all intricacies of the real-world mission scenarios involving the use of multiple systems of varying complexities and pedigrees working together to achieve the desired lethal effect. The emergence of highly network-centric concepts, greater dependency on connectivity, and the use of large amounts of data from a wide array of shooters and sensors across multiple domains, at machine speeds, warrants commensurate operational and live fire test and evaluation. Evaluating warfighting capability is further challenged by asynchronous updates and continuous evolution of the various components that comprise these system-of-systems operations. This complexity demonstrates an inherent need to continually characterize the interoperability of such systems and their effectiveness as employed by the combatant commands. With the emergence of mission engineering, joint all domain command and control solutions, and the concept of kill-webs, it is important to have operational and live fire test and evaluation also effectively measure the success rates of joint warfighting concepts, kill-webs, mission threads, and other system-of-systems solutions. Ongoing DoD efforts are investigating the feasibility of these activities under the Joint Test Concept initiative.

Joint Test Concept

Initial studies have validated the need to revamp traditional operational and live fire test and evaluation to focus on the operational and mission context in which the system under test is expected to perform throughout the system life cycle. The resultant Joint Test Concept initiative further investigates how operational and live fire test and evaluation could be transformed to either leverage existing exercises and experiments or establish a complementary process by which the department can evaluate the *lethality, suitability, resilience, survivability, agility, and responsiveness* of the joint force. The Joint Test Concept considers an end-to-end capability life cycle approach—anchored in mission engineering and a digital environment—calling for a more holistic yet dynamic and flexible approach to assess system performance across three overlapping layers:

- *System Performance Layer*, where the system is evaluated in isolation
- *Capability Immersion Layer*, where the system and mission threads are evaluated in pre-defined systems of systems
- *Joint Capability Demonstration Layer*, where the system is evaluated in a joint multi- or all-domain environment

Joint Test Concept: Leading Tools and Practices

There are key leading practices that may enhance the implementation of the joint test concepts across the three identified layers: (1) M&S, including those used by mission engineering; (2) test infrastructure and networking; and (3) data and artificial intelligence (AI).

Modeling and Simulation

Organizations across the DoD are developing policies and strategies to move forward with implementing digital engineering. A leading practice used with digital engineering is modular open system architecture (MOSA). MOSA approaches encourage interoperability and more rapid integration of capabilities throughout the system life cycle by using open system standards and architecture modularity. Systems designed with a MOSA approach, avoiding vendor and solution-specific interfaces, are designed to more easily integrate and test for joint missions. As emergent threats and new missions illuminate additional joint use cases that may not be part of original system designs, a MOSA backbone will make joint integration more feasible to implement and test, supporting enhanced integration of joint operational and live fire testing—at the mission scenario level—with mission engineering.

Another leading practice within digital engineering is model-based system engineering (MBSE). MBSE models that define system interfaces and functionality can be a critical asset to help the joint test concepts capture and understand how various systems should integrate and function together as a whole. System-of-systems models of the enterprise architecture can be used to better define the combined joint mission, identify joint test cases, and illuminate joint test gaps. A continued focus on MOSA implementation will enable programs to better respond to evolving threats by being able to swap out and upgrade components more easily across the system life cycle. As more programs throughout the DoD successfully implement MBSE and

MOSA approaches, the joint test concepts can leverage these designs to facilitate more effective evaluation of joint interoperability and mission scenario success.

Digital twins offer the capability to model and simulate a system's physical, digital, and functional characteristics in a digital format, enabling testing to shift left—all the way to mission engineering—in the product life cycle. Digital twin technology is a key enabler in M&S as the DoD moves toward a Live Virtual Constructive (LVC) testing approach that blends traditional live simulations with virtual and constructive environments. This approach enables more realistic, effective, and affordable joint testing and training environments that are difficult and prohibitively expensive to test in a purely live test format. Due to the complexity of the joint mission, LVC environments are seen as an essential piece of joint testing concept with the potential to enable large-scale joint testing events that are integrated across the DoD components and distributed across multiple geographic locations. Joint LVC environments, such as the Joint Simulation Environment, are enabled by a growing digital engineering backbone across DoD programs and offer significant opportunities to improve joint training, testing, and mission engineering of the future. Improvements to network connectivity and integration are a key enabler to facilitate LVC capabilities that are integrated across multiple DoD ranges offering the opportunity to dramatically reshape how joint testing can be executed in the future.

Test Infrastructure and Networking

As the threat landscape and joint missions continue to evolve, test infrastructure must also continue to evolve to meet the specific needs of newer technologies. Emerging mission sets—including hypersonics, space operations, autonomous systems, and electromagnetic spectrum operations, to name a few—all require new infrastructure to fully support testing at a joint level and scale. Operational test and training infrastructure could construct realistic training and testing environments that are integrated to provide warfighter training across distributed sites, providing the environment to collect mission-level operational data (Marler at al., 2022).

For example, the Joint Integrated Test and Training Center (JITTC) is intended to be the first facility to allow Air Force, Navy, and international pilots to fly integrated live and simulation missions together. The facility plans to link live aircraft tracking data over the Joint Pacific–Alaska Range Complex with simulators inside the JITTC. The JITTC is planned to be "first center capable of joint and multinational force training," providing the capability to "blend synthetic and live-fly training while focusing on training events specific to employment of tactical joint assets" (Air Force, 2023). This could serve as an excellent source of operational test data in support of mission engineering.

The Space Force is also investing heavily in its National Space Test and Training Complex (NSTTC) to build a virtual testing and training environment for space missions that are impossible to physically test on the ground (Albon, 2022). The NSTTC aims to build digital environments to represent satellites' behavior under different operational conditions across a variety of space missions. The NSTTC also plans to include ground and space-based instrumentation, command and control support, and a dedicated cyber test range. In its NSTTC vision document, Space Force (2022) identified joint applicability as one of four focus areas, highlighting the need to support development of joint multi-domain operating concepts and integrate joint mission partners. All test and training complexes could support the collection of operational test data in support of mission engineering objectives.

Investments in computing infrastructure, including supercomputers, cloud computing, and quantum computing, could also help facilitate modeling, simulation, and analysis. For example, the Air Force Research Laboratory has established a new supercomputer, named the Raider, which can calculate about 12 petaFLOPS, offering opportunities to run simulations at a higher level of accuracy and significantly accelerated timelines (Castrejon, 2023). Advanced computing capabilities will be essential to the joint test and mission engineering communities as M&S increasingly plays a major role in joint testing of complex missions.

Data and AI

The DoD set a vision for big data analytics, data governance, and AI in its DoD Data, Analytics, and Artificial Intelligence Adoption Strategy (DoD 2023). Providing data in a secure and trusted manner is critical to allowing AI and other digital engineering tools to function optimally and to enable reuse and analysis. Quality data are needed to build accurate models and insights. This need becomes more challenging with big data analytics and the collection, storage, and analysis of vast datasets to extract meaningful insights. Big data analytics can help joint test concepts identify trends to make better decisions and improve efficiency.

The effective use and application of data and AI will be foundational for joint test concepts to create a holistic picture of the joint environment and evaluate the mission scenarios within it. AI is increasingly being applied to various test and evaluation processes to enhance efficiency, decision-making and security. Some examples of this from the DoD's (2023) *Data, Analytics, and Artificial Intelligence Adoption Strategy* include

- **Cybersecurity Testing:** AI is used to simulate and detect cyber threats, vulnerabilities, and potential attacks on DoD networks. Automated tools help in identifying weaknesses and improving the overall cybersecurity posture.
- **Autonomous Systems Testing:** AI plays a crucial role in testing and evaluating autonomous systems, such as unmanned aerial vehicles and ground vehicles. It assists these systems to meet performance standards and can operate effectively in diverse environments.
- **Data Analysis for Intelligence:** AI applications are employed to analyze vast amounts of intelligence data, providing faster and more accurate insights. This aids in decision-making processes and enhances the efficiency of intelligence analysis.
- **Simulated Training Environments:** AI-driven simulations are used for training military personnel, creating realistic scenarios for test and evaluation of decision-making skills, strategic planning, and tactical execution.

These examples demonstrate how AI applications are strategically implemented within the DoD to address a range of current challenges, from cybersecurity to simulated training environments. The goal is to leverage technology to enhance capabilities, readiness, and overall effectiveness of joint tests. Advancements in AI and machine learning bring forth innovative opportunities and streamlined joint test concepts to help automate and optimize various evaluation tasks and processes, from automated testing and test generation to data collection, analysis, reporting, and more. When combined, these efforts have far-reaching immediate and future implications for joint testing that will enable the community to better validate and deliver the necessary critical technologies and systems to the warfighter to support a continued tactical, operational, and strategic military advantage. Adopting data, analytics, and AI technologies will help the DoD make decisions more accurately, efficiently, and expeditiously to support joint test and mission engineering (DoD Responsible AI Working Council, 2022).

TTPs in the Context of Mission Engineering

As TTPs evolve to reflect emerging technologies and warfighting needs, an opportunity exists to leverage data collected in operationally relevant testing to inform mission engineering and vice versa. DoD's Joint Test and Evaluation (JT&E) program considers emerging technologies and the increasingly complex and dynamic, joint, multi-domain operational environment to plan and execute test projects intended to deliver data-driven TTPs, concepts of operation, and other non-materiel solutions. Given the increased integration and dependencies of platform, network, and command and control solutions across the domains, JT&E's mission and its unique focus on system-of-systems testing is becoming increasingly critical to the department's strategic objectives. JT&E's extensive use of operational testing techniques and reach-back are essential to the adequate evaluation of the effectiveness of proposed solutions needed in operational plans across the combatant commands.

JT&E and mission engineering complement each other, especially when mission engineering is evaluating new capabilities for which the TTPs are still evolving. Choosing the specific scenarios and vignettes for test and analysis becomes increasingly difficult as the range of options grow. By working together, the JT&E program can integrate information from mission engineering, exercises, operational tests, and current operations to determine the best TTPs in a high-end fight. Understanding how to adequately represent an operationally realistic contested environment is essential to correctly develop and evaluate those TTPs. The use of JT&E joined with mission engineering will provide a powerful means of developing new, optimal joint warfighting TTPs to suffocate the enemy's ability to sustain the war.

Conclusion

The shift towards multi-domain operations and combined, joint all-domain command and control is driving a need for data-backed mission engineering. Underpinning the connections between mission engineering and operational and live fire test and evaluation, including JT&E, is the collection of operationally relevant data. The ultimate success of mission engineering depends upon the integration of extant and future operational test data to accelerate learning and increase the cycles of innovation. Conversely, the success of the transformation of operational and live fire test and evaluation depends upon the integration of mission engineering architectures to advance from a single system focus to a future joint warfighting concept and capability focus.

There are a variety of ways these two disciplines can enhance each other, but those opportunities will not be realized until operational testing becomes better integrated in system development. Overall, the emphasis needs to continue moving beyond dedicated operational testing to support production decisions, to gathering and integrating operationally relevant data to learn about systems' capabilities and how those capabilities support mission outcomes. Industry has embraced getting feedback from operations to improve its systems (to include hardware-based systems), using methods such as development, security, and operations (DevSecOps) and digital twins as part of Industry 4.0 (Madni et al., 2019). Operational feedback guides development of new features at Tesla, Amazon, and Netflix, helping these companies achieve a dominant position in their respective fields.

DoD's (2023) *Data, Analytics and Artificial Intelligence Adoption Strategy* has a similar focus on speed of delivery and continuous improvement, calling for "a tight feedback loop between technology developers and users through a continuous cycle of iteration, innovation and improvement of solutions that enable decision advantage." This strategy calls for the creation of effective, iterative feedback loops between developers, users, subject matter experts, and test and evaluation experts to ensure that the developed capabilities are more stable, secure, ethical, and trustworthy (see Figure 4).

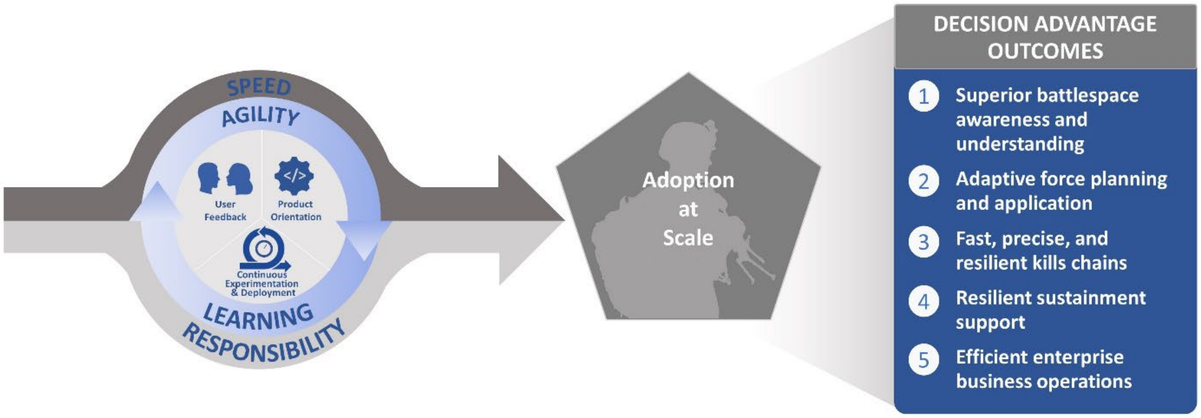

Figure 4. Agile Approach to Accelerate Decision Advantage.

Finally, as we look toward the future, the flexibility afforded by digital engineering and AI-enabled and autonomous capabilities, it is imperative to learn the most effective way to employ these capabilities. To accelerate the cycles of innovation, organizations need to agree on the key information needed from these learning efforts. The operational test community is working to quantify the benefits of digital engineering for operational testing and how improvements in knowledge management can be used to integrate all credible information in its evaluations. Models linking system designs and capability to mission outcomes have immense power to inform decision-making at multiple levels. Connecting mission engineering initiatives to operational and live fire test and evaluation, and JT&E, offers a tremendous potential to improve the ability to learn as an enterprise and effectively translate that learning to action, ensuring enduring mission success.

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