Emerging Techniques Forum

3 – 5 December 2024 | Hilton Alexandria Mark Center | Alexandria, Virginia

ETF

In This Issue:

- **Organizing the Data That Drives Our Models**
- **First Female MORS Fellow**
- **Enhancing Operational Readiness**

In This Issue

MORS

Professional Features

In Touch

Sponsor's Corner

Last Word

Phalanx Staff

**Printed
On Recycled
Paper**

[*The* **First Word**]

Harrison Schramm, *Phalanx* Editor

*I*t's been another quarter, which means it's time to get another issue of *Phalanx* off my metaphorical "desk." It's been a real pleasure to see this issue come together, with a focus on a meeting that holds a special place in my heart—the Emerging Techniques Forum (ETF), now in its 9th (!) offering. In addition to our other content is a deeply technical article led by Chandler Swallow, who has been a leader in both Navy and now, Air Force analytics.

As is my privilege as your Editor, I'd like to step back and talk about something that may be news to some and old-hat to others; I'd like to talk about *winning*. Now, in the United States, and particularly in the Type-A dominated personalities of our profession, we tend to have a focus on Winning, in the sense that we are constantly *seeking the win*, that sometimes we don't really think through what we would do if we actually *got the win*. This is because in our culture—both nationally as well as in the OR Profession—we are permanently fixated on the question "What's next?"

That question is useful until it isn't. It's a pretty good one to ask smaller children who are just learning what they can do, in the context of "what awesome thing will be next." It's a passible question to ask high schoolers—frequently in the form of "what do you want to be when you grow up"—an unfair question that always puts young people on their back foot. It's a terrible question to ask mid-career professionals.

This is because truly "winning" generally means that the next "thing" isn't "your thing" at all. At some point, you stop measuring your own accomplishments and begin to count your success in the accomplishments of others. Therefore; the next "thing" should belong to someone else.

Have a safe and productive fall. I hope to see many of you at ETF.

And finally: *your article is late!!!*

Kind Regards,

Harrison

MORS PRESIDENT

Engaging and Integrating with the National Security Community to Achieve Interoperability

Ms. Sarah E. Stewart, President, Military Operations Research Society

This article is the first in a series of four throughout the MORS year on our theme, "Engaging the National Security Community." Each of the four issues of Phalanx will focus on one aspect of the theme. This fall issue discusses how engagement and integration can help achieve interoperability, and why that is important. The winter issue will discuss how engaging the national security community fosters collaboration and innovation. The spring 2025 issue will discuss how engagement can help influence decisions. Finally, the summer 2025 issue will identify how engaging in the national security community will impact your career. Each issue will offer ways that MORS can help you engage with your community. Please join me throughout this MORS year in engaging the national security community.

National security analysis relies on the integration of people responsible for both decision making and decision support. Engaging or getting more involved with organizations or components within the national security community allows analysts and leaders to build relationships and become integrated. Strong relationships and integration are key to interoperability, allowing organizations to leverage resources and make more effective decisions to support deterrence and defense.

Interoperability is a strategic imperative that underpins effective national security. It ensures that those conducting national security operations can effectively respond to diverse threats and challenges in a coordinated and unified manner, thereby safeguarding national interests and stability. Engagement plays a pivotal role in achieving and maintaining interoperability by promoting unity of effort, mutual understanding, and effective collaboration across the national security community.

SANDIA NATIONAL LABORATORIES

is a world-class institution providing real-world solutions for today's most complex problems. A strong science, technology, and engineering foundation enables Sandia's mission through a capable research staff working at the forefront of innovation.

We want you to join our team!

Sandia offers employees and interns exciting opportunities in National Security Analysis, Systems Research and Analysis, Hypersonic Flight Systems, Missile Defense, Cyber Security, Military System Modernization, Spacecraft Modeling, and much more.

Sandia National Laboratories

National Security is our business. We apply science and engineering to help detect, deter, defeat, and mitigate threats. Find out how you can be part of the solution.

World-changing technologies. Life-changing careers.

Learn more at sandia.gov/careers

U.S. DEPARTMENT OF **ENERGY**   NNSA National Nuclear Security Administration

Build Relationships

Effective engagement enables communication and coordination between organizations, the Services, and our partners and allied forces. It ensures that all parties understand each other's capabilities and systems, procedures, and culture. Engaging and integrating with others in the national security community builds trust and cooperation—the pillars of a strong relationship.

Analytic organizations that have built strong relationships through engagement efforts are more willing to share information and collaborate. Building relationships between decision makers and analysts breaks down stovepipes, enables real-time robust analytic support to better inform decisions, and allows for a more effective feedback loop that turns lessons observed into lessons learned.

Enable Interoperability

Interoperability is crucial for the Department of Defense and Department of Homeland Security and our partners and allies because it enables us to work together seamlessly. This coordination is essential for a timely and effective response to various security threats, whether they are military, humanitarian crises, or natural disasters. In an increasingly interconnected world, many security challenges require joint or coalition efforts. Integration plays a crucial role in achieving interoperability by connecting diverse organizations and allowing them to communicate and interact effectively, build trust and

relationships, and share information and resources. Strong relationships facilitate interoperability, which is essential for addressing national security threats effectively. Engagement helps build interoperability through a shared understanding of the technical, procedural, and human dimensions of interoperability.

For analytical organizations, technical interoperability can be achieved through centralized integrated systems or platforms that can more easily house and exchange data. Consolidated and integrated data improve accuracy, auditability, and consistency and enable repeatable efforts. Procedural interoperability can be achieved through the creation of standard formats and processes provided in a way that makes the information easily digestible to decision makers. Integrated, diverse teams enable human interoperability through information sharing and collaboration with those with different backgrounds and skills.

Interoperability promotes adaptability and flexibility. It allows forces to quickly adjust tactics, deploy resources, and collaborate in response to evolving threats or changing conditions. A cohesive and interoperable national security capability enhances deterrence by demonstrating readiness and resolve to potential adversaries.

Maximize Resources

Integrated and interoperable organizations better optimize resources. Organizations coordinate efforts more effectively, ensure resources are used efficiently, and minimize redundancies. This can lead to cost savings by reducing duplication of effort and providing scalability and flexibility to more efficiently solve problems.

Organizations that are integrated are aware of the various efforts being conducted in support of national security. This integration allows organizations to take advantage of prior or ongoing work being conducted by others, and thus avoids duplication.

Organizations can use existing relationships to surge study team support as needed to assist decision makers, particularly in short-turn efforts. They can also take advantage of diverse skillsets that may be lacking or fully burdened within their own organizations. This surge capability and flexibility allows for more efficient problem solving. Outside the organization, additional expertise provides more technical oversight and robustness of analytic products.

Through interoperability, resources are better allocated to support priorities and enable decision support. By integrating systems, processes, and people, organizations communicate and work together seamlessly. This is critical in national security, where multiple organizations need to cooperate in complex environments.

What You Can Do to Engage with the Community

As analysts, you should seek out opportunities to network and engage with the broader national security analytics community. There are several ways to do that: volunteer for external rotations, deployments, or leadership cohort programs. Get involved with professional societies. Attend workshops and conferences, publish articles, or read what others are working on. All of these options will expose you more broadly to other analysts, leaders, and organizations conducting or consuming national security analysis.

How MORS Can Help You

MORS provides opportunities to integrate through various offerings and services. Every year, we hold a symposium that brings together 1,000 analysts from across the Department of Defense and Department of Homeland Security. This event provides broad engagement and networking opportunities. Following the symposium, we have several smaller special meetings that focus on a particular analytical method (e.g., wargaming) or functional topic (e.g., the March 2024 Joint All-Domain Global Moving Target Indication workshop). MORS also offers 24 active communities of practice, which are designed to continue the conversations, engagement, and integration of technically or functionally focused communities throughout the year. MORS also offers three publications: our peer-reviewed *Military Operations Research* journal and *Journal of Wargaming* and *Phalanx* magazine. Publishing your own work or reading others' contributions to our profession is a great way to engage with the community.

Our meetings, communities of practice, and publications are a great way to engage and integrate with the national security analytic community.

National security analysis is a team effort that requires interoperability to be successful; nothing is more important than national security. I encourage you to get integrated and stay engaged. 🌐

Calling all Innovators! 2024 MORS Emerging Techniques Forum

ETF

Capt Garth Terlizzi, USAF, and Maj Marc Chalé, USAF, PhD

The MORS Emerging Techniques Forum (ETF) is one of the most exciting events of the year for MORS enthusiasts. This event brings together those working on, and interested in, the most cutting-edge applications of analysis in the defense sector. The ETF seeks advancements in tools and techniques that enable decisive action in complex operational environments. Our expert presenters explore the use of information aggregation, processing, and computation for risk assessments, predictive analytics, and combat critical operations support. Many of these analytical technologies have undergone technical leaps and even technology transfer to operations to support recent global crises. We welcome you to attend the ETF and learn how the defense sector is harnessing the power of these revolutionary capabilities to stay ahead of our adversaries.

In 2024, the ETF will be held December 3–5 at the Hilton Alexandria Mark Center in Northern Virginia. This three-day event will be host to insightful presentations on emerging technologies, strategic viewpoints presented by our distinguished keynote speakers, and critical discussions raised in expert-packed panels. The year's theme is "Analytical Edge in the Decisive Decade." In the wake of Great Power Competition, we will be exploring how the

United States can use the most pioneering innovations to strengthen our internal systems and challenge our nation's brewing adversaries. We encourage abstract submissions from a range of topics, including generative artificial intelligence, autonomy and robotics, augmented reality, advances in campaign analysis, and much more!

This year's event follows our spectacular turnout at the Johns Hopkins University Applied Physics Laboratory last year, where ETF hosted three days of 40+ presentations, three panels on overcoming near-term emerging analytical challenges, and four keynote speakers across government, academia, and industry.

Members frequently bring their colleagues and teams back to ETF year after year, forming a community of innovation. Professional networking makes attendees more effective; tutorials equip them with hard skills; and senior leader keynotes empower attendees to incorporate their works toward a broader vision of defense strategy. For this year's ETF, we will double down on career value by incorporating a career vectoring track. This track will provide the opportunity to connect with technical leaders who have thrived in our career field. There will be a panel on career growth as well as a resume review tutorial and a civil

service career mentorship session. For military attendees close to their end of service, this forum offers an excellent opportunity to network with MORS sponsor organizations, other military industry organizations, and other peers going through the transition process. The career vectoring track is open to anybody interested in getting a leg up in their career in analysis!

Early-career analysts making waves in national security operations research may compete for the annual Eugene P. Visco Prize, which recognizes outstanding contributions from junior analysts. This prestigious award celebrates those who demonstrate excellence in research quality, innovation, and presentation. Eligibility is open to attendees 40 years or younger who have been doing operations research for less than 10 years.

We encourage you to compete! Your research should be original, self-contained, and advance the field through novel applications or methodologies. Winners will be announced at the ETF, offering a unique opportunity to gain recognition, advance your career, and join a legacy of excellence! The winner will also receive funding to travel and present their work at the International Symposium

on Military Operations Research (ISMOR) in the United Kingdom. Those interested in competing for the Visco Prize should select their interest in competing when submitting an abstract through the MORS ETF abstract submission portal.

Registration for ETF is now open, and abstract and tutorial submissions have been extended through October 31. Additional information, conference registration, and the abstract portal can be found on the MORS ETF website (mors.org/Events). Don't miss out on this chance to be part of a cutting-edge event and connect with leaders in the field. We look forward to seeing you there! 🌐

Emerging Techniques Forum

3 - 5 December 2024
Hilton Alexandria Mark Center
5000 Seminary Road
Alexandria, Virginia

Highlighting Women in OR and Their Achievements

The Women in MORS Community of Practice is highlighting groundbreaking women in operations research (OR) past and present.

Helaine G. Elderkin

Helaine "Lannie" Elderkin was born and raised in Westchester County, New York. She was the only child of older parents. She says she had a very short-statured adulthood because they were not inclined to treat her as a child. Her parents were both professionals, her mother in education and public affairs and her father in medicine, and they ensured that she had a classical education. She graduated early from Florida Atlantic University, where she was drawn to study under a political scientist, John DeGrove, who had started a program focused on international administration—basically the bureaucracies of countries—earning an undergraduate degree in political science and then a master's in public administration. She enrolled in law school, but her law education was derailed after she was in a serious equestrian accident. During her rehabilitation, she became involved in the Carter campaign.

To her surprise, Jimmy Carter won the election, and she was asked to be a part of his administration. Initially starting as an appointee at the U.S. Agency for International Development (USAID) in the Office of Disaster Response, before long she was invited to go over to DoD's Defense Civil Preparedness Agency. As a political scientist with experience in normative analysis and coalition formation, she began her work supporting nuclear targeting policy and modeling of post-attack scenarios. The work was largely through the then Defense Civil Preparedness Agency (now part of FEMA) and the Studies Analysis and Gaming Agency (now part of J8). This was during the development of the Red Integrated Strategic Offensive Plan (RISOP), a hypothetical Russian nuclear strike plan against the United States created and used for decades by U.S. nuclear war planners to improve U.S. nuclear strike plans against Russia, as part of the Single Integrated Operational Plan (SIOP) [the Cold War name for the overall U.S. strategic war plan]. In 1979, she was a lead participant in the creation of FEMA from multiple department and agency programs, now part of the U.S. Department of Homeland Security.

She was introduced to MORS when she was asked to participate on a panel at the 42nd symposium held at the Naval War College in Rhode Island in 1978. She enjoyed meeting the other attendees, especially some of the very few women in attendance, particularly Amie Hoeber and Sydell Gold.[1] After the first meeting, she became active in MORS and started advocating for more inclusion of the social sciences, with a particular focus on normative analytical techniques. She credits the mentorship she received from MORSians such as Amie Hoeber, who became a life-long friend, and Dick Wiles. After serving on various committees, she was elected to the Board of Directors in 1982 and, in 1985, elected as VP for Administration (VPA). She stayed on as pro bono General Counsel for MORS for more than two decades. In 1991, she became the first female MORS Fellow.

1. Women in MORS has featured both these women as trailblazers: Amie Hoeber in Fall 2021 and Sydell Gold in Summer 2024.

She had always been interested in the law and, after her stint in government, was focused on federal procurement and its role in the success and failure of government programs—the proverbial long pole in the tent for everything from weapons development to contingency ops and intelligence. Back then, there was no Federal Acquisition Regulations (FAR), just the Armed Service Procurement Regulation. So, she took a job with Systems Planning Corporation and attended George Mason School of Law at night, earning her Juris Doctor.

Ms. Elderkin went on to serve as Vice President and/or General Counsel for a number of organizations, including Analytics Incorporated, Computer Sciences Corporation, and CSRA, Inc. She also had federal appointments to serve on the Army Science Board. She believes her years of performing systems analysis served as a good foundation for her legal analysis of regulatory systems.

Sarah Stewart

Sarah Stewart is an operations research and systems analyst at the Center for Army Analysis (CAA). While

at CAA, she has led numerous analytic studies, including wargame modeling, cost analysis, stationing analysis, resource allocation, and force structure composition studies. Ms. Stewart completed two six-month deployments to Afghanistan in support of Operation Enduring Freedom and a two-year rotation to the Headquarters Department of the Army G-3/5/7 Force Management, where she conducted Total Army Analysis. She is currently serving in the Deployment and Enablers Analysis Division of CAA. Ms. Stewart has a Bachelor of Science in Industrial and Systems Engineering from Virginia Tech and a Master of Science in Operations Research from George Mason University and is a Certified Cost Estimator Analyst.

What is an aspect of your career that you are most proud of?

I'm most proud of my service to our country. My dad retired from the Navy, and both my grandfathers are veterans. My dad's father retired from the Air Force after serving in

World War II and the Korean and Vietnam Wars; my other grandfather also served in World War II.

A few years ago, I worked on a project for the Secretary of the Army. It was a controversial project, and I briefed the results to several senior leaders. Shortly after completing the effort, I attended my agency's annual dinner dance, where one of those leaders was the guest speaker. He talked about the impact of our work and the quality of our analysts—using me as a specific, recent example. My dad happened to be visiting that week and attended the event with me and had the opportunity to hear about the quality and impact of my work directly from an Army Senior Leader. I know he's always been proud of me and proud of my career but that was extra special.

What are the key events that got you where you are now in your career?

Most of the key moments are from opportunities afforded to me. I had the opportunity to deploy twice to Afghanistan and to participate in an external rotation and internal rotations during my time at CAA. These opportunities allowed me to improve my communication and leadership skills as well as my technical and functional knowledge and skills. The deployments and external rotation embedded me directly with the decision makers using my analysis. This gave me a deeper insight into how to provide timely and relevant decision-support analysis. My deployments also gave me a deeper understanding of the challenges of the warfighter and how analysis can support tactical and operational warfighting. All these opportunities, along with my involvement in MORS, have expanded my network and improved my skills as an analyst and leader.

What advice would you offer to young analysts?

Seek out opportunities and get out of your comfort zone. The times spent outside my comfort zone are when I grew the most as an analyst and leader.

Build a trust team. A trust team is a network of people who believe in you, understand your personal and professional goals, and support you unconditionally. It takes time to build that support, so seek out individuals who you trust to provide you with advice and support early and often.

Be engaged! Get (more) involved with your organization. Get (more) involved in MORS. I believe you get far more out of professional societies and volunteer activities than you put in.

Know your limits. Understand your bandwidth and don't overcommit. Lean on your trust team to help identify the best opportunities and weigh them against other priorities in your personal and professional life.

Who are your role models?

My dad is my biggest role model. He loves to learn and is one of the hardest working people you'd ever meet. I've always been in awe of how driven he is.

My other role models are individuals who have supported me through various stages of my career. They possess qualities I admire; they are the epitome of professionalism, they are charismatic, and perhaps most importantly, they are empathetic and inclusive leaders. Giving back and welcoming others is so important, and I admire their dedication to mentoring and support. A few of my role models that embody these qualities are Chris Hill, Myles Miyamasu, Bill Tarantino, Mike Kwinn, Renee Carlucci, and Norm Reitter. 🌐
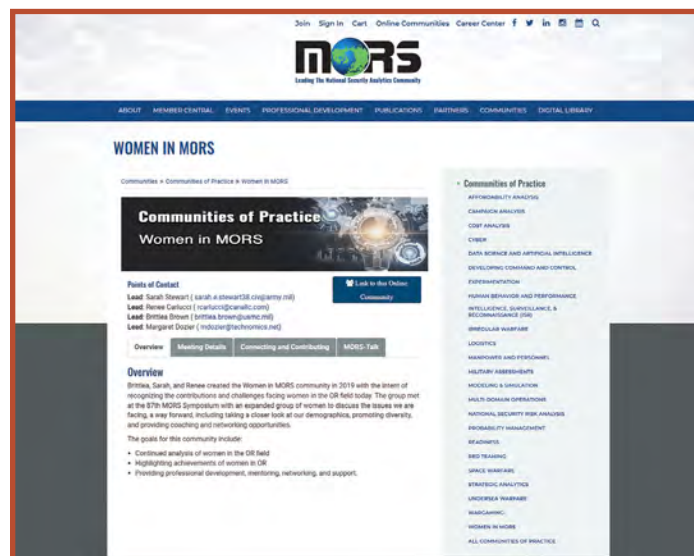
WIM Community of Practice Website

A compilation of female MORS oral histories, past articles on historical and contemporary female OR trailblazers, as well as links to some of their work can be found on our WIM CoP website. We will continue to add to these, so please let us know if there is an analyst you'd like to see interviewed or someone from the history books you'd like to learn more about or whom we should include.

What is
Powered by CANA Analytics®?

We're glad you asked!

It's Our People

This is the human side of CANA. It is the power of having subject matter experts in Applied Analytics, Supply Chain & Logistics Operations, Technology Integration, Operational Energy, Warehousing, and Software Development all in one bucket to deliver this perfect fusion of data and information to our clients.

It's Our Solutions

Our team brings agile software development, customized product development, and seamless data & systems integration to the forefront. We transform complex data into something accessible and understandable. It's more than just analysis; it's about making information clear and insightful.

It's The Art of Analytics

Our subject matter experts can quickly map out the process flows and reduce model development time. They can test and validate solutions to improve the quality of the final solutions. Most importantly, CANA translates "MATH TO ENGLISH." This means we make the complex simple, providing you with reports and presentations that effectively communicate findings, recommendations, and insights to stakeholders.

It's Our CANA Core Algorithms

Through the utilization of our CANA Core Algorithms, CANA is dedicated to helping our clients unlock the potential of their data. Our cloud analytics modernization solutions enable seamless integration and transformation of the data ecosystem, empowering organizations to make data-driven decisions with confidence, all Powered by CANA Analytics®!

Powered by CANA ANALYTICS®
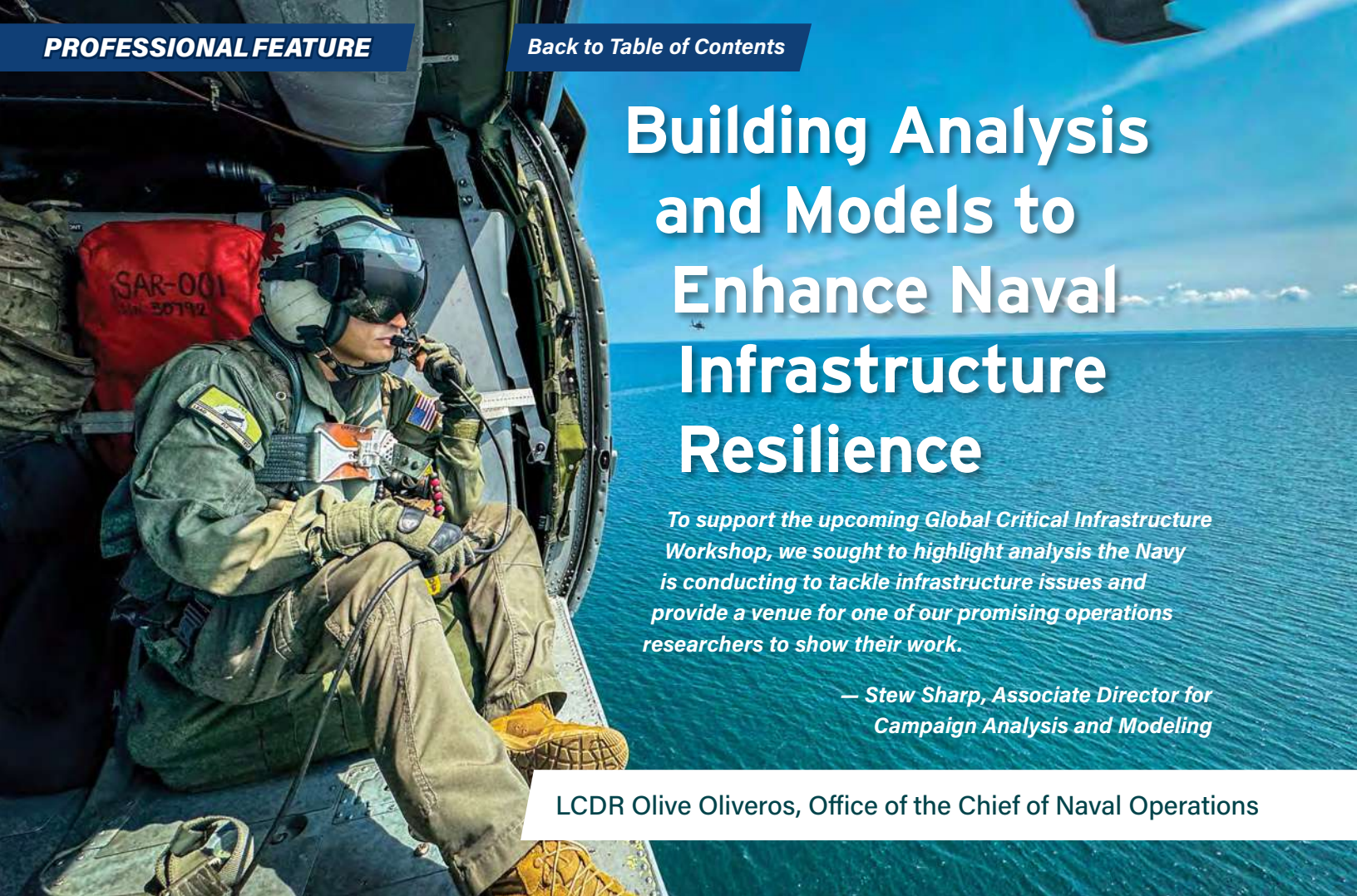
Join us in Unlocking the Future of Analytics!

CANA LLC

ANALYZE. ASSESS. EXECUTE.

Building Analysis and Models to Enhance Naval Infrastructure Resilience

To support the upcoming Global Critical Infrastructure Workshop, we sought to highlight analysis the Navy is conducting to tackle infrastructure issues and provide a venue for one of our promising operations researchers to show their work.

— Stew Sharp, Associate Director for Campaign Analysis and Modeling

LCDR Olive Oliveros, Office of the Chief of Naval Operations

Navy Petty Officer 1st Class Miguel Velez participates in a joint defense training exercise during Operation Northern Strike in Alpena, Mich., Aug. 13, 2024. Northern Strike is designed to build readiness with joint and partner forces in all domains of warfare. Credit: Navy Petty Officer 1st Class Juel Foster.

The power grid across the Department of Defense (DoD) portfolio of installations worldwide is intrinsically aligned with the capacity to support mission-critical operations and quality of life for personnel living or working at these installations. Natural events and equipment failures from service providers can and will cause grave damage to critical infrastructure, including power grids at these installations. For instance, tropical storms generated from El Niño events that impacted Naval Base Coronado, wildfires at Naval Air Station Point Mugu's Sea Range, and drought conditions at Naval Air Station Key West have all severely degraded infrastructure and equipment at these installations (Office of the Under Secretary of Defense for Acquisition and Sustainment, 2019). In response to these challenges, Commander, Navy Installations Command (CNIC) and Naval Facilities Engineering Systems Command (NAVFAC) are collaborating to enhance infrastructure resilience—defined as the ability to prepare for and adapt to changing conditions and rapidly recover from disruptions (Office of the Press Secretary, 2013). This

resilience also encompasses the capacity to withstand adversarial threats and accidental incidents, considering human factors. Given the unique features and specific mission sets of each naval installation, improving resilience involves navigating a complex and multifaceted array of challenges.

Most military installations lack appropriate models to support analyzing resilience. The only publicly available datasets are unsuitable for this purpose because military installations have similar needs to conventional power distribution systems, but are designed and operated differently due to specialized needs, including mission-critical assets, multiple services and stakeholders, and connections inside and outside the fence line to public and private systems. Using publicly available power test systems in the civilian sector, combined with efforts from key stakeholders at the Naval Postgraduate School (NPS), NAVFAC, and the Naval Expeditionary Warfare Center (NAVFAC EXWC), I studied this gap by developing a test system that incorporates representative features of naval

installations across several feeder power line models that can be used to facilitate vulnerability analysis (Figure 1). In this test system, I gathered data from multiple installations, both in CONUS and OCONUS, to create a realistic view of a single installation's power grid. Data gathering required multiple in-person site visits to installations to view the in situ condition of power distribution systems as well as discussions with subject matter experts on nuances and challenges the installation faced. As more insights were gathered, exploratory data analysis was conducted to identify critical loads and detect any discrepancies in the dataset. The next step in development was to geospatially map out an anonymized power distribution system, using realistic distribution feeder lines from our site visits and on a fictitious naval installation to allow for public use using geographic information system software. This step, along with several techniques to estimate missing power test system parameters, filled in gaps where data was insufficient. Along with this step, bus diagrams shown in Figure 1 were created for each feeder as a visual representation of the network of nodes and arcs. Once a completed test dataset was compiled, I built a Python-based tool called an electrical grid research and

engineering tool (EGRET) to conduct alternate current optimal power flow (ACOPF) analysis to ensure viability and compatibility of the newly developed test system (Knueven et al., 2019).

Each feeder facilitates vulnerability analysis and highlights variations in critical loads and system designs. Building off Alderson et al.'s article "Operational Models of Infrastructure Resilience," the risk of possible disruptions is assessed in the simplest way by conducting an exhaustive enumeration of N-1 and N-2 component failure scenarios and demonstrating impacts on mission-critical loads (Alderson et al., 2015). These failure scenarios represent nondeliberate hazards or adversarial attacks on specific arcs of the power system. Due to structure and functional differences among feeders, different feeders are more or less vulnerable to blackout. Moreover, some feeders serve a large diversity of mission and nonmission loads, whereas others serve only mission-critical loads. Combining these models in the same test system provides a way to compare impacts on small, critical feeders when compared to larger, more diverse load profiles. Figure 2 shows an example of one feeder's failure analysis. The final product was a new

Figure 1. Example feeder bus diagram that delineates between the types of loads included within the feeder power line model

Figure 2. Feeder N-1 failure analysis showing the amount of critical and noncritical load shed depending on the N-1 scenario
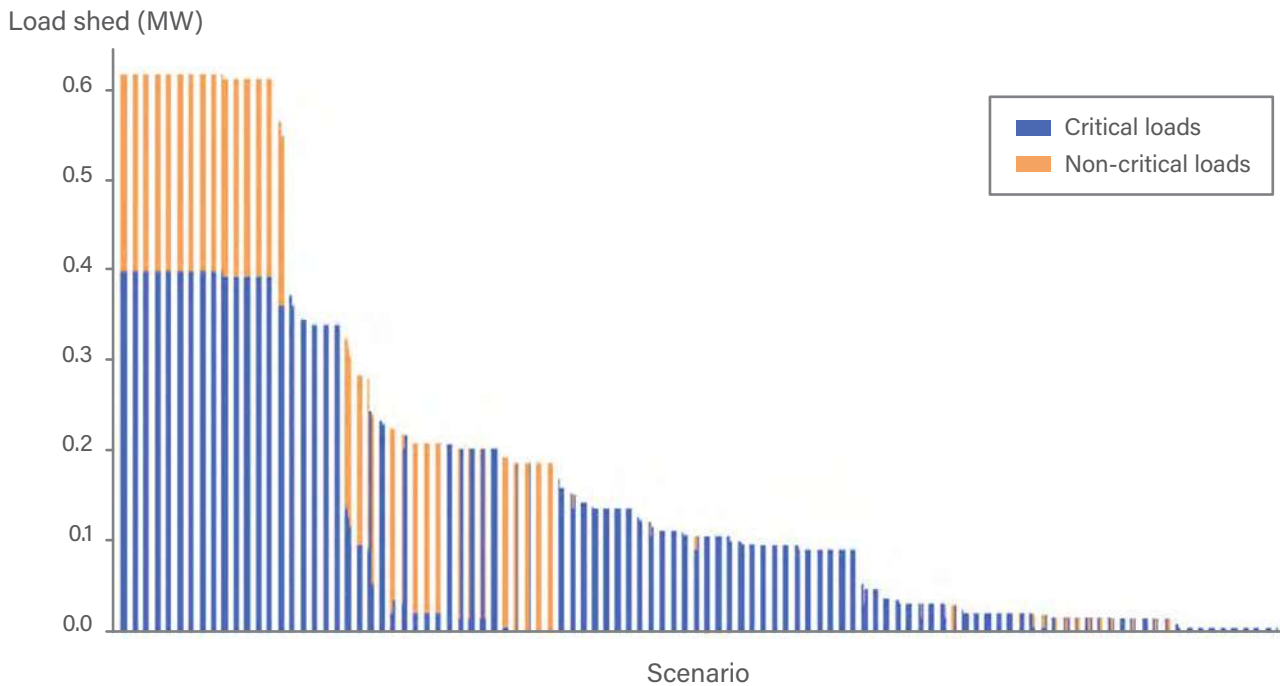
test system, which is broken into 10 standalone feeder models, 462 arcs, and 161 total loads, and all vary in feeder size, load size, load type, physical distances, and facility types.

The newly developed test system can be used widely across all organizations, even outside of the DoD, for further development and in-depth analyses related to funding, modernization, and maintenance of infrastructure. At a minimum, this work provides an initial baseline for

Navy Chief Petty Officer Dennis Brown secures a mooring line aboard the USS Ronald Reagan as the ship pulls into Naval Base Kitsap in Bremerton, Wash., Aug. 13, 2024. Credit: Navy Seaman Ryan Freiburghaus.

DoD power test system analysis and provides opportunities for improvement and tailoring for the analyst's needs.

To further enhance infrastructure resilience across the Navy, OPNAV N81 initiated a series of analytical studies aimed at optimizing investment in facility improvements. These studies focus on two primary goals: (1) identifying which infrastructure investments will most effectively improve facility conditions and (2) ensuring these investments deliver the greatest value by minimizing costs. One study specifically addresses the issue of inaccurate cost estimates for Navy military construction (MILCON) projects, aiming to ensure that funding is properly allocated and that projects critical to infrastructure readiness are not delayed. Another study takes a different approach by analyzing the facility sustainment, restoration, and modernization (FSRM) budget. This study aims to develop a balanced budget profile that improves facility conditions over the long term while minimizing cost. Both studies will provide crucial insights for decision makers, ensuring alignment with the Chief of Naval Operations' priorities and overall DoD guidance.

OPNAV plans to utilize these methods at the upcoming Military Operations Research Global Critical Infrastructure workshop this fall, which will highlight some of the

INGENUITY SECURES THE HIGH GROUND.

Digital engineering commands control over your technical enterprise.

See all the ways we are Redefining Ingenuity® at saic.com.

SAIC
Redefining Ingenuity

20-0297 | SAIC COMMUNICATIONS
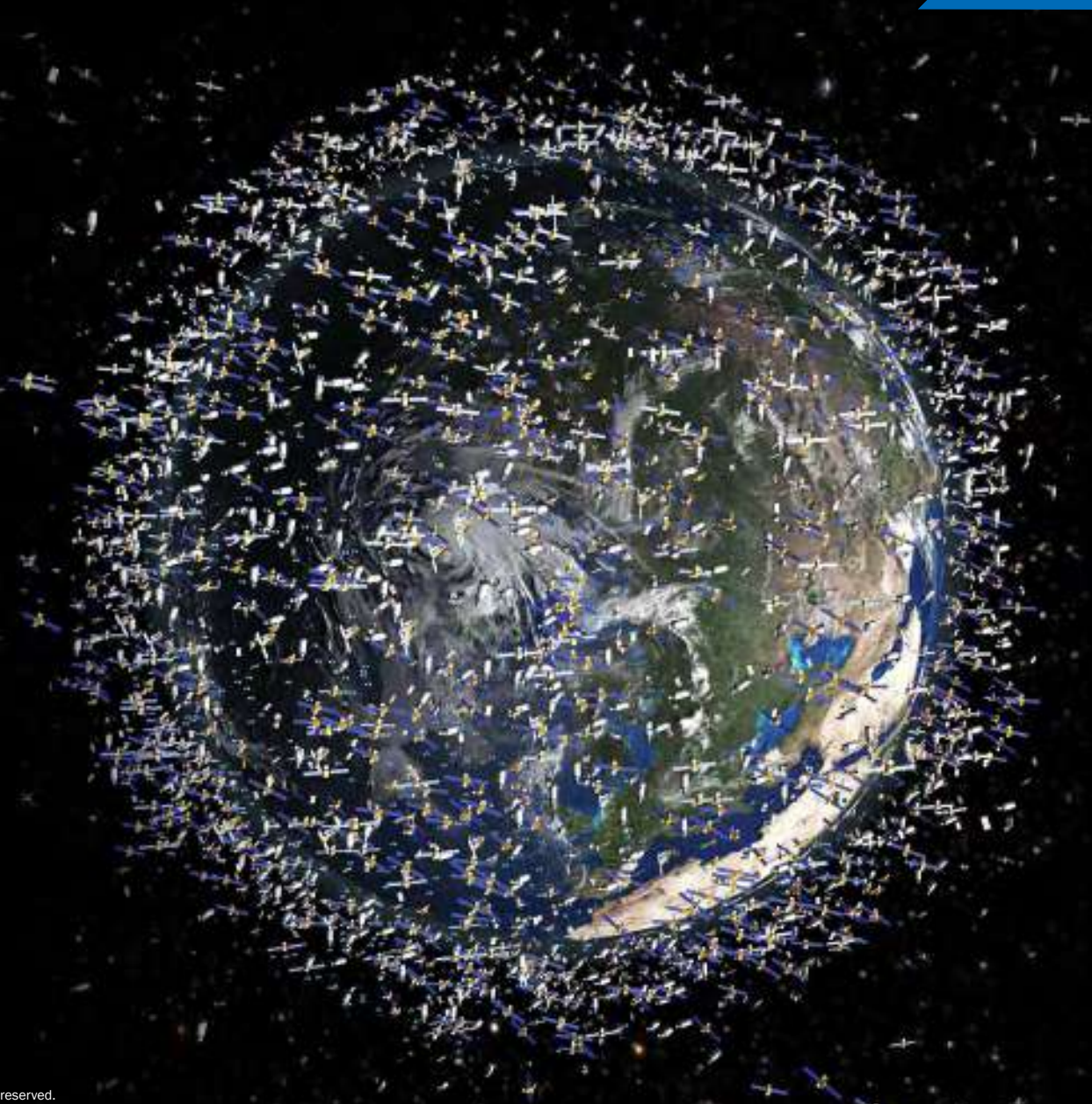
concerns about damage to military infrastructure. Additionally, the workshop will highlight the need to address risks associated with the evolving state of the U.S. military's critical infrastructure, tackle the challenges in mitigating these risks, and explore how the analytic community can leverage ideas from allied nations to enhance data-informed decision making. The workshop will focus on three key areas: development and modernization, threat and vulnerability analysis, and resilience. OPNAV N81's focus falls into development and modernization and resilience, as it relates to funding priority investments with the most warfighting impact.

Enhancing resilience of DoD infrastructure, particularly the power grid, is essential for maintaining operational readiness and ensuring the well-being of service members. Collaboration from CNIC and NAVFAC, coupled with the analytical studies from OPNAV N81, aim at the issues that will be discussed at the Global Critical Infrastructure Workshop and are in alignment with the Chief of Naval Operation's Navigation Plan of 2022 (NAVPLAN) and the NAVPLAN Implementation Framework (NIF) (Office of the Chief of Naval Operations, 2022). The development of a new test system represents an advancement in understanding and improving naval power grid systems. By bridging gaps in current models and providing a robust tool for analysis, this work not only supports the immediate needs of the DoD but also offers valuable insights and methodologies that can benefit broader applications and future infrastructure development. Resiliency of the power grid at DoD installations throughout the globe is critical in the delivery of a higher level of confidence to withstand natural or human impacts toward swift recovery in support of military peace and wartime operations. Developing additional models and analysis to understand how to increase resilience and address facility conditions while balancing cost will be critical to maintain the Navy's force generation and improve quality of service for our Sailors. 🌐

The submarine USS Scranton prepares to depart Naval Base Point Loma, Calf., Sept. 4, 2024. Credit: Navy Petty Officer 1st Class Aaron T. Smith.

References

Alderson, D. L., Brown, G. G., and Carlyle, W. M. 2015. Operational Models of Infrastructure Resilience, *Risk Analysis*, Vol 35, No 4, 562–586.

Knueven, B., Laird, C., Watson, J. P., Bynum, M., and Castillo, A. 2019. EGRET v. 0.1 (beta), v.0.1 (beta), Albuquerque, NM. Accessed May 17, 2023, https://www.osti.gov/biblio/1498854.

Office of the Chief of Naval Operations. 2022. Navigation Plan. Defense.gov, accessed August 14, 2024.

Office of the Press Secretary. 2013. Presidential Policy Directive—Critical Infrastructure Security and Resilience. Accessed August 2, 2024, https://obamawhitehouse.archives.gov/the-press-office/2013/02/12/presidential-policy-directive-critical-infrastructure-security-and-resil/.

Office of the Under Secretary of Defense for Acquisition and Sustainment. 2019. *Report on Effects of a Changing Climate to the Department of Defense*. Technical report, Office of the Under Secretary of Defense. Accessed August 2, 2024, https://media.defense.gov/2019/Jan/29/2002084200/-1/-1/1/CLIMATE-CHANGE-REPORT-2019.pdf.

About the Author

LCDR Olive Oliveros is a shore readiness operations analyst at the Office of the Chief of Naval Operations, assessment branch. She holds a BS in civil engineering from the University of Washington, and a MS in operations research from the Naval Postgraduate School. Her 13 years of service with the Civil Engineer Corps has led to experiences in public works, facilities management, and expeditionary construction with the Seabees. She is looking to expand her newfound knowledge of operations research into the shore infrastructure realm to improve data management and assessment.

Win Great Power Conflict: Solve For Agility

Mr. R. Chandler Swallow, Maj Megan Burk, Capt Petar Jackovich,
Headquarters Air Force, Studies & Analysis

In a September 5, 2023, memorandum, Secretary of the Department of the Air Force Frank Kendall directed his senior leaders to prioritize winning great power conflict (GPC). Chief of Staff of the Air Force David Allvin, in turn, challenged Air Force leadership to "solve for agility." Many claim that artificial intelligence (AI), machine learning, and large language models (LLMs) can accomplish the task to win GPC. However, the technology seems to always be just on the cusp of greatness, as long as the Department of Defense (DoD) keeps funding the model developers, just as fusion technology has been for decades. The promise of anything but narrow AI should be judged critically. Instead, consider the axioms presented here, grouped at the war college/strategic, staff college/operational, and initial skills training/tactical levels, as tools in a toolbox. These tools might be useful individually, but when used together, they will provide the agility needed to compete, deter, and win GPC.

These axioms serve three purposes. First, to help senior leaders fully leverage the operations analysts,[1] data scientists, and systems-of-systems engineers in their teams. Doing so allows leaders to make difficult decisions, in which hundreds of thousands of lives are in the balance, using more than just their instincts and best military judgment. Second, to aid operations analysts, data scientists, and systems-of-systems engineers to maximize

---

1. For this article, an operations analyst is defined as a hard-problem solver who leverages economics, wargaming, and analytic/mathematical/computational skills to produce defendable solutions. Engineers in general, and systems of systems engineers in particular, often can gain these same traits quickly.

their high-demand, low-density capacity, the high-demand, low-density super-compute available, and the expensive data curation. And third, to help supervisors and instructors train and assess operations analysts, data scientists, and systems-of-systems engineers ramp up to the levels required for GPC to meet Chairman of the Joint Chiefs of Staff C.Q. Brown's direction to "accelerate change or lose."

Consider these expressions as an equation sheet you can take into an exam, a ready reference, to remind you to put first principles first. Analysts should not wait for promotions to think across all the levels of warfare on the equation sheet.

War College Strategic-Level Warfare Axioms

Axiom 1: $Value_{Obj} > Cost_{Obj}$

The value of the object should be greater than its cost. This is self-evident to evaluate in hindsight, hard to measure with foresight, and even harder if political pressures prevent more likely but expensive estimates from being considered. Current estimates for the costs of the U.S. post-9/11 wars in Iraq and Afghanistan come in at $8 trillion dollars and 900,000 deaths, with over two-thirds of the costs incurred in Iraq (Kimball, 2021). Imagine how strategic planning after 9/11 might have been different if you told leadership, you have $8 trillion to work with and 20 years. For perspective, the U.S. government budget for fiscal year 2022 came in just under $5 trillion.[2] More on debt in another axiom below, but at the strategic level with a focus on flexibility, consider the opportunity costs for $8 trillion dollars. Four examples of costs to help with this opportunity cost thought experiment follow:

▶ The State Department's 2023 budget is $84 billion (B not T).[3]

▶ The Health and Human Services 2023 budget is $1.8 trillion, over 80% of which is Medicaid and Medicare mandatory spending.[4]

▶ The U.S. National Debt measured in September 2023 was $33 trillion, requiring $879 billion in interest payments to maintain the debt, 14% of total federal spending.[5]

▶ The DoD budget for fiscal year 2023 was $816.7 billion (Garamone, 2020).

Axiom 2: $Win_{Phase\ III} \neq Win_{Phase\ V}$

With a nod to Stephen Covey's *Seven Habits of Highly Effective People*, we should "begin with the end in mind" when studying at the strategic level of war. An earlier version of Joint Publication 3-0 categorized the phases of war as: 0. Shape, I. Deter, II. Seize Initiative, III. Dominate, IV. Stabilize, V. Enable Civil Authority, and then in a continuum, back to 0. Shape (see Figure 1 on page 20).

The current Joint Pub 3-0 talks about a continuum of warfare more broadly emphasizing that offensive, defensive, and stabilization activities can occur simultaneously, and this is certainly true, especially for the complex tribal-civil-international wars fought in Iraq and Afghanistan. This operational perspective of warfare obfuscates the big picture: if your thorough planning of ends, ways, and means across all the phases of warfare indicates a low probability of success transitioning all the way through to stabilize and enable civilian control, then spending blood and treasure to dominate likely is playing into the adversary's strategy.

Osama bin Laden attempted to do just that under the assumption that the United States' war in Afghanistan was analogous to that of the Soviet Union, in that they were both declining empires. Under that assumption he pushed to a protracted conflict as a way of overcoming the perceived U.S. weakness in Phase V by never letting the conflict exit Phase III. In a video-recorded speech sent to Aljazeera in November 2004, bin Laden stated "All that we have to do is to send two mujahidin to the furthest point east to raise a piece of cloth on which is written al-Qaida, in order to make the generals race there to cause America to suffer human, economic, and political losses without their achieving for it anything of note other than some benefits for their private companies."[6] Thus, illustrating his attempt to use axiom 2 in an otherwise outmatched conflict.

2. https://www.cbo.gov/publication/58891#:~:text=Revenues%20 received%20by%20the%20federal,percentage%20of%20 gross%20domestic%20product.

3. https://www.usaspending.gov/agency/department-of-state?fy=2023

4. https://www.hhs.gov/about/budget/fy2023/index. html#:~:text=HHS%20proposes%20%24127.3%20billion%20 in,budget%20authority%20for%20FY%202023.

5. https://fiscaldata.treasury.gov/americas-finance-guide/national-debt/#:~:text=How%20much%20the%20government%20 pays,over%20the%20past%20ten%20years.

6. https://www.aljazeera.com/news/2004/11/1/full-transcript-of-bin-ladins-speech

One might see how the United States seeks to execute a similar strategy in Ukraine to keep Putin's Russia in a slow bleed without escalation to nuclear warfare, which echoes Central Intelligence Agency Afghanistan Covert Program Action Program Officer Michael Vickers's escalation dominance strategy against the Soviet Union (Vickers, 2023, pp. 115–138).

The war between Israel and Hamas in the Gaza Strip highlights the difficulty of thinking and executing past seizing the initiative and dominating and emphasizes Simon Sinek's main theme in his book, *The Infinite Game*, which is that the war ends when the loser decides to quit for good, and to not reengage after a respite. Referencing Sun Tzu's dictum in the *Art of War* to not place your adversary on "death ground," with both the Palestinians and Israelis feeling like they have been on death ground since the early to mid-20th century, sets the stage for Axiom 3.

> **Axiom 3:** $Victory = f(Debt_{Blue}, Will_{Blue}, Capacity_{Blue}, Debt_{Red}, Will_{Red}, Capacity_{Red})$
>
> $\cong (Will_{Blue} \times Capacity_{Blue} - Debt_{Blue}) - (Will_{Red} \times Capacity_{Red} + Debt_{Red})$

Because both Palestinians and Israelis sense that they are on death ground, their will is exceptionally high. Depending on international support, both Hamas and Israel may be able to sustain the costs of war for a considerable period. The capacity term is included in this axiom to account for the specifics of planning and executing war. From an economic perspective, companies go bankrupt often because they are not able to pay short-term debt; in other words, they have insufficient liquid funds available for immediate must-pay bills and are vulnerable to a bank run. A recent example is the March 2023 default of the Silicon Valley Bank, the 16th largest bank in the United States at the time, and second largest bank default in U.S. history (Van Gansbeke, 2023).

In preparing for war, senior leaders must carefully weigh what to buy today, and how much to spend to modernize the force. The balance is a series of risk assessments and is the key operations analysis behind SecAF Kendall's direction that we must be prepared to "win today, tomorrow, and forever." Thus, the question often comes down to how many weapons and what current readiness do I need today and tomorrow, and how much do I need to invest in modernizing to be ready for tomorrow's/forever's fight. Each budget season, the natural tension of this

Figure 1. Phases of War from Joint Pub 3-0 Joint Operations, 2011
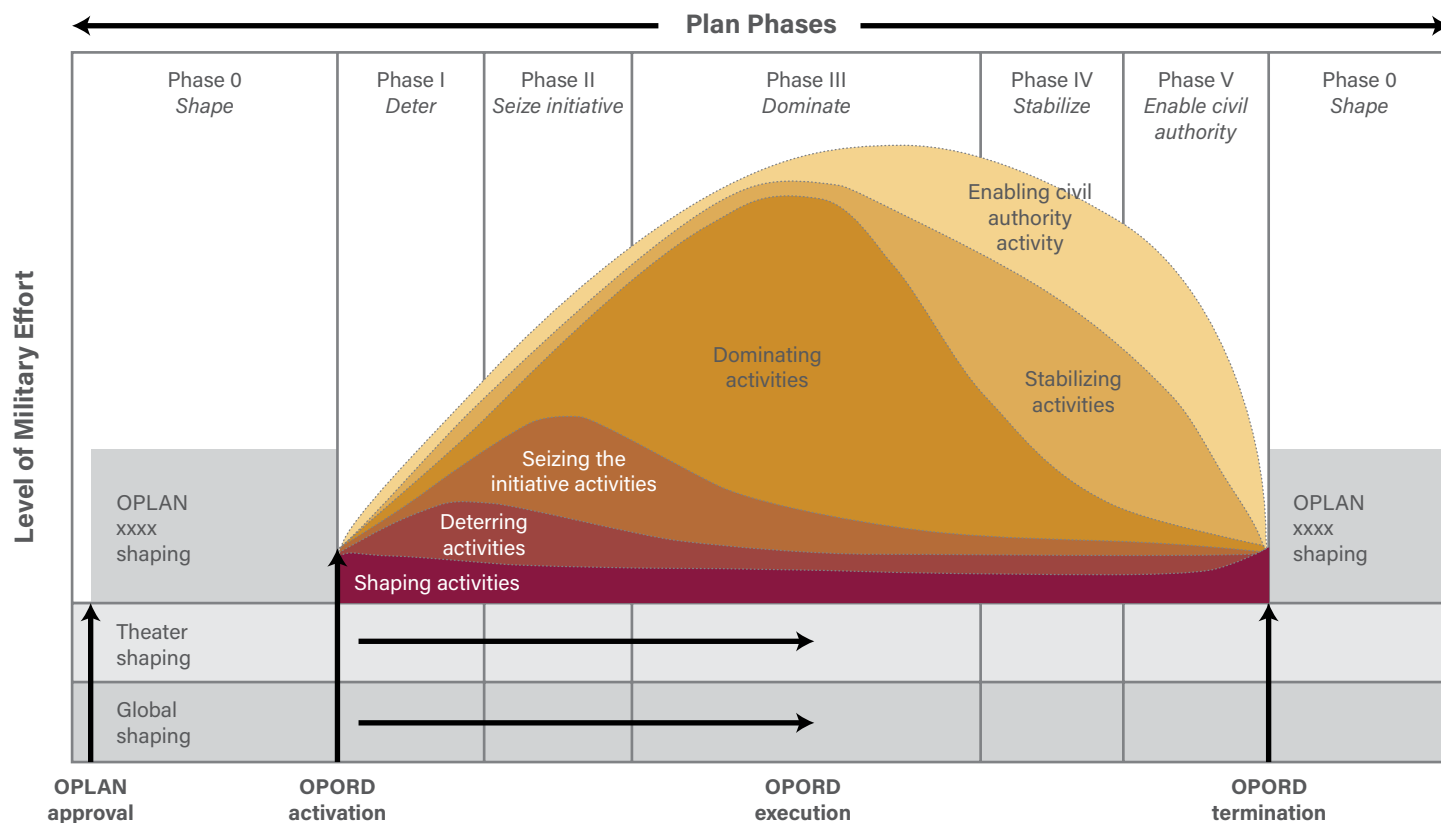
question arises with the U.S. combatant commanders, such as the European Command Commander, who currently has a hot war in his area of responsibility, arguing for near-term capacity, while the Service chiefs charged to man, train, and equip both today's and tomorrow's forces must emphasize modernization funding higher. Knowing how to balance these competing requirements depends on an assessment of your adversaries' and partners' outlooks and strategies.

$$\text{Axiom 4: } \lim_{n \to \infty} \sum_{i=1}^{n} P(\ Red\_Strategy_i \ \text{is selected} \ \cap \ Red\_Strategy_i \ \text{puts Blue in dilemma}) \ = \ 1$$

Axiom 4 in words reads, the probability of your adversary selecting a strategy that places you on the horns of a dilemma approaches 1. Axiom 4 provides the first step to thinking about strategy versus strategy. Air Force Associate Deputy Chief of Staff for Intelligence, Surveillance, Reconnaissance, and Cyber Effects Operations Ken Bray used a phrase about not underestimating an adversary that stuck in my head, "you know, they have 23 pairs of chromosomes too." A long while back, while learning

chess, my mentor taught me to play as if my opponent was a grandmaster and let their number of mistakes prove that to be inaccurate. The following quote elucidates this point: "Among Vladimir Putin's most conspicuous traits is a predator's keen sense for his enemies' weaknesses" (Hockstader, 2023). In a meeting at a very high level in the Pentagon, a senior leader needed reminding to plan for a worthy adversary's advancements in both capability and capacity. Speaking truth to power was difficult, but fortunately, a Service Vice Chief concurred and the analytic effort continued. Making budget cuts in the hopes your adversary will blunder leans too closely to unilateral disarmament and away from solid deterrence thinking.

The key to deterrence is to convince the adversary, or to introduce enough doubt that the adversary leadership decides "not today" day after day. Both players in a two-player game are seeking this outcome. Taking Axiom 3 into account, if both have the will, borrowing ability, and capacity to fight, then the question is what strategy will you seek, and what strategy must you blunt. This relationship is the essence of CSAF Allvin's direction to solve for agility.

Call for Fellow Nominations
Deadline: 15 November

The 2024–2025 Call for Fellow Nominations is now open until November 15, 2024. If you know a MORS member who has shown long-standing, significant, and dedicated volunteer service to MORS and wish to nominate them, please inform the Membership Committee Chair, CDR Phil Baxa (Philip.S.Baxa@uscg.mil), of your intention. The Membership Committee will gather supporting information from the MORS database to complement and enhance your nomination package. Complete the 2024–2025 MORS Fellow Nomination form and submit it to the Membership Committee Chair by November 15.

The power of MORS is in its membership, particularly those who volunteer their time, knowledge, enthusiasm, and talents to lead and enrich the society. MORSians who have witnessed the volunteer efforts of our members, we seek your nominations for this year's MORS Fellows!

The Membership Committee thanks you for your help in identifying dedicated individuals who have earned the privilege of being nominated as a MORS Fellow.

MORS
Military Operations Research Society

To solve for agility, operations analysts should simultaneously think about blunting their adversary's strategy, and sustaining their own strategy. A quick way to start this thinking is a four-by-four grid, with Blue and Red on the y-axis, and strengths and weaknesses on the x-axis. You will notice some entries in both strengths and weaknesses, as is appropriate for war college thinking. Table 1 is an incomplete list, but hopefully you get the point of the work required.

Table 1. First Steps to Blunting the Adversary's Strategy and Selecting Your Own

	Strengths	Weaknesses
Blue	• High GDP • Democracy • Allies and Partners • Geography • High Level of Training and Experience	• High Debt • Democracy • Tyranny of Distance
Red	• High GDP • Autocracy • Population • Short Internal Supply Lines • Intellectual Property Theft • Capacity	• High Debt • Autocracy • Demographics • Long External Supply Lines • Social Credit Scores

Axiom 5: *Multi-Round Fight = Transitory Advantage = Dueling Theories of Victory*

Axiom 5 pulls the primary lesson from Leo Tolstoy's epic novel *War and Peace* into strategic thinking: that the strongest of all warriors are the two—time and patience. Rarely do wars end in the quick fashion envisioned in movies. There are many reasons for this protracted time period, but a big part is that the adversary can react and try a different strategy, including a delay strategy. As Tolstoy details, Russia gave up time and land stretching Napoleon's timelines and allowing the Russian winter to play its decisive role. The Soviet Union played the same strategy versus Hitler's Germany.

In the U.S. system, the Services would like their capabilities to be part of the Joint Chiefs of Staff overarching strategy so that their systems modernization and personnel requirements will have a measurable requirement to drive funding. Determining strategies is tough, long work that requires deep thinking and introspection. In World Wars I and II, the United Kingdom built strategies based on the strength of their naval industrial base. Germany sought to blunt this strategy with submarine warfare. Prime Minister Churchill fortunately was able to bring the United States into the war to help win the Battle of the Atlantic. Germany thought they could use air bombardment to break the will of the British to sustain the fight. The U.K. used superb radar advancements, the tyranny of distance against the Germans, and outstanding air-to-air combat capability to win the Battle of Britain. The Japanese laid bare any U.S. strategies with battleships as the primary lever in the fight with their devastating attack on Pearl Harbor. However, their inability to sustain the fight, and in particular, to sustain pilot production, contributed to their defeat. The pace that the enemy catches up to a modernizing advantage is often underestimated. The United States' lead in nuclear weapons versus the Soviet Union after World War II is a good example. The People's Republic of China (PRC) in space operations today is another.

Part of the role of the operations analyst is to prompt and lead these strategic discussions. The debates over selection of strategy quickly force operations analysts to conduct modeling and simulation at the operational level of war. This modeling and simulation should include assessments of cost imposed and cost-imposing strategies, and a wide aperture across all six phases of war, not just phase III, "dominate."

Before jumping into the next section on operational level warfare, the war college strategic thinking ops analyst needs to think a few moves ahead, following former Vice Chief of Staff of the Air Force Stephen "Seve" Wilson's direction to think of the transitory advantage of warfare. The PRC studied how the United States dominated Iraq in the Gulf Wars and developed strategies emphasizing space, cyber, and rocket forces to conduct an anti-access area denial strategy paid for by reducing their land forces significantly. One of the things to be passionate about with respect to analysts playing war games is that the loser tends to use their disgrace as a spur to try another strategy to regain the transitory advantage. Fight's on, games on, Ready Player One? (Cline, 2011).

Staff College Operational Level Warfare Axioms

Axiom 6: $5A's + 1F < 6B's$

While in academia, this inequality would be inverse (3.33 GPA > 3.0 GPA). Operationally, it is more important to do well at most things than perfect at a few. There are many corollaries to this mindset, most famously from Gen Patton: "A good plan, violently executed now, is better than a perfect plan next week" (Patton and Harkins, 1947, p. 354).

Many operations analysts start their career with a history of achieving everything they were asked to accomplish. However, at some point, usually early in their career, they realize they will not be able to accomplish everything to the level of detail/perfection that they would like. It is therefore vital that an operations analyst understand the power of "good enough" and the skills required to understand when something is good enough. A coach at the Air Force Academy used to compare a similar concept to juggling. Each ball is like a focus area for cadet life (academics, military, athletics, relationships, etc.) and if any of those areas becomes too far out of alignment it can cause the whole performance to come to a halt, i.e., the cadet can end up on probation, or even get kicked out. As this system goes, it is far easier to make slight corrections to each ball passing through your hands while they are all still in good orbit, than it is to correct one ball that somehow ended up by Pluto while the rest are still in perfect rotation. Therefore, skip a practice to study for an exam so you don't end up on academic probation and unable to play in the upcoming tournament.

With interdependent efforts, like military strategy, one weak link impacts the rest of the team. Poor planning or understanding of one area, the F in expression 6, can impact the rest of the mission areas, dragging the overall grade point average down, but more important, enabling the adversary to exploit unexplored weaknesses. Think of medieval warfare, where one weak shield impacts the entire frontline. Therefore, it is more important to strive for good enough in all mission areas, rather than making some "perfect" while neglecting others. As operations analysts, we are responsible for understanding space, cyber, information, air, land, sea, undersea, nuclear, economic, and diplomatic. How do the A's and F's look now? What about

modernization across low-cost drones and attritables, AI, LLMs, and autonomy? We are responsible for assessing and measuring these proficiencies and, therefore, need to exercise due diligence in ensuring that our models capture these areas effectively so we can deter the adversary by keeping them on the horns of many dilemmas.

Axiom 7: *Tragedy of the Commons = Exploited Gaps*

In economics, the tragedy of the commons describes the concept that unfettered access by many to a finite resource results in overuse. For example, a public pasture owned by no one but used by everyone is likely to fall to disrepair, unable to be used by any for grazing. Additionally, once in disrepair, there is no one willing to take the responsibility of maintenance and repair. Think of the same pasture where each farmer grazes two cows. If one person decides to bring a third cow, that might create unbalance and escalation for others to take more of their "share" of the pasture. As a result, all farmers might start increasing their use of the pasture until it is overgrazed and unusable. The commons are the most used assets by the population at large, making them an exceptionally vulnerable target. Couple the vulnerability with the lack of centralized security, and the commons are major gaps ripe for exploitation. Other examples of the tragedy of the commons include air pollution, the Great Pacific Garbage Patch of plastic, which is about twice the size of Texas, the rapidly proliferated low Earth orbit region, overfishing, groundwater use, and traffic congestion (Spiliakos, 2019). Now add the concept of an outside player convincing a few locals to add the appropriate "third cow," achieving a cost-imposing cheap strategy to resolve.

Think broadly leveraging the tragedy of the commons concept to look for ungoverned spaces or gaps. Think about where gaps occur between combatant commands, between services, between nations, between tribes, between divisions, and between standards organizations. As one example, think about near-space. The U.S. Air Force and Space Force start speaking real specifically when the area of near-space comes up because it is an unspecified region of responsibility. Of note, the PRC created a fifth military force, the Near-Space Command (Saballa, 2023). A way to start to notice tragedy of the commons, ungoverned spaces, is to look for graffiti, trash, and dirty areas in a typically clean environment. Then start asking who owns that spot. You will likely find ambiguity in who owns that region, and fingers pointed at others.

Because no single point of ownership exists for "the commons," it is easy to overlook not only the lack of maintenance and neglect but also unaddressed vulnerabilities ripe for exploitation. In the development of strategic options, operations analysts should look for Red tragedy of the commons gaps to see how they can be exploited by Blue, and vice versa. The question almost always comes down to where should funds and personnel go based on these weaknesses and opportunities.

It is important for commanders and operations analysts to know these gaps likely exist so they might use their expertise and tools to shed light on an otherwise obscured vulnerability. They may be the only ones looking.

Axiom 8: *Closed Seams ≅ Opened Gaps*

As gaps are identified in organizations like the tragedy of the commons noted earlier, there is a problem with repairing those gaps with finite resources. "Closing one seam opens up another," to quote Ms. Nancy Dolan, Air Force Deputy Director of Staff. Such is the complexity and tradeoffs in zero-sum budget and manpower decisions. Axiom 8 can also be thought of as "For every decision, there are tradeoffs."

There are many ways the military tries to close organizational seams. For example, take Napoleonic staff structures. In a traditional Napoleonic staff like the Air Force, MAJCOMs, Centers, and now Wing Staffs, the "A staff" is structured by functional area. A1 is traditionally manpower and personnel, A2 is traditionally intelligence, and in the Air Force, the A9 is analysis. However, organizing a staff in this way may cause seams between functional areas. It is possible that the data needed for analysis might be with intelligence or logistics, both different functional areas on the staff, making it difficult to coordinate and cooperate and identify a single point responsible for data management. (If you are thinking data management could be a tragedy of the commons, you grasped Axiom 7.) To combat this, organizations develop cross-functional teams or shift to a matrixed structure. Matrixed structures are

intended to close the seams between each functional area while working on specific projects. However, closing a seam opens another gap. By matrixing, there are some tradeoffs. Rather than "stove-piping" into a functional area, teams are isolated by project. Therefore, there are still seams in the system; they are just in different places. Different organizational structures have strengths and weaknesses. Over time, the weaknesses will begin to stress the organization, creating demand for reorganization.

There are always tradeoffs with any decision, and it is the responsibility of the analyst to think of the second- and third-order effects for decisions made by Blue and Red.

Axiom 9: $\frac{9}{10}$ *of a System* $= 0 +$ *Significant increase in Co$t*

When purchasing large, complex systems, such as those required to make Joint All Domain Command and Control viable, it is important to make sure they function and are capable of mission success. For example, 9/10[th]s of a bridge is not a functioning bridge and cannot do 9/10[th]s of its role. It is just an unfinished bridge that costs time, resources, and labor without any return on investment.

As systems get more complex, an operations analyst must sometimes show that there is only 9/10[th]s of a system of systems in place because the complexity might obscure the bigger picture. One way to illustrate a common obfuscation is back in Boolean logic. Table 2 shows the truth tables for AND and OR functions.

For *A OR B = true*, either *A* or *B* need to be true, meaning either *A* or *B* can be false. For *A AND B = true*, both *A* and *B* must be true. Though this distinction is obvious in this format, when placed in a systems engineering diagram, it isn't always clear if the interdependencies are AND or OR functions.

The lack of clarity in these diagrams can result in erroneous assumptions and difficulty identifying errors in the system. Back to expression 9, if one nonredundant portion of the system fails, the entire system fails. Operations analysts

Table 2. Truth Tables for AND function and OR function

A	B	A *and* B
True	True	True
True	False	False
False	True	False
False	False	False

A	B	A *or* B
True	True	True
True	False	True
False	True	True
False	False	False

should seek resilient, redundant, and affordable systems and avoid fragile and expensive systems for Blue and seek to exploit fragile and expensive systems against Red.

Axiom 10: $1\ v\ 1\ =\ Blue\ vs.\ Red\ \neq\ Reality$

Any 1 versus 1 war is out of context of the bigger picture of reality. The operations analyst should zoom out when considering one operations plan (OPLAN) to maintain the strategic objectives. Clear examples of others outside of the *1 v 1* scenario are sanctuaries in irregular warfare: Laos being a sanctuary to the Vietcong during Vietnam, Pakistan being a sanctuary to the Taliban during the second Gulf War, and NATO being a sanctuary for Ukraine today.

Additionally, there might be third parties in the form of another warfront that needs to be considered. Often, planners think only of the war they are planning for and not the resources that might go to other combatant commands. Simultaneous operations requiring significant material support, to include Space Force assets, are ongoing as this paper is written in AFRICOM (Somalia), CENTCOM (Israel, Yemen, Iraq, etc.), EUCOM (Ukraine), and INDOPACOM (North Korea, not to mention PRC deterrence with the January 2024 Taiwanese presidential election.) Thus, OPLANS that use 100% of the assets worldwide should be at best highlighted as an optimistic assumption.

Axiom 11: *Yesterday's war ≠ Tomorrow's war*

Time between wars offers an opportunity for self-reflection and strategic planning. However, it is a mistake to place too much emphasis on the most recent conflict (i.e., recency bias). Each player has the tape to evaluate and measure how they can improve and optimize their strategy. Those who truly win the interwar periods decipher how to plan for tomorrow's war. Rear Admiral Patrick Piercey, U.S. Navy (retired) recapped past theories of war planning being both art and science:

> "Art refers to the creative, imaginative, intuitive, human factors. Military art emphasizes mastering war through the human lens, including experience, judgment, and intuition, stressing the subjective decision-making abilities of commanders. Military science emphasizes mastering war through an analytical lens, stressing the systematic and analytical study of warfare, using scientific methods and theories to solve military problems." (Piercey, 2023)

Prior to WWI, military planners thought horse calvary could be adapted to fight "tomorrow's war"; for the most part they could not, although horse cavalry proved effective at times in the rugged mountains of Afghanistan. When should planners "discard old ways of fighting?" The evolving information environment will drastically change how future wars are waged. Operations analysts' knowledge of the current and changing environment will be paramount in visualizing and testing the likely future. Between WWI and WWII, military theorist B.H. Liddell Hart was influential in the evolution of tanks from slow, ungainly infantry support vehicles to a quick calvary function capable of breakthrough and rapid movement. This advancement led to Liddell Hart's view of succeeding in war via an indirect approach. As paraphrased by Potter (2016), Liddell Hart argued that "conflicts are generally won when the means of war are applied in a way that an opponent is unprepared to meet, that is, employed in an indirect fashion." You may also hear the phrase *asymmetric warfare* to convey a similar perspective. "A strategy does not need to overcome resistance, but rather exploit the elements of movement and surprise to achieve victory by throwing the enemy off balance before a potential strike" (Potter, 2016). Just like Liddell Hart envisioned better use of tanks in WWII, the military analyst must envision how to leverage the information environment to seize decision advantage. Our peer competitors, Russia and the PRC, are adept across the information environment. Operations analysts should expect rain and headwinds when challenging the status quo. Opponents vilified Liddel Hart for his views on changing warfare, as they did air warfare pioneer Brigadier General Billy Mitchell.

Initial Skills Training Tactical Level Warfare Axioms

Axiom 12: $Truth = Data + Error$

Missing data, dirty data, and incorrect data constantly fog analysis and create uncertainty. Risk derives from uncertainty (Toma, 2012). Operations analysts should seek to understand how to navigate between each while communicating both clearly to leadership. Commanders and other consumers of operations analysis will gravitate toward point estimates: means, medians, and modes. A good analyst will attempt to communicate measures of uncertainty as well: ranges and standard deviations. Virtually no analysis is complete without assumptions, constraints, sensitivity analysis, etc., as these are all

methods to understand the prevalent error in the data and indicate robustness or brittleness of a particular insight.

Axiom 13: *False Precision ≠ Valued Insights*

As noted earlier, National Defense was the fourth largest federal budget function in fiscal year 2023 at $816.7 billion. The largest organizations in DoD are rounding at the billions; others are placing the cut line in the single-digit thousands. There are many leaders and peers who may request precision beyond the means of what is available because, as common knowledge dictates, "People are more comfortable acting on measurements that they believe to be precise" (Kahnke, 2020). Axiom 12 introduced this issue, but there are two values to adhere to with regard to false precision:

- *Measure what's accessible instead of what you are asked.* It is the responsibility of the analyst to understand the limitations of the data and not use higher precision in an instance where it is not defendable. Analysts should avoid providing false insights with over-extrapolated data.

- *There are times data must be precise and times it doesn't have to be.* Analysts should not waste unnecessary time adding digits when they've already found a good answer. Instead, they should mark it complete and move to the next problem. Keep your trillions, billions, and millions distinct.

Similarly, recall Axiom 6 with the 5 A's and 1 F. Why have great precision on parts of the problem set while you are ignoring another? You may need to help your commander grasp this. You may need to help your chief data officer grasp this.

Axiom 14: *Numbers < Ratios < Trends < Insights < Solutions*

Singular observations are not useful without context. Ratios add context to these observations, and trends of ratios are even better, adding the context of time. Operations analysts should analyze these first three elements to draw insights for commanders. Finding and creating actionable insights is where analysts make a great impact. When operations analysts turn insights into warfighting solutions, they are at the top of their craft. They should expect to brief these results for the next few months to multiple seniors.

Figure 2. Barack Obama scale photo

President Barack Obama puts his toe on the scale as Trip Director Marvin Nicholson tries to weigh himself during a hold in the volleyball locker room at the University of Texas in Austin, Texas, Aug. 9, 2010. Official White House Photo by Pete Souza.

When considering this continuum from numbers to solutions, operations analysts should consider what tools expedite conclusions and recommendations. Brandwatch CTO, Chris Bingam, discussed the implications of AI on this same topic during the 2023 Brandwatch Masterclass. He described how AI was traditionally viewed as only being capable of handling data and measurement due to its limited ability to understand the larger context of data.[7] Therefore, insights and solutions were largely out of reach of what AI could accomplish. Bingham depicted the limits of AI using an image of former President Barack Obama (see Figure 2 above).

At first glance, there are many subtle contextual inferences that allow a viewer to understand why this image is funny. The smiles, the prank, the secrecy, weight being taboo at times, etc. The collection of pixels that makes up each of these visuals helps us uncover the humor of this image in mere seconds. AI struggles to aggregate all of this. However, over the past five years, AI has improved in this area, which changed the way Brandwatch viewed the technology; specifically, its ability to supplement users and help them spend less time on consolidating data and day-to-day tasks. LLMs are just one advancement that has drastically improved AI's ability to better understand context. The improvement is enough that when taking a textual description of the image in Figure 2, ChatGPT will discuss that the image is funny and describe why. Operations analysts should think about how analytic tools can expedite the rate at which we draw insights from data, while accounting for bias, hallucinations, error rates, and

---

7. http://karpathy.github.io/2012/10/22/state-of-computer-vision/

the possibility of deception. Automatic target recognition algorithms continue to be an area of high potential where the adversary will leverage multiple techniques to reduce the efficiency of the kill chain. This iterative thinking on how to seize and maintain the decision advantage leads directly to our next expression.

Axiom 15: *Good Now > Better Late*

While past wars have been fought with decisions consisting of limited information and insufficient time, information overload and separating insights from the noise is becoming increasingly important. Today, many commanders are drowning in, at best, poorly displayed incomplete information that has not been distilled to insights at the speed required to maintain momentum against a peer competitor. At all levels of conflict, there is an immense and constant flow of redundant, wrong, conflicting, and absolutely crucial information. Sifting through, making sense of the data at speed, and sharing the key insights across the coalition at pace is imperative. Operations analysts are the centerpiece to winning in this environment as their skills are necessary to outmaneuver our opponents during a time when the maneuver is achieved by exploiting the information environment faster than the opposition. Information dominance is contingent on providing solid courses of action that achieve the commander's intent at the speed of relevance and this necessitates analysts supporting at the tactical edge and being readily available to help commanders tame the information environment. Good answers, when needed, outperform better answers too late. A potent aphorism often attributed to Carl Von Clausewitz drives this point home: "The greatest enemy of a good plan is the dream of a perfect plan" (Bogle, 2017, p. 204).

Axiom 16: *Iterated Task Objective Question >> Face Value Task Objective Question*

To build upon *Good Now > Better Late*, the information environment is constantly changing. When players in that environment don't continuously communicate, the outcome will be far less than desired.

All players in the information environment must iteratively update each other and/or refine what is being asked to provide better solutions. Deadlines change, data changes, misunderstandings occur. Iterated questioning helps avoid

these situations and avoids the Arc of Distortion[8] where the communication between a sender and a receiver can have a large disparity between the goal of the sender and the result produced by the receiver (see Figure 3). Feedback, questioning, reflecting, behavior, climate, etc., all influence the potential communication gap and the variance between the potential differing outcomes. Operations analysts should iterate and listen, as former Chief of Staff of the Air Force General Goldfein liked to say, "Squint with your ears."[9] Rather than thinking of the next question, or how others may respond, analysts should use these opportunities to focus on listening to what is being expressed. The value of analysis depends on the art of understanding the real problem and by providing the solution that the consumer/commander actually want. Using words like "this is what I believe you are asking for" often helps to gain alignment.

Figure 3: Arc of Distortion
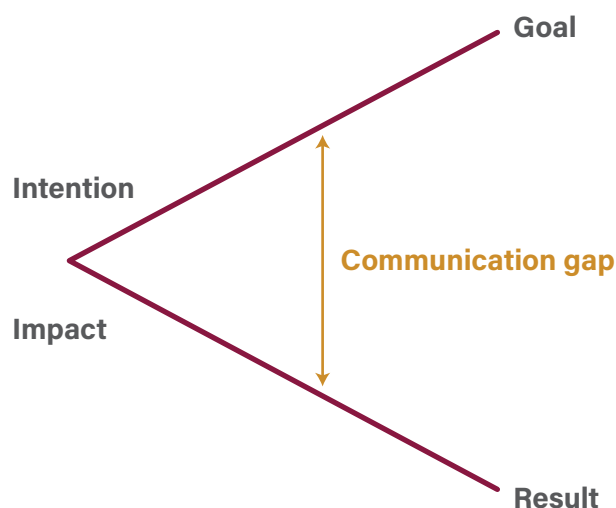
Axiom 17: *Truth to Power = No Christmas Cards*

(attributed to Maj Gen Rosenberg, a Lt Gen Kent leadership award winner)

Operations analysts should seek to be unbiased consultants and take pride in that. If analysts feel that something is incorrect, something can be done better, or something is unnecessary they should voice those concerns and be willing to say it in any direction of the

---

8. https://www.projectsmart.co.uk/communications-management/the-arc-of-distortion.php
9. https://genpsmith.com/learning-to-lead-part-1/

chain of command. Analysts must challenge themselves to go above and beyond by not just criticizing others' ideas but proposing possible solutions as well. This is analytic leadership and should be part of the analyst's DNA. Sometimes an analyst will have to tell others that their baby, their idea, which might have had billions of dollars sunk into it, is ugly, and they won't be thanking the analyst for that (i.e., analysts won't be on many Christmas card lists.)

> **Axiom 18:** $Analysis \cdot Comms = Impact, Corollary:$ $if\ comms = 0\ then\ impact = 0$

Solid operations analysis communicated well will be impactful. Much like the Arc of Distortion example in Figure 3, if an analyst wants to meet their goals, they must ensure that the intention of their analysis is communicated in a fashion that reaches that goal. Good analysis lies at the cross-section of technology, leadership, and communication. An analyst should seek to master the art of visual storytelling and marketing. Good analysis is a story that deserves to be told. Analysts should keep it simple and let the good work show. If need be, they should partner with a great communicator to make Axiom 18 not solve to zero.

> **Axiom 19:** $Good_{OA} \neq Unaffordium$
> $corollary: unaffordium\ can\ be\ explored\ to\ see\ if\ the$
> $needle\ can\ be\ moved$

Operations research is built on the concept of modeling real-world systems to reveal relationships, aid in experimentation, and help win battles. Analysis is meant to help define the solution set and see what constraints are holding back the operation and, by extension, the war effort. Therefore, cost should always be considered from the very beginning per the debt term in Axiom 3.

It is also a mistake to assume that good analysis is unaffordable. This misconception may strongly tie to not following Axioms 12–16, as well as paying for the latest technological advances and models to solve common problems for which a napkin would work. As stated at the beginning of this paper, an analyst should beware of those expensive technologies that are somehow always "almost ready" or require expensive cleaned data that costs more

than the value of the decision they are designed to assist. Instead, analysts should ask what legacy techniques are available and use them as the baseline to determine the return on investment for taking on the project. Good analysis is flexible. An analyst should choose the right tools for the right problem given the deadline. Recall Bacon's analogy, "(analysts) must not be like Pygmalion and fall in love with (their) model" (Box, 1976, pp. 791–792). Only pay for, learn, and leverage new technology where it drives decision advantage.

As emphasized by the "no Christmas cards" to operations analysts referenced earlier, conducting this level of work year after year, decade after decade takes resilience. So, with that, we offer a final expression.

> **Axiom 20:** $\sum_1^n Gratitude = Resilience$

Count your blessings. Air Force Major General Troy Dunn included in his signature block the motivating words, "Be great and be grateful." Science is starting to reveal the powers of General Dunn's words.[10] Operations analysts should remember their blessing to have the opportunity to use their abilities to solve our nation's hardest problems affordably. Further, analysts should be grateful for all those that enable them to accomplish this worthy work: the security officials, the personnel/administration team, the financial team, the information and technology team, the data scientists, and especially our senior leaders who place their trust in us. Of course, this list spirals out, foremost to our families, who enable us to do the work we love. With an attitude of gratitude, we hope these axioms help operations analysts and their supervisors to solve for peace and deterrence often, but for effective warfare when required. Stay resilient, my friends.

---

10. Hidden Brain Podcast, "The Enemies of Gratitude." Shankar Vedantam hosted guest Thomas Gilovich, October 2023.

Author Statement

The appearance of external hyperlinks does not constitute endorsement by the United States Department of Defense (DoD) of the linked websites, or the information, products, or services contained therein. The DoD does not exercise any editorial, security, or other control over the information you may find at these locations.

SMX
ELEVATE ISR

Commercial ISR Platform

Enhanced Awareness through Commercial Intelligence

- ✖ **Rapid Answers** Delivered at the Speed of Need

- ✖ AI-Powered Watchboxing Providing Global **Tailored Alerts**

- ✖ Instant Virtual Environments For **Self-Service Analytics & Testing**

- ✖ **Synthesize Big Data in Seconds with Gen AI** via an Interactive Dashboard

Check Out Our Catalog of Services:

References

Bogle, J. C. 2017. *The Little Book of Common Sense Investing: The Only Way to Guarantee Your Fair Share of Stock Market Returns*. Wiley.

Box, G. E. P. 1976. Science and Statistics, *Journal of the American Statistical Association*, Vol 71, No 356, 791–799.

Cline, E. 2011. *Ready Player One*. Ballentine Books.

Garamone, J. 2020. Biden Signs National Defense Authorization Act into Law, DoD News, December 23, https://www.defense.gov/News/News-Stories/Article/Article/3252968/biden-signs-national-defense-authorization-act-into-law/.

Hockstader, L. 2023. For Putin, a Very Good October, *Washington Post*, November 2, https://www.washingtonpost.com/opinions/2023/11/02/putin-ukraine-october/

Kahnke, B. 2020. Beware False Precision Iin Your Analytics, Forrester, October 6, https://www.forrester.com/blogs/beware-false-precision-in-your-analytics/

Kimball, J. 2021. Costs of the 20-Year War on Terror: $8 Trillion and 900,000 Deaths, News from Brown, September 1, https://www.brown.edu/news/2021-09-01/costsofwar.

Patton, G. S., Jr, and Harkins, P. D. 1947, republished in 1995. *War as I Knew It*. Pyramid Books.

Piercey, P. 2023.Planning for the Next War Must Be a Mixture of Art & Science, *Proceedings of the USNI*, Vol 149, No 9, 1447, https://www.usni.org/magazines/proceedings/2023/september/planning-next-war-must-be-mixture-art-science.

Potter, A. B. 2016.B. H. Liddell Hart, Strategy (1954). Classics of Strategy and Diplomacy, January 19, https://classicsofstrategy.com/2016/01/19/liddell-hart-strategy-1954/.

Saballa, J. 2023. China Launches Fifth Military Force – "Near-Space Command," Defense Post, November 23, https://www.thedefensepost.com/2023/11/23/china-near-space-command/.

Spiliakos, A. 2019. Tragedy of the Commons: What It Is & 5 Examples, *Harvard Business Review*, February 6, https://online.hbs.edu/blog/post/tragedy-of-the-commons-impact-on-sustainability-issues.

Toma. S. 2012. Risk and Uncertainty. *Procedia Economics and Finance*, Vol 3, 975-980.

Van Gansbeke, F. 2023. The Silicon Valley Bank Collapse and the Polycrisis, *Forbes*, March 12, https://www.forbes.com/sites/frankvangansbeke/2023/03/12/the-silicon-valley-bank-collapse-and-the-polycrisis/?sh=6b0677852909.

Vickers, M. G. 2023. *By All Means Available*. Alfred A. Knopf.

About the Authors

Mr. R. Chandler Swallow is the Principal Deputy Director, Studies and Analysis (SAF/SA), Office of the Secretary of the Air Force (SecAF), responsible to the Secretary, Chief of Staff of the Air Force, and the Chief of Space Operations for leading, carrying out, reviewing and ensuring the analytic integrity of studies and analysis supporting operational, investment, and strategic decisions of the Department of the Air Force (DAF). Prior to serving as a Senior Executive, Chan drove ships and operated nuclear reactors.

Megan "Nermal" Burk is an Air Force Major with 11 years of service as an Operations Analyst and Flight Test Engineer. She holds an MS in Flight Test Engineering from the Air Force Test Pilot School and an MS in Applied Mathematics from the Air Force Institute of Technology. She is currently the Director of Operations of the Community College of the Air Force. Her career has focused on both Developmental and Operational Test of various platforms in the Air Force as well as strategic level analysis at Headquarters Air Force Studies and Analysis. She is a non-rated aircrew member with 240 flying hours in 29 aircraft.

Petar Jackovich is an Air Force Captain with 9 years of service as an Operations Analysis Officer. He holds a MS in Operations Research from the Air Force Institute of Technology and is currently the Lead for Analyst Development at the Office of the Secretariat of the Air Force Studies & Analysis. His career has focused on researching military recruiting and he looks forward to leveraging his insights on marketing and influence from Education with Industry at Molson Coors Beverage Company.

Become a MORS Partner!

Earn exposure, memberships, advertising, and more! MORS offers your organization continuous visibility and access within the worldwide military operations research and national security analytic communities.

Benefits can include:
(depending on level)

▶ Up to 12 individual MORS memberships per year

▶ 5 30-day online job postings (a $1,495 value)

▶ 2 Symposium registrations per year

▶ 4 full-color ads per year in the *Phalanx*, which has a circulation of 1,200 and a readership of 6,000

▶ Free exhibits at select MORS events

Current Industry Partners

For further information, contact Katherine Miller, Director, Partner and Member Relations: kmiller@mors.org or (703) 933-9078

www.mors.org/Partners/Partner-Program

Platinum

▶ Alteryx
▶ LinQuest
▶ Lockheed Martin
▶ Raytheon Missiles/ Defense
▶ SAIC
▶ Sandia National Lab
▶ SMX

Gold

▶ DCS Corp.
▶ Group W
▶ JDSAT

▶ KaDSci, LLC
▶ L3 Harris
▶ Lawrence Livermore National Laboratory
▶ MITRE
▶ RAND
▶ System Planning and Analysis, Inc
▶ Technomics

Silver

▶ Argonne National Lab
▶ CANA
▶ Research Decisions Alliance, LLC

Bronze

▶ Analytics HQ
▶ Anyar, Inc.
▶ ARA
▶ Coursera
▶ Databricks
▶ George Mason Volgenau School of Engineering
▶ Hartley Consulting
▶ Hewlett Packard Enterprise
▶ ITA International

▶ JMP
▶ Leidos
▶ NC State Engineering
▶ OptTek Systems
▶ Performance Management Simulation Analysis Group

▶ Qlik
▶ Serco
▶ The Analytical Group
▶ The Ranger Group
▶ Yurts

MORS
Military Operations Research Society

Current National Research Partner
▶ Institute for Defense Analyses (IDA)

Enhancing Military Operational Readiness Through Advanced Manufacturing Technologies: Insights from Recent Exercises

LCDR Zachary Vrtis, CDR (Ret) Scott Cohick, LT Michael Tisdall, and Dr. Emre Gunduz

In a contested environment, conventional supply logistics and battle damage repair in future military operations will face substantial challenges. The ability to swiftly and effectively repair and maintain equipment in environments where traditional supply chains are compromised is critical to mission success. This article explores the application of advanced manufacturing (AdvM) technologies (metal 3D printing) during two recent military exercises and highlights their potential to significantly enhance operational readiness.

Challenges of Contested Logistics

Contested logistics refer to the difficulties encountered in maintaining traditional supply chains in environments where access and transportation are restricted or under threat. In such environments, relying solely on conventional methods to obtain and deliver spare parts can endanger logistics vessels or force warships to leave contested areas for repairs.

Exacerbated by a weakened U.S. industrial base, the traditional supply system grapples with prolonged acquisition lead times, steep procurement costs, and limited part availability. Now, imagine a battle damage

repair situation in this context—the stakes are even higher! Whether fixing a broken system or repairing battle damage, AdvM can reduce the impact of contested logistics by producing parts at the point of need. AdvM technology offers advantages, including reduced manufacturing timelines, enhanced operational availability (A_O), production of obsolescent parts, cost-effective prototyping, and production of customized or complex parts.

Exercise Overviews

To showcase the benefits of AdvM technologies, the Naval Postgraduate School participated in two exercises in Hawaii this summer: SALVAGE EXERCISE 2024 and TRIDENT WARRIOR 2024.

SALVAGE EXERCISE 2024 (S24)

S24 (May 20–June 7, 2024) focused on battle damage assessment and repair (BDA/R). The exercise used the decommissioned USS TARAWA to simulate battle damage and test the repair capabilities of AdvM. Before being sunk during Rim of the Pacific (RIMPAC) 2024, the ship was intentionally damaged (simulating battle damage), and exercise participants used AdvM technologies to manufacture replacement or repair solutions. Since participants were not informed which components

Figure 1. **Seawater piping flange**

(Left) 3D printed flange (red/orange color) next to broken original. Photo by Matthew Harbidge, SPEE3D. (Right) Installed part. Photo by LCDR Zachary Vrtis, NPS.

were damaged ahead of time, the exercise was a true test of AdvM to design, print, post-process, and test manufactured repair components. Students from the Naval Postgraduate School used the XSPEE3D, a cold spray metal printer, and the SPEE3DCell, a post-processing cell with subtractive machining and heat treatment capabilities. Systems like XSPEE3D blow heated metal powder at supersonic speeds, which accumulate on a moving build plate. During S24, XSPEE3D printed critical repair parts, including cable bundle supports, a seawater piping flange, and a heat exchanger cooler head.

TRIDENT WARRIOR 2024 (TW24)

TW24 (June 24–August 2, 2024) was the largest joint exercise focused on AdvM to date. It concentrated on manufacturing real-world readiness solutions in a joint military expeditionary construct using the Snowbird laser wire directed energy deposition (DED) system. This containerized (10.5' x 8' x 8.5') system combines metal 3D printing capabilities with a CNC milling head for rapid post-production subtractive machining.

While producing real-world parts, TW24 also featured a comparative analysis of the quality of parts printed ashore versus afloat. This study set out to answer several questions, including the following:

▶ Do at-sea operating conditions (varying temperatures, increased humidity, ship pitch and roll, and vibrations) affect the AdvM printer or the quality of its output?

▶ Do the quality of parts printed afloat equal the quality of parts printed ashore?

▶ What is the demand and acceptance of this technology from the Naval community?

To immediately assess printer output quality, test pieces (coupons) were printed and tested to compare metal hardness and chemical composition to established standards for 316L stainless steel at Bear Machinery LLC, a local machine ship in Kaneohe, HI. To verify those results and also assess ultimate tensile strength (UTS) and ductility, coupons were also tested at the Naval Postgraduate School.
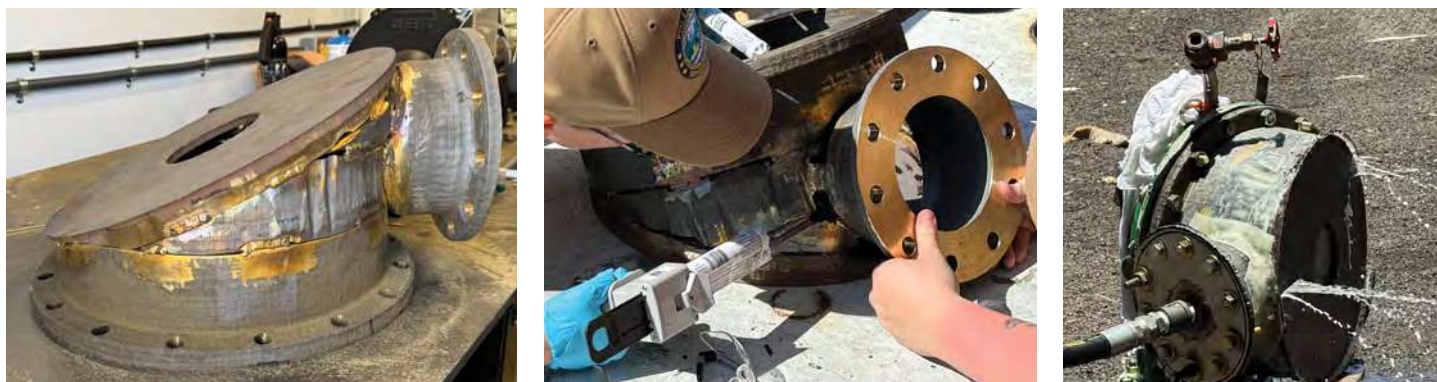
Figure 2. Heat exchanger cooler head

(Left) Heat exchanger in early assembly. (Center) Strengthening with resin. (Right) Test to failure (100 PSI). Photos by LCDR Zachary Vrtis, NPS.

TW24 also featured the military's first Joint Advanced Manufacturing Cell (JAMC). The JAMC managed all AdvM processes from request intake, to design (reverse-engineering), printing, part qualification, and delivery to the end user.

Advanced Manufacturing in Action

During S24, the XSPEE3D printer successfully produced several critical parts to repair the "damaged" ex-TARAWA. Two key examples include:

▶ **Seawater piping flange:** Printed from aluminum bronze, this metal's properties most closely match the properties of the original part. Using the XSPEE3D cold spray metal printer and post-processing technology, the flange was made pier-side in nine days (one day for printing and heat treating and eight days for machining) and was successfully hydrostatically tested to 61 PSI (135% system pressure).

Figure 3. Reverse osmosis pump repair

(Left) Computer-aided design of reverse osmosis shaft collet. Photo courtesy of Mr. Jacob Lopez, NSWC Corona. (Right) Part just after printing. Photo courtesy of LT Charles Wallace, NPS.

▶ **Heat exchanger cooler head:** Due to its complex geometry, the cooler head was printed in four pieces and assembled using tack welding, structural adhesive, and resin patches over a period of 10 days. After final assembly, the cooler head was tested at its operating pressure of 45 PSI. Additional testing at 61 PSI (135% operating pressure) resulted in a ¼ gal/min leak, within acceptable standards for a battle damage repair.

TRIDENT WARRIOR 2024

TW24 was conducted both ashore and afloat. Ashore, the JAMC managed a network of AdvM systems to design and produce real-world readiness needs. A replacement gear-shaft bevel for a U.S. Army mobile field kitchen was printed at a cost of $45.30 of consumables in four days using Snowbird. Importantly, this gear-shaft bevel is a subcomponent of a larger assembly that would have cost $2,313.80 with a two-month lead time if purchased conventionally. This case highlights an advantage of AdvM over traditional supply limitations—significant cost savings and reduced lead times are achieved by avoiding the purchase of the entire assembly.

TW24's afloat activity began on July 10, 2024, when the Snowbird container was craned onto the USS SOMERSET (LPD-25). Within hours after embarking the printer, the ship suffered a casualty to one of its reverse osmosis pumps, responsible for making fresh water. Since no computer-aided design or technical specifications were available for the broken shaft collet, the embarked TW24 team began reverse-engineering the part. After testing the design's form, fit, and function with a plastic prototype, the TW24 team used Snowbird to print, machine, and install a new shaft collet. Despite taking nine days and costing over 10 times the listed original equipment manufacturer (OEM) replacement cost, Snowbird allowed a ship to repair a critical system at sea, compared to the alternative of the

Figure 4. Comparative materials analysis data and plots

Sample number	Printer	Identifier	NPS average hardness (HRB)	NPS standard deviation	Bear average hardness (HRB)	Bear standard deviation	Ultimate tensile strength (MPa)	Ductility (%)
1	Snowbird	June 24 SB	95.99125	0.890497579	91.75	2.046338193	-	-
2	Snowbird	July 16 USCG	95.75	2.019832914	87.875	1.082531755	625.34	59.08
3	Snowbird	LPD 25	98.73	0.667832314	93	0.661437828	636.36	69.65
4	Snowbird	July 22 1	96.98125	1.555212506	90.875	0.414578099	642.89	40.03
5	Snowbird	July 22 2	100.5625	2.662103257	94.9375	1.309520427	657.74	51.54
6	Snowbird	July 22 3	96.5425	0.606336334	91.9375	1.260890063	658.67	48.54
7	XSPEE3D	RO bushing 1	98.77375	0.552583421	90.1875	0.242061459	-	-
8	XSPEE3D	RO bushing 2	98.7275	0.470578102	92.75	0.829156198	-	-

(Top) Table of hardness, tensile strength, and ductility measurements. (Bottom left) Graphical depiction of hardness results. (Bottom right) Graphical depiction of tensile strength and ductility results.

ship having to wait the advertised nine+ months for an OEM shaft collet.

This reverse osmosis casualty underscores a critical tradeoff when AdvM solutions are possible: time versus money. When faced with the need for a critical part, military leaders must decide if spending more money to manufacture a part using AdvM is justified. In the case of the reverse osmosis part, the choice was easy. The part was made in nine days for $257 of consumable feed material. Even at 10+ times more than a new OEM part ($23), the decision to spend 10 times more money to keep the USS SOMERSET operable and at sea wasn't hard. But what if the cost multiplier was 100 or even 10,000 times? Having AdvM systems on high-value ships or with expeditionary units provides options and alternatives to avoid being forced to return to port or wait nine months for a $23 part.

Concurrent to manufacturing real-world critical parts during TW24, six test coupons were printed and tested.

The comparative analysis of the coupons showed that print quality was not affected by environmental conditions or shipboard operations. During the 20 days in use while afloat, Snowbird logged over 102 hours of printing. Environmental and motion data from USS SOMERSET was analyzed, and ship pitch/roll movement and higher relative humidity resulted in no observed differences in quality when printing ashore versus afloat.

The eight test coupons printed (six on Snowbird and two on XSPEE3D) were tested for elemental composition and hardness at Bear Machinery LLC (Figure 4). After the six Snowbird coupons were machined into tensile testing dogbone samples (Figure 5), tensile strength and ductility were also tested at NPS, and the test results for all but one tensile test measurement met or exceeded the 316L stainless steel specifications. Sample 2's tensile strength measurement (yellow line) was low by a margin so extremely small it could have been the result of measurement error.

Figure 5. Coupons for materials analysis
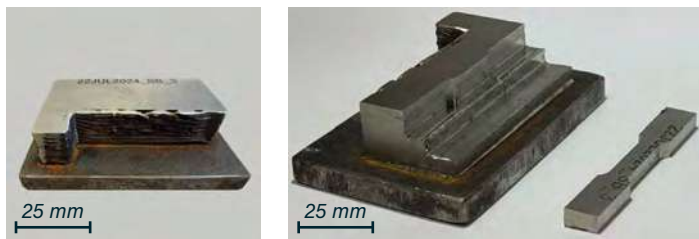
(Left) Test coupon with top machined. (Right) Coupon with dogbone removed. Photos by LCDR Zachary Vrtis, NPS.

Strategic Impact of AdvM and Lessons Learned

The recent exercises, S24 and TW24, demonstrated the transformative potential of AdvM technologies in military logistics, particularly in expeditionary or contested environments. AdvM significantly enhances operational readiness and reduces damage repair time by enabling onsite production of parts, which minimizes reliance on traditional supply chains that are at risk in contested scenarios.

Key lessons learned from the exercises emphasized the suitability of AdvM technologies for expeditionary operations, particularly containerized laser wire DED 3D printers such as Snowbird. These printers are well suited for expeditionary and shipboard environments due to the high laser operating temperatures, slow build rates, and no heat treatment requirement. The exercises demonstrated that training for CNC operators and skilled machinists is a critical component, highlighting that human expertise is as vital as the technology itself. Standing up the first JAMC emphasized efficient AdvM management involves careful sequencing of manufacturing processes. Lastly, unique and counterintuitive machining strategies can further optimize production by minimizing post-processing time. Such strategies include:

▶ Overbuild parts by 5–10% dimensionally: Allows proper surface finishing by removing surface imperfections.

▶ Simplify designs: Remove small holes and other features with tight tolerances. Such features are easier to machine than to program and print successfully.

▶ Think like a machinist: When necessary, incorporate design features that will help a machinist attach or grip the part during machining.

▶ Consultation with an experienced machinist is invaluable: A quick 10-minute design conversation between the print and machining teams can save hours during post-processing.

Conclusion and Future Directions

Advanced manufacturing technologies offer transformative benefits for battle damage repair and supply chain augmentation, especially in contested logistics environments. By enabling rapid, onsite production of critical parts, AdvM addresses key challenges associated with traditional supply chains, enhancing operational readiness and efficiency. The insights from the Navy's two recent exercises underscore the practical advantages of AdvM and highlight the critical need for continued exploration and investment in AdvM technologies to bolster operational readiness and efficiency in contested environments.

Looking ahead, future research and development should concentrate on several key areas to maximize AdvM's impact on military logistics. This includes optimizing processes through predictive modeling, integrating Internet of Things sensors for enhanced data collection, expanding AdvM to include a broader range of materials for more readiness solutions, and conducting lifecycle analyses of 3D printed parts to inform production practices. 🌐

About the Authors

Zachary Vrtis is a Lieutenant Commander in the U.S. Navy with 13 years of service as a submarine officer and engineering duty officer. He holds bachelor's and master's degrees in materials science and engineering from the University of Pennsylvania. He is a PhD student at the Naval Postgraduate School studying under the guidance of Dr. Emre Gunduz, and his dissertation is titled "Advanced Aluminum Alloy Fabrication Methods using Liquid Metal Jet Printing and Operational Use of Metal Additive Manufacturing in Support of the Fleet." After graduation, he reports to Pearl Harbor Naval Shipyard.

Scott Cohick (CDR Ret., U.S. Navy) is a principal operations research analyst for CANA, LLC. With over 23 years of experience as a Naval Aviator and defense analyst, his focus areas include resilience modeling, operations management, and advanced manufacturing. He has a master's degree in operations research from the Naval Postgraduate School and was just elected as the Vice President of the INFORMS Veterans Forum.

LT Michael Tisdall is a U.S. Navy Surface Warfare Officer, studying mechanical engineering at NPS. He holds a bachelor's degree in naval architecture from SUNY Maritime College and is continuing his studies in ship construction here at NPS in the Total Ship Systems Engineering Program. Michael's prior service includes division officer tours on USS COMSTOCK (LSD 45) and USS MICHAEL MONSOOR (DDG 1001). In his academic pursuits at NPS, Michael is researching advanced additive manufacturing techniques, aimed at rapid repair of complex metal parts, and the future of additive manufacturing logistical support.

Dr. Emre Gunduz is an associate professor in the Mechanical and Aerospace Engineering Department at NPS and an adjunct associate professor in the School of Mechanical Engineering at Purdue University. His research interests include additive manufacturing of energetics, metals, ceramics, and food. As the technical director of the consortium for additive manufacturing (AM) research and education, he has been leading the efforts for AM experimentation in contested environments at NPS.

MORS
Military Operations Research Society

DISCOVER Membership

Why Join
Join **MORS** and you'll be a part of a **unique professional organization** that has served the OR professional community and the United States National Security community for more than 55 years.

When you become part of the MORS community, and contribute to and benefit from important MORS opportunities, you'll be better positioned to produce optimal results, **enhance your career** and advance the profession.

Our Membership
Members of the Society include a **cross-section of the best defense analysts**, operators and managers from government, industry and academia.

The involvement of such a wide range of practitioners fosters professional interchange, the sharing of insights and information on challenging national security issues and supports decision makers in the many organizations and agencies that address national defense.

Being a MORS member gives you an opportunity to **stand out from the crowd** and demonstrate your technical and leadership abilities.

Thousands of operations research professionals make MORS the **leader of the national security analytic community** through their membership, attendance at meetings, and through the quality and importance of their published reports and presentations.

MORS Programs:
- The annual MORS Symposium with 600+ classified and unclassified sessions
- Year-round Professional Development Communities organized around the 35 Symposium Working Groups, specialized Communities of Practice and geographic Chapters
- The annual Education and Professional Development Colloquium for students and young analysts

For more information, please contact Katherine Miller at kmiller@mors.org or 703-933-9078.

Visit www.MORS.org

Upcoming Events

The Military Operations Research Society (MORS) offers opportunities for professional development and training via courses, tutorials, workshops, and the annual Symposium. Payment can be made via credit card, check, or form SF182.

Dec 3-5 — Emerging Techniques Forum

Location: Alexandria, VA

The Emerging Techniques Forum (ETF) is driven to improve analysis and understanding throughout the defense community by seeking out novel and leading-edge approaches, methods, and techniques—wherever they are conceived.

Dec 6 — Lead to Succeed: Strategies for Managing Analytical Teams

Location: Alexandria, VA

This interactive course is designed for emerging and established leaders. Participants will dive deep into the unique challenges and opportunities that accompany the management of analytical teams.

Jan 27-31 — Certificate in Wargaming

Location: Online

This five-day course aims to teach participants the theory behind wargames before diving into research, design, development, execution, analysis, and reporting. Building on Peter Perla's theory of the "Architect, Artist, and Analyst" model for game designers, the course strives to cover each style of wargame design. On the last day, students will develop and execute their own game.

Feb 11-13 — Wargaming in the Southern Region Workshop

Location: Miami, FL

This workshop will focus on all aspects of professional gaming (wargaming) but with special emphasis on topics and issues relevant to SOUTHCOM and southern region national security challenges. This workshop is another in a series of workshops with previous sessions being held in Hawaii and San Diego in the INDOPACOM area of responsibility.

Mar 4-6 — Certificate in Homeland Security Gaming

Location: Online

This Certificate examines the challenges of gaming homeland security incidents. The course will introduce homeland security operations and how games and exercises can be used for planning, training, and analysis.

Mar 10-14 — Certificate in Critical Skills for Analytics Professionals (CSAP)

Location: Online

The course begins with the theoretical basis for effective and accurate presentation of project results in a military or government setting. Participants will attain an enhanced understanding of the methods and techniques utilized in effective analysis project management.

Mar 31 to Apr 4 — Certificate in Cyber Wargaming

Location: Online

Examine wargaming challenges of gaming cyber through a combination of lectures and practical exercises. Participants will experience different types of cyber games assessing requirements, planning budgets, practicing response procedures, and examining player actions during play.

Mar 31 to Apr 3 — Department of the Air Force Data, Analytics, and AI Forum

Location: Colorado Springs, CO

This multi-day gathering of the Air Force's top Data Analytics and AI experts will be a vital opportunity to exhibit use cases, engage in discussions on threat briefs and research, and learn through tutorials and workshops.

?

If you have any questions, please don't hesitate to contact Ms. Sarah Madonia, Billing & Office Manager, at sarah.madonia@mors.org or 703.933.9074.

MORS has a lot of upcoming events and activities. Make sure to visit mors.org/events to stay updated.

MORS Young Analysts
The Next Generation of Leaders

The future of operations research and the national security community depends on new analysts taking the helm. MORS' Young Analyst Initiative facilitates this process by providing paths for emerging analysts to engage with MORS through publishing, meeting participation, volunteering, mentorship, and recognition.

To highlight the achievements, interests, and aspirations of young analysts, we turn the spotlight on one deserving individual in every issue of the *Phalanx*.

To learn more about the Young Analyst Initiative and connect with other young analysts, please visit

mors.org/Member-Central/Become-a-Member/Junior-Analyst

Mr. Jacob Yost
Operations Research Analyst
United States Space Force

When did you join MORS?
I decided to join MORS in the spring of 2024. One of my co-workers asked me to join and to co-lead the Space Warfare Community of Practice he was starting.

What was your childhood ambition?
Growing up I always had an interest in academics and learning. My childhood ambition was to be a professional athlete as I was always active and involved in extracurricular activities. While I enjoyed every aspect of being an athlete, I knew it was something that would not last forever. Early on in my academic journey I had a handful of fantastic teachers who guided me to find a passion for mathematics. Ever since then I fell in love with numbers and how they can be applied to represent many aspects of the world. As a result, I received my undergraduate degree in mathematics and a master's degree in business analytics.

How did you get started in OR?
Once I obtained a master's degree, I had the opportunity to join the Space Force, Chief of Technology and Innovation Office (CTIO/S9), through the Air Force's Palace Acquire program (PAQ). As I did not have prior government or military experience, this program was a great chance to get a foot in the door and is what really introduced me to the field of operations research. Learning through this program has offered me growth through firsthand knowledge of how the government and military operate, and how I could start applying mathematical concepts towards a specific area of study.

What is special about your current projects?
What is unique about the setup of my current organization is how I get to see operations research applied to many different areas across the Space Force, including space operations, intelligence, human capital, space warfare, and strategy and resourcing. While I am exposed to each area, my efforts are specifically aligned with providing analytical support to the Chief of Human Capital Office in matters pertaining to personnel, manpower, and end strength. One of our main goals is to help the Space Force hit end strength at the end of each fiscal year, which is the target we set for the number of Guardians we will end up with. It has been rewarding to see the work we do come full circle as we have helped the Space Force achieved its end strength goal for the past two years!

What do you value most about your MORS membership?
The main thing I value about my MORS membership is being a part of a group of knowledgeable individuals who are also involved with the organization. I had the opportunity to attend my first event this past year, the MORS Symposium. This allowed me to connect with many different people within the industry, as well as exposing me to the immense number of topics in the operations research community.

Department of Homeland Security Strategies Point the Way for Mission Impact

Mr. Jonathan McEntee, Operations and Requirements Analysis Director, Department of Homeland Security Science and Technology Directorate Office of Science and Engineering

New Orleans, L.A. (October 23, 2020) U.S. Customs and Border Protection agent on a helicopter flight above New Orleans, LA. Photo by U.S. Department of Homeland Security/Benjamin Applebaum.

Today, the U.S. Department of Homeland Security (DHS) Science and Technology Directorate (S&T) Operations and Requirements Analysis Division (ORA) continues its eighth year as a Military Operations Research Society (MORS) Government Sponsor. S&T is the Secretary of Homeland Security's science advisor and serves as the Department's research and development (R&D) arm, providing sound, evidence-based scientific and technical expertise to inform policies and address current and emerging threats.[1] ORA, located in S&T's Office of Science and Engineering, collaborates and delivers analyses to DHS, its operational and support components, and its headquarters offices. Recent strategic guidance within DHS, including the *2023 Quadrennial Homeland Security Review* (QHSR) and the new fiscal year 2024–2030 Innovation, Research and Development (IRD) Strategic Plan, offer key perspectives on homeland security and IRD for the wider MORS community.

2023 Quadrennial Homeland Security Review

National, departmental, and component strategies provide focus for S&T's work. Notably, the QHSR is the Department's capstone strategy document, which is updated every four years as required by law. The report offers recommendations on long-term strategy and priorities for the Homeland Security Enterprise. Each QHSR cycle entails an extensive three-year-long review process before the report is finalized and submitted to

---

1. See About S&T, Homeland Security, https://www.dhs.gov/science-and-technology/about-st

Congress.[2] The 2023 QHSR highlights five long-standing DHS missions and introduces a new sixth mission:

▶ Mission 1: Counter-Terrorism and Prevent Threats

▶ Mission 2: Secure and Manage Our Borders

▶ Mission 3: Administer the Nation's Immigration System

▶ Mission 4: Secure Cyberspace and Critical Infrastructure

▶ Mission 5: Build a Resilient Nation and Respond to Incidents

▶ Mission 6: Combat Crimes of Exploitation and Protect Victims

2.   See https://www.dhs.gov/quadrennial-homeland-security-review.

The Department strives to make the QHSR as thorough and inclusive as possible by working with a wide range of stakeholders inside and outside government, who share responsibility for safeguarding the homeland. The QHSR provides the strategic foundation to ensure that the Department is ready to meet future challenges.

Fiscal Years 2024–2030 DHS Innovation, Research and Development Strategic Plan

Following the April 2023 QHSR publication, in May 2024 S&T released the first-ever department-wide DHS IRD Strategic Plan. Developed at the direction of Secretary Alejandro N. Mayorkas, the IRD Strategic Plan serves as a blueprint for DHS to keep pace with emerging threats by leveraging innovation and R&D to address homeland
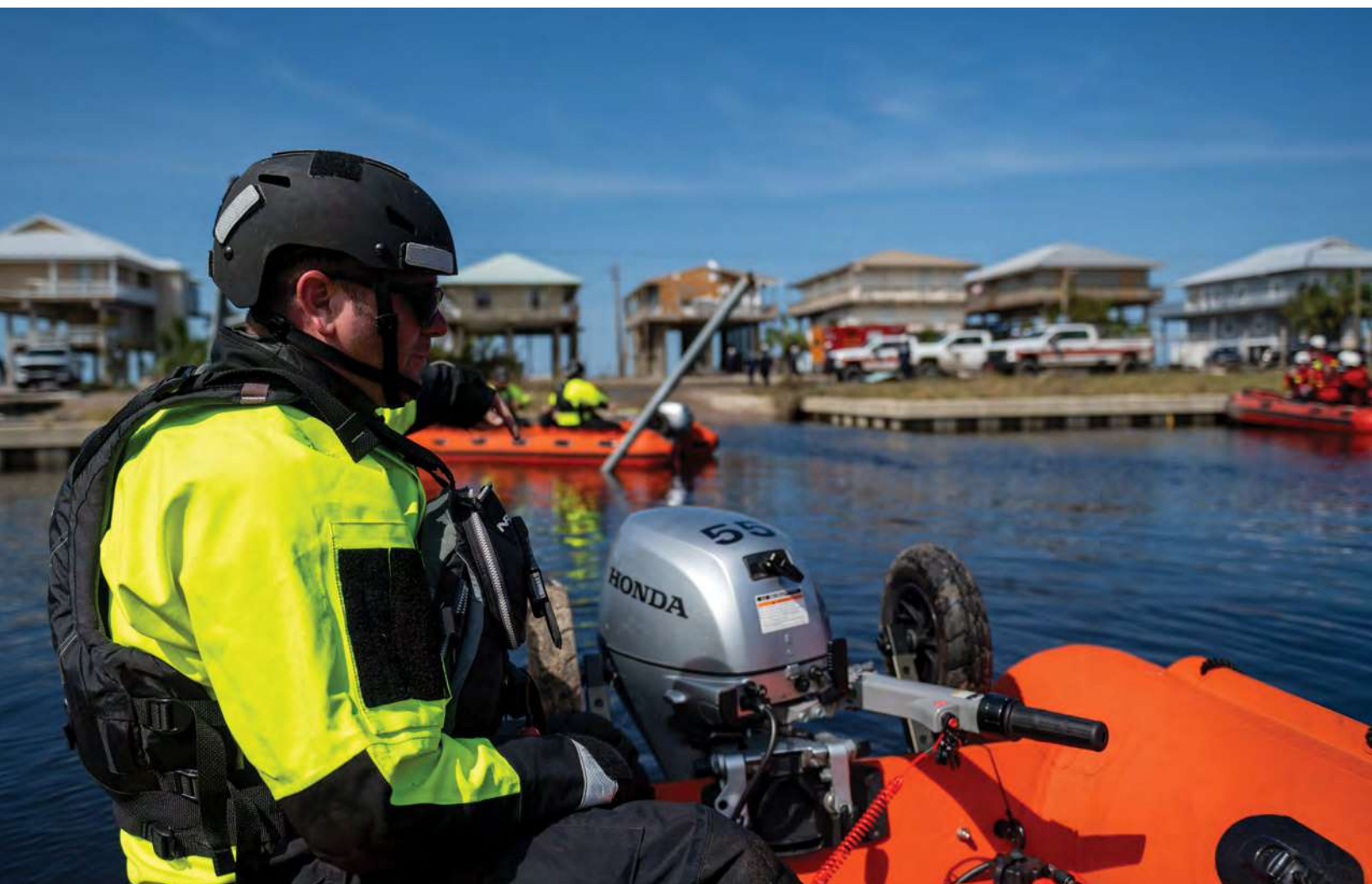
The Coast Guard and partners agencies conduct coastline and canal searches in the wake of Hurricane Helene, Keaton Beach, Florida, Sept. 28, 2024. Coast Guard Gulf Strike Team worked alongside Florida Task Force 2, Florida Task Force 8, and Florida Fish and Wildlife Commission, to inspect areas for structural damage and possible pollution concerns. Photo by Petty Officer 3rd Class Jaiden Hartley, U.S. Coast Guard.

security challenges. In 2022, Secretary Mayorkas tasked S&T with examining DHS's R&D execution, including development of a coordinated strategy focused on areas for long-term Departmental research. The resulting IRD Strategic Plan helps the Department and its partners coordinate and maximize investments.

"This visionary roadmap, informed by scientific efforts, will empower DHS and its components to reduce risks to the homeland through optimized innovation, research and development investments," said Dr. Dimitri Kusnezov, DHS Under Secretary for Science and Technology. "The technologies resulting from our IRD investments play a critical role in equipping the Department's front-line operators with necessary tools to outpace our adversaries and enhance our preparedness and response capabilities."

The IRD Strategic Plan supports enhanced internal DHS collaboration and seeks to leverage opportunities with external partners on common IRD needs. The plan was built on robust, cross-component analysis that identified key IRD themes and opportunities. In pursuing these IRD needs, S&T can optimize mission impacts and meet multiple desired outcomes across the Homeland Security Enterprise. The following are

strategic priority research areas (SPRAs) for fiscal years 2024–2030:

▶ **Advanced Sensing:** Next-generation sensor capabilities to provide enhanced detection performance against a broad spectrum of threats.

▶ **Artificial Intelligence (AI) and Autonomous Systems:** Automated technologies to provide predictions, recommendations, or decisions across a wide variety of operating environments, including means to deal with adversarial AI.

▶ **Biotechnology:** Augmented capabilities to predict, detect, and defend against current and emerging bioagents and biotechnologies of concern.

▶ **Climate Change:** Technologies to strengthen climate adaptation/resilience, improve equity, protect critical infrastructure, and reduce carbon emissions.

▶ **Communications and Networking:** Enhanced communications and networking capabilities, while maintaining security and resiliency.

▶ **Cybersecurity:** Enhanced resiliency, protection, and operational assurance across data, software, hardware, and communications networks.

▶ **Data Integration, Analytics, Modeling, and Simulation:** Enhanced, integrated data ecosystems, analytics, and modeling to enable more accurate data-driven insights, predictions, and decisions.

A rescue worker uses FINDER technology pioneered by the Department of Homeland Security's Science and Technology Directorate. Photo by U.S. Department of Homeland Security.

▶ **Digital Identity and Trust:** Enhanced capabilities to establish and verify both individuals' identities and the validity, integrity, and privacy of associated data.

Through collaborating with stakeholders across DHS, S&T is advancing implementation of the IRD Strategic Plan and developing IRD investment roadmaps for each SPRA. These roadmaps will inform the Department's budget process for FY 2027 and beyond.[3]

---

3.   See IRD Strategic Plan Prepares DHS for Future Homeland Security Challenges | Homeland Security, https://www.dhs.gov/science-and-technology/news/2024/05/28/ird-strategic-plan-prepares-dhs-future-homeland-security-challenges.

Engaging through MORS

The guidance provided in the 2023 QHSR and the IRD Strategic Plan prioritizes activities for the DHS operations research and data science community. Together, these documents identify the most urgent and complex DHS mission needs and enable improvements in efficiency and effectiveness of DHS operations in the face of a shifting threat landscape. As MORS kicks off another calendar year of events, these topics offer opportunities for collaboration, presentation, and future-focused analyses inside and outside the Department. 🌐

About the Author

Jonathan McEntee is the Operations and Requirements Analysis Director within DHS S&T Office of Science and Engineering. He leads S&T's integrated product teams to identify, collect, and prioritize R&D needs from DHS operational components to inform S&T investments, and manages the collaboration and coordination of R&D investments across DHS. Mr. McEntee also manages S&T's analytical tool capabilities that provide operations, requirements, and business case decision support services to DHS. Prior to his current position, Mr. McEntee was detailed to the S&T front office as the Senior Official Performing the Duties of the Chief of Staff. From 2016 to 2020, Mr. McEntee was the Acting Borders, Immigration, and Maritime Director for S&T, where he worked closely with Customs and Border Protection, Immigration and Customs Enforcement, U.S. Coast Guard, and U.S. Citizenship and Immigration Services to research, develop, test, and evaluate technical alternatives to meet overall Homeland Security Enterprise capability gap needs. Mr. McEntee was the Deputy Director for S&T's Borders and Maritime Security Division (BMD) from 2013 to 2016 and held several program management

roles since 2011, which included managing maritime security systems, border information exchange architectures, and cargo security initiatives. Prior to that, he served one year as a DHS Legislative Fellow on Capitol Hill, working as an advisor to a U.S. Senator on the Homeland Security and Governmental Affairs Committee. From 2007 to 2010, Mr. McEntee worked as the Chief of Business Operations for BMD. From 2005 to 2007, Mr. McEntee provided systems engineering and technical assistance to BMD as a Booz Allen Hamilton employee.

Mr. McEntee also has a background in the U.S. Department of Defense, working for BAE Systems, Northrop Grumman Information Technology, and AMCORP from 1999 to 2005. Specifically, Mr. McEntee was the Undersea Warfare Command and Control lead for the Chief of Naval Operations Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance Requirements Office. He also acted as a liaison for the Naval Sea Systems Command, Program Executive Office of Integrated Warfare Systems in which he provided programmatic, systematic, and financial support for various Undersea Warfare programs.

Mr. McEntee holds a Master of Business Administration degree from Salisbury University and a Bachelor of Science in Finance from Frostburg State University.

THE SECURITY OF PARTNERSHIP.

Global security encompasses a broad spectrum of challenges. Today's leaders look to companies with wide-ranging capabilities, technological expertise and broad perspectives to solve complex challenges. Our global team partners with customers and approaches each challenge as our own. When it comes to success in complex environments, we know partnerships make a world of difference. Learn more at lockheedmartin.com

LOCKHEED MARTIN

A Data Hierarchy Corresponding to Our M&S Hierarchy

Dr. Mark Gallagher, FS

As the community of military operations research analysts, we have focused considerably on our models. We should apply more effort to organizing the data that drives our models. We have made our models and, more importantly, our modeling environment, to be much more flexible. For example, the Threat Modeling and Analysis Program standardized adversary missile models and the Joint Munitions Effectiveness Manual provide reusable weapon effectiveness models. The Advanced Framework for Simulation, Integration, and Modeling (AFSIM) environment enables building and sharing simulations. Currently, our data is collected and organized to support a particular model. Can we also collect and structure our data to support more applications?

Since the 1990s, the military analytic community has been defining and categorizing our models according to a pyramid reflecting the model's resolution. Analysts need to apply a model at the resolution appropriate for the decision they are supporting. Our engineering and physics models represent detailed interactions of subcomponents to evaluate system performance. The engagement models few-on-few combat. Mission-area models assess functional capabilities such as communications or logistics. Campaign simulations support the examination of the integration of the various systems to assess force effectiveness.

Analysts may employ enterprise models to investigate the theater operational military strategies. The results of the more aggregated models are used to set the conditions for the higher-resolution models. The outputs of higher-resolution models are aggregated as inputs into the broader simulations. I use the term "resolution" rather than "fidelity" because the issue is what is being evaluated, not the accuracy of the representation. High-resolution engineering models provide insights into

MISSILE DEFENSE

Connecting vision
with precision

Across all tiers, enabling all missions, prepared
for all threats — Raytheon Missiles & Defense solutions
are ready now to defend warfighters and safeguard
nations. We combine vision, precision and partnership
to deliver for customers and drive success.

**Raytheon
Missiles & Defense**

RTX.com

system performance, but not whether a particular force can execute a military strategy to win a war. Our combat models and simulations (M&S) hierarchy continues to be useful today.

What has changed in recent years? Warfare has become more complex. We are employing, and hence modeling, multidomain approaches. Individual kill chains employ sources from across the military services, such as airborne intelligence, surveillance and reconnaissance, space communications, and ground or navy strikes. Modeling this increased complexity has driven requirements for more data. Now, our models both need and generate considerably more data. Computer grids have significantly improved the speed for the additional calculations for the complexity of modern warfare. As a result, in general, our models have become much more data intensive. Campaign models may require megabytes of input data on system effectiveness from disparate domains. I contend that no single organization has the expertise to generate or maintain the effectiveness data across all the combat domains.

Therefore, our community should develop an approach to share data on combat effectiveness. What are the desired values that drive a data-sharing approach? I categorize my ideas into four areas: useful, structured, flexible, and traceable.

Usefulness includes the ability of individuals to access and contribute easily and promptly. Other users of effectiveness data may include exercises and wargames. Allowing contributors to maintain control over the release of their data significantly hinders its usefulness for other users. Obviously, any data approach must conform to security classification requirements. The scheme should promote structured data so users know how to find the data they want and understand its meaning. The data descriptions should include its resolution. Flexibility is critical to allow for the database to be extended. New missions, systems, and approaches will continuously arise. Can the structure include or be adapted to incorporate their corresponding new data? Ideally, adding a new aspect should not require updating the existing data. Traceable implies the data source is identified. Of course, the data or its representation must be worthwhile. Traceability may be more important than data integrity. Perhaps contractors should be able to submit notional data on potential concepts with an indication of the data's quality. One possibility might be to let other users rate the reasonableness of data. A shared database becomes a common good, which typically fails since everyone wants to use it and few are willing to contribute. An incentive for contributing is enabling entrepreneurs and proponents to share the data supporting their concepts.

Where might the Department of Defense want to develop a shared database? I briefly describe two possibilities, each of which would be an interface between the different resolutions in our combat M&S hierarchy. The first proposes using kill chains as the organizing construct between engagement/mission models and campaign simulations. The second suggests that the campaign simulations could be provided mission effectiveness data for use in enterprise models, exercises, or wargames.

A shared database of kill chain effectiveness data could provide an interface from engagement and mission models to campaign simulations. An engagement model evaluates various tactics in a mission. Those combat results could be encapsulated into a reduced-order model, surrogate,

PHALANX

The Magazine of National Security Analysis

Advertisement Rates and Specifications

The *Phalanx* is the ideal place for members of the national security analytic community to publish articles, share milestones, and advertise. Published quarterly in the spring, summer, fall, and winter, our magazine has a print circulation of over 1,200 MORS members and reaches thousands more readers across our 30+ industry partner organizations, six government sponsors, and institutional subscribers.

Phalanx readers and contributors include leaders in government, industry, and academia. Advertising in the *Phalanx* allows you to reach a highly influential and diverse audience across the United States Department of Defense and wider national security community.

MORS offers flexible and economic advertising plans that will fit the budget of any organization. A budget friendly option to consider would be an ad swap for same-size ads.* (See restrictions below.)

Phalanx Advertisement Rates

Placement	1 Issue	2 Issues	3 Issues	4 Issues	Size (W" x H")
First Spread/Right Read	$2,000	$3,840	$5,640	$7,360	8.5" x 11"
Inside Back Cover	$1,850	$3,550	$5,220	$6,800	8.5" x 11"
Interior Full Page	$1,750	$3,360	$4,950	$6,440	8.5" x 11"
Interior Half Page	$1,050	$2,100	$3,000	$3,800	8.5" x 5.5"
Interior Quarter Page	$650	$1,250	$1,800	$2,300	4.25" x 5.5"

Note: All advertisements should include 0.125" bleeds on all sides. For more detailed information, contact Mr. Romain Falloux at romain.falloux@mors.org.

Accepted File Formats: PDF, EPS, AI, TIFF, or JPEG (with fonts outlined where applicable) with crop/printer's marks. For TIFF or JPEG submissions, set art in CMYK at a minimum of 300 ppi at full size.

Ad Submission Deadlines:

Spring Issue .... January 15
Summer Issue .... April 15
Fall Issue .... July 15
Winter Issue .... October 15

For more information on advertising options, contact Ms. Katherine Miller at kmiller@mors.org.

MORS
Military Operations Research Society

or emulator to represent the effectiveness of links in a kill chain. A campaign simulation could then evaluate mission effectiveness based on a series of kill-chain emulators. In this schema, the kill chains should be defined into small discrete steps so changes in one link would not require reconstructing the surrogate models for another link. For example, the communication link should be separated from an action link so either can be updated without requiring a revision in the other. As new systems are proposed, developed, and fielded, new emulators of link effectiveness could be added. This schema is extendable in that new kill chains could be incorporated.

In my second example, analysts could use the results of campaign simulations to produce mission effectiveness data. In this context, a mission is a collective representation of an entire kill chain. For example, in the Bilateral Enterprise Analysis Model (BEAM), missions are the collection of offensive capabilities and encounter a set of defensive capabilities to have an effect on a group of targets. Currently, BEAM includes a database of millions of missions. That or a similar database could be shared to support other aggregate models, exercises, or wargames.

The essence of this proposal is that as an analytic community, we should organize and share data. We have made significant advancements in organizing our models in resolution hierarchy and reusing some of the models in various applications. I propose organizing our data along the lines of interfaces between those levels of resolution.

Whereas in the past, we tied data collection and formats to a specific model, I suggest the data schema should be separate and sufficiently flexible to support various models, simulations, exercises, and wargames.

About the Author

Dr. Mark A. Gallagher is a Professor of Practice of Operations Research in the Department of Operational Sciences at the Air Force Institute of Technology, Wright-Patterson AFB. Dr. Gallagher served as Technical Director, Senior Leader at AF/A9 from 2009–2019. He also served in U.S. Strategic Command and the Office of the Secretary of Defense Cost Analysis Improvement Group in the now Cost Analysis and Program Evaluation. Dr. Gallagher is a MORS fellow, council member of the Military Application and Security (MAS) Society, member of the Institute for Operations Research and Management Science (INFORMS), and a life member of the Air Force Association and Fellowship of Catholic Scholars. He has published numerous articles in peer-reviewed journals and has received several MORS awards: the Clayton J. Thomas Award, Rist Prize, and Barchi Prize.

Coming Soon to *Military Operations Research*

Development and Analysis of Military Cost-Imposing Actions

Jacob P. Batt, Colton C. Blatchford, Isaac P. Coolidge, Kevin E. Cruz, Glen R. Drumm, Daniel F. Feze, Daniel T. Flynn, Mark A. Gallagher, Norma Ghanem, Alexander J. Hancock, Rhett C. Harms, Brian T. Johnson, Michael M. Maestas, Connor P. McCormick, Matthew J. Milner, Adrian T. Robinson, and Alec B. Schrank

The United States Congress has directed the Department of Defense to investigate strategies that impose significant costs on our adversaries. Air Force Institute of Technology students propose an approach for finding and evaluating cost-imposing actions. They apply risk techniques to identify an adversary's vulnerabilities to potential United States actions along with the adversary's potential responses to mitigate the impacts of those actions. They conducted a hypothetical demonstration of their approach, where military effectiveness is evaluated with the Bilateral Enterprise Analysis Model (BEAM).

A Framework for Using Priors in a Continuum of Testing

Victoria R. C. Sieck, Justin Krometis, and Steven Thorsen

This article develops a framework for thinking about how differently characterized priors can be appropriately used throughout the continuum of testing. The application of the evolution of priors is also addressed. The evolution of priors can start with priors attempting to provide no information and evolve toward priors that capture (newly) available information. This article further discusses priors based on institutional knowledge, as well as those based on previous testing data. A real-world example using the Stryker family of vehicles demonstrates how priors can be employed in a continuum-of-testing construct.

Multi-Level Optimization of Military Air-to-Ground Weapon Purchases Across Time Segments

David M. Goldberg and Matthew S. Goldberg

The military's requirement for conventional (non-nuclear) air-to-ground weapons is posed as a nonlinear program. The problem is high-dimensional, with many combinations of aircraft, weapons, and targets. The current research extends prior work on heuristics that reduce the dimensionality of the problem to multisegment conflicts. A decomposition approach reduces the optimization problem into a set of single-segment subproblems. The overall budget manager sets the weapon procurement budgets for the lower-level managers of the subproblems, who each solve a smaller-scale problem to maximize the utility of expected targets destroyed within their respective time segments.

Adversarial Analysis and Confidence

Madeline A. Stricklin and Aparna V. Huzurbazar

The authors use adversarial analysis for informing aspects of security for nuclear facilities and whether these facilities are likely to be attacked. This problem is particularly difficult in that decisions must be evaluated and made in an incomplete information space. The authors provide a qualitative overview of the aspects considered in adversarial analysis and propose a quantitative method that illustrates how attacks can be assessed to determine whether an adversary will proceed with a given attack.

Improvement of SAR Target Classification Using GAN-based Data Augmentation and Wavelet Transformation

Jaeoh Kim, Chulhee Han, Jungman Lee, Woo-Seop Yun, Seojin Lee, Taehoon Yang, Donghyeon Yu, and Seongil Jo

This article considers the synthetic aperture radar (SAR) target classification problems when available SAR images having target labels are limited. To improve the classification performance, the authors propose a learning technique combining data augmentation using generative adversarial network (GAN) models and wavelet transformation. They conduct experiments to investigate the improvement of the proposed learning technique. From the results, the proposed learning technique combining GAN-based data augmentation and wavelet transformation has shown greater improvement in SAR image classification when the available learning data is scarce.

Military Operations Research Society (MORS) Oral History Project Interview of McKie

Robert Sheldon

Franklin McKie was an operations research analyst for the United States Army Center for Army Analysis from 1973 to 2004, where his final role was Chief of the Mobilization and Deployment Division. Frank received two Analyst of the Year Awards at Army Operations Research Symposiums. After retiring from federal service, he taught math at the University of the District of Columbia and at the Bethesda, Maryland, branch of Central Texas College at Walter Reed National Military Medical Center and Bolling/Andrews Air Force Base. His oral history appears in the online version of *Military Operations Research*, volume 29, number 3.

LEADING THE NATIONAL
SECURITY ANALYTIC
COMMUNITY

MORS

Military Operations Research Society