Enabling Distributed Maritime Operations Through Live, Virtual, Constructive Technologies

Jennifer Pagan MS, LCDR Joseph Geeseman
NAWCTSD, PMA-205
Orlando, FL, Patuxent River, MD
jennifer.pagan1@navy.mil, joseph.w.geeseman.mil@us.navy.mil

CAPT Joseph Cohn PhD, Peter Squire PhD, Natalie Steinhauser MS
Office of Naval Research, Code 34
Arlington, VA
joseph.v.cohn.mil@us.navy.mil, peter.n.squire.civ@us.navy.mil, natalie.b.steinhauser.civ@us.navy.mil

Rudolph Darken, Christian Fitzpatrick
Naval Postgraduate School
Monterey, CA
darken@nps.edu, christian.fitzpatrick@nps.edu

ABSTRACT

Distributed Maritime Operations (DMO) is a Naval operating concept focused on reclaiming and expanding the United States' naval ability and effectiveness where land, air, sea and information superiority are challenged, logistics are contested, and forces are distributed over large distances. Key to DMO is the ability to plan and execute synchronized operations across multiple geographically distributed warfighting domains using a diverse range of forces. Realizing this vision requires new approaches to integrating a range of systems, platforms and people, new ways of developing and assessing DMO operational plans and new abilities to teach, in real time, key DMO concepts in an integrated, synchronized, and cross-platform manner. Live, Virtual, and Constructive (LVC) technologies, which link high-fidelity simulations, real world activity and, virtually constructed teammates and adversaries using integrated networks, provide one approach to realizing the types of large scale and distributed actions that DMO will require to succeed as a warfighting concept. Aligning LVC to the current and future needs of DMO requires understanding both the concepts underlying DMO, the current state of LVC capabilities, and an assessment of where advances, through focused Research and Development (R&D) investments, are required. It also requires a coordinated approach to integrating these investments into the acquisition process, and, ultimately, into the warfighters' toolkit. This paper provides an overview of DMO as a warfighting concept and LVC as an enabling capability for DMO, analyzes the R&D areas necessary to align LVC to support DMO and offers considerations for governance, policy and acquisition to realize this alignment. The analysis presented here is a first step in delivering an integrated and focused LVC approach to support further refining, and implementing DMO – and the Marine Corps' complementary Expeditionary Advanced Base Operations - concepts for a ready and combat-capable force that can outthink, outperform and overwhelm our adversaries.

ABOUT THE AUTHORS

Jennifer Pagan is an accomplished Senior Research Psychologist at the Naval Air Warfare Center Training Systems Division. She has an integrated research portfolio devoted to transitioning Live, Virtual and Constructive (LVC) state-of-the-art products to enhance the training and operational capabilities of the nation's war fighters.

CAPT Joseph V. Cohn Captain Joseph Cohn is a pioneer in creating, fostering and leading diverse teams across the Department of Defense to deliver innovative performance and readiness -enhancing capabilities. He is a Fellow of the American Psychological Association and the Society of Military Psychologists as well as Associate Fellow, Aerospace Medical Association.

LCDR Joseph Geeseman is the Military Director for the LVC program of record at the Naval Aviation Training Systems and Ranges Program Office (PMA-205). He also provides strategic planning for PMA-205 and manages the extensive research and development portfolio for the program office.

Natalie Steinhauser is a Program Officer at the Office of Naval Research (ONR). She has 18 years of Navy experience conducting Live, Virtual, and Constructive training technologies research, training effectiveness evaluations, developing adaptive training and intelligent tutoring systems, and conducting decision-making research.

Peter N. Squire is a Program Officer at the Office of Naval Research where he oversees and guides ONR's Navy and Marine Corps research and development efforts focused on Human Performance, Training, and Education (HPT&E), and Tactical Artificial Intelligence.

Christian Fitzpatrick is currently a Faculty Associate – Research at the MOVES Institute, Naval Postgraduate School. Within the Department, he teaches Advanced Simulation Networking and the Design & Implementation of LVC Environments. Prior to joining the Faculty at NPS, Mr. Fitzpatrick served in the Marine Corps as a KC-130 pilot and Air Support Control Officer.

Rudolph Darken is a Professor of Computer Science at the Naval Postgraduate School and a founding member of the MOVES Institute. He has worked extensively in virtual environments and spatial cognition, more recently in innovation and tech transfer.

Enabling Distributed Maritime Operations Through Live, Virtual, Constructive Technologies

Jennifer Pagan MS, LCDR Joseph Geeseman
NAWCTSD, PMA-205
Orlando, FL, Patuxent River, MD
jennifer.pagan1@navy.mil, joseph.w.geeseman.mil@us.navy.mil

CAPT Joseph Cohn PhD, Peter Squire PhD, Natalie Steinhauser MS
Office of Naval Research, Code 34
Arlington, VA
joseph.v.cohn.mil@us.navy.mil, peter.n.squire.civ@us.navy.mil, natalie.b.steinhauser.civ@us.navy.mil

Rudolph Darken, Christian Fitzpatrick
Naval Postgraduate School
Monterey, CA
darken@nps.edu, christian.fitzpatrick@nps.edu

INTRODUCTION

Distributed Maritime Operations (DMO) is a relatively new concept developed by the United States (U.S.) Navy. This concept aggregates fires and effects of distributed forces across a wide area of operations. DMO involves a variety of forces working together across different levels of command and control (C2), and distributed over large geographical regions. Applying DMO concepts operationally requires new approaches to delivering training, new methods of developing doctrine, and new ways to test and evaluate (T&E) the systems and platforms that support distributed combat. Live, Virtual, and Constructive (LVC) environments aggregate any combination of these three capabilities to create a comprehensive environment that can be used for training, T&E, and doctrine development. The strength of LVC is its flexibility to address multiple levels of participants in a large-scale exercise. Here, we propose LVC is a critical enabling capability to develop and operationalize DMO and that DMO concepts can focus LVC Research and Development (R&D) to make it more relevant - specifically, more comprehensive, deployable, and manageable. Following an overview of DMO and LVC, we provide three use cases to motivate core challenges that should be addressed from a research perspective. We conclude with a short discussion addressing the challenge of implementing research solutions resulting from these investments, leveraging approaches from the Department of Defenses' Joint Capabilities Integration and Development System.

Distributed Maritime Operations

The U.S., like many nations, relies on free and safe maritime access to ensure its security (Braithwaite et al., 2020; CNO NAVPLAN, 2021; Gilday, 2019). For the last seven decades, working with its different services as well as in partnership with allied nations, the U.S. has succeeded in deterring major at-sea conflicts and overt power competition from its adversaries by maintaining technological advantage and combat-credibility (A Design for Maintaining Maritime Superiority, 2018). Today, our technological advantage is continuously challenged by adversaries, placing our combat edge at risk (Gilday, 2019). The Navy's response to this threat is to adopt a Fleet-centric agile, sustainable, and cooperative warfighting approach, known as the DMO warfighting concept (Braithwaite et al., 2020; Filipoff, 2023). At its most basic, DMO is a decentralized approach to fighting that allows commanders to quickly bring together the necessary combat capabilities on their own terms (Braithwaite et al., 2020). It relies heavily on an overarching common set of mission objectives, shared across *disaggregated forces*, *disbursed sensors, and weapons* whose actions and plans are *integrated* across different domains, timescales and locations to support combat *maneuvers* that can quickly join together to overwhelm adversaries and then disperse (Braithwaite et al., 2020, Clarity, 2023).

DMO is associated with the following key elements and principles (Filipoff, 2023; Hoehn, 2022):

1. <u>Distributed Force</u>: Dispersed naval forces over a larger geographic area rather than concentration in a single location. By spreading out assets, DMO aims to increase survivability, reduce vulnerability to attacks, and challenging adversaries' targeting processes - this comes at a cost of increasing complexity of communication and coordination.

2. Networked Operations: Integration and coordination of distributed naval forces through advanced communication and information-sharing networks. These networks enable real-time situational awareness, rapid decision-making, and effective C2 across widely dispersed units. Security and timely coordination issues abound.
3. Offensive Operations: Proactive and offensive actions to project power and achieve operational objectives. Distributed forces are capable of conducting any type of offensive operation but must coordinate strike missions, precision targeting, and offensive counter-air operations from a distance.
4. Defensive Operations: Defensive measures to protect distributed forces including layered air and missile defense, anti-submarine warfare, and anti-surface warfare, to manage threats and protect the force.
5. Resilience and Adaptability: Enhanced resilience and adaptability of naval forces in the face of changing operational conditions. Distributed forces can dynamically reposition, adjust tactics, and leverage their networked capabilities to respond to evolving threats and exploit emerging opportunities.
6. Joint and Combined Operations: Each service has its version of "distributed operations" and each service relies to an extent on integration and interoperability of all branches of military forces, as well as international partners to achieve an effective, unified response to maritime challenges.
7. Technological Enablers: Leveraging advanced technologies and capabilities to enable distributed operations. This includes improved sensors, unmanned systems, artificial intelligence, cyber capabilities, and long-range precision weapons, among others, to increase situational awareness, extend operational reach, and maintain a competitive advantage.

Figure 1 depicts a simplified DMO concept, where a variety of warfighting elements (air, land, sea), are coordinated via a secure network toward an offensive operation against a single target. While not in-scope of this paper, Figure 1 includes an expeditionary element, in recognition of the Marine Corps' Expeditionary Advanced Base Operations (EABO) warfighting concept, which emphasizes "…integrating Fleet Marine Force and Navy capabilities to enable sea denial and sea control…" and leveraging LVC to realize this integration (Department of the Navy, 2021).

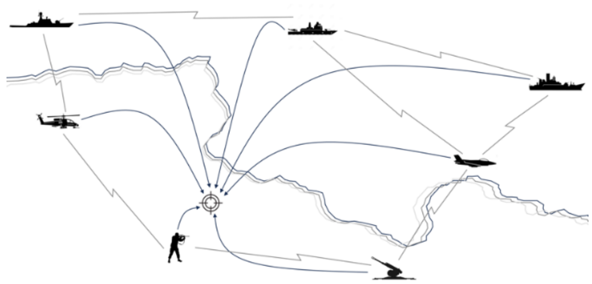

Figure 1. DMO illustration off Mediterranean coastline showing Navy and Expeditionary aviation, surface and ground platforms linking to mass fires (inspired by Clarity, 2023; Eyer & McJessy 2019; Hoehn, 2022).

Live, Virtual, Constructive Environments

DMO requires warfighters to collaboratively work across domains, understanding and embracing their respective roles in complex and coordinated actions using advanced technologies –including novel networked sensors, artificial intelligence-supported decision aids, and unmanned systems (Winegar, 2022; Hoehn, 2022). The ability to train at the scale necessary to support DMO is constrained by the ability to amass and geographical distribute real platforms and systems. LVC combines live, virtual, and constructive elements in any combination to create a comprehensive and realistic environment. The *Live* element refers to real operators using actual platforms. The *Virtual* element involves simulators operated by real operators. Lastly, the *Constructive* element is injected into the architecture as entirely computer generated, simulated representations of people, platforms, weapons, emitters, etc. (Department of Defense [DoD], 1998). LVC capabilities vary in maturity by warfare area and mission domain and are commonly associated with training (Varshney, et al., 2011), but other uses exist including developing and validating doctrine (Mansikka et al., 2021); and supporting Test and Evaluation (T&E) of systems (Hodson & Hill, 2014).

By combining live, virtual, and constructive elements, LVC offers several advantages that are critical to developing and implementing DMO warfighting concepts (Best & Rice, 2018):

1. Realism: Realistic experience by integrating real-world assets with virtual and constructive elements. This enhances the fidelity of the environment, allowing personnel to execute or practice and refine their skills in scenarios that closely resemble actual operational conditions.

2. Scalability: Achieved through accommodation of a wide range of scenarios, from small unit tactics to large-scale joint and multinational exercises, as demanded by DMO. The use of virtual and constructive elements allows for the replication of multiple forces and complex operational environments, regardless of the availability of physical assets.
3. Cost-Effectiveness: Cost reduction is associated with live exercises or experimentation. By utilizing virtual and constructive elements, training and analysis can be conducted without the need for expensive equipment, ammunition, and other resources. It also allows for repetitive training and scenario iteration, enabling personnel to practice and learn from mistakes in a safe and controlled environment.
4. Flexibility and Repeatability: LVC simulation offers flexibility in designing and modifying scenarios. Because DMO is a concept, flexibility is critical. Changes can be made to the composition of forces, environmental conditions, and mission parameters to meet specific objectives. Additionally, scenarios can be repeated and varied to reinforce learning and skill development.
5. Operations Security: LVC simulations allow warfighters to practice Tactics, Techniques and Procedures (TTPs) in a secure environment that prevents disclosure to our adversaries.

APPLYING LVC TO DMO

We hypothesize that DMO includes unique attributes that make it well-suited for using LVC as a foundry to provide DMO capabilities. To illustrate, we focus on three specific applications: training, doctrine development, and T&E. We situate these applications in frameworks derived from existing guidance, to not only ground these applications in current-world terms but, also, to make clear that a foundation for governance and policy development is already established for delivering effective R&D-driven LVC in support of DMO. Figure 2 depicts how LVC addresses DMO needs. Figure 1 is replicated above, but here, each participant is identified as live, virtual, or constructive and assigned a letter label. The inset shows where participant actually resides. The LVC configuration for this DMO exercise includes a ship underway (A), aircrew in simulators at Yuma (D) and Fallon (E), a live ground combat element at Twentynine Palms (F), constructive ships (B) and (C), and constructive artillery (G) provided by the simulation center at Marine Corps Air Ground Combat Center. The DMO exercise, however, is taking place off the Mediterranean coastline. Using this as context, we now focus on showing how LVC enhances and enables training, doctrine development, and T&E for DMO.

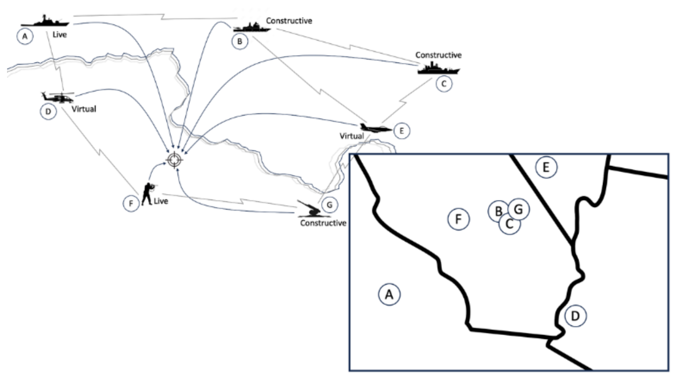

Figure 2. The same concept from Figure 1 executed in an LVC environment.

Training

Full-scale training in the military involves realistic and comprehensive exercises that simulate real-world operational scenarios (Chairman of the Joint Chiefs of Staff [CJCS], 2015). These exercises are designed to train and assess the readiness of military units and personnel. There are a number of key steps in conducting full-scale exercises that connect LVC to DMO.

1. Exercise Planning: The planning phase begins with identifying the objectives and scope of the training exercise. This includes determining the type of exercise (e.g., field training exercise, command post exercise, combined arms live-fire exercise), selecting the location, and establishing the duration. Exercise planners also define the scenario, set the mission parameters, and allocate roles and responsibilities for participating. LVC removes the requirement that all participants co-locate and allows for each to join the exercise via the most effective means.

2. Scenario Development: A realistic scenario is developed to replicate operational conditions for a specific training objective that may involve simulated enemy forces, political and humanitarian considerations, logistical challenges, and other factors. The scenario is designed to test various aspects of military operations, including C2, intelligence, logistics, communication, and tactical execution. LVC enables a deeper set of training considerations than are possible in conventional live training.
3. Resource Allocation: Adequate resources and assets are allocated to support the training exercise includes providing military equipment, vehicles, aircraft, ships, and other necessary resources. Additionally, personnel such as role players, observers, evaluators, and safety personnel may be assigned to ensure the smooth conduct of the exercise. LVC gives exercise planners greater flexibility and cost effectiveness.
4. Pre-Exercise Training: Before the full-scale exercise, participating units and personnel undergo preparatory training to ensure they have the baseline set of skills to execute exercise objectives including individual and collective training, rehearsals, and briefings, rules of engagement, etc. Live and virtual training typically can be used independent of a full LVC exercise.
5. Exercise Execution: During the exercise, participating units carry out their assigned missions based on the given scenario. This may involve coordinated movements, tactical engagements, logistical support, communications, and decision-making processes. The exercise is closely supervised by exercise controllers and evaluators who monitor the progress and provide feedback to participants. LVC allows for greater access to performance measurement, in-situ and after-action feedback (see below), and contextual instruction, among other advantages.
6. After-Action Review (AAR): Following the exercise, an AAR is conducted to evaluate the performance and identify areas for improvement. Captured digitally inside an LVC framework, this feedback is used to TTPs for future training exercises. These AAR data can further be incorporated into training and operational procedures - insights help shape doctrine, TTPs, and may lead to adjustments in equipment, training programs, and organizational structures. The objective is to iteratively enhance readiness and effectiveness based on real-world training experiences.

Full-scale training exercises are crucial for maintaining military readiness, fostering unit cohesion, improving decision-making capabilities, and validating operational plans and concepts. They provide a valuable opportunity for warfighters to integrate and synchronize efforts, identify and address weaknesses, and ensure they are prepared for a range of operational scenarios. The novel aspects of DMO further amplify the need for LVC due to its distributed-nature, flexibility, cost reduction, and access to measurable performance.

Doctrine Development

Military doctrine is developed through a structured and iterative process that involves a combination of research, analysis, experimentation, and expert input (CJCS, 2020). The following steps outline the general process of military doctrine development, and highlight how LVC capabilities can enhance development of DMO doctrine:

1. Research and Analysis: The development of military doctrine begins with studying past conflicts, examining current trends in warfare, studying technological advancements, and reviewing lessons learned from military exercises and operations. LVC can play a role in rendering real-time key elements to help clarify their potential impact on DMO doctrine.
2. Threat Assessment: Military doctrine development takes into account the assessment of potential threats and challenges that armed forces may face in a rapidly changing theater as envisioned for DMO. This involves evaluating the capabilities, strategies, and intentions of potential adversaries, as well as identifying emerging threats such as cyber warfare, hybrid warfare, or asymmetric threats. Portions of the threat assessment may lay the foundation for crafting the LVC scenario, to include identifying the types of LVC assets to incorporate in the final capability.
3. Conceptualization: Based on the research and threat assessment, conceptualization is conducted to define the fundamental principles, strategies, and objectives that the military doctrine aims to achieve. This stage involves formulating a vision of how the armed forces should operate and what capabilities and tactics should be emphasized. LVC capabilities can provide a foundry for ideation and visualization of different iterations of doctrine, including enabling real-time testing of outcomes.
4. Doctrine Drafting: A team of subject matter experts, often drawn from various branches of the military, is tasked with drafting the initial doctrine document, outlining the principles, guidelines, and procedures that guide military operations and decision-making.

5. Experimentation and Validation: Once the doctrine draft has undergone initial drafting, it is critical that it be explored and assessed through a well-developed LVC construct. These experiments help assess the effectiveness of the proposed doctrine and identify any potential gaps, vulnerabilities, or unforeseen consequences. The results of these exercises inform further refinements and adjustments to the doctrine.
6. Approval, Implementation, Revision: Following multiple rounds of review and refinement, the final version of the military doctrine is approved and disseminated for adoption and integration into training programs, operational planning, and decision-making processes. LVC artifacts associated with developing doctrine can facilitate adoption and integration - doctrine evolves over time to changing threats, technology, and operational requirements. LVC provides a dynamic capability to support monitoring and updates to incorporate new lessons learned, emerging best practices, and advancements in military capabilities.

While LVC does not play a direct role in every step of doctrine development for DMO, it can serve as a focal capability to formulate, test, measure, modify - and test again – new ideas in an interactive, shared and real time context. Today, DMO is a concept. What will emerge from a series of LVC exercises will be a refined DMO concept ready for adoption and implementation.

Test and Evaluation

The military conducts T&E to assess performance, effectiveness, and suitability of equipment, systems, procedures, and concepts during acquisition prior to operational deployment (DoD, 2020). DMO involves integrating a wide range of technologies, many of which are continually evolving. LVC provides a unique "testbed" to continually validate that these capabilities meet the required standards and objectives. The steps involved in conducting T&E LVC for DMO include:

1. Test Planning and Design: The T&E process begins with defining the objectives, scope, and parameters of the evaluation leading to a test plan which includes establishing the testing environment and conditions, the scenarios and data collection requirements. LVC can provide the context, environment and data traceability to incorporate the T&E plan elements.
2. Test Execution: The testing phase involves executing the planned tests according to the test plan. This may include field exercises, live-fire demonstrations, computer simulations, or a combination of these methods. Test procedures are followed, and data is collected and recorded.
3. Data Collection and Analysis: During test execution, data is collected vis sensors, instrumentation, observers, participant feedback, etc. These data are then analyzed to assess the performance, reliability, effectiveness, and other relevant attributes of the system being tested. LVC, by virtue of being network-based and including Modeling and Simulation (M&S) resources, can gather a wide range of data that supports a variety of analyses and visualization needs.
4. Evaluation and Assessment: Based on the analysis of collected data, an evaluation and assessment are conducted. The performance and suitability of the system are compared against predetermined criteria. LVC can provide added depth to this step by allowing for real-time interaction with the analyses, and supporting collaboration across different experts to identify strengths, weaknesses, limitations, and areas for improvement.
5. Reporting and Decision-Making: A comprehensive report is prepared, documenting the T&E process, results, and findings. Results may also influence procurement decisions, operational planning, training programs, and future requirements. When conducted in an LVC environment, the corresponding T&E artifacts may be directly portable to these training and acquisition systems.

LVC can provide DMO with enhanced M&S-based tools for acquisition that can deliver the building blocks for more comprehensive training and doctrine-focused applications. Because the T&E process is iterative, LVC also provides a dynamic repository from which to conduct more comprehensive, longitudinal assessments, which can highlight effective and ineffective changes over time. Lastly, T&E varies in scale and complexity depending on the system being evaluated, ranging from individual equipment to large-scale joint exercises or operational assessments. LVC provides a similar scalability.

ALIGNING LVC WITH DMO THROUGH FOCUSED R&D INVESTMENT

There are many opportunities for LVC to accelerate the development, adoption, and deployment of DMO capabilities. At the same time, LVC capabilities will need to further mature to meet these new opportunities. We next explore key gaps that should be addressed through focused research and development investment, to fully align LVC as a DMO enabler. Below, we characterize these investments in terms of three primary thrust areas: Architecture and

Interoperability, Environmental Content, and Performance Assessment. Addressing these investments requires more than conducting research. It also requires better understanding of the governance necessary to implement that research. This includes updating or changing governance relating to using LVC, ensuring personnel are ready to use these capabilities, and providing the right materiel, and non-materiel support.

Thrust Area I: Architecture and Interoperability

Thrust Area I focuses primarily on engineering and frameworks on which LVC environments operate. It involves software architectures and interoperability across modular components. Further, it assumes that interoperability is multi-tiered where models aggregate with other models in predictable ways.

1. Open, Modular, Microservices Architecture

Modern enterprise software architectures are quickly trending towards modular microservices due to the need (1) for increased flexibility to meet future functional demands, (2) for reduced costs due to module reuse, and (3) to provide scalability. Microservices are loosely coupled but usually very specific functional components. LVC environments should encourage an open architecture but not necessary demand all open modules. Open architecture, if constructed properly, enables the interoperation of proprietary and open modules.

2. Distributed Interoperability

In M&S, interoperability historically means how a linear functionality between two simulations - simulation “A” functions with simulation “B”. To truly support DMO, an order of magnitude advance in the interoperation of software modules to allow multiple simulations to flexibly interoperate in as broad a way as possible – simulation “A” functions with simulations “B” and “C”, simulation “C” interoperates with simulation “D” and so on. This interoperation must start at the model level, and include interoperation of models to create specific simulated behaviors (see human behavior simulation below), as well as the interoperation of simulations (virtual and constructive), live entities, and operational C2 systems of all types.

3. C2 System Integration

LVC environments must integrate seamlessly with service-specific, joint, and coalition C2 systems to track scenarios as they unfold. Integration must account for applications developed using various systems and provide a means of translation across these disparate systems including the Joint Simulation Bus (J-BUS), Architecture Management Integration Environment, or System of Systems Technology Integration Tool Chain for Heterogeneous Electronic Systems. It must also account for different messaging formats utilized by various C2 systems including Over-the-Horizon Gold, Cursor on Target, C2 Simulation Interoperability, or the Variable Messaging Format.

4. Multilevel Security Integration

LVC environments must allow for classified simulations to interoperate with unclassified simulations within the constraints of DoD policies for such interoperation. It is not an exaggeration to say that the interoperability component of LVC is the most complex and carries with it the most technology risk, when coupled with the inherent associated need to validate multiple classification levels.

5. After Action Review (AAR)

A critical part of any LVC effort is the capture of performance data for AAR and other analytics processing. The differences in data collection between different platforms may be vast. Yet, at AAR’s most basic level – the common theme exists to record data, analyze it, and reconstruct events or play back sequences to benefit a range of users. An ongoing challenge that must be resolved is the amount of data produced after a scenario is exercised and a corresponding lack of tools to effectively make use of it.

Critical to DMO execution is C2 of disparate, distributed forces in unknown environments. To address this, the Architecture and Interoperability Thrust Areas must focus on the R&D of key enablers including 5G communications, secure data transfer, edge compute, interoperability standards, operational energy, and force sustainment. Scenario developers will be able to place developing technologies whether live, virtual, or constructive into synthetic training environments where commanders at all echelons can assess utility or identify limitations. This feedback loop between operational forces and Naval Research Enterprise (NRE) will inform and guide S&T investments. A similar develop, deploy, assess process must be a part of each Thrust Area as we try to eliminate capability gaps.

Thrust Area II: Operational and Environmental Content

Thrust Area II focuses on the design of accurate operational environments. Accuracy is based on simulating unit behaviors that are aligned to doctrine. Force structures and supporting assets need to be modeled based on their (known) current states. This area will also allow for investigation of how the Services integrate new warfighting environments including space and cyberspace into traditional sea, air, and land missions. As one example, the "Pivot to the Pacific" has spurred interest in contested logistics, Expeditionary Advanced Base Operations (EABO), and hypersonic missiles, challenges exacerbated by the large distances involved in interacting across that region.

1. Human Behavior Simulation
A key capability that LVC provides to DMO is the ability to create dynamic "friendly" and "adversary" force behaviors within simulation scenarios. Recent advances in artificial intelligence (AI) and machine learning (ML) may lead to accelerated development in this area. These advances should be enabled through greater interaction with the Fleet, in real time, to ensure the behaviors developed closely align to expected maneuvers at sea and on the battlefield.

2. Whole Earth Multi-Scale Database
DMO spans large geographical distances, requiring large scale models of broad regions. However, creating a whole earth database is computationally intensive and can reduce effectiveness of LVC. An alternate approach is to identify a "minimum viable model" of the geographical areas of interest, to ensure efficient use of computing assets that produce required visualizations. Just-in-time "compiling" of terrain databases from intelligence data may also be an option worthy of exploration.

3. Integration of Real-World Data
Similar to efforts to integrate C2 and other operational systems into LVC environments, it is often desirable to integrate real world data in support of a specific exercise scenario. That data comes in many forms, but each must have a data conduit to the LVC environment that allows for the simulations to read the external data and influence the simulation appropriately.

4. Composable Model Aggregation
As the scale of tactical scenarios increases to better support more complex realities of DMO, low-level models will need to be developed in a manner that allows them to be composed into aggregate models and vice-versa. Done correctly, this will reduce the need to conduct Verification, Validation and Accreditation (VV&A) each time the composition of the force structure in a simulated scenario is altered.

5. Autonomous Entities
Unmanned systems will be critical to future DMO concepts as they will augment human capabilities serving as a force multiplier to increase lethality and performance. LVC environments are ideal for training to these new, more technically complex skills associated with human machine teaming.

6. Scenario Authoring
In the future, LVC scenarios for training will need to be created by the Sailors and Marines as they know their training and readiness (T&R) requirements best and will need the flexibility to create new scenarios at the point of need. Analysts also must be able to author scenarios to test concepts.

7. Real-time Scenario Support Tools
As LVC environments increase in scale (particularly for training) instructors/operators will need additional support tools to verify scenarios elicit relevant objectives. While the introduction of AI and ML will support increased autonomy of execution, instructors/operators will still be required to monitor large numbers of entities and assess their tactical execution for representativeness of real-world performance to prevent negative outcomes (e.g., training). Tools to support rapid, real-time, identification of unrealistic live, virtual, or constructive performance will be needed. Additionally, instructors will still need the capability to modify scenarios real-time (e.g., regenerating trainee that should be attrited) to ensure trainees receive the number of sets and repetitions necessary for skill acquisition.

This Thrust Area has a number of challenging research areas to be addressed including human-machine teaming, trust in autonomous systems, data fusion, and environmental modeling. For training, testing, and evaluation, it is imperative that the environments we create are realistic and authentic to ensure operational force buy-in. Negative training may occur in some LVC environments if the environment is not an accurate representation of operations. In addition, collaboration between humans and robotic systems will require extensive training time to make operations feel more routine. This Thrust Area could be considered the most challenging as it is where systems and environments merge with human operators.

Thrust Area III: Performance Assessment

Thrust Area III focuses on assessing, refining, and enhancing LVC environments and assessing systems under test within the LVC environment. This thrust area includes performance assessment tools that can be adapted to any role in any LVC event (i.e., individual human performance, team performance, unit performance, and equipment performance) to ensure the right data is collected, aggregated, and analyzed ensure correct inferences may be drawn from the data.

1. Effectiveness

LVC used for DMO will require the ability to measure performance, record performance, and assure that structured exposures to scenarios results in achieving the desired objectives. A benefit of LVC's complexity is that if affords a range of configurations and at multiple levels, from individual warfighters to leadership and staff at all levels, across a range of domains (e.g., supply, cyber). Over the years, much has been learned about assessing effectiveness for a given application, but this approach does not scale to the range of layers offered by LVC.

2. Verification, Validation and Accreditation

Verification is the process of determining models/simulations implementation and associated data accurately represent developer's conceptual description and specifications; validation determines the degree to which they are accurately representative of the real world; and accreditation is the official certification that they are acceptable for use for a specific purpose. Because so many models will be aggregated into a DMO LVC exercise, it is critical to develop a scalable repeatable approach to VV&A to understand what can and cannot be concluded from the exercise data.

3. Exercise Design

Exercise design includes creation of a simulated wartime operation that involves planning, preparation, execution, and after-action review. Standardized and repeatable processes for building federations of computer simulations using Distributed Simulation Engineering and Execution Process should be used. Additionally, this work should focus on user testing, training, and exercise requirements for LVC environments.

4. Wargaming

Wargaming is an effective mechanism for assessing high level TTPs and doctrine (Appleget, et al., 2020) whose fidelity can be enhanced using LVC environments. Integration of live or synthetic systems into game-play increase realism and enable real-time decision-making that provides higher level of fidelity of assessed outcomes. Wargaming research should include investigations of how to improve realism, increase difficulty, and align to DMO. The data collected from these wargames can further be used refine larger scale LVC events for T&E and training.

5. Automated AAR Analytics

Large data sets will be available in networked, distributed LVC environments. Making sense of these large data sets remains a critical and as yet unsolved issue. The research agenda should seek to develop ways of using those data sets to develop AAR tools for rapid analysis. This will enable real-time feedback for training within the integrated simulation environments we develop. The AAR tools need to be aligned with Fleet T&R requirements to ensure there is a means to evaluate individual performance.

The third Thrust Area proposed is unique to LVC environments as they allow for repetition, playback, and significant modification of the environments to address specific training gaps. In this domain, a commander can tailor unit training to both the training and readiness (T&R) requirements and the preferences/needs of the training audience. This is unlike the training ranges we saw 5 or 10 years ago. There is more of a human element involved which requires detailed control of LVC environments used. Simultaneously conducting training while making use of time available for mission preparation will require a deep understanding of how each member of a unit responds to synthetic training.

Governance, Policy, and Acquisition Recommendations

LVC provides a capability usable across a range of environments and platforms resulting in potential to deliver the types of training necessary for DMO, develop doctrine critical to implementing DMO, and test and refine the technical components that drive DMO. Realizing this potential requires focused R&D investments across a variety of areas to improve LVC's ability to integrate an increasingly broader range of platforms, connect with and share data from a wider range of simulators, and incorporate increasingly complex simulations from a range of sources.

Characterizing the R&D needs is *necessary* but not *sufficient* to delivering effective LVC in support of DMO. Ensuring these capabilities are delivered to, and supported/maintained for, their users requires that LVC capability development be aligned with the Acquisition lifecycle. That process includes understanding which LVC enhancements are inside and which are outside the purview of R&D. Key to developing this understanding is the "Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, and Facilities (DOTMLPF)" framework (Weissman, 2005; Department of Defense, 2021). A DOTMLPF analysis is typically conducted to determine *whether* a change in a capability may be needed, and if so, *what* the nature of that change should be. Consequently, before investing in the above areas, we also recommend conducting a DOTMLPF analysis. This analysis would provide an examination of the non-R&D challenges and opportunities that should be addressed when considering how LVC systems should support DMO. It would facilitate broader acceptance of LVC in support of DMO and it would provide a foundation to build appropriate governance to guide interactions of the many different participants in DMO. This approach has been used in other domains in a similar manner to provide a structure for understanding the current state and future needs for technical and non-technical capabilities (Freshour, 2015; Rowan, 2009).

CONCLUSION

DMO is a concept that offers a new way to fight, based on *disaggregation* and *distribution* of Naval forces, and *integration* of and *cooperation* across these forces. LVC is a technology that similarly leverages *distributed* systems *integrated* to provide a service to a wide range stakeholders *cooperating* to achieve a shared goal. Since many of the technologies underlying DMO are common to LVC, it seems natural to consider how LVC can advance the development and implementation of DMO concepts. We have shown, for several different applications, that LVC could enhance DMO, and we have highlighted future development efforts to consider in order to realize this goal. We propose, as a next step in aligning LVC and DMO, conducting a DOTMLPF analysis as a way of further examining the challenges and opportunities that should be addressed when considering how LVC systems should be researched and developed to support DMO.

In parallel to DMO, the U.S. Marine Corps has developed EABO (Department of the Navy, 2021). Importantly, the guiding document for EABO "Tentative Manual for Expeditionary Advanced Base Operations (TM EABO)" explicitly notes that its primary intent is to "…to provide a baseline of information, …to inform the live, virtual, and constructive experimentation that will test and refine force structure and capabilities…enable development of the detailed TTPs for employment by the future force." The overview and analyses provided here for DMO lays a foundation for application to EABO, with the provision that the unique challenges of supporting expeditionary-focused assets would need to be considered throughout.

More generally, Distributed Operations (DO) as a warfighting concept is now part of each Service's warfighting toolkit (Foltermann, 2021). The analyses provided in this paper may contribute to other Service's effort to leverage LVC to enable their respective DO concepts (Priebe et al., 2019; Feickert, 2022). These analyses may also serve as a starting point to ensure that LVC capabilities support a Joint approach to conducting DO – from the Joint training, doctrine development and, system T&E perspectives – to ensure our Nation retains its technical edge and its combat advantage at sea, on land and in the air.

REFERENCES

Appleget, J., Kline, J., & Burks, R. (2020, November 17). *REVAMPING WARGAMING EDUCATION FOR THE U.S. DEPARTMENT OF DEFENSE*. Center for International Maritime Security. https://cimsec.org/tag/wargaming/

Best, C., & Rice, B., F.L.T.L.T. (2018). Science and Technology Enablers of Live Virtual Constructive Training in the Air Domain. Air & Space Power Journal, 32(4), 59-73. https://go.openathens.net/redirector/armyuniversity.edu?url=https://www.proquest.com/scholarly-journals/science-technology-enablers-live-virtual/docview/2153565256/se-2

Braithwaite, K.J., Berger, D.H., Gilday, M.M., & Schultz, K. L. (2020) *Advantage at Sea: Prevailing with Integrated All-Domain Naval Power*, Department of the Navy. https://apps.dtic.mil/sti/pdfs/AD1118532.pdf

Chairman of the Joint Chiefs of Staff. (2015). Joint training manual for the armed forces of the United States (CJCSM 3500.03E). https://www.jcs.mil/Portals/36/Documents/Doctrine/training/cjcsm3500_03e%20.pdf?ver=2017-12-29-171247-397

Chairman of the Joint Chiefs of Staff. (2020). Joint doctrine development process (CJCSM 5120.01B). https://www.jcs.mil/Portals/36/Documents/Doctrine/allied_doctrine/cjcsm5120_01b.pdf?ver=3kyPPVtkbvamFj28esWgGA%3D%3DClarity, T. (2023, January 6). Distribute DMO to Tactical Commanders. U.S Naval Institute. https://www.usni.org/magazines/proceedings/2023/january/distribute-dmo-tactical-commanders

Clarity, T. (2023, January 6). *Distribute DMO to Tactical Commanders.* U.S Naval Institute. https://www.usni.org/magazines/proceedings/2023/january/distribute-dmo-tactical-commanders

Department of Defense (1998). *DoD instruction 5000.59-m modeling and simulation management* (DODI 5000.59-m). Department of Defense, https://acqnotes.com/attachments/DODI5000.59-m.pdf

Department of Defense (2020). *DoD instruction 500.89 test and evaluation* (DoDI 500.89). Department of Defense, United States, https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/500089p.PDF

Department of Defense (2021). *Manual for the operation of the joint capabilities integration and development system* (JCDIS Manual).

Department of the Navy (2021). *Tentative Manual for Expeditionary Advanced Based Operations.* Headquarters, United States Marine Corps Washington DC. https://mca-marines.org/wp-content/uploads/TM-EABO-First-Edition-1.pdf

Eyer, K., & McJessy, S. (2019, March 5). *Operationalizing Distributed Maritime Operations*. CIMSEC. https://cimsec.org/operationalizing-distributed-maritime-operations/

Feickert, A. (2022). *Defense Primer: Army Multi-Domain Operations (MDO).* Congressional Research Service. Retrieved June 14, 2023, from https://crsreports.congress.gov

Filipoff, D. (2023, May 15). FIGHTING DMO, PT. 10: FORCE DEVELOPMENT REFORM FOR MANIFESTING DMO. Center for International Maritime Security. https://cimsec.org/fighting-dmo-pt-1.0-force-development-reform-for-manifesting-dmo/

Freshour, J.F. (2015). Marine Corps Aviation Intelligence: A DOTMLPF-P Analysis. Army Command and General Staff College. https://apps.dtic.mil/sti/citations/ADA623998

Folterman, A. Y. (2021) *Adapting Together: A Unified View of Distributed Operations*. Proceedings of the United States Naval Institute. https://www.usni.org/magazines/proceedings/2021/august/adapting-together-unified-view-distributed-operations.

Gilday, M. (2019). *FRAGO 01/2019*: *A design for maintaining maritime superiority*. [Memorandum] Department of the Navy. https://media.defense.gov/2020/Jul/23/2002463491/-1/-1/1/CNO%20FRAGO%2001_2019.PDF

Hodson, D.D, & Hill R.R. (2014) The art and science of live, virtual, and constructive simulation for test and analysis. *The Journal of Defense Modeling and Simulation*. 2014;11(2):77-89. doi:10.1177/1548512913506620

Hoehn, J. R. (2022). *Joint all domain command and control (JADC2).* Congressional Research Service. Retrieved June 14, 2023, from https://crsreports.congress.gov.

Lundquist, E. (2021, February 2). DMO is navy's operational approach to winning the high-end fight at sea. Seapower. Retrieved June 15, 2023, from https://seapowermagazine.org/dmo-is-navys-operational-approach-to-winning-the-high-end-fight-at-sea/.

Mansikka H, Virtanen K, Harris D, & Salomäki J. (2021) Live–virtual–constructive simulation for testing and evaluation of air combat tactics, techniques, and procedures, Part 1: assessment framework. *The Journal of Defense Modeling and Simulation*. *18*(4):285-293. doi:10.1177/1548512919886375

Priebe, M., Vick, A. J., Heim, J. L., & Smith, M. L. (2019). Distributed Operations in a Contested Environment. RR2959 *(Santa Monica, CA: RAND Corporation, 2019),* 55.

Rowan, J. R. (2009). A Quick Look Across the DOTMLPF Domains. Army Engineer School Fort Leonard Wood, MO.

Varshney, M., Pickett, K., & Bagrodia, R. (2011). A Live-Virtual-Constructive (LVC) framework for cyber operations test, evaluation, and training. Military Communications Conference.

Weissman, J. (2005). *Technical Training Strategy for a Transforming Army*. United States Army War College.

Winegar, S. H. (2022, December). The Eyes of the Fleet: Distributed Maritime Operations in the First Island Chain. U.S. Naval Institute. https://www.usni.org/magazines/proceedings/2022/december/eyes-fleet-distributed-maritime-operations-first-island-chain