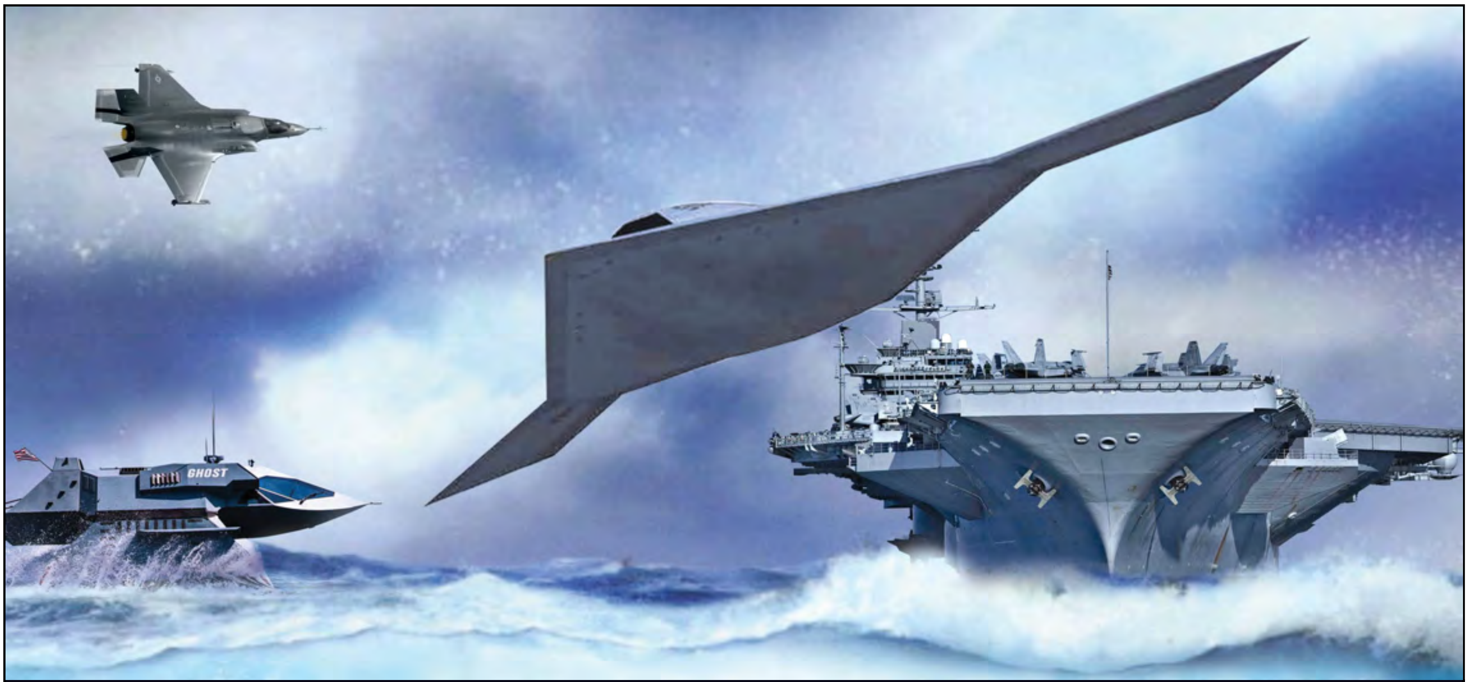


NAVAL RESEARCH PROGRAM

SHARPENING THE SPEAR

NAVAL POSTGRADUATE SCHOOL

NPS
PRAESTANTIA PER SCIENTIAM
1909

DEPARTMENT OF THE NAVY · UNITED STATES OF AMERICA

DEPARTMENT OF THE NAVY · UNITED STATES MARINE CORPS

NAVAL RESEARCH PROGRAM · NAVAL POSTGRADUATE SCHOOL

2016 ANNUAL REPORT

2016 Annual Report

6 JULY 2017

NAVAL RESEARCH PROGRAM

NAVAL POSTGRADUATE SCHOOL

The information within this report is unlimited distribution, and has been prepared by:

Naval Postgraduate School (NPS) Naval Research Program (NRP)
Research & Sponsored Programs Office 699 Dyer Road, Bldg 234
Monterey, CA 93943
NPS_NRP_POC@nps.edu

Provided by:
President, NPS: Ronald Route, VADM USN, (Ret)
NPS Provost: Dr. Steven Lerman
Dean of Research, NPS: Dr. Jeffrey Paduan
NPS NRP Program Manager: Dr. Rodman Abbott, CAPT, USNR (Ret.)
NPS NRP Deputy Program Manager: LtCol Lou Camardo
NPS NRP National Capital Region Representative: Robert Osterhoudt, CAPT, USN (Ret)

MESSAGE FROM THE DEAN OF RESEARCH

The Research and Sponsored Programs Office is pleased to support the Naval Research Program (NRP) in the third complete fiscal year of the program. The Naval Research Program is an official Navy and Marine Corps chartered program, having had the charter officially signed jointly by the Chief of Naval Research and Commander, Marine Corps Battle Lab in August of 2015. The results of the research sponsored within FY16 have made significant contributions in the Department of the Navy (DON), providing input to key operational decision-makers and in areas that support cost savings in a fiscally constrained environment. The NRPs funding and program goals are also directly in line with SECNAV's goal to provide research to "support[s] the Navy in reaching well-informed, objective decisions on strategic, operational, and programmatic issues through collaborative research."

This report highlights salient features and activities across the spectrum of NPS NRP research activities conducted on behalf of both Navy and Marine Corps topic sponsors during the 2016 fiscal year. Each of the 86 research projects' executive summary included herein outlines key results. While most of the summaries detail final results, some projects have multi-year project lengths and, therefore, progress-to-date is reported.

The NRP is one critical component of the NPS research portfolio. Under the stewardship of the NPS president, it utilizes direct funding to assist the naval community while also informing NPS students and faculty about the latest operational questions. Looking forward to FY17, the program management will continue to be under the direction of Mr. Rodman Abbott. His leadership builds upon the already well established program foundations that have been laid down in FY14 -16. My hope is that the naval communities will join with me in the continued support and contribution of the Naval Research Program.

Sincerely,

Jeffrey D Paduan

Dr. Jeffrey Paduan NPS Dean of Research

TABLE OF CONTENTS

NAVAL RESEARCH PROGRAM OVERVIEW

The Naval Postgraduate School (NPS) Naval Research Program (NRP) is funded by the Secretary of the Navy (SECNAV), and supports research projects for the Navy and Marine Corps. The NRP research projects are comprised of individual research teams, where projects are conducted, NPS expertise is developed, and then maintained on behalf of the Navy and Marine Corps. The NPS NRP serves as a launch-point for new initiatives which posture naval forces to meet current and future operational warfighter challenges. The primary mechanism for obtaining NPS NRP support, is through participation at the NPS Naval Research Working Group (NRWG) that brings together fleet topic sponsors, NPS faculty members, and students to discuss potential research initiatives.

Background

The NRP was established in 2013 to leverage the expertise and experience of NPS' multidisciplinary faculty and naval (Navy and Marine Corps) student body to complete relevant, cost-effective research that addresses operational issues for the Naval community*. Naval research, analyses topics, and focus areas are sponsored by numerous agencies within the DON. The NPS NRP has developed as a standardized, systematic vehicle to leverage NPS multidisciplinary faculty and student research capabilities in response to demand signals across the DON. It serves to execute research that adds value to the Department of the Navy through research efforts (Research Development Test and Evaluation (RDT&E) funding) at NPS. The NPS NRP in no way replaces the traditional, independent, external research development processes used by NPS faculty (e.g. Broad Area Announcements, Requests for Proposals), but rather is intended to complement those efforts.

*Other Federal Agency sponsors may choose to participate in the NPS NRP working groups with their own funding.

Organization

The organization of the NPS NRP is based upon an annual research-topic solicitation process that helps merge DON research requirements with NPS faculty researchers and students who have unique expertise and experience within the DON. This process creates opportunities for NPS to actively contribute to real-world issues within the DON by providing relevant, high-quality, and timely research. The process starts annually with the convening of the NRWG on site at NPS each spring. The working group creates a forum for open discussion between NPS faculty, students, and DON topic sponsors.

The NPS NRP also draws ideas from a Topics Review Board (TRB) comprised of senior military and/or civilian representatives from each of the responding operational command/activities, headquarters, or systems commands. The TRB also includes a senior leader from NPS. The USMC executes and establishes a parallel Executive Review Board (ERB) process to conduct the same service-level research-topic exploration. TRB and ERB recommendations are forwarded to the NPS president for concurrence and coordination with the Vice Chief of

Naval Operations and Assistant Commandant of the Marine Corps. The review boards conduct thorough reviews of proposed topics and research, to ensure funding is available to support topics with the highest priority within the DON.

Mission and Goals

The mission of the NPS NRP is to facilitate a continuum of Navy and Marine Corps research projects for the purpose of meeting current and future naval research requirements, integrating NPS faculty into the total naval Research and Development (R&D) capability space, and disseminating the knowledge and expertise gained to NPS students. The goals of the NPS NRP are to:

- become a recognized partner from which naval R&D organizations seek out research in response to short, medium, and long-term time frame requirements
- develop a ready pool of faculty research expertise to address these requirements
- offer a venue for NPS students to identify thesis research opportunities in areas directly relevant to naval challenges and research needs
- become the recognized leader for providing cutting-edge graduate education for naval officers that includes research complementary to the U.S. Navy's and USMC's R&D requirements.

The NRP supports the awareness that "an active academic research program is vital to the quality of education provided to students, the attraction and retention of exceptional faculty members, and the provision of real-time, directly relevant deliverables to government sponsors (SECNAVINST 1524.2c dtd 21 Oct 2014)," and is postured to fulfill this DON requirement. The NPS NRP convenes the annual NRWGs as a forum for communicating, reviewing, validating, prioritizing and recommending research-topic challenges for consideration. Other topic solicitation methods may be employed in coordination with the NRWG to maximize the breath and scope of research topics. The process includes: opportunity for faculty dialogue with topic sponsors; faculty proposed responses to proposed topics that match academic interests and capabilities; and review, validation, and prioritization of matched topics against the most pressing joint requirements.

Program Administration

The NPS NRP is directed through NPS' Research and Sponsored Programs Office. The Dean of Research (DOR) at NPS is designated as the lead agent and is responsible for NRWG execution, routing of post-TRB research requirements to NPS faculty and sponsors, and program management of the NPS NRP. The NPS NRP Program Office includes a program manager, deputy program manager, and small staff who are delegated the responsibility for day-to-day program management of the NRWG, as well as program and individual research project oversight on behalf of the DOR. The NPS NRP Program Office coordinates and liaises with NPS NRP designated points of contact/Program Area Manager (PAM) counterparts from the various research sponsors.

Accomplishments

The NPS NRP represents a strategic statement about the tangible and intangible value that NPS provides the entire naval community. It has proven to be a significant integration vehicle for partnering naval sponsors and NPS researchers to deliver cost-efficient results. The NRWG is one manifestation of this integration process. Over 50 Navy and Marine Corps organizations throughout the naval community have actively supported opportunities to engage NPS faculty and students through participation in the NRWG event: To date, the NRP has collected over 2000 potential and current research topics through these events, while funding over 300 of them. Embedding the NRP into the fabric of the NPS strategic planning process enables the school to rapidly respond to current and future "compass swings" in naval research requirements.

As a result of NRP's operations, NPS research is more directly aligned with the naval community than in prior years:

- In FY16, NPS received $8.6M, which it translated into over 78 distinct U.S. Navy and Marine Corps projects that cover the entire Office of the Chief of Naval Operations (OPNAV) staff, Fleet Forces (FF), Assistant Secretary of the Navy for Research, Development and Acquisition (ASN (RDA)), Strategic Systems Programs (SSP) and Marine Corps functional organizations.
- One-hundred percent of FY16 projects are directly traceable to the Navy's Strategic Plan and/ or the Marine Corps Expeditionary Force 21 Concept.
- The NRP has mobilized the NPS faculty to focus more of their research on naval issues. To date, over 200 faculty and military faculty from all four academic schools have joined the NRP effort, highlighting NPS' campus-wide commitment to naval research.
- Cross-campus, inter-departmental research partnerships represent nearly a quarter of the projects. They provide an advantage from the application of integrated perspectives and resulting multidisciplinary approaches.
- The NRP enjoys robust student engagement, leveraging the students' previous operational experience and new-found knowledge from graduate studies. There were over 170 United States and foreign thesis students collaborating with faculty on 56 of the 70 projects.

FY16 Research Highlights

NAVY

NPS researchers Dr. Nita Lewis Shattuck, Dr. Panagiotis Matsangas, Dr. Chad Seagren and student LT Ian Meredith, USN sought to explore the effects of manning levels on the operational performance of the Littoral Combat Ship (LCS). Three models of the core enlisted crew members of the LCS (Freedom variant) were developed. As a conclusion, the findings suggest that there is a lack of adequate spare capacity on the Freedom variant of the Littoral

Combat Ship when the ship is manned with 41 enlisted crew members. The critical rates are Enginemen, Gas Turbine System Techs, and Electrician's Mates. The results also suggest that adding a couple of crewmembers may ameliorate the problem of workload, but not to the extent initially envisioned. The LCS community should consider using insights from these models to help make future manning decisions regarding the Freedom variant of LCS.

NPS researchers Dr. Simona Tick, Dr. Mark Eitelberg, Capt. Michael Smith, RAN, and student LT David Mundell, USN, MSA studied the definition and measure of gender integration in the Navy using a combined, quantitative and qualitative, perspective. The Military Leadership Diversity Commission (MLDC) of 2011 and top Navy leaders have stressed the importance of achieving gender integration in the military, making it one of Navy's top priorities. Using data on over 16,000 Navy officers commissioned from 1999 to 2003, and followed annually, the results from regression analyses show that women are less likely than men to stay in the Navy, but show no difference in promotion rates to O-4 and lateral transfers to another community. Also, officers who obtain graduate-level education or transfer laterally to another community by 10 years of service have higher rates of retention and promotion.

NPS researchers Dr. Shelley P. Gallup, Dr. Tom Anderson, Mr. Victor Garza, Dr. Nelson Irvine, Mr. Brian Wood and student LT Kevin Dougherty, USN studied Darknet and obfuscated net traffic. There is no process or system capable of detecting obfuscated network traffic on DOD networks, and the quantity of obfuscated traffic on DOD networks is unknown. The presence of obfuscated traffic on a DOD network creates significant risk from both insider-threat and network-defense perspectives. A set of concepts were identified and proposed as a set of testable Key Cyber Concepts (KCCs) for obfuscation behavior. Each characteristic was evaluated individually for its ability to detect obfuscated traffic and in combination in a set of Naive Bayes multi-attribute prediction models. The best performing evaluations used multi-attribute analysis and proved capable of detecting approximately 80 percent of obfuscated traffic in a mixed dataset.

NPS researchers Young Kwon and Jarema Didoszak along with student ENS Jean B. Loomis, USN studied critical port infrastructure. This is especially vulnerable to waterborne improvised explosive devices (IED) and other underwater explosions (UNDEX). Findings from physics-based modeling and simulation of the shock event reveal the damage potential of UNDEX as a function of charge weight and standoff distance, and serve as a template for future efforts for other bridge structures in direct contact with significant bodies of water.

NPS researchers Dr. Alejandro S. Hernandez, Matthew Boensel, and student Adam Haag, LT, USN undertook a research project at the specific request from N46 in order to determine the viability of Waste-To-Energy (WTE) technology at existing Navy facilities. This research project has created an additional module to an existing in-use tool. The new module allows a user to determine whether investment for implementing one of three types of WTE in a facility is warranted. The cost models estimate the capital investment required, the time period for return on investment, annual costs (including labor), and potential input and output streams required. Use of this cost model will help decision makers select DOD sites for further study that currently have the required local assets that would make WTE investments worthwhile.

NPS researcher Timour Radko, John Joseph and NPS students Christopher Merriam, LCDR, USN, Troy Benbow, LT, USN, Michael Martin, LT, USN, and Zachary Moody, LT, USN studied the problem of hydrodynamically-based detection of the surface and subsurface wakes generated by transiting submersibles. The primary objective was to investigate the wake intensity, its thermal signatures and detection potential. Research activities involved numerical, laboratory and field experiments.

NPS Researcher Giovanna Oriti and student LT Mitchell Stewart, USN investigated an alternate railgun power supply design in order to minimize railgun muzzle flash. Railgun muzzle flash, or post-fire arcing, is a major concern to the Navy because of the potential thermal stress associated with post-fire arcing. In this project a new railgun power supply was compared to the thyristor-based one, which is the state of the art. Quantification of the post-fire rail energy reveals that the proposed buck-boost converter topology is better suited for the railgun than the thyristor-based one, particularly at minimizing the post-fire muzzle energy. The minimization of the post-fire energy allows for an extended rail life and potentially longer usage.

NPS researcher Joseph Hooper and NPS students LCDR Tabitha Booth-Seay, USN and LT Tina Pryne, USN developed an analytic model for the multiphase combustion of a reactive material debris cloud inside an enclosed target for an enhanced lethality warhead. Starting metal, product oxides, and gases are tracked explicitly but mass and energy equations are solved by homogenizing the mixture into a single fluid. A single Arrhenius term is used to describe the combustion process. Model calculations for an aluminum dust cloud show good agreement with pressure rise times, but over predict peak overpressures inside the target. Though it lacks the complexity of full flow simulations, this fast calculation could be used to quickly analyze experimental pig data and be used to fit an improved combustion rate term.

NPS researcher Jeff Kline, Dr. Thomas Lucas, and NPS student LT Kristen Ericksen, USN created, developed, and then assessed an agent based model within Naval Surface Warfare Center Dahlgren Division's (NSWCDD's) Orchestrated Simulation Model (OSM) to represent naval surface-to-surface engagements in order to aid in the development of the distributed lethality concept. The Distributed Lethality OSM (DL-OSM) simulation was assessed through wargaming, a fleet exercise, and using advanced experimental design to explored best tactics for organic helicopters, emission control, and formations during surface to surface engagements. The simulation was determined to be satisfactory to explore tactical variables in the distributed lethality concept.

MARINE CORPS

NPS researchers Tom Murphree, Arlene Guest and students LCDR Rich Ilczuk, USN and LCDR Tyler McDonald, USN, developed data sets and tools to facilitate coastal marine spatial planning (CMSP) for the U.S. Pacific islands. These included: (a) collecting data sets; (b) developing data sets and tools for data analysis and decision support. The team coordinated and collaborated with the Pacific Islands Regional Planning Body to help in their efforts in CMSP. They have created a prototype data portal and developed several types of geographic information system (GIS) mapping applications for visualizing and analyzing the data.

NPS researchers John H. Gibson, Karen L. Burke, Douglas J. MacKinnon and NPS students MAJ Christopher A. Jones, USMC and MAJ David M. Yorck, Maj, USMC researched ways to improve the understanding of the Development Test and Evaluation (DT&E) cybersecurity testing to minimize cybersecurity vulnerabilities prior to fielding equipment and systems to the operational forces. The research included case studies of two existing United States Marine Corps (USMC) systems, lab testing in a test bed developed at the Naval Postgraduate School to fine-tune suggestions for DT&E, and a study of system-of-systems testing. Opportunities to improve resilience were determined and offensive-type laboratory testing is recommended.

NPS researcher Doug MacKinnon, Shelley Gallup and NPS student MAJ Greg Lizak, Major, USMC Studied the expeditionary nature of USMC operations requiring highly maneuverable forces. A highly fluid battle space, typifying maneuver operations, results in rapidly changing unit locations. The exchange of unit position location information (PLI) between force elements on the battlefield, regardless of service organization, is critical to joint operations. However, current policy regarding the classification of PLI data may not reflect the transient nature of tactical forces or the ability to derive the location of force elements through open sources. This study examined the operational impacts of policy and technology on the implementation of PLI systems, of which there is considerable variety. This was done within the current construct of the Marine Corps Operating Concept (MOC).

United States Navy (USN)

N1: Personnel, Training and Education

NPS-N16-N154-A: Improving Navy MPTE Studies with Model-Driven Big Data

Researcher(s): Dr. Thomas Lucas and Dr. Susan Sanchez
Student Participation: LT Allison Hogarth USN, LT Peter Bazalaki USN, and ENS William DeSousa USN

Project Summary
The goal of this research was to improve upon the ability of OPNAV N1 analysts to quickly and efficiently obtain experiment-based information from their computational models. The enhanced information will enable N1's analysts to better support Navy leadership in resource and policy decisions that shape the future Navy and help it retain and develop its most talented Sailors. This project built on previous collaborations with N1 using data farming to enhance the information gleaned from their Navy talent management models, such as the Officer Strategic Analysis Model (OSAM) model, the Production Resource Optimization (PRO) model, and the Navy Total Force Strength Model (NTFSM). During this research period, (1) Ensign William Desousa (2015) investigated the behavior of economic inputs in NTFSM; (2) Lieutenant Peter Bazalaki (2016) used the new data farming capabilities we developed in OSAM to investigate Surface Warfare Officer (SWO) inventory across a breadth of possibilities; and (3) Lieutenant Allison Hogarth (2016) built, tested, and demonstrated a user interface in Excel that enables users of the PRO model to automatically execute a sophisticated design of experiments—the tool that enables this new capability is known as Production Resource Optimization Model With Experimental Design (PROMWED). In addition to working with the student-officers, the faculty supporting this project performed an empirical study of statistical software packages that may provide better understanding of the high-dimensional behavior of manpower models in the future (Erickson, Ankenman, & Sanchez 2016).

Keywords: Navy talent management, manpower, recruiting, data farming, simulation, design of experiments.

Background
Navy planners face the challenge of balancing manpower requirements and mandated end strength with budget constraints. The uncertainties associated with human behavior and economic factors, complicates forecasting end strength and developing policies that ensure that the Navy has Sailors with the right skills in the coming years. The Chief of Naval Personnel (N1) is responsible for analyzing manpower inventory forecasts and estimating the Navy's

manpower requirements and expenditures. His findings affect the budget and Program Objectives Memorandum (POM) submitted to the Secretary of the Navy every two years.

The Chief of Naval Personnel has a dedicated staff that provides him with the necessary information and associated risks to make decisions on manpower, such as where and how recruiting resources should be spent. Of course, forecasting Navy personnel levels is a complex problem compounded by numerous uncertainties. Therefore, the staff relies critically on manpower, personnel, training, and education (MPTE) models that allow them to project future force levels given a set of assumptions and historical experience. Three models used for manpower analysis at N1 are the Navy Total Force Strength Model (NTFSM), the Officer Strategic Analysis Model (OSAM), and the Production Resource Optimization (PRO) model. These models, and others used at N1, have many input variables and generate multiple outputs of interest. Such models may be more useful to N1 analysts if they are embedded in an environment that allows analysts to quickly and efficiently obtain experiment-based information. The SEED Center advanced the ability to data farm all three of these models during the performance period covered in this report.

Findings and Conclusions

New software was developed, tested, and applied in data farming proof-of-concept applications with NTFSN, OSAM, and PRO. In one application, Lieutenant Peter Bazalaki (2016) utilized the new data farming capabilities in OSAM to simulate Unrestricted Line Officer (URL) inventory over a seven-year period. Specifically, his research used design of experiments (DOE) to project Surface Warfare Officer (SWO) inventory across a variety of assumptions, including a proposed Enhanced Probationary Officer Continuation and Redesignation (EPOCR) policy. He found that current policy will reduce FY2016 URL inventory by 8% over a seven-year period, and over-execute SWO inventory authorizations by 40%. However, if implemented correctly, EPOCR has the potential to decrease the operating standard deviation to modest levels with minimal risk of under-execution.

ENS Desousa (2015) investigated the behavior of economic inputs to NTFSM. After manually implementing a sophisticated design of experiments (DOE), he simulated and analyzed a variety of scenarios to better understand the behavior of NTFSM and to determine the sensitivity of the user defined economic factors. The results of the analysis unexpectedly showed that NTFSM's economic factors have no significant impact on NTFSM's end-strength output—this unanticipated finding warrants further investigation.

Ongoing research is underway with the PRO model by LT Allison Hogarth. She is building, testing, and using an intuitive and easy-to-use user interface in Excel that enables users to run a sophisticated design of experiment over a breadth of input variables. LT Hogarth has named this new capability the Production Resource Optimization Model with Experimental Design (PROMWED), see Hogarth et al. (2016). She is testing and assessing PROMWED on an N1-approved scenario.

Naval Postgraduate School faculty continue with their research in developing design of experiment algorithms that improve upon our ability to explore high dimensional models of manpower (and beyond). This past year we performed a large-scale empirical study of several Gaussian process (GP) software packages, and found differences in their suitability for creating metamodels of high-dimensional behavior (Erickson, Ankenman, & Sanchez 2016). This is a first step toward enhancing recent work on sequential methods (Duan, Ankenman, Sanchez, & Sanchez 2017) in order to develop adaptive methods that dynamically focus on interesting parts of the trade space as experiments are executed and evaluated.

Recommendations for Further Research

Follow-on work has already commenced. NPS student-officers who are participating in this research will shortly be coordinating with OPNAV N1 staff—in partnership with SEED Center researchers—to identify studies and models (e.g., NTFSM) that will use and test the data farming capabilities being developed. If the new capabilities in OSAM, PRO, and NTFSM prove valuable, they will be applied to support other N1 studies such as the results of various policy options on retention. Additional models used by N1 will be considered as candidates to make data farmable. If requested, focused workshops will be scheduled to facilitate adoption of the new data farming capabilities by N1 analysts.

References

Bazalaki, P. (2016). An exploratory analysis of projected Navy officer inventory strength using data farming. M.S. in Operations Research, Naval Postgraduate School, Monterey CA.

DeSousa, W. P. (2015). An exploratory analysis of economic factors in the Navy total force strength model (NTFSM). M.S. in Operations Research, Naval Postgraduate School, Monterey CA.

Duan, W., Ankenman, B.E., Sanchez, S.M., & Sanchez, P.J. (2017). Sliced full factorial-based Latin Hypercube designs as a framework for a batch sequential design algorithm. Forthcoming in *Technometrics*.

Erickson, C., Ankenman, B.E., & Sanchez, S.M. (2016). Comparison of Gaussian process modeling software. *Proceedings of the 2016 Winter Simulation Conference,* Institute of Electrical and Electronic Engineers: Piscataway, NJ, 3692-3693.

Hogarth, A.R., Lucas, T.W., & and McLemore, C.S. (2016). Improving Navy recruiting with data farming. *Proceedings of the 2016 Winter Simulation Conference*, Institute of Electrical and Electronic Engineers: Piscataway, NJ, 3576-3577.

NPS-N16-N181-A: Resilience Assessment and Intervention in the Fleet

Researcher(s): Dr. Edward Powley and Dr. Frank Barrett
Student Participation: MAJ Alicemary Trivette USA, LCDR Dominic Raigoza USN, LCDR Melissa Gonzales USN, and Student Interns (NREIP): Alexandra Henderson (BGSU); Jordan Ruff (XULA) and Ian Clark (NU)

Project Summary
This project on resilience was conducted at the Basic Enlisted Submarine School in Groton, CT. The study involved enlisted submariners in two cohorts or classes. Surveys on resilience, and other validated constructs, were given at four different time points over an eight-week training period. One class (the Control group) only received the surveys; the other class (Treatment group) received a resilience building intervention. Results show that submariners in both classes rate resilience consistently and at a high level (Somewhat Agree 6, on a 7 point Likert scale) and as such, the intervention did not appear to be a deciding factor. Additional analyses show that for all participants, resilience is the key explanatory factor for reducing stress and increasing well-being. That is, the ability to frame challenging situations positively (measured at T1 and T2) does not increase well-being and reduce stress at T4, unless submariners report high levels of resilience.

Keywords: resilience, stress, well-being, U.S. Navy

Background
The impetus for this project revolves around ongoing effort within the submarine force to maintain current levels of manning and to retain submariners. Unplanned losses in the submarine fleet remain a challenge for the submarine force. The goal of this research was to demonstrate the effectiveness of a proven intervention (Challburg & Brown, 2016) and to provide a reasonable tool to assess resilience. Our research team, which included three Master of Business Administration (MBA) students in Graduate School of Business and Public Policy (GSBPP) at Naval Postgraduate School (NPS) and three summer interns, set out to design a study to assess resilience at different times in the schoolhouse period and to introduce an intervention to strengthen resilience.

Our assessment tool included measures related to resilience (Smith, Dalen, Wiggins, Tooley, Christopher, & Bernard, 2008), such as positive framing techniques, (Chong & Druckman, 2007), stress levels (Schneiderman, Ironson, & Siegel, 2005; Schaufeli, Bakker, & Van Rhenen, 2009; Bono, Glomb, Shen, Kim, & Koch, 2013) and subjective well-being (Diener, Lucas, & Oishi, 2002) among others, including control variables. We expected that (1) the Treatment class would show higher levels of resilience than the Control class after the intervention was given; (2) resilience would mediate the relationship between positive framing and stress; and (3) resilience would mediate the relationship between positive framing and subjective well-being. Our past research suggests that these relationships would prove a critical demonstration to the role of resilience (Challburg & Brown, 2016).

Methodology
The study involved enlisted submariners in two cohorts or classes at the Basic Enlisted Submarine School (BESS). Surveys on resilience, and other validated constructs, were given at four different time points over an eight-week training period. One class (the Control group) only received the surveys; the other class (Treatment group) received a resilience building intervention.

We used a Guided Conversation intervention (the resilience building intervention) consisting of pairs of submariners discussing with each other successes and challenges / setbacks associated with military service. The intervention was approximately 60 minutes.

Despite the number of participants, we collected a significant number of incomplete surveys; Class 1 had 33 usable surveys across time points and Class 2 had 47 usable surveys across time points. To address low number of participants in Class 1 at T1, we modified the T2 survey for those who had already completed T1 and combined all participant responses at T2.

In terms of analysis, we compared scores across the four time points and used statistical regression to conduct a mediation analysis to see if resilience plays a role in stress reduction or well-being.

Students were not directly involved in the data collection; they performed the majority of the analysis with the help a PhD candidate intern. Two of the interns travelled to the research site to help collect the data.

Findings and Conclusions
The findings suggest that resilience trends high in the schoolhouse environment as compared to the boot camp environment (Challburg & Brown, 2016). Moreover, results show that submariners in both classes rate resilience consistently and at a high level (Somewhat Agree 6, on a 7 point Likert scale) and as such, the intervention did not appear to be a deciding factor. This was not according to our expectations. This is a positive sign though about the culture and atmosphere of the schoolhouse environment and may be attributed to the flexibility and freedoms during the training period, unlike the strictures of boot camp or deployment.

The resilience intervention, though it did not have an observable effect in this study, shows promise in more stressed environments (boot camp, fleet, etc.). The intervention draws on positive organizational studies and positive psychology. It is consistent with current theory and practice in the field. We add to and help clarify the literature on social relationships in the workplace (high quality connections) and their role in fostering better work outcomes (Dutton, 2003).

Because of our work on this project, we have a clearer understanding of the role of resilience to reduce stress and increase well-being. Those participants in the study reporting high levels of resilience are more likely to have lower levels of stress and increased levels of subjective well-being.

We worked closely with the submarine community leadership to develop and design the study. They provided important resources and personnel for us to complete the study. We faced some difficulty in scheduling for dates when we administered the surveys, but we were able to work through those challenges in order to move forward. This raises for us one the key limitations of our study: the sample size. Further studies in the schoolhouse environment would confirm our results.

While our study did not directly address the manning or unplanned losses, our study provides the submarine force an assessment tool for resilience that could be used for research or for more applied purposes.

Recommendations for Practice and Further Research

We offered the following overarching recommendations to the command and the submarine leadership:

- *Resilience requires setbacks and challenges*: Increase the opportunities for learning from failure and setbacks vice focusing training to achieve minimum qualification levels

- *Resilience requires hopeful vision of success*: Teach system thinking and situational awareness, long-term thinking and perspective-taking to encourage toughness, perseverance, and mission accomplishment

- *Resilience requires positive relationships*: Place emphasis on building high quality relationships with peers and superiors who can provide support and sustainment during tough times

- *Resilience requires a learning orientation*: Focus efforts to (1) help sailors frame challenging situations positively by asking the right questions and (2) foster a climate where individuals can discuss and learn from challenges, failures and worries non-punitively

Specifically, we recommend additional research and work to integrate intervention into existing programs. We recommend building on and extending current intervention: focus on learning about factors that build resilience, and provide practice with constructive questions with emphasis on building high quality relationships. Additional time required to maximize effect (½ day to 1-day vs. 60 minutes).

In terms of research, we recommend additional testing of resilience tool at BESS: (1) use measures to reassess resilience with additional classes; and (2) provide class-level feedback of resilience and other select measures.

We believe that the assessment and intervention could be integrated within the Submarine Cultural Workshops: (1) use tool and other measures to assess resilience at specific times: pre- and post-workshop assessment; pre- and post-deployment assessment - before short underway deployments in workups or sea trials at three or six month intervals (based on availability); (2) compare individual and command resilience measures against objective measures, such as psych visits, early departures, turnover within community, productivity measures, physical fitness progress, etc.; and (3) review aggregated results within commands and across commands. A future research project within the Submarine Cultural Workshop framework might include comparison with units that receive the intervention and assessment vice those only receiving the assessment. Such a project would yield opportunities for the submarine develop and measure resilience.

Additionally, we suggest, that a short version of the resilience tool might be included within standard command climate surveys.

References

Bono, J., Glomb, T. M., Shen, W., Kim, E., & Koch, A. J. (2013). Building positive resources: Effects of positive events and positive reflection on work stress and health. *Academy of Management Journal*, *56* (6), 1601–1627.

Challburg, M. & Brown, C. C. (2016). *Resilience among naval recruits: A quantitative and qualitative analysis of interventions at recruit training command and implications on fleet readiness.* (Master's thesis.) Naval Postgraduate School. Monterey, CA. Retrieved from Calhoun http://calhoun.nps.edu/handle/10945/ 48501

Chong, D. & Druckman, J. N. (2007). Framing public opinion in competitive democracies. *American Political Science Review*, *101*(4), 637–655.

Diener, E., Lucas, R. E., & Oishi, S. (2002). Subjective well-being: The science of happiness and life satisfaction. *61*(4), 305–314. *The Oxford Handbook of Positive Psychology* (2nd ed.). doi: 10.1093/oxfordhb/9780195187243.013.0017.

Dutton, J. E. (2003). Energize Your Workplace: How to Creates and Sustain High Quality Connections at Work. Jossey-Bass: San Francisco.

Schaufeli, W. B., Bakker, A. B., & Van Rhenen, W. (2009). How changes in job demands and resources predict burnout, work engagement, and sickness absenteeism. *Journal of Organizational Behavior*, *30*(7), 893–917. DOI: 10.1002/ job.595

Schneiderman, N., Ironson, G., & Siegel, S. D. (2005). Stress and health: Psychological, behavioral, and biological determinants. *Annual Review of Clinical Psychology*, *1*, 607–628. DOI: 10.1146/annurev.clinpsy.1.102803.144141. Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2568977/pdf/nihms70622.pdf

Smith, B. W., Dalen, J., Wiggins, K., Tooley, E., Christopher, P., & Bernard, J. (2008). The brief resilience scale: assessing the ability to bounce back. *International Journal of Behavioral Medicine*, *15*(3), 194–200.

NPS-N16-N210-A: The Effect of Shipboard Manning Levels on Operational Effectiveness – An LCS Case Study: Phase 3

Researcher(s): Dr. Nita Lewis Shattuck, Dr. Panagiotis Matsangas, and Dr. Chad Seagren
Student Participation: LT Ian Meredith USN

Project Summary

This project had two goals. First, we sought to explore the effects of manning levels on the operational performance of the Littoral Combat Ship (LCS). Three models of the core enlisted crewmembers of the LCS (Freedom variant) were developed. Crewmembers were involved in planned activities (e.g., watch, planned maintenance, sleep), and unplanned events (e.g., corrective maintenance, drills). Results showed that watchstanding crewmembers worked over 14 hours of duty per day with less than 6.5 hours of sleep per night. Enginemen, gas turbine system technicians, and electrician's mates had the highest workload and slept the least. We also explored the operational effect of an "extreme" unplanned event on the crew. Results suggested that an "extreme" event causes sustained wakefulness (i.e., approximately 30 crewmembers did not sleep for close to 40 hours during the event).

The second goal of this project was to assess the appropriate manning levels of the Sea Duty Unit Identification Code (UIC) at LCS Squadron 1 (LCSRON ONE), i.e., the crewmembers responding as temporary replacements to crews and detachments that suffer unplanned losses. Results show a tradeoff that occurs as billets are added to the Sea Duty UIC. The more sailors assigned to the Sea Duty UIC, the greater the probability one will be available to respond to an emergent request for temporary assignment, and the lower the expected time crews spend waiting for temporary replacements. However, as more sailors are added to the Sea Duty UIC the time those sailors spend in an unassigned status and simply waiting for work also increases.

Keywords: Littoral Combat Ship, ship performance, manning.

Background

The Littoral Combat Ship (LCS) is one of the United States Navy's newest platforms and is specifically designed to operate in the littoral areas (U.S. Fleet Forces Command, 2016). In an attempt to reduce life-cycle costs, ship designers expended considerable effort to reduce the crew size required to operate the LCS. Original plans called for a core crew of 40 sailors, but the Navy since increased that to 50 (nine Officers and 41 Enlisted personnel). Unfortunately, inadequacies in the manpower models may compromise the operational envelope of ship's crew, exacerbating existing operational problems and degrading the ship's ability to react to unexpected events. This may result in reduced mission capability and degraded combat effectiveness (Fuentes, 2011).

Phase 1 (2013-2014) of this effort focused on the use of IMPRINT Pro Forces module to develop a model for naval applications. It included a conceptual design and initial development of the model using data cards collected by the Center for Naval Analyses (CNA) during an underway with LCS-1 Freedom. Phase 2 (2014-2015) involved further development and a further proof of concept of the IMPRINT Pro Forces software. Overall, Phases 1 and 2 provided exceptionally useful insights into the utility of this modeling approach. Using a model designed in the IMPRINT Pro Forces module can help inform leadership of the Manpower, Personnel, Training and Education (MPT&E) enterprise in order to prevent crew size over-estimation or under-estimation, and identify specific personnel ratings and designators with increased workload. Detailed information about the Phases 1 and 2 of this project can be found elsewhere (Hollins & Leszczynski, 2014; Shattuck & Matsangas, 2015). Building on the results from Phases 1 and 2, Phase 3 (2015-2016) focused on further development and a systematic re-evaluation of the LCS crew and mission package manpower model (Meredith, 2016). After discussions with the leadership of LCSRON ONE, the research team was asked to expand the scope of the Phase 3 effort to include how Sailors were assigned as temporary replacements when ship crews experience unplanned losses to the crews. Sailors who are available to fill these unplanned losses are currently assigned to a Sea Duty Unit Identification Code (UIC). There is interest in determining how many Sailors are needed in the Sea Duty UIC to provide manning in the event of unplanned losses. This analysis and assessment of the Sea Duty UIC was conducted at the squadron level. Therefore, Phase 3 includes the development of the LCS manning model at the ship level, and the assessment of the Sea Duty UIC at the squadron level.

Findings and Conclusions

Goal A: LCS manning model

Overall, our results show that the manning model of 41 enlisted crewmembers on the Freedom variant of the Littoral Combat Ship puts a demanding load of work on the ship's crew, especially on the watchstanders. This is evident both in the baseline model, which includes only the planned activities, and on the second model with the inclusion of the unplanned events. Specifically, in the baseline case, even though it includes the least amount of workload, the watchstanders work approximately 14 hours per day. Including unplanned events in the daily workload tends to increase duty time and decrease sleep time, especially for the crewmembers in the Engineering and the Combat Systems departments. Our results showed that crewmembers in the Engineering and the Combat Systems departments worked long hours (on average approximately 13 hours per day) with all watchstanders exceeding the duty hour threshold (OPNAV, 2015). The increased workload of the Engineering department is evident also in the maximum contiguous wakefulness periods, with an average maximum wakefulness period of 26 hours. The crewmembers in the Combat Systems departments follow with approximately 21 hours, and 19 hours for the Operations department. With the introduction of unplanned events we identified two more issues of concern. First, four of the six divisions responsible for the planned maintenance (PM) tasks failed to accomplish all the PM tasks assigned to their crewmembers. Three of the four divisions were in the Engineering department, and one in the Combat Systems department. Two points of importance further emphasize the general pattern of results. First, the Engineman/Gas Turbine (EN/GS) Division fails to accomplish 25% of PM tasks. Second, three of the four divisions with non-accomplished PM sleep the least of work the most compared to the other divisions. Results also showed that corrective maintenance (CM) tasks experience delays in repair. For the ship service diesel generators (SSDG), main propulsion diesel engines (MPDE), and most importantly the GT CM tasks, the percentage of delays are 24%, 28%, and 51% respectively. These findings suggest that the delays associated with the EN/GS Division could potentially impact the operational effectiveness of the ship because required maintenance and repairs cannot be conducted in a timely manner. To our surprise, augmenting overworked ratings by replacing crewmembers did not yield the expected results.

Building on the findings from the first two models, we explored the impact of a major event (for example, an actual Damage Control (DC) event) on crewmembers' workload. As expected, the major DC event further emphasized the lack of adequate spare capacity, i.e., have adequate number of crewmembers to respond to the major event and at the same time have crewmembers available to man all watch stations (including the non-critical ones). The major event also caused sustained wakefulness with approximately 30 crewmembers not sleeping for up to 40 hours.

As a conclusion, our findings suggest that there is a lack of adequate spare capacity on the Freedom variant of the Littoral Combat Ship when the ship is manned with 41 enlisted crewmembers. The critical rates are Enginemen, Gas Turbine System Techs, & Electrician's Mates. Our results also suggest that adding a couple of crewmembers may ameliorate the problem of workload but not to the extent initially envisioned. The LCS community should consider using insights from these models to help make future manning decisions regarding the Freedom variant of LCS.

Goal B: Unplanned losses

Unplanned losses are a reliable source of friction and inefficiency for LCSRON ONE. In response to this problem LCSRON ONE stood up a Sea-Duty UIC. The simulation model we develop provides them with a quantitative basis for deciding the number of sailors to assign to that unit. We find that for the rates under consideration a distinct tradeoff exists between ensuring sufficient sailors stand ready to expeditiously fill a gap left by an unplanned loss in an effort to minimize wait-per-loss, and the likelihood that sailors assigned to the Sea-Duty UIC spend a disproportionate amount of their time in an unassigned status. An Excel workbook that contains the output of this paper's rate-specific analysis will be given to LCSRON ONE.

Recommendations for Further Research

Goal A: LCS manning model

Based on the findings from this study, we recommend that the developed LCS models should be further improved by collecting workload data from actual LCS underway. Future work should focus on including a more comprehensive set of operational scenarios in the list of modeled unplanned events, for example boat personnel transfer, underway replenishments, and exercises with other ships, etc. With the assistance of LCSRON, the mission package personnel should be integrated with the core crew. Furthermore, the developed manning models should be extended to include the Independence variant of the LCS, as well as and other platforms (e.g., DDG-1000).

Goal B: Unplanned losses

We have two categories of recommendations for future work. The first category is work that might provide additional benefit to LCSRON ONE. Specifically, we recommend LCSRON ONE consider extending the analysis to include Navy Enlisted Classification (NEC) qualifications, rather than just rates, refine analysis of attrition rates, and revise as necessary to accommodate any changes to the concept of operations (i.e. mission packages fused with crews, etc.)

Lastly, we recommend that the analysis we conducted for LCSRON ONE should be extended to include LCSRON TWO.

References

Fuentes, G. (2011, February 6). Optimal manning went too far. *Navy Times*. Retrieved from http://archive.navytimes.com/article/20110206/NEWS/102060305/Top-official-Optimal-manning-8216-went-too-far-

Hollins, R. N., & Leszczynski, K. M. (2014). *USN manpower determination decision making: A case study using IMPRINT PRO to validate the LCS core crew manning solution* (Master's thesis). Naval Postgraduate School, Monterey, CA.

Meredith, I. C. (2016). *The effect of shipboard manning levels on operational effectiveness - An LCS case study* (Master of Science). Naval Postgraduate School, Monterey, CA.

OPNAV. (2015). Navy total force manpower policies and procedures (OPNAVINST 1000.16L). Washington, D.C.: Department of the Navy.

Shattuck, N. L., & Matsangas, P. (2015). *Optimization of Shipboard Manning Levels Using IMPRINT Pro Forces Module* (Technical Report No. NPS-OR-15-008). Monterey, CA: Naval Postgraduate School.

U.S. Fleet Forces Command. (2016). Littoral Combat Ship platform wholeness concept of operations (CONOPS) Revision E.

NPS-N16-N213-A: NETC Acquisition Planning Framework for Managing Training Delivery Requirements

Researcher(s): Mr. Perry McDowell and Mr. Rudy Darken

Student Participation: No students participated in this research project.

Project Summary

In 2015, we conducted an analysis of the Science of Learning (SoL) literature to determine how the Navy might augment or modify its current practices with regard to training system development and employment to better account for how Sailors learn, how they develop expertise, and how they retain that expertise over time. The goal of that work was to develop a methodology that would inform the training system design process in a way that could predict training outcomes to a reasonable degree within the constraints that it could not require a major overhaul of the existing procedures that Naval Education and Training Command (NETC) currently uses. We reported the results of this study in (Darken & McDowell, 2017A).

All training starts with recognition and identification of a human performance shortfall. Personnel need to be able to execute a specific set of tasks at a specified level of performance. The process ends with a training solution being developed and/or employed. However, what happens in between is the concern of this report.

Under perfect conditions (e.g. adequate resources, time, and support) a training requirement is analyzed by identifying exactly what tasks need to be trained and exactly what level of performance is required. To be completed properly, this requires (a) a detailed task analysis to a usable level of detail, and (b) measures of performance (MOP) that are known to measure the skill level of the performer on the real world task. If we have a detailed task analysis and training objectives (the objective, trained performance level of the trainee), then these should inform the design of the training intervention. Here is where media selection occurs, sequencing of materials, and pacing of instruction that all make up the final course of instruction (COI). However, often the process is short-circuited by jumping directly from the requirement to the solution without analysis, or the analysis is abbreviated with a high-level task analysis that does not inform the training designer about the demands of the tasks to be trained.

Keywords: Science of learning, task analysis, JDTA, Navy, military, training

Background

The original project was born from a realization and expectation that increased attention to how people learn should have a profound impact on how the Navy acquires training assets and builds curricula to train its Sailors. The Navy is quickly becoming more technical in its use of computing systems and other innovations in the changing landscape of warfare. Coupled with the continued issues pertaining to retention of skilled personnel, the Navy has a new training problem – How do we develop technical knowledge and skills in untrained recruits quickly and efficiently such that they can function at an acceptable level of performance immediately when they report to their duty station?

The days of requiring months of on-the-job training (OJT) after reporting for duty must end. The Navy can no longer afford that approach in terms of time or cost. If we are to have a highly technical Navy with highly skilled personnel, we must learn how to learn better. Furthermore, the Navy cannot afford a "one off" approach to this problem. Many have already shown that, given a problem domain and sufficient resources, we can develop a training regime that rapidly develops skills that are less subject to atrophy (see Fletcher & Casebeer, 2014). What the Navy needs now is a scientific approach that can apply across the extraordinarily broad set of problem domains and disciplines that constitute Navy training. It must be repeatable, predictive, and effective – and it must inform the Navy's acquisition professionals responsible for training Navy personnel.

The Science of Learning (SoL) is a way of thinking about learning that is always centered on the learner – never on the technology. As such, it is the foundation for this research. The approach for this project has been to investigate what we know about the Science of Learning, then identify and document Navy processes for developing, acquiring, and delivering training to the fleet, and finally, to show how and where in the process the SoL might be able to achieve the desired goals of the program – repeatability, predictability, and effectiveness.

Findings and Conclusions

This report and the methodology it espouses, fit mostly within the NETC End-to-End (E2E) process shown in Figure 1. The requirements begin external to the process identified as (1) in the figure. The core process is shown in the gold box starting with the job duty task analysis (JDTA) (2), the front end analysis (FEA) (3), and developing the training project plan (TPP) (4) where the actual specification of the training solution emerges. The SoL framework developed here fits primarily within the FEA as described in Naval Education and Training (NAVEDTRA) 138.

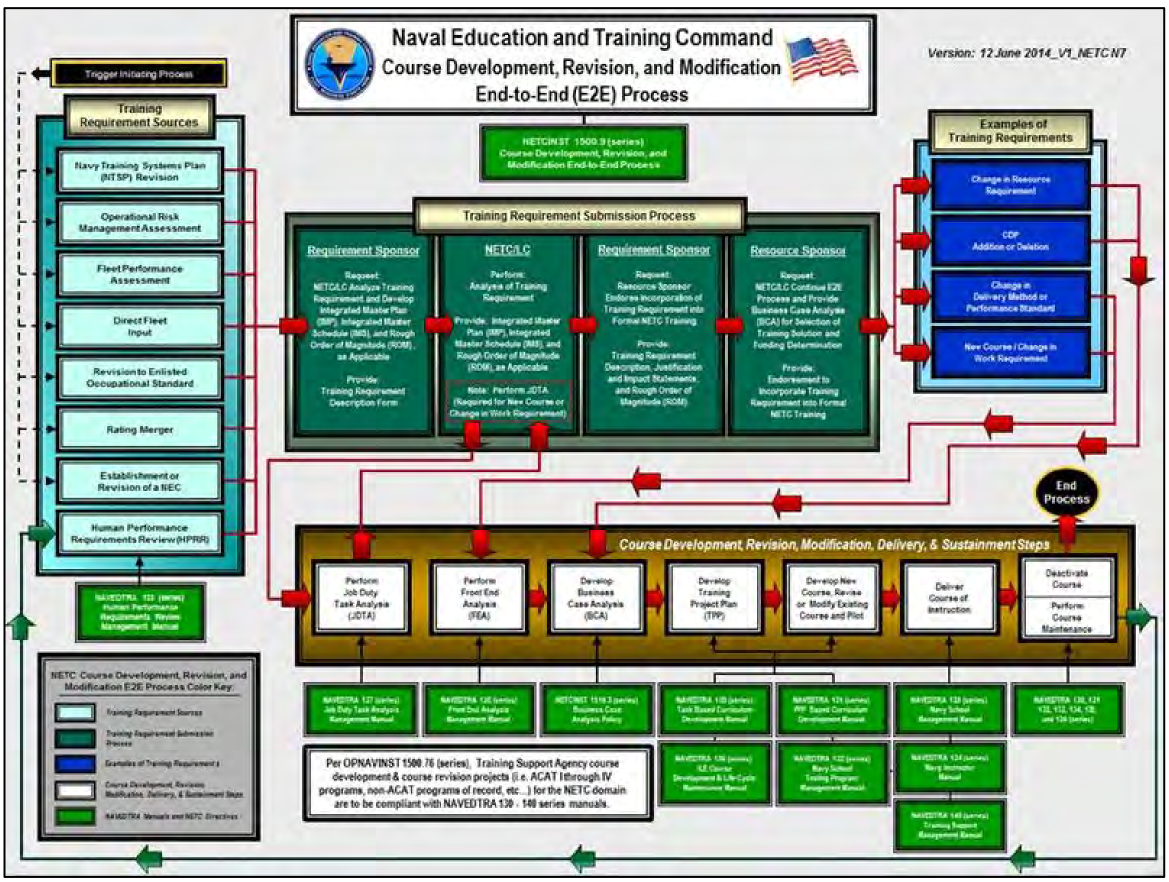


Figure 1. The NETC End-to-End (E2E) Process

The overview of the SoL process is shown in Figure 2. Relating back to the E2E process in Figure 1, the inputs to the needs analysis and training objectives come from external OPNAV sources (see (1) in Figure 1). Here is where the training need is defined and (roughly) ideal performance is characterized. This may not be in the form of a measurable MOP yet, however. If it is not, then an MOP must be developed that will indicate whether the measured performance will equate to skilled performance on the job. This defines what is to be trained.

Next, we recommend using the existing JDTA documentation wherever it is available (see (2) in Figure 1). At a minimum, this yields a baseline description of task execution that will be used later in the process. However, our investigation has suggested that most, if not all, JDTAs are coarse-grained descriptions of the task that are inadequate for the SoL method. We propose using them as the starting point, but they must be further modified to cover all elements of task execution. For example, under the job of Electronics Technician, the task description of "Identify function, uses, and troubleshooting techniques used with common test equipment." Defines a high level task. But for the SoL procedure, we need to know (a) what steps does the technician take to accomplish each part of this task, and (b) how is the task described for novice performance, advanced beginner, competent, proficient, and expert levels of expertise? Each of these will be different.

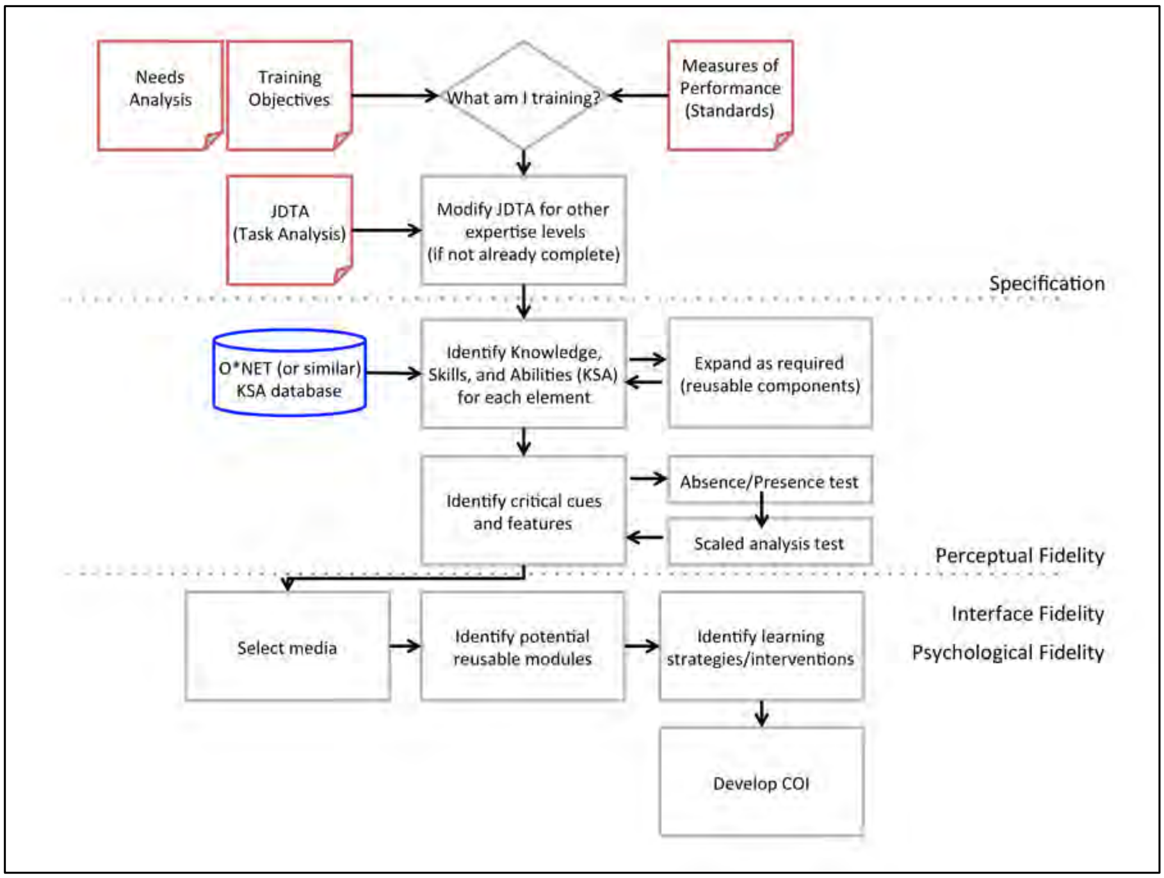


Figure 2. The SoL framework roadmap.

Next, once we have a JDTA at an adequate level of detail that also outlines how a task is performed at different levels of expertise, we need to identify the critical cues needed to perform the task. The Electronics Technician above, in order to use common test equipment, must be able to visually see the controls and displays. Thus, visual display of controls and displays on the test equipment would be a critical cue.

The task analysis now must be mapped to what the human operator (the trainee) must to do accomplish the task. Here we use an existing job inventory of knowledge, skills, and abilities (KSAs) maintained by the U.S. Department of Labor, O*NET (see http://www.onetonline.org). Filtering this analysis with the objectives of the training highlights the features that must be present in the training intervention to develop the required skilled performance. From this, media can be selected and eventually, the full COI.

Linking the SoL procedure to existing NETC practice, as outlined in the E2E documentation NAVERTRA 138, the “AS-IS” baseline (Chapter 3) is the JDTA and enhancements. The “TO-BE” requirements (Chapter 4) are the training outcomes and MOPs. Finally, the GAP requirements (Chapter 5) are the application of the O*NET KSAs to the JDTA filtered by the training objectives. All components of the proposed SoL methodology proposed here already exist in the adopted NETC procedure, albeit in a modified form.

The remainder of this research performed a case study analysis of portions of the Crane Operator job tasks. This validated that our approach was correct and we can use this methodology to correctly examine an existing JDTA. The entire case study can be found in (Darken & McDowell, 2017B).

Recommendations for Further Research

The next steps in the evolution of this methodology would include conducting a full analysis of a full JDTA. At this point, we would either (a) compare it to an actual training system acquired to meet that training requirement (a post-hoc analysis), or (b) use a new candidate training system as the focus and then determine if the resulting training transfer of the system can be predicted by the methodology (a priori analysis).

References

Darken, R., and McDowell, P. (2017A). NETC Acquisition Planning Framework for Managing Training Delivery - Applying the Science of Learning Methodology to Navy Training (Tech Report NPS-MV-17-001). Monterey, CA: Naval Postgraduate School.

Darken, R., and McDowell, P. (2017B). NETC Acquisition Planning Framework for Managing Training Delivery - Applying the Science of Learning Methodology to Navy Training: A Case Study Analysis (Tech Report NPS-MV-17-002). Monterey, CA: Naval Postgraduate School.

NPS-N16-N246-A: Women and Minority Officers in the Navy: Defining and Measuring Integration

Researcher(s): Dr. Simona Tick, Dr. Mark Eitelberg, and Capt. Michael Smith
Student Participation: LT David Mundell, USN

Project Summary
The Military Leadership Diversity Commission (MLDC) of 2011 and top Navy leaders have stressed the importance of achieving gender integration in the military, making it one of Navy's top priorities. The study explores the definition and measure of gender integration in the Navy using a combined, quantitative and qualitative, perspective. The study focuses on the Navy's officer corps. Further, since previous research shows that gender integration can vary significantly by race/ethnicity, the study looks at differences between racial/ethnic groups, including persons of Hispanic/Latino origin. The study aims to develop a conceptual model that can assist in interpreting the quantitative results of the study and in assessing the Navy's progress toward integration. Further, this theoretical and practical tool includes guidelines for decision makers as they measure current conditions and plan for the years ahead. The quantitative part uses quantitative multivariate analysis to provide a baseline capture of the position and performance of female and minority officers in the Navy. It examines the demographic and professional factors, such as gender, race/ethnicity, educational level, commissioning source, and Navy designator (military occupational specialty) that explain differences in outcomes of retention, promotion, and lateral transfers to another community. Based on our findings we formulate a detailed plan for continued research to define, measure, and evaluate integration of women and minorities in the Navy's officer corps.

Keywords: gender integration, minority integration, population representation, Navy officers, women officers, talent management, diversity, gender fairness, Navy manpower and personnel policy, equal opportunity policy

Background
What constitutes gender integration in the Navy, and how do we know when it has been achieved? Is it the presence of barriers, direct or indirect, that prevents women from serving in certain Navy occupations? Is it equal opportunities, regardless of gender, for all Navy personnel? Is it an organizational culture that treats women as equal partners with their male counterparts? Or is it measured more practically in terms of participation, where women constitute a specific portion of personnel within the Navy or some organizational component? The answer to what constitutes gender integration is *all of these*—and more.

Measures of success for gender integration are best described both qualitatively and quantitatively. For example, indicators of success can be (and have been) viewed in terms of accession rates, attrition/retention rates, occupational assignment trends, promotion rates, leadership opportunities, perceptions of command climate, sexual assault statistics, and many other factors. At the same time, integration has been examined more generally in terms of equity or fairness, legitimacy based on law or policy, institutional behavior and attitudes, and military effectiveness.

The study examines exclusively at the Navy's officer corps. Further, since previous research shows that gender integration can vary significantly by race/ethnicity, the present study investigates differences between major racial and ethnic groups, including persons of Hispanic or Latino origin.

The study combines a qualitative and a quantitative approach to analyze gender and minority integration in the U.S. Navy's officer corps and support policy planning in the years ahead.

Findings and Conclusions

The objective of the study is to assist policy makers in their efforts to achieve levels of gender integration desired by the MLDC and Navy leaders. The study focuses on the retention and promotion rates of female junior officers in the Navy, recognizing from previous research that these rates may differ significantly by race/ethnicity. By analyzing retention and promotion, the quantitative part of this study aims to identify factors that may influence the earlier career outcomes of women and their ultimate decision to leave or remain in the Navy for a full (20-year or longer) career. Using data on over 16,000 Navy officers commissioned from 1999 to 2003, and followed annually, the results from regression analyses show that women are less likely than men to stay in the Navy, but show no difference in promotion rates to O-4 and lateral transfers to another community. Also, officers who obtain graduate-level education or transfer laterally to another community by 10 years of service have higher rates of retention and promotion. Thus, one approach toward retaining more women in the Navy might be to expand their opportunities for graduate-level education and lateral transfer. Further research is needed to study the influence of these factors, particularly lateral transfers, on the stay–leave decisions of women.

The qualitative part of the study provides a thorough literature review to examine integration trends, issues, and policies. The review focuses on factors related to demographic differences in promotion and retention, as well as indicators of organizational commitment, fairness, and equal opportunity. The review draws heavily upon existing databases and other information from a variety of sources. No structured surveys, interviews, or original data collection are currently undertaken. Researchers rely on existing networks of subject matter experts and professional associations, as well as data collected and maintained by the U.S. Navy. These documents and databases are catalogued, analyzed, and integrated to document results, assess implications, draw conclusions, and develop recommendations. The present study explores the definition and measure of gender integration in the Navy using a quantitative and qualitative perspective. The findings from the literature review are used to develop a conceptual model to assist in interpreting the quantitative results of the study and in assessing the Navy's progress toward integration. The conceptual model has two major objectives: first, to serve as a practical tool for Navy policymakers in evaluating policy outcomes and charting future plans; and, additionally, to inform the quantitative phase of the study in identifying data requirements and performing statistical analysis.

Recommendations for Further Research

An important diversity goal is to increase the number and proportion of women in senior officer positions in the Navy. An effective way to improve gender integration and increase the representation of women in top leadership positions is through policies and programs that focus on retaining women. The number of women in higher positions in the Navy will only increase by raising the retention rate of women to a point that is at least equal to the rate of their male counterparts. The present study shows that graduate education and lateral transfers are associated with higher retention rates, regardless of gender. Consequently, further study should search for an approach that would increase the opportunities for women to obtain graduate education or complete lateral transfers. The study would need to be comprehensive, identifying new initiatives that would benefit retention while minimizing associated costs or unintended consequences, such as shifting gender representation in certain Navy communities. In the end, as the MLDC observes, improved representation of women in the higher echelons of Navy leadership would have a long-lasting, positive impact on organizational effectiveness and, ultimately, the nation's security.

NPS-N16-N271-A: Estimating the Depth of the Navy Recruiting Market

Researcher(s): Dr. Samuel Buttrey and Dr. Lyn Whitaker
Student Participation: Capt Emilie Monaghan USMC and MAJ Brandon Fulton USA

Project Summary

This report summarizes work done for the Navy Recruiting Command (NRC) through the Naval Postgraduate School's Navy Reimbursable Program (NRP). It includes a description of two theses, those of Monaghan (2016) and Fulton (2016). Both theses are deliverables for this project. We get around the problem that numbers of recruits are determined by recruiting effort by considering national leads. We conclude that using ZIP-code level can induce both noise and correlation and common approaches neglect important spatial correlations. If ZIP codes are to be used there should be a process to detect those that can never produce recruits. Zero-inflated negative binomial and random forest models both tend to over-predict recruits in highly-populated areas. We recommend fitting separate models in separate areas using Navy-specific data.

Background

Navy recruiting has a chicken-and-egg problem. In order to estimate the number of available recruits in an area, we can only look at the area's production in the past. But this depends on recruiter effort, and recruiter effort is determined by past production. In this research we discuss ways to measure the inherent propensity to enlist of the young people in an area. We use ZIP codes as preferred by the sponsor.

Findings and Conclusions

Using leads [on prospective recruits] as a proxy for inherent propensity is reasonable but the measurement of leads is problematic. The Navy has not focused data-integrity efforts on this measure. The approach of Fulton (2016) collapses large numbers of demographic variables into a small number of informative attributes. This approach seems to have worked well for the Army and should be pursued by the Navy. ZIP codes may not be the right level at which to measure propensity.

Recommendations for Further Research

- Use larger regional areas. NRC requested that this effort use ZIP codes, because those map directly to recruiting stations. However, using ZIP codes introduces errors and missing values in the features. It also makes modeling challenging for a couple of reasons.
- If ZIP codes are to be used, NRC should initiate a program to more carefully remove those ZIP codes that recruiters know will never produce a recruit, e.g. those belonging to single-address businesses. The issue of ZIP codes that can never produce a recruit must arise in every analysis of this sort, and being able to discard a large number of unproductive ZIPs in advance would help data analysts focus on real effects. Moreover the resulting models should, in principle, be simpler, if removing these ZIPs leads to removal of the zero-inflation portion of the models.
- Augment the five class-specific cluster membership features with other features taken from Fulton (2016). Fulton's work demonstrated one way to capture real predictive power across a set of hundreds of predictors in a much smaller number of carefully designed variables. It may be possible to produce even better models with additional features.
- Augment the features with features that capture potential Navy-specific influences on the number of leads in a region. Anecdotal evidence suggests that some areas are rich in recruits across all services, and that some areas are particularly rich in potential Navy recruits. Our models include features that intend to measure military influence in a community by, for example, its distance to the nearest military base and the number of veterans who live there. Using Navy-specific numbers might prove to be of value here.
- Construct a set of models rather than just one. In this work we tried to construct a single model that would predict the depth of the market at every occupied ZIP code. These "global-type" regression models were better than no model at all, but were also not spectacularly successful. (We say "global-type" because if a particular model parameter had a value in Florida in our model, it had that same value in Maine and Arizona.) A next step might be to divide the country into a fairly small number of regions and fit entirely separate ("local-type") models to each region. Perhaps weights for military presence should be higher in some areas of the country, whereas in others proximity to university is a more important factor.
- Consider modern statistical models. Newer models like random forests, ensembles of gradient boosted trees, and neural networks have seen success (in terms of predictive power) in many applications. These models have the drawback that they are rarely interpretable. Instead they act as "black boxes" that produce a prediction for an input. If these type of models are acceptable they might produce significant improvement.

References

Fulton, B. (2016). “Determining market categorization of United States ZIP codes for purposes of Army recruiting”, Master’s Thesis in Operations Research, Naval Postgraduate School, Monterey, CA.

Monaghan, E. (2016). “Estimating the depth of Navy recruiting market” Master’s Thesis in Operations Research, Naval Postgraduate School, Monterey, CA.

NPS-N16-N308-A: Diversity in the Navy: The Shape of Things to Come

Researcher(s): Dr. Mark Eitelberg and CAPT Michael Smith USN
Student Participation: Ten research papers by twenty-three students in the Manpower Systems Analysis Curriculum; Independent Readings Course project paper; two Master’s theses.

Project Summary

Previous studies by the project’s researchers assisted Department of Defense diversity planning and management by identifying and analyzing selected trends likely to affect military manpower and personnel issues in the years ahead. The present study replicates this previous work and examines diversity policy implications for the U.S. Navy. The study focuses on selected areas of interest, including national demographics, immigration, societal changes and population attitudes, Navy-qualified and available, aptitude test scores and education, and technological change. In considering the near-term and more distant future, researchers explore how trends and projected changes in selected areas are likely to influence Navy diversity policy, planning, and management.

The study benefited from the combined efforts of Manpower Systems Analysis (MSA) students in the Graduate School of Business and Public Policy. This included the following: a major course project for twenty-three MSA students working in research teams on related topics; an independent readings course; and two Master’s theses.

The expected completion date is late summer 2017. Initial results indicate a number of significant challenges for Navy manpower policy makers. Issues of major importance include population changes (demography, immigration, generational shifts, skill levels, attitudes, fitness, and language), technological advancement (workforce transformation, talent management, and labor supply/demand), and societal trends (particularly work-life balance, values, and culture).

Keywords: Diversity; Navy Population Representation; Navy Manpower Planning; Navy Manpower Policy; Talent Management; Trends; Recruiting; Personnel Retention

Background

As the Cold War concluded in the late 1980s, the U.S. military was preparing for a very uncertain future, described as a “fundamental metamorphosis, the likes of which have not occurred since the advent of the All-Volunteer Force and possibly since the end of World War II" (Eitelberg & Mehay, 1994a). Pushing such uncertainty were new missions, relatively large force reductions, base closures and a consolidation of functions, along with other major organizational changes. At the same time, the nation was undergoing significant environmental shifts—demographically, economically, politically, strategically—that would ultimately redefine important military policies, programs, and missions.

The Mobilization Concepts Development Center, an arm of the National Defense University's Institute for National Strategic Studies, commissioned Naval Postgraduate School (NPS) researchers to conduct a demographic trends study. NPS researchers explored how American demographic trends would affect national security over the following quarter-century (Eitelberg, 1988). Just a few years later, NPS researchers directed a comprehensive "Army Futures" project for the Program Analysis and Evaluation Directorate of the U.S. Army Recruiting Command. The second study was a major, multi-year effort that included over twenty commissioned papers by distinguished scholars and subject area experts from several government agencies. The "Army Futures" project culminated in a two-day conference held in January 1992 in Arlington, Virginia. The project results were published as an NPS technical report (Eitelberg & Mehay, 1992), three book chapters (Eitelberg, 1993b; Eitelberg & Mehay, 1994b; Eitelberg & Mehay, 1994c), a workshop proceedings for the Army Research Institute (Eitelberg & Mehay, 1993a), and an edited book, titled Marching Toward the 21st Century: Military Manpower and Recruiting (Eitelberg & Mehay, 1994a).

Fortunately, population diversity is an area that lends itself to prediction, since "data on the demographic features of the nation are abundant, including fairly reliable projections on the future aspects of the population, especially those that relate to military-age youth" (Eitelberg & Mehay, 1994a, p. xvi.). Indeed, these demographic factors are perhaps the most predictable trends of those influencing diversity. At the same time, numerous other factors likewise affect policies and programs to achieve or manage diversity in the U.S. Navy. This theme is supported in Managing Diversity in the Military (Dansby, Stewart, & Webb, 2001), which observes that a combination of various forces—such as political changes, technological and scientific advancements, economic fluctuations, and health trends—as well as demographic changes, both nationally and internationally, will continue to affect U.S. military personnel policies significantly in the years to come. The present research replicates previous work to assist diversity planning and management by identifying and analyzing selected trends likely to influence Navy manpower and personnel policy.

Findings and Conclusions

This study draws heavily upon existing databases and other information from a variety of sources (e.g., U.S. Census Bureau, 2015; Sackett, Eitelberg, & Sellman, 2010). No structured surveys, interviews, or original data collection were undertaken as part of the project. Researchers relied on existing networks of subject matter experts and professional associations, as well as data collected and maintained by the U.S. Navy and various U.S. government departments. The study has three primary research questions regarding the impact of selected trends on Navy diversity policy, programs, planning, and general management. In sum, given the identified trends and implications, how can the Navy "draw upon the widest possible set of talents and Backgrounds" (Chief of Naval Operation's Diversity Vision) most effectively in its planning and strategy?

The study was integrated with the MSA educational program in FY2016 and early FY2017, encouraging students to apply their research skills toward better understanding and appreciating diversity policies in the Navy. For example, as part of an advanced elective course, twenty-three MSA students worked in teams on ten separate projects related to the present study. These projects examined the possible effects on diversity of trends in technology, generational culture and values, expectations for work-life balance, immigration, employing non-citizens, population attitudes, youth propensity to join the Navy, and declining test scores among prospective recruits. Additionally, another MSA student studied the manpower implications of advances in robotics for an independent readings course. Finally, two MSA Master's theses supported the present research: a study of immigrants in the U.S. Navy and a study of how changing laws, attitudes, and behaviors regarding marijuana could affect Navy recruiting.

The revised study completion date is late summer 2017. An NPS technical report will present and discuss findings and conclusions.

Recommendations for Further Research

The project will develop a research plan for the Navy as it strives to study, measure, and attain diversity throughout the officer corps and enlisted force. The study uses previous research and publications (e.g., Eitelberg, 1988; Eitelberg & Mehay, 1994a, 1994b, 1994c) as a guide to analyze and report the project's results and Recommendations for Further Research.

References

Dansby, M.R., Stewart, J.B., & Webb, S.C. (Eds.). (2001). Managing diversity in the military. New Brunswick, NJ: Transaction Publishers.

Eitelberg, M.J. (1988). American demographic trends and national security: Issues for the 21st century, NPS-54-88-001. Monterey, CA: Naval Postgraduate School.

Eitelberg, M.J., & Mehay, S.L. (1992). The shape of things to come: Trends and projections affecting military recruiting and manpower in the 21st Century. NPS-AS-92-023. Monterey, CA: Naval Postgraduate School.

Eitelberg, M.J., & Mehay, S.L. (1993a). The shape of things to come. In D.R. Segal (Ed.), Sociological designs for the future Army: Workshop proceedings. ARI Research Note 93-14. Alexandria, Virginia: U.S. Army Research Institute for the Behavioral and Social Sciences.

Eitelberg, M.J. (1993b). Military manpower and the future force. In J. Kruzel (Ed.), American defense annual, 1993. New York: Lexington Books.

Eitelberg, M.J., & Mehay, S.L. (Eds.). (1994a). Marching toward the 21st Century: Military manpower and recruiting. Westport, CT: Greenwood Press.

Eitelberg, M.J., & Mehay, S.L. (1994b). The shape of things to come. In M.J. Eitelberg & S.L. Mehay (Eds.), Marching toward the 21st Century: Military manpower and recruiting. Westport, CT: Greenwood Press.
Eitelberg, M.J., & Mehay, S.L. (1994c). Demographics and the American military at the end of the twentieth century. In S.C. Sarkesian, & J. Flanagin (Eds.), U.S. domestic and national security agendas: Into the 21st century. Westport, CT: Greenwood Press.
Eitelberg, M.J. (2001). Women and minorities in the military: Charting a course for research. In M. R. Dansby, J. B. Stewart, & S. C. Webb (Eds.), Managing diversity in the military. New Brunswick, NJ: Transaction Publishers.
Sackett, P.R., Eitelberg, M.J., & Sellman, W.S. (2010). Profiles of American youth: Generational changes in cognitive ability. FR-09-22. Alexandria, VA: Human Resources Research Organization.
U.S. Census Bureau (2015). Population. Retrieved from: http://www.census.gov/topics/population.html (Note: A number of U.S. Census Bureau online sites were used as sources for the summary.)

NPS-N17-N316: Feature and Activity Recommendations to Support Outcomes of VW Training

Researcher(s): Dr. Kathryn Aten and Dr. Marco DiRenzo
Student Participation: LT Jennifer Bower USN and LT Jonathan Richmond USN

Project Summary
This is an in-progress summary. This study extends past research by exploring how innovative features of virtual worlds (VWs) influence learning outcomes across individual characteristics (e.g. age, gender, rank, psycho-social factors). The study assessed outcomes of cutting edge Submarine Learning Center- virtual schoolhouse (SLC-VSH) features and activities with a focus on competencies required for success in virtual world training. The study developed a model based on an initial analysis, which is summarized in this in-progress report. Additional analysis will test the model.

Keywords: Virtual world; training; synchronous, dispersed learning; learning competencies

Background
Virtual worlds may have advantages over traditional distance training and education environments. In particular, virtual worlds may enable collaborative learning activities, which have been shown to increase learner performance and satisfaction in face-to-face settings. These activities have proven difficult to conduct using more traditional distance learning technologies. Research suggests that successfully using virtual worlds for training and education may require adaptations in student and instructor behavior.

Virtual worlds offer the potential to provide reduced training costs compared with face-to-race training, increased engagement compared with other distance education tools, and better learning outcomes resulting from collaborative training activities. However, although new the technologies and work arrangements allow individuals separated by distance to work and learn together, this distributed learning and collaboration has proven challenging (Kirkman, Rosen, Gibson, Tesluk, & McPherson, 2002; Cramton, 2001; Desanctis & Monge, 1998; Gibson & Gibbs, 2006). Research suggests these challenges stem from difficulties inherent in communication technologies and distance learning.

For example, early research on virtual teams documented lower performance and satisfaction in distributed teams compared with their face-to face counterparts and often attributed these outcomes to challenges presented by technology-mediated communication (Cramton, 2001; Desanctis & Monge, 1998; Gibson & Gibbs, 2006). More recently, research and practice provide examples of success, and sometimes even better outcomes, through virtual than through co-located work (see Kock, 2006). Early research related to distributed collaboration often compared distributed and face-to-face teams. This research identified challenges facing distributed teams including, developing trust among members, creating synergy, and building group identity (see Kirkman et al., 2002; Cramton, 2001; Desanctis & Monge, 1998; Gibson & Gibbs, 2006). Suggested recommendations to overcome challenges included periodic face-to-face meetings and limiting complicated and ambiguous collaborative work to face-to-face settings. Recent research on distributed teams and on-line communities suggests that successful distributed collaboration requires different behaviors than face-to-face collaboration (Kock, 2004). In other words, successful distributed collaborators adapt their behavior to the task and medium (Maznevski & Chudoba, 2000; Kock, 2004; Kirkman et al., 2002). However, adapting behavior, while possible, is cognitively demanding and may reduce engagement and enjoyment (Kock, 2004; Guinea, Webster, & Staples, 2012).

Findings and Conclusions

This in-progress summary focuses on the thesis completed by Jonathon Richmond and Jennifer Bower (2016). This study was initiated to identify and illustrate with a visual model the key student learning competencies that most fundamentally contribute to a student's ability to achieve desired learning outcomes in a synchronous, dispersed virtual learning environment. We answered the following research questions: (1) which learning competencies can best be leveraged to support learning in a synchronous virtual-learning environment? (2) how can relevant learning competencies be transmitted to students during learning events? (3) which, if any, individual-level cognitive factors can be extracted during the pre-training phase that positively influence students' learning processes? and (4) which learning competencies can be added to existing models on learning in virtual environments?

By surveying students participating in the U.S. Navy's Virtual Schoolhouse, we were able to attain and analyze quantitative data. We discovered that virtual world efficacy is a meta-competency composed of autonomous learning, multiple level operation, and collaborative adaptability. Our research findings suggest that a student's capability to understand and learn in the virtual world is a broad competency and is a significant predictor of his/her success in the virtual environment. Based on our findings, we recommend a familiarity period to allow students to develop these competencies prior to their participation in virtual learning. Additional analyses will test these initial findings.

Recommendations for Further Research

The dramatic increase in popularity of asynchronous, dispersed learning institutions, such as the University of Phoenix and a growing number of public institutions, has generated a plethora of research, which can provide a valuable baseline for the Submarine Learning Center (SLC), Navy, and military in general to begin to understand the application of such environments for military training. There remains, however, a dearth of research on synchronous, dispersed learning environments, such as virtual worlds. Most studies of synchronous environments focus on synchronous gaming in virtual worlds. Given this lack of research and inherent between military and civilian contexts, we recommend that the Navy continue to refine and enhance the virtual schoolhouse (VSH) competency model.

First, we found that virtual world efficacy was a broad overarching competency from which other competencies such as articulation, synchronous chat, and ability were comprised. We speculate that a “familiarization period” before commencement of class has the potential to affect some second tier competencies, leading to greater student satisfaction and overall performance. The SLC and the Navy could gain significant insight by testing in greater size and scale the effects of a familiarization period on students’ second tier competencies according to the Bower Richmond model and measuring if the development of one or several of these competencies had a positive effect on students’ virtual world efficacy and satisfaction and performance.

Second, additional research should investigate interactivity and collaboration in terms of student-to-student competencies as well as the student-to-system and student-to-instructor competencies, previously included in the Spears model (2014), as potential predictors of student success. Student-to-student interactivity and collaboration are increasingly vital forms of learning and problem solving in the classroom and workplace. Future studies could include enhanced opportunities for students to work together on specific problem-solving or decision-making situations related to the class material. Then students’ reaction to these student-to-student learning opportunities could be measured and evaluated. These student-to-student research results could then be used to refine the current Bower Richmond VSH Competencies Model.

Third, instructor competencies are closely related to student performance and should also be measured in future research. Aten and DiRenzo’s research included several indications that instructor competencies can significantly impact each student’s learning experience in the VSH and the authors suggested priming designed to enhance students’ perceptions of instructor competency be included in future research (2014). Instructor competency is a vital key to the success of any learning experience and this competency may be even more important in remote learning settings like VSH.

Finally, our findings did not identify significant relationships between autonomous learning and multiple level operation and cognitive processes and/or learning outcomes. We believe this was due to our small sample size. However, this could be due the nature of a military environment, where rank structure and rigid adherence to classroom procedures may have affected these competencies. Likewise, since the VSH is a synchronous environment, perhaps autonomous learning and multiple level operations are not make as profound and significant a contribution to students' cognitive processes and overall achievement as they might in an asynchronous environment. Thus, we suggest additional research with a greater sample size be conducted to further identify and explore such relationships.

References

Aten, K., & DiRenzo, M. (2014). *Assessing the potential of virtual worlds for Navy Training and Education: cognitive learning processes and outcomes in the virtual school house (VSH)* (Professional Report). Retrieved from Calhoun http://calhoun.nps.edu/handle/10945/45529.

Carlson, J. R., & Zmud, R. W. (1994). *Channel Expansion Theory: A Dynamic View of Medial and Information Richness Perceptions.*

Cramton, C. D. (2001). The mutual knowledge problem and its consequences for dispersed collaboration. *Organization Science*, *12*(3), 346-371.

Desanctis, G., & Monge, P. (1998). Communication processes for virtual organizations. *Journal of Computer-Mediated Communication*, *3*(4), 0-0.

Gibson, C. B., & Gibbs, J. L. (2006). Unpacking the concept of virtuality: The effects of geographic dispersion, electronic dependence, dynamic structure, and national diversity on team innovation. *Administrative Science Quarterly*, *51*(3), 451-495.

Guinea, A. O. d., Webster, J., & Staples, D. S. (2012). A meta-analysis of the consequences of virtualness on team functioning. *Information & Management*.

Kirkman, B. L., Rosen, B., Gibson, C. B., Tesluk, P. E., & McPherson, S. O. (2002). Five challenges to virtual team success: Lessons from Sabre, Inc. *The Academy of Management Executive (1993-2005),* 67-79.

Kock, N. (2005). Media Richness or Media Naturalness? The Evolution of Our Biological Communication Apparatus and Its Influence on Our Behavior Toward E-Communication Tools. *IEEE Transactions on Professional Communication*, *48*(2), 117-130.

Kock, N. (2004). The Psychobiological Model: Towards a New Theory of Computer-Mediated Communication Based on Darwinian Evolution. *Organization Science*, *15*(3), 327-348.

Maznevski, M. L., & Chudoba, K. M. (2000). Bridging space over time: Global virtual team dynamics and effectiveness. *Organization Science*, *11*(5), 473-492.

Spears, W. (2014). *Factors affecting training effectiveness in synchronous, dispersed virtual environments* (Master's thesis). Retrieved from Calhoun http://hdl.handle.net/10945/42730

NPS-N16-N320-A/NPS-N16-N146-C: Development of a Big Data Application Architecture for Navy MPTE

Researcher(s): Dr. Magdi N Kamel
Student Participation: LT Khristian Caindoy USN, LT Armin Moazzami USN, and LT Anthony Santos USN

Project Summary

Navy Manpower, Personnel, Training, and Education (MPTE) decision makers require improved access to the information obtained from the vast amounts of data contained in a number of disparate databases/data stores in order to make informed decisions and understand second- and third-order effects of those decisions. Toward this end, the effort of this research was two-fold. First, it examined and proposed an end-to-end application architecture for performing analytics for MPTE. Second, it developed a decision tree model to predict retention of post-command aviators, using the Cross-Industry Standard Process for Data Mining (CRISP-DM), in support of one Navy MPTE's main concerns: retention in post-command aviator community.

This research concluded that with the exponential collection and growth of diverse data, there is a need for a combination of Big Data and traditional data warehousing architectures to support analytics at MPTE. The data-mining effort developed a preliminary predictive model for post-command aviation retention and concluded that the number of Navy Officer Billet Classification (NOBCs), particularly non-aviation NOBCs, was the most important indicator for predicting retention. Additional data sources particularly those that contain Fitness Reports/Evaluations need to be included in order to improve the accuracy of the model.

Keywords: Big Data, application architecture, enterprise architecture, OPNAV N1, manpower, personnel, training, education, predictive modeling, CRISP-DM, aviation community retention

Background

The Chief of Naval Personnel (CNP) is responsible to the Chief of Naval Operations (CNO) for Navy's manpower readiness (Department of the Navy [DON], n.d.-a). Dual-titled as the Deputy Chief of Naval Operations (Manpower, Personnel, Training Education/OPNAV N1), the CNP oversees the Bureau of Naval Personnel (BUPERS), Navy Personnel Command (NPC), Naval Education and Training Command (NETC), and the Navy Manpower Analysis Center. Combined, these organizations create and implement the overall strategy and policies concerning manpower and training programs (DON, n.d.-a).

The overall mission of the CNP is to "anticipate Navy warfighting needs, identify associated personnel capabilities, and recruit, develop, manage, and deploy those capabilities in an agile, cost-effective manner" (Hall, 2006, para. 8). In order to achieve this mission, CNP has set forth three strategic objectives for the MPTE domain: Responsive Force Management, Effective Personnel Readiness, and Sound Organizational Alignment (Navy Personnel Command [NPC], 2013). Responsive Force Management focuses on bettering distribution, training, recruiting, and retention in order to meet Fleet manpower requirements (NPC, 2013). Effective Personnel Readiness focuses on developing a ready Sailor through proper training and education and supported by services and resources they and their families need (NPC, 2013). Sound Organizational Alignment focuses on ensuring the decisions and actions made by OPNAV N1 are aligned with the needs of the fleet (NPC, 2013). It is through these strategic objectives that MPTE will continually support the CNO's principles of Warfighting First, Operate Forward, and Be Ready (NPC, 2013).

Findings and Conclusions

The main objectives of this research were to examine and propose an end-to-end application architecture for performing analytics for Navy MPTE, and to develop a predictive model for retention to address Navy MPTE's concerns regarding retention of the post-command aviators. The following are the specific research questions posed by this research, how they were addressed, and answers to these questions as uncovered by the research effort.

1. Data Architecture Questions

-What are the various internal and external data sets that need to be analyzed?

This research mainly focused on internal data sets of MPTE, such as Officer Personnel Information System (OPINS) and Navy Enlisted System (NES) for officer and enlisted data, NTMPS for training data, NSIPS for pay and personnel information, and NMPBS for historical records. External data sources such as social media were beyond the scope of this thesis as access was not available to those data sets.

-How is the ingestion of the data into the Hadoop environment accomplished from the data sources?

With the majority Navy MPTE's databases classified as relational databases, the best tool for ingestion into a Big Data platform is Sqoop, which is specifically designed to support the ingestion of data from relational database management system (RDBMS) to Hadoop Distributed File System (HDFS) (Teller, 2015). Sqoop automates most of the ingestion process and can support incremental imports of data, only retrieving records newer than the previously imported set ("Sqoop User Guide," 2016). This feature would be helpful to Navy MPTE as their databases update monthly.

-What are the necessary Hadoop infrastructure hardware and software components?

The two infrastructures that can support Big Data are in-house and cloud infrastructures. In-house infrastructures are owned and maintained by the organization, while third-party vendors provide the infrastructure for cloud computing. In recent years, the Department of Defense (DOD) has pushed towards establishing the DOD Cloud Environment in order to reduce the current information technology (IT) infrastructure (Department of Defense, 2012). In line with the DOD Cloud Computing Strategy, our recommendation is to use cloud computing as the underlying infrastructure for a Big Data architecture. According to the DOD (2012), the benefits

of cloud computing include improved server utilization, immediate increase or decrease of servers, the ability to take advantage of emerging technologies of the private sector, and a shift from managing and maintaining hardware to only managing services.
Many analytic tools are available that can support Navy MPTE's mission by creating a common operating picture. Impala and Mahout are good candidates that can provide the necessary capabilities to meet the requirements of Navy MPTE. Impala provides the capability to process data of different types and formats, including text, efficiently. Mahout is a machine learning library of algorithms that can analyze data sets of different sizes to create predictive and other models.

-What are the different types of NoSQL databases that are most suitable to store Navy MPTE data?

Based on the current data sources, we theorize that the most suitable NoSQL database to meet Navy MPTE's business needs is a graph data store. This type of database provides for the analysis of complex relationships of data, and is suited for recommendation systems (Hecht & Jablonski, 2011). Additionally, a column-oriented database, like HBase, can be used to store data from social media (Sawant & Shah, 2013).

-Does Navy MPTE need Big Data technology or should it instead use a high-performing, relational database management system (RDBMS) and traditional Data Warehouse technology?

The overall architecture we recommend for Navy MPTE is a combination of Big Data and traditional relational database management systems. Depending on the type of analysis Navy MPTE requires, they can take advantage of what both Big Data and RDBMS has to offer. RDBMS allows for the inserting, updating, and deleting of records, while Big Data processing tools like Hive and Impala does not. In addition, RDBMS are beneficial for Navy MPTE for analyzing small data sets and providing immediate results (Cloudera, 2014). However, Big Data analytics and processing tools like Pig, Hive, and Impala are optimized for large amounts of data, can support complex data types, and scale at relatively low cost (Cloudera, 2014).

Analyzing data is a challenging task as Navy personnel data is distributed across multiple databases. A Big Data architecture provides a way to integrate multiple data sources without needing to replace current RDBMS. In addition, a Big Data architecture takes advantage of NoSQL databases in storing structured and unstructured data, allowing for a more efficient way of organizing data vice having multiple records for a single person in a relational database, which does not scale well when data grows.

2. Data Mining Project Questions

-What are the substantive issues that a Navy MPTE Common Operating Picture is trying to solve?

Navy MPTE's motivation for developing a Common Operating Picture is to identify and retain the most talented Sailors. There are several factors that can be used to identify the most qualified Sailors such as their educational level, training, billet history, and fitness reports (FITREPs). Currently, the Navy is losing a good amount of experienced and talented officers to the private sector, which is an important concern for Navy leadership and the health of the fleet in the future.

-What are some indicators that would lead an Officer to leave the service?

Navy Officer Billet Classifications (NOBCs) were discovered as the most important indicator to determine whether an officer leaves the service. Aviators are likely to leave the service if they have eight or fewer NOBCs.

Recommendations for Further Research

The effort of this research was limited to only using OPINS as the primary source of data for developing a predictive model of retention of post command aviators. Other data sources can significantly improve the accuracy of the developed predictive model and should be incorporated in any future research. For example, training data, located in Navy Training Management and Planning System (NTMPS), can pinpoint what talent is being retained or lost. NES can also be incorporated to predict retention for enlisted Sailors. FITREPs/Enlisted Evaluations contain information regarding billets, performance trait average, physical fitness scores, and milestone recommendations of the reporting senior. This information can be found in relational databases like Navy Standard Integrated Personnel System (NSIPS). Reporting senior's comments on the performance of the officer could also be very helpful in improving the accuracy of the predictive model.

References

Cloudera. (2014). Choosing the best tool for the job [Lecture notes]. Retrieved from https://cle.nps.edu/access/content/group/a20708ea-7b82-4441-9119-97ad0b401f77/Lecture%20Presentations/Week%2010%20Lectures.pdf

Department of Defense. (2012). Department of Defense cloud computing strategy. Retrieved from http://dodcio.defense.gov/Portals/0/Documents/Cloud/DOD%20Cloud%20Computing%20Strategy%20Final%20with%20Memo%20-%20July%205%202012.pdf

Department of the Navy. (n.d.-a). Chief of Naval Personnel – Responsibilities [Information on page]. Retrieved January 6, 2016, from http://www.navy.mil/navydata/leadership/cnp_resp.asp

Hall, T. S. (2006). CNP shares strategic vision while visiting NAS Pensacola [Newspaper story]. Retrieved from http://www.navy.mil/submit/display.asp?story_id=24088

Hecht, R. & Jablonski, S. (2011). NoSQL evaluation: A use case oriented survey. 2011 International Conference on Cloud and Service Computing, 336–341. doi: 10.1109/CSC.2011.6138544

Navy Personnel Command. (2013). 2020 Strategic vision 2013 update. Retrieved from http://www.public.navy.mil/bupers-npc/organization/npc/spio/Documents/2020%20Vision%20FINAL%20041013.pdf

Sawant, N., & Shah, H. (2013). Big data application architecture Q&A: A problem - solution approach (1st ed.). Berkeley, CA: Apress.

Teller, S. (2015). Hadoop essentials. Birmingham, UK: Packt Publishing.

NPS-N16-N334-A: Retention of High Quality Officers: A Quantitative and Qualitative Approach to Assess the Importance of STEM Degrees and Other Factors

Researcher(s): Dr. Simona Tick, Dr. Mark Nissen, and Dr. Elda Pema
Student Participation: LT William V. Maugeri III USN

Project Summary
The U.S. Navy strives to manage talent by recruiting, developing and retaining quality, diverse personnel that meet the requirements of current and forecasted billets and weapons systems. Recent efforts in officer recruitment have focused on increasing the number of newly commissioned officers with technical degrees. These are often referred to as Science, Technology, Engineering and Mathematics (STEM) majors, assumed to train faster and perform well in junior officer positions, but also posing higher retention risks as they are in higher demand in the industry. This study uses a quantitative analysis approach to examine whether STEM background officers have different retention, promotion and performance measures compared with those of non-STEM background officers. To better understand what motivates high-talent officers to stay or leave the Navy, this study uses a qualitative approach to build up a grounded understanding *talent* and identifying both positive and negative issues driving talented people's decisions to leave or stay in the Navy in the Information Warfare Community (IWC). The IWC provides a vital, sophisticated capability to address increasingly dynamic and unpredictable threats around the world. The problem is, the same skills and capabilities that make IWC personnel so valuable to the Navy also make them valuable to myriad firms in industry and organizations elsewhere beyond the Services. The findings elucidate unique aspects of IWC talent and retention, in addition to attributes and issues that information warriors share with other service members, and highlight opportunities for Navy leaders to address talent and retention in the IWC and beyond.

Keywords: talent management, officer quality, quantitative multivariate analysis, qualitative analysis, interview, IWC officers, STEM degree officers' retention

Background
As highlighted in two recent initiatives, the "Design to Maintain Maritime Superiority" and "Sailor of 2025", one of the Navy's priorities is to increase its efforts to better identify, promote and retain the most talented, highest quality personnel. Identifying talent is a challenge for any organization, as a definition of talent is tied to the values of the organization.

Are technical, STEM, degrees a signal of talent, and quality? As weapon systems become more technically sophisticated the demand for technical expertise continues to grow. In addition, traditionally it has been assumed that officers with STEM degrees are more likely to complete their skill training than those with non-technical degrees. It is also assumed that officers with STEM majors are more productive on-the-job, especially as junior officers; that they are more likely to choose initially or to later transition into technical jobs (e.g., engineering departments on nuclear combatants, engineering duty officers, and test pilots); and that they are more likely to choose and be selected for technical graduate education programs. On the other hand, the perception is that the Navy faces a higher retention risk from STEM officers. This is due in part to the lucrative civilian employment opportunities available in the labor market, particularly as the economy becomes strong.

To better understand what motivates high-talent officers to stay or leave the Navy, this study uses a qualitative approach to build up a grounded understanding of Navy Information Warfare Community (IWC) talent and identifying both positive and negative issues driving talented people's decisions to leave or stay in the Navy. The Navy Information Warfare Community (IWC) provides a vital, sophisticated capability to address increasingly dynamic and unpredictable threats around the world. The problem is, the same skills and capabilities that make IWC personnel so valuable to the Navy also make them valuable to myriad firms in industry and organizations elsewhere beyond the Services. Moreover, such skills and capabilities are *directly transferrable* to industry. As a result, many talented information warriors are leaving the service at the midpoints of their military careers. Further, unlike other Navy communities (e.g., Aviation, Nuclear), in which clear career guidance and well-established incentives (e.g., bonus and retention pay) are in place, the comparatively inchoate IWC does not appear to benefit similarly, and given the unique nature of the IWC, it's not entirely clear what "talent" means in this community. Indeed, *talent* seems likely to be a highly situated and nuanced concept—far from general and monolithic—that is aligned with a person's knowledge and capability within an organization setting. Understanding talent represents the first step toward identifying and retaining the best IWC people before they leave the service.

Findings and Conclusions

Using an integrated qualitative and quantitative approach, our study focuses on (STEM) college majors as a potential indictor of quality while investigating new, more nuanced measures of talent through a pilot interview-based investigation tool applied to the technical Information Warfare Community (IWC), community known for intense competition for talent with the private sector.

This quantitative part of the study examines how well matched STEM background officers are to their initial job assignments. As part of talent management, the hypothesis is that a better initial match may contribute toward a higher retention rate at Minimum Service Requirement (MSR). We examine whether STEM majors achieve stronger job-related performance, especially as junior officers, compared with non-STEM background officers. The findings find no support for the hypothesis that STEM background officers are better matches for Navy billets, as compared with non-STEM background officers.

The qualitative part of the study describes how *talent* is a highly situated and nuanced concept—far from general and monolithic—aligned with a person's knowledge and capability within an organization setting. Indeed, we identify what constitutes talent in the IWC: IT technical knowledge and the competence that it enables are fundamental, but we find nuanced differences between the cyber warrior and information communicator tribes. For the cyber warriors, IT technical knowledge and the ability to take effective actions within cyberspace are central to talent. For the information communicators, technical system knowledge and the ability to communicate within the organization are key. For both tribes, talent does not appear to correlate positively with rank. We identify four significant retention risks: 1) Rotation out of cyber jobs, 2) generalization through job breadth, 3) dearth of command opportunities, and 4) repeated exposure to toxic leaders. Results elucidate unique aspects of IWC talent and retention, in addition to attributes and issues that information warriors share with other service members, and they highlight opportunities for Navy leaders to address talent and retention in the IWC and beyond.

Recommendations for Further Research

Quality among Navy personnel is not easy to define. One definition of high quality Navy personnel refers to the quality of the match between individual's skills and capabilities, and the job requirements. Our study provides support to the Navy's effort to identify and measure quality. We test the hypothesis that STEM college majors might be an indicator of talent, and thus quality among Navy officers. Our findings did not find support for this hypothesis. However, due to shortcomings in the Navy data further research needs to validate these findings. Future work can be done to examine which STEM majors are most likely to succeed, and how lateral transfer and graduate education opportunities impact STEM officer performance and retention.

Through the qualitative part we identify what constitutes talent in the IWC: IT technical knowledge and the competence that it enables are fundamental, but we find nuanced differences between the cyber warrior and information communicator tribes. For the cyber warriors, IT technical knowledge and the ability to take effective actions within cyberspace are central to talent. For the information communicators, technical system knowledge and the ability to communicate within the organization are key. For both tribes, talent does not appear to correlate positively with rank. One recommendation is to propose an alternate career path for talented officers who do not seek command, one that would enable such officers to "homestead" in cyber and other jobs as specialists instead of generalists. This could potentially address the first two retention risks directly, and it could have an indirect effect on the third by reducing the amount of competition for the limited number of milestone and command billets. Another recommendation could consider breaking some very large commands into smaller parts, which could accommodate more officers seeking command. The final recommendation proposes to include command climate survey results on leaders' fitness reports; to identify talented IWC personnel; and to grant them limited access to more-senior officers above their direct superiors. Of course, much work would be required to implement recommendations along these lines, and it is unclear what impact they would have upon the detailing process, morale, perceived fairness, recruiting, the chain of command and other areas. Hence we leave the answers to such questions as topics for future research. Nonetheless, they offer potential to help to keep talented information warriors from leaving the Navy.

N2/N6: Information Warfare

NPS-N16-N200: Crowd Sourcing Human Analyst Playbooks for Insider Threat Mitigation

Researcher(s): Dr. Shelley P. Gallup, Dr. Nelson Irvine, and Dr. Tom Anderson
Student Participation: Capt William (Will) Campbell USA

Project Summary
There are many features to the design of an Insider Threat Hub. Past research obtained crowd source recommendations for the organizational structure and relationships in a hub. This research extends that work, and begins a close look at some specific relationships. Current hub configurations rely heavily on user activity monitoring (UAM) as the source for input to the analysis team. UAM provides a huge amount of information and will use some tools to discern alerts worthy of analysis from Background routine information. This research takes a position that in addition to UAM data, inputs from other databases can refine the alerts being presented to analysists and reduce false alarm rates (alerts that are not significant for further processing).

Background
In response to incidents arising from personnel internal to organizations in the DOD, the Department of Defense (DOD) was with building programs to combat this rising threat (Executive Order No. 13587, 2011; Department of Defense, 2014). The resultant insider threat hubs rely heavily on user activity monitoring (UAM) tools to provide insider-threat alerts to the analytic cell. The DOD currently employs 2.8 million personnel and military members consisting of active duty, reserve, and National Guard units (Department of Defense, 2015, para. 4). The challenge these hubs face is identifying insider threats among the workforce as a whole. The Defense Insider Threat Management Analysis Center (DITMAC) is overall responsible for the processing of insider threat data; however it is likely that this center will be faced with a very large false alarm rate of alerts to identification of a bona-fide threat. A system of systems approach was used in the accompanying thesis work by CAPT Will Campbell, U.S. Army. This work details the inclusion of amplifying data from other sources that could be brought together with UAM data to create a more contextually relevant understanding of the threat potential, thereby reducing the false positive rate and increasing the efficiency of the hub.

Findings and Conclusions
The hypothesis being treated in this research: A systems of systems (SoS) approach to data collection can improve insider-threat hub analysis. This approach has the potential to make the hub more efficient at preventing, detecting, deterring, and mitigating insider threats by integrating the external data sources with the internal data sets thus improving the efficiency of insider-threat hub analytics. Research questions to support this hypothesis are as follows:

- How are DOD organizations constructing their insider-threat hub architecture?

- What is the current data-collection ecosystem for insider threats, and how does it affect information flow?
- What are the challenges surrounding data collection within the insider-threat architecture?
- How can a SoS approach be implemented to enhance the data-collection ecosystem and improve the analytic processing insider threats?

Data for this work was obtained through interviews with several agencies all working the same set of insider threat needs. In addition, U.S. Army counter intelligence was used as a model for bringing together a range of other inputs that could contextualize the user activity monitoring being employed by all hubs.

With data in hand, a simulation was constructed in order to determine the effects of having additional information would have on the performance of the hub organization and the impact on false alarm rates.

The results of the simulation showed that there are many potential contributors to the data available to insider threat hubs. However, bringing the additional data comes with a cost to efficiencies of the hub in their current configurations. Although false alarm rate may decrease, there are trade-offs with processing time and the number of analysts necessary to use the increased range of data inputs.

Recommendations for Further Research

There are two recommended points of emphasis for future work: (1) implementing and testing a SoS approach to insider-threat hubs, and (2) conducting analysis of additional insider-threat hubs as they become operational. The first will present insider-threat hubs with additional data. Although, this may add to the false-positive rate, the assumption is analysts may be able to narrow their focus on sources and individuals with multiple insider-threat alerts from internal and external sources versus focusing primarily on clearing UAM alerts. Additionally, as the threat of insiders continues to change so too does the technologies and processes implemented to detect these changes. It is critical to our cyber security to continue to conduct analysis on insider-threat hubs in order to improve DOD's methods of detecting these threats. Additionally, raw data from insider-threat hubs may provide more accurate results in the simulation used for this thesis (From Campbell's thesis).

In addition the application of additional tools for big-data analysis needs to be investigated. A current follow on NRP project "Insider Threat Mitigation Using Lexical Link Analysis (LLA) Methods" is in progress at this time.

References

Anderson, R. H., & Brackney, R. (2004). *Understanding the insider threat: Proceedings of a March 2004 workshop.* Santa Monica, CA: RAND. Retrieved from http://www.rand.org/pubs/conf_proceedings/CF196.html

Blyth, A., & Charitoudi, K. (2013). A socio-technical approach to cyber risk management and impact assessment. *Journal of Information Security*, *4*(1) 33–41. http://file.scirp.org/pdf/JIS_2013013014352043.pdf

Cole, M., & Esposito, R. (2013, August 26). How Snowden did it. *NBC News.* Retrieved from http://www.nbcnews.com/news/other/how-snowden-did-it-f8C11003160

Defense Security Services. (2015, April 16). *DOD insider threat management and analysis center: DOD insider threat OV-1 (notional) and DITMAC OV-1* [PowerPoint Slides]. This document is For Official Use Only.

Department of Defense. (2015, August 27). About DOD. Retrieved from http://www.defense.gov/About-DOD

Department of Defense. (2012, May 4). *Countering espionage, international terrorism, and the counterintelligence (CI) insider threat* (DOD Instruction 5240.26). Washington, DC: Author.

Department of Justice. (n.d). *The insider threat: An introduction to detecting and deterring an insider spy* [Brochure]. Retrieved from https://www.fbi.gov/file-repository/insider_threat_brochure.pdf

Executive Order No. 13587, 3 C.F.R. 276–280 (2011).

Fox, W. M. (1995). Sociotechnical system principles and guidelines: Past and present. *Journal of Applied Behavioral Science, 31*(1), 91–105.

Gosztola, K. (2016, March 18). Insider threat program uses Chelsea Manning as example to criminalize whistleblowers. *Shadowproof*. Retrieved from https://shadowproof.com/2016/03/18/insider-threat-program-uses-chelsea-manning-as-example-to-criminalize-whistleblowers/

Headquarters, U.S. Army Intelligence Center and Fort Huachuca. (2008, July 22). *Intelligence systems* (Military Intelligence Handbook 2–50). Fort Huachuca, AZ: Author. This document is For Official Use Only.

Hutchins, E. M., Cloppert, M. J., & Amin, R. M. (2011). Intelligence-driven computer network defense informed by analysis of adversary campaigns and intrusion kill chains. *Leading Issues in Information Warfare & Security Research, 1,* 80.

Irvine, D. N. (2016, September). *ExtendSim simulation of the Navy insider threat hub* [Technical Report]. Naval Postgraduate School.

Lockheed Martin. (2015). *Seven ways to apply the cyber cill chain with a threat intelligence platform* [white paper]. Retrieved from http://lockheedmartin.com/content/dam/lockheed/data/corporate/documents/Seven_Ways_to_Apply_the_Cyber_Kill_Chain_with_a_Threat_Intelligence_Platform.PDF

National Geospatial Agency (NGA). (2016). (FOUO) *NGA insider threat office: overview.* [PowerPoint Slides]. Springfield, VA: Author. This document is For Official Use Only.

National Insider Threat Task Force. (n.d). *National insider threat task force mission* [Fact Sheet]. Retrieved from https://www.ncsc.gov/nittf/docs/National_Insider_Threat_Task_Force_Fact_Sheet.pdf

Obama, B. (2012, November 21). *National insider threat policy* [Memorandum]. Washington, DC: White House.

Office of the Under Secretary of Defense for Intelligence. (2013, November 20). *Internal review of the washington Navy yard shooting. A report to the Secretary of Defense.* Washington, DC. Retrieved from http://www.dtic.mil/get-tr-doc/pdf?AD= ADA602573

Ponemon Institute. (2016, September). *2016 cost of insider threats.* Traverse City, MI: Ponemon Institute. Retrieved from https://dtexsystems.com/cost-of-insider-threat/

Sellen, J. (2016, September). *Insider threat data sharing.* (Master's thesis). Retrieved from Calhoun: http://hdl.handle.net/10945/50480
United States Joint Chiefs of Staff. (2013). *Joint intelligence* (JP 2–0). Washington, DC: Author.
Vormetric Data Security. (2015). *2015 Vormetric insider threat report*. San Jose, CA: Vormetric. Retrieved from https://www.vormetric.com/campaigns/insiderthreat/2015/

NPS-N16-N201-C: Darknet and DoD Networks: Obfuscation, Spoof Detection, and Elimination

Researcher(s): Dr. Shelley P. Gallup, Dr. Tom Anderson, Mr. Victor (Bob) Garza, Dr. Nelson Irvine, and Mr. Brian (Woodie) Wood
Student Participation: LT Kevin Dougherty, USN

Project Summary

There is no process or system capable of detecting obfuscated network traffic on DOD networks, and the quantity of obfuscated traffic on DOD networks is unknown. The presence of obfuscated traffic on a DOD network creates significant risk from both insider-threat and network-defense perspectives. This study used quantitative correlation and simple network-traffic analysis to identify common characteristics, relationships, and sources of obfuscated traffic. A set of concepts were identified and proposed as a set of testable Key Cyber Concepts (KCCs) for obfuscation behavior. Each characteristic was evaluated individually for its ability to detect obfuscated traffic and in combination in a set of Naive Bayes multi-attribute prediction models. The best performing evaluations used multi-attribute analysis and proved capable of detecting approximately 80 percent of obfuscated traffic in a mixed dataset. By applying the methods and observations of this study, the threat to DOD networks from obfuscation technologies can be greatly reduced (Abstract from LT Kevin Dougherty NPS 2017 thesis "Identification of low latency obfuscated traffic using multi-attribute analysis".)

Background

OPNAV N2 is seeking ways to mitigate network vulnerabilities and capabilities to meet the evolving cyber threat. A considerable vulnerability to cyber security is the unfettered network access to users with obfuscated identities. Currently obfuscation technologies allow users to act anonymously, without attribution, thus creating a hostile cyber culture where both inside threats and outside may snoop, act outside of protocol, or sabotage systems. Developing a capability to discern obfuscated traffic from non-obfuscated traffic would allow policies to be put in place to block obfuscated users where it is deemed appropriate. This effort produced LT Dougherty's Master's thesis that provides details for the research discussed here, and was honored as an Outstanding Thesis.

We sought to identify obfuscation indicators that can be used to evaluate whether low-latency Transmission Control Protocol/Internet Protocol (TCP/IP), specifically HyperText Transfer Protocol Secure (HTTPS) traffic, is employing obfuscation techniques. The research questions pertaining to this explored were: Can low-latency obfuscated network traffic be identified in real time? What IP traffic indications can be used to identify obfuscated low-latency network traffic? Can multiple indications be incorporated into a multi-attribute analysis model to accurately identify obfuscated traffic? Can a multi-attribute analysis model be used in a tool to provide a real-time processing capability to analyze obfuscated traffic data for automated response? Can the key cyber concepts be easily adapted to an architecture framework for ad hoc implementation of cyber solutions into an operational system?

Findings and Conclusions

We used a quantitative correlation approach to examine analysis techniques for identifying low-latency obfuscated network traffic. Real-world network data was analyzed using traditional network traffic analysis. We examined the characteristics, and the relationships between characteristics, associated with obfuscated traffic. We conducted independent statistical analysis of network traffic attributes first to determine each attribute's viability to function as a single discriminator. We then used a Naïve Bayes classifier model for multi-attribute analysis with the assumption that all variables are independent. The Naïve Bayes classifier utilized the individual characteristics together, some with higher false-positive rates (FPRs), to detect obfuscated traffic.

A virtual lab was configured with an Internet-facing SharePoint page, that enabled testing and evaluation of obfuscated and non-obfuscated network traffic for a variety of popular operating systems. To generate non-obfuscated network traffic, a standard Firefox browser was used. To standardize the datasets, Selenium IDE, a Web browsing automation tool, was used to script 'normal' browsing activity on the webserver.[1] Baseline data consisting of several hours of network traffic from regionally distributed actors was used to evaluate and determine the performance of each indicator prior to constructing the multi-attribute detection model. A combination of physical and virtual machines was used to gather 24 hours of Tor and non-Tor traffic, respectively. All data was written to database, and subsequent statistical analysis was conducted on the data.

We examined four separate indicators (KCCs) to determine whether network traffic was obfuscated. Key Cyber Concept One: Low TTL Count, this examined the time-to-live (TTL) field of the IP header to determine whether incoming traffic originated from Tor or routine network traffic. Key Cyber Concept Two: Common Tor Packet Sizes, this is a measure to discern common Tor packet sizes. Key Cyber Concept Three: High TCP Offset, we analyzed the average TCP offset of Tor and non-Tor Web traffic to test whether it was possible to categorize each new instance of traffic into the webserver as either obfuscated or non-obfuscated. Key Cyber Concept Four: Known Tor Exit Node, a blacklist of published Tor nodes was used to verify whether any network traffic originated from a known Tor exit node.
Analysis of 702,376 unique packets showed distinct attributes for the key cyber concepts (KCCs) in this study. Each KCC was tested both with and without filtering to determine its ability to discern Tor traffic. The testing was conducted in two ways. First, using the list of attributes as a

[1] Selenium IDE is a Firefox extension that is also compatible with the Tor Browser. A full description of Selenium IDE capabilities is available at http://www.seleniumhq.org/projects/ide/.

pre-filter, the datasets were filtered to include only those rows that exhibited the observed attribute, and second, the datasets were evaluated in their unfiltered states. After individual testing, each KCC's attributes were applied in a multi-attribute analysis model to increase the probability of classifying Tor traffic.

KCC1: Analysis showed 56 unique IP time-to-live (TTL) values present in Tor traffic and 77 unique TTL values present in non-Tor traffic. Interestingly, most Tor TTL values were concentrated between 30 and 60 with very few observations above 100. Non-Tor TTL values were also observed between 30 and 60, but many exhibited a value above 60, albeit in lower quantities.

The observed Tor TTL is consistent with the default operating system TTL count of 64, which is normally attributed to Linux-based systems. Notable concentrations were observed in Tor traffic at 44, 45, 46, 47, 48, 49, 50, 52, 53, and 54 while non-Tor IP TTL values were concentrated at 51, 57, 116 and 128. Confirming these TTL values enables their use as discriminants in both single and multi-attribute analyses.

KCC2: Analysis of packet sizes showed Tor packets were observed only at sizes 52 and 1500 and accounted for 54.5 percent of all Tor packet sizes. However, additional analysis observed a low number of Tor and non-Tor packets with a size of 1500 and a very high number of both exhibiting a packet size of 52. Thus, it is determined that solely using packet sizes of 52 and 1500 will not serve as a good discriminator in either single attribute or multi-attribute analysis.

KCC3: Analysis showed that 92 percent of Tor packets and 92.6 percent of non-Tor packets exhibited a TCP offset value of either 5 or 8. Based on this observation, only TCP offset values greater than 9 could be viable discriminators for traffic type. There was very little difference between the mean and standard deviation of Tor and non-Tor packets. This suggests the additional TCP header data required by Tor has a negligible effect on the overall TCP offset.

KCC4: We used R-script to identify unique IP addresses in both Tor and non-Tor datasets separately. The unique rows were then compared to a listing of known Tor exit nodes active during the testing period. Results showed 1,218 unique Tor IP addresses, 2,091 unique non-Tor IP addresses, and 1,106 unique Tor exit node IP addresses. Each set of unique addresses was compared to identify intersections, or collisions, with the other datasets. There were only 178 intersections between the known Tor IP address dataset and the known Tor exit node dataset. These results confirm that a majority of known Tor traffic did not originate from a published exit node. Further comparisons showed zero intersections between the known Tor exit node dataset and known non-Tor dataset. Based on these two data points, when packets originate from a known Tor exit node, they are obfuscated.

The results from this research provide the basis for DoD to adapt to the DarkNet cyber threat using available cyber sensors and information (log files). We demonstrate data analytics of Network behavior to establish knowledge, and then did the preliminary development of an operational model based application. The data analysis of network traffic confirm expectations that a multi-attribute approach to classification improves certainty of classification. The exploitation and analysis of the TTL and packet length demonstrates that basic rules for classifying network entities and behavior may be developed through empirical analysis of available information, as in this case Snort log files.

The study of each KCC did result in either the confirmation of previously observed indicators or in new identifiable characteristics. In the second best performing test, error rates were roughly 20 percent for both Tor and non-Tor traffic. Although the observed False Negative Rates and False Positive Rates were high, use of this type of analysis on a network in real-time could result in a reduction of Tor traffic by approximately 80 percent—significantly reducing the overall threat level.

We implemented the obfuscation rules learned in the KCC analysis into the USAF's Behavior Based Network Management (BBNM) model for operational testing. Due to emphasis on data analytics, a preliminary implementation of the DarkNet KCCs into the Global Information Network Architecture (GINA) framework and AF BBNM model was accomplished, however, evaluation was left for future work.

Recommendations for Further Research
We recommend research and analysis on additional indicators of Tor traffic. 1. High RTT. Based on Tor's geographically dispersed architecture and routing schema, the linear correlation between geographic distance and round-trip time (RTT) may be present in Tor traffic; 2. HTTP Flow Analysis: Determine if there is a sufficient separation in the sizes for flow packet three; 3. Varied Source IP: Explore the possibility to identify Tor traffic by monitoring for a IP address change from an authenticated user during a session.

Further research into Vector Relational Data Modeling in the GINA Framework and Joint Cyber model BBNM in the Joint Network Model Development and Testing: To facilitate real-time detection. Recommended future research is the operational testing of the axioms in the BBNM model that was extended with KCCs from this work. This work would be a logical extension of this effort, and may be either Master's level or PI executed research.

NPS-N16-N273-A: Applying the Soar Architecture to Model Cognitive Functions in a Kill Chain

Researcher(s): Dr. Ying Zhao, Ms. Bonnie Johnson, and Mr. Tony Kendall
Student Participation: LCDR Emily Mooren USN

Project Summary
Accurate, relevant and timely combat identification (CID) enables the warfighter to locate and identify critical airborne targets with high precision. The current CID processes include the use of Naval and Joint combinations of platforms, sensors, networks and decision makers. There are diversified doctrines, rules of engagements, knowledge repositories and expert

systems used in the current process to address the complexity of decision making challenges. However, the process is still very manual and decision makers can experience cognitive overload.

Soar is a software and architecture system that models complex reasoning, cognitive functions and decision making. It can be used to model cognitive decisions for tactical warfare such as engagement decisions in a kill chain. The cognitive functions include decision making, sensor fusion, analytic processes and workflow. We used Soar to aid in the in the CID decision making process.

We used Soar and specifically the reinforcement learning (RL) method for the cognitive functions of the CID decision making process. For this focus, the problem space has been characterized. Soar production rule pseudocodes, and the procedural knowledge and basis for reasoning were formulated in the project. We also produced a use case, a prototype and a student thesis.

Background

Soar is cognitive architecture and software system that has been developed by the University of Michigan (Soar, 2017) to model complex reasoning, cognitive functions and decision making. Soar is continually being updated and has recently added reinforcement learning. The Navy's current methods for tactical airspace combat identification are largely manual. The process of CID involves diversified doctrines, rules of engagements, knowledge repositories, and expert systems to some degree. Decision makers such as Tactical Action Officers (TAOs) and Mission Commanders (MCs) can experience cognitive overload because of the demanding process of CID. For example, the current CID process requires complex decision making capabilities from the TAOs/MCs in order to conduct the CID process which includes evaluating traditional sensor measures, indications and assessing data driven models (e.g., rules such as Rules of Engagement (ROE), expert systems, and analytic models). These models may be developed historically or separately from legacy sources. These models may not be complete, can have low confidence levels, or even contain conflicting and wrong data. Furthermore, advanced Big Data, Deep Analytics, Machine Learning (ML) and/or Artificial Intelligence (AI) can also result in analytic models (e.g., new threatening behavior models fused from massive data sources) with various confidence levels. These new models need to be incorporated and adapted to a holistic CID decision making process.

The core questions for the project in the past year are the following:

- Can Soar, incorporated in a CID process, learn and better use the existing knowledge models for CID cognitive functions, timely and automatic decision making?
- Can Soar, incorporated in a CID process, learn from the feedback of human operators?

Soar is especially suitable for DOD applications because it can accept and use knowledge systems including English-language based rules as well as Deep Analytics or Smart Data. Therefore, it has the potential to learn and discover the optimal combinations of existing knowledge models for CID and can generate ML/AI that can automate and speed up the complex decision making for CID. Ultimately this has the potential to reduce the cognitive and mental burden on human CID operators.

We compared Soar with commercial AI systems such as DeepMind (DeepMind, 2017), developed by Google, which is a system that taught itself to play the games, Breakout (Breakout, 2017) and Go (Go, 2017). Soar-RL is different from DeepMind-RL. DeepMind-RL is learning from low-level data (e.g. pixels for games) and uses Deep Learning, e.g., CNN (Caffe, 2017), for function approximation of the value function. Soar is –based on more traditional AI, which makes it easier to adapt to symbolic/rule-based problems like in the kill chain and CID applications. Furthermore, for the CID application, a model is needed that looks at a representation of the common operating picture (COP) such as a Common Tactical Air Picture (CTAP) and bases its decisions on this knowledge. The model must provide visibility of the objects in the COP and their properties. The model must learn. Soar satisfies these requirements. It is also a requirement for human operators to have insight into how decisions are made for validation. An advanced AI model such as Hidden Markov Models (HMM, 2017) does not perform the work; Soar can do it. One also wants to plug the cognitive models into a simulation to assess system of systems effectiveness. The Naval Simulation System (NSS) and Soar were selected after evaluating alternatives for Navy.

Findings and Conclusions

In the past, the NPS team worked with a thesis student, who was an experienced E-2 Mission Commander (MC), who demonstrated the feasibility of this idea and built a prototype Soar-RL model using simple three rules for a CID use case for this project. From the NPS prototype results, after a period of time for a learning phase, the Soar prototype allows the operator to gradually put a trained agent into the operational phase. The correct decision rate (i.e., deciding hostile or non-hostile for unknown airborne object) went from 62.5% to 87.5% with a statistical significance p-value<=0.04. The results are documented in the NPS thesis (Mooren, 2017).

In conclusion, the team is using the Soar-RL method, the team has characterized the problem space and has developed Soar production rule pseudocode as the procedural knowledge and basis for reasoning. We proved, in a small scale, that Soar can incorporate existing knowledge as production rules into long-term and short-term memories for decision making. The Soar-RL can improve, validate, simplify and even generate new rules based on feedback from external elements (e.g., human operators or other training data).

We showed it is feasible that Soar-RL can learn and better use the existing knowledge models for CID cognitive functions, timely and automatic decision making.

We also demonstrated that it is feasible that Soar-RL incorporated in a combat system can learn from the feedback of human operators. The trained Soar agent can be used to adapt to the future situations, perhaps making decisions like human operators and reduce the cognitive burdens of human operators.

Recommendations for Further Research

This continuation of the cognitive modeling will build on the prior effort that introduced Soar-RL. Future work will expand on the sensory and data analytics input and experience of the cognitive model. A prototype will be refined that uses the Soar cognitive architecture. The Soar model will be added to the simulations to be informed by wargames for mission planners. For example, recommendations are to incorporate the Soar prototype into the Naval Simulation System (NSS) and the Warfighting Impact by Simulated Decision Makers (WISDM).

It might be feasible to examine ML/AI in Soar-RL for the cross-validation Deep Analytic models. It might be feasible to examine ML/AI in Soar-RL to learn from the delayed ground truth after actions taken.

The models could not only automate many current manual CID processes but also have the potential to be applied in other DOD applications of decision making that require overwhelming cognitive functions of experienced warfighters. For example, a need from the Spectrum Technology Advanced Research (STAR) NAVSEA NSWC Crane is to use Soar to learn new rules.

References

Breakout. (2017). Retrieved from https://github.com/kuz/DeepMind-Atari-Deep-Q- Learner

Caffe . (2017). Retrieved from http://caffe.berkeleyvision.org/ *DeepMind.* (2017). Retrieved from DeepMind: https://deepmind.com/ *Go.* (2017). Retrieved from https://deepmind.com/research/alphago/ *HMM.* (2017). Retrieved from Hidden Markov Models

Laird, J. E. (2012). *The Soar Cognitive Architecture.* Cambridge: MIT Press

Mooren, E. (2017). *Reinforcement Learning Applications to Combat Identification.* Monterey: Naval Postgraduate School.

Soar. (2017). Retrieved from http://soar.eecs.umich.edu/

NPS-N16-N432-A: Long-Endurance, Integrated UUV/USV Tactical Environmental Sensing System

Researcher(s): Mr. John Joseph and Mr. Doug Horner

Student Participation: LCDR Christopher Bade USN and LT Bradley Nott USN

Project Summary

This study continued our investigation into the cooperative use of small undersea gliders (e.g., Spray, Slocum and Seagliders) and surface-based gliders (e.g., Wave Gliders, AutoNaut) as an integrated, long-endurance Intelligence, Surveillance, and Reconnaissance (ISR) and environmental sensing system that provides the warfighter with real-time acoustic and oceanographic information. Our efforts focused on advancing a collaborative Unmanned Underwater Vehicle(UUV)/ Unmanned Surface Vehicle (USV)system and demonstrating an at-sea capability for operational situational awareness and timely wide-area environmental assessment applicable to Undersea Warfare and Battlespace Awareness missions. The research leveraged existing NPS glider assets and USV platforms owned by our collaborators at the Monterey Bay Aquarium Research institute (MBARI) to build upon our initial theoretical/modeling results and preliminary field datasets. The research initiative has been a unique effort in that it emphasizes both engineering (collaborative navigation strategies) and science (acoustic propagation) objectives. Students using the data collected for thesis work have the opportunity to develop research topics in a variety of areas such as controls for a multi-asset system, acoustic communication of critical data and navigational information in challenging environments, and impacts of environmental factors affecting system performance and optimization. Students will also be able to use these data in future thesis work to investigate innovative methods of fine-tuning and adapting this distributed system in response to changing environmental conditions and/or partial loss in capability.

Keywords: unmanned systems, battlespace awareness, environmental sampling, acoustic communications, undersea warfare

Background

The literature is rich with potential uses of unmanned systems in support of environmental sensing and acoustic monitoring applications (Baumgartner 2014, Bingham 2012, Howe 2010, Rudnick 2004), however this project leverages unique attributes of unmanned systems that have potential to provide long-endurance sensing and surveillance functionality to support specific Navy needs. Results from our initial theoretical-modeling study and initial field work supported the hypothesis that integrated UUV/USV systems can provide continuous wide-area environmental sensing and characterization that support Battlespace Awareness (BA) and Undersea Warfare (USW) missions. This project has built upon our previous effort to further develop a proof-of-concept long-endurance UUV/USV system that incorporates the strengths of the individual components to provide additional capability that neither system can provide alone. Our primary goal was to conduct a more extensive field study program to examine and validate concepts of operation envisioned for such a system.

Findings and Conclusions

The field work conducted under this project continues to support our hypothesis that multiple deep-diving glider UUVs working collaboratively with one or more USVs can provide a highly effective long-endurance environmental sensing and surveillance system capable of supporting BA and USW missions.

During the course of this study, the control system of a NPS Spray glider capable of diving to a depth of over 1000 meters was upgraded to allow integration of a mid-frequency (MF) Benthos Directional Acoustic Transducer (DAT) modem (figure 1).

Figure 1. Modified NPS Spray glider with a mid-frequency Benthos DAT modem installed just forward of the tail (science bay cover is removed)

The normal mode of operations for gliders like Spray, which were originally designed for environmental sampling only, is to repeatedly submerge and resurface to collect environmental data and, while surfaced, exchange via satellite communications environmental data, navigation information and command and control (C2) information with remote operators. However, from an acoustic perspective, the constant movement of the glider through the water column is highly suboptimal for USW objectives. By allowing the glider to stay at depth for extended periods, two major USW-mission advantages are potentially gained. First, an acoustic receiver on the glider can be positioned at an optimal depth for continuous surveillance and secondly, interfering glider self-noise is significantly reduced or eliminated. The addition of a DAT modem on the glider provides the opportunity for opening a critical cross-domain link that allows gliders to communicate via a USV platform with a remote C2 center (land-based or at sea) in real-time while submerged. The DAT modem was specifically selected because it has the capability to provide range, depth and directional information between a glider and USV for navigation purposes in addition to passing critical C2 and environmental information in near real time.

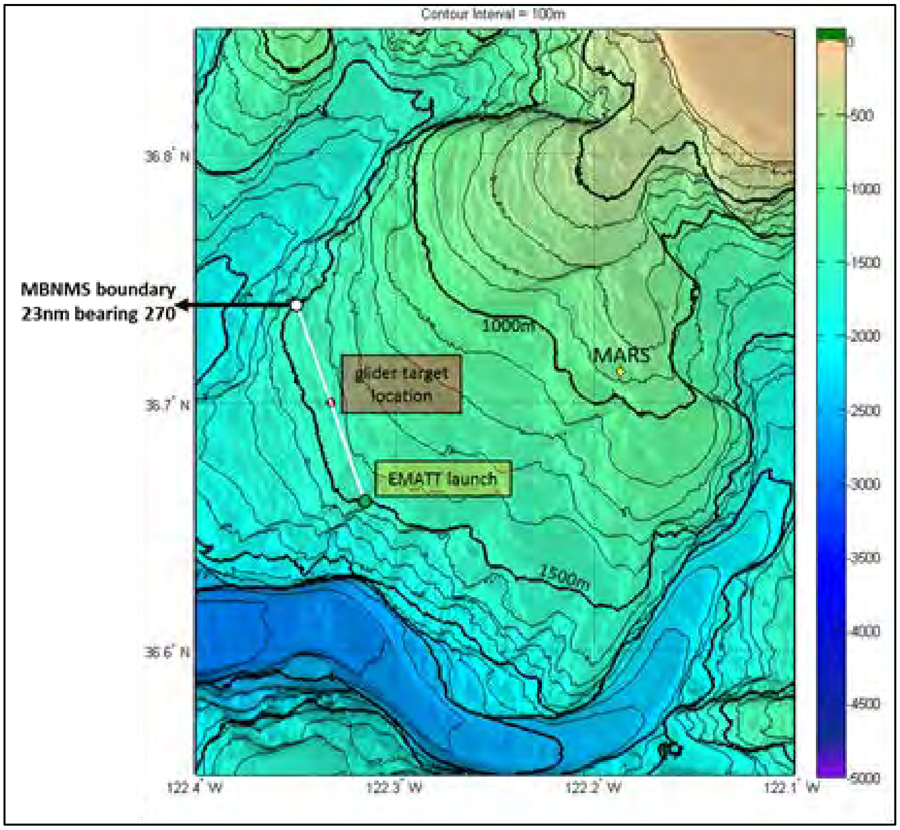


Figure 2. NPS glider target location and EMATT tracks over Smooth Ridge in Monterey Bay planned for the Tactical Oceanography class field experiment.

The project culminated with a 10-day field test scheduled in late January 2017 and conducted in conjunction with collaborators from MBARI and NPS students in the Tactical Oceanography (OC4270) course. A modified NPS Spray glider with a MF DAT and an acoustic receiver was deployed from Moss Landing and commanded to swim out to a deep-water location over Smooth Ridge in Monterey Canyon approximately 25nm west of the deployment site (figure 2). A MBARI Wave Glider USV with a low-frequency (LF) DAT modem was already deployed in the area. Initial test communications were successfully conducted between the NPS Spray and MBARI Wave Glider on Day 2 while the Spray was en route to its target location. The quality of the communication was better than expected as both ranging and directional information were successfully exchanged despite the frequency mismatch (MF vs LF) of the DAT modems.

As the glider approached its target location on Day 3 of the test, NPS OC4270 students aboard the National Oceanic and Atmospheric Administration (NOAA) research vessel (RV) R4107 transited from Monterey to the area over Smooth Ridge to deploy a set of tracking sparbuoys with shallow acoustic receivers (~100m depth) and an Expendable Mobile Anti-Submarine Training Target (EMATT) used a mobile acoustic source. The Spray glider was commanded to go to 750m depth and remain there for three hours while the EMATT repeated a five nm track (figure 2) at different depths over the same three hour period. On Day 4 of the test, NPS students repeated the EMATT test with the glider. Due to a mechanical problem with the research vessel that required the ship to return to port early, the EMATT was deployed a couple of miles shoreward of the planned launch location. However, the glider once again was commanded to drift at depth for three hours, this time at 950m. It should be noted that despite the problem with the manned research vessel, the unmanned components of the test (NPS Spray, MBARI Wave Glider and NPS EMATTs) worked flawlessly to complete a very successful field test.

A spectral snapshot of results from the Day 4 EMATT-glider test are shown in figure 3. The EMATT was programmed to transmit a different tonal for 1 hour on each of the three 5nm legs with the glider drifting at depth (2.7kHz on leg 1, 2.8kHz on leg 2, 2.9kHz on leg 3) and a 3.0kHz tone as the EMATT travelled over 20nm westward out to sea on its final leg. The signal-to-noise ratio (SNR) captured on the glider's hydrophone (fig 3) shows the received EMATT signal is well above the Background ambient noise during the entire 3-hr period the glider was drifting at depth. As the EMATT turned to head out to sea, the signal was still detectable even as the glider began its climb towards the surface with its pumped CTD instrument switched on, despite the increased Background noise from the CTD pump motor.

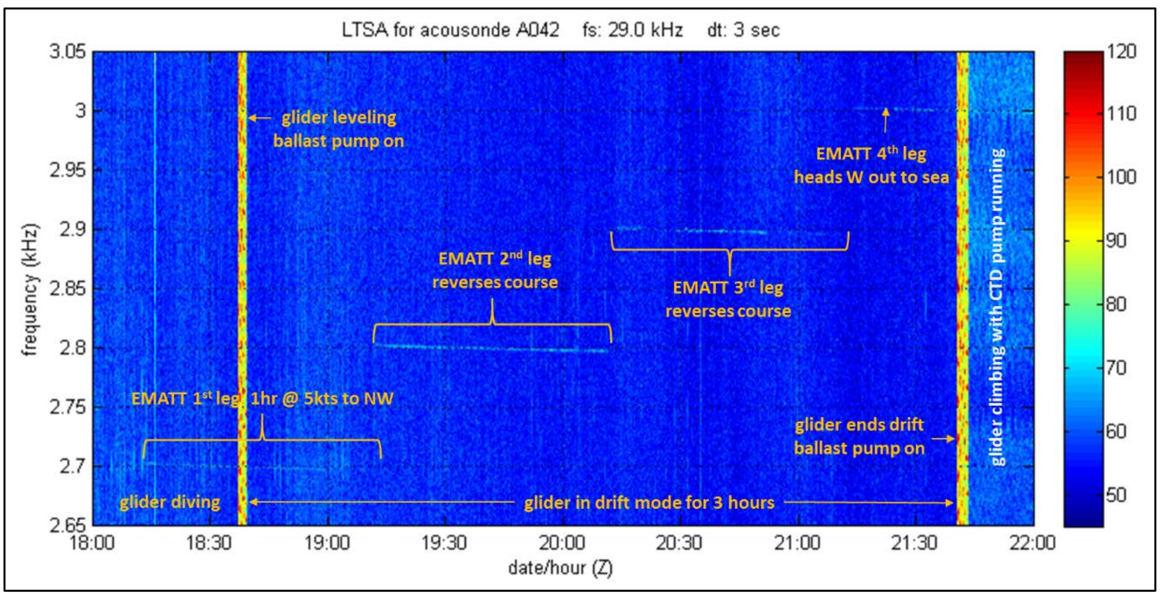


Figure 3. Spectral display of EMATT signals received by the glider while it was in a 3-hour drift at 950m depth. The signals were clearly received during the entire drift period against the low Background ambient noise.

As the Spray glider was directed to return to its recovery point, a second DAT communications test with the MBARI Wave Glider was conducted on Day 7. Results shown in figure 4 show the Wave Glider was able to track the glider well in both range and direction, however, the reported depth is not consistent with the known depth of the glider. This issue will be examined in future work.

In this project, significant advances were made towards development of a long-endurance, integrated UUV/USV system that is capable of supporting both USW and BA missions. Our field test efforts have enabled us to collect valuable data in real-world environments.

Analysis of the data thus far supports our hypothesis that a system of this design can take advantage of the operational environment to optimize both its surveillance and environmental sensing capabilities, however, there is more work to be done in areas such as (but not limited to) multi-asset vehicle control, adaptive sampling of the environment, maximizing data throughput, autonomous response to changing environments and system scalability.

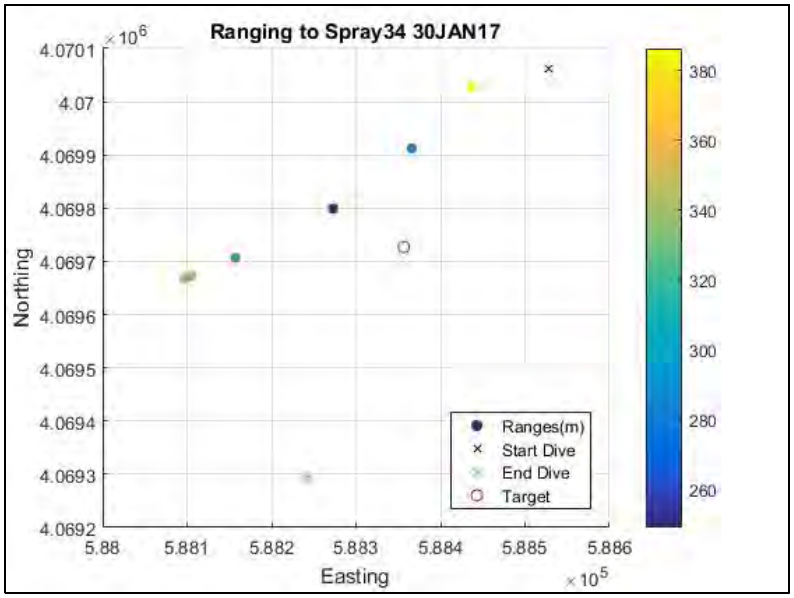


Figure 4. Ranging test between the NPS Spray and MBARI Wave Glider show the predicted position of the glider at depth midway between its GPS-based start and end dive points

Recommendations for Further Research

This effort has laid the groundwork for development of a UUV/USW system that has potential for supporting USW and BA missions over extended periods using a remotely-piloted C2 approach. It is our hypothesis that a collaborative system can take advantage of the strengths of both UUV and USV platform types to produce gains greater than the sum of the individual parts. Further development of a prototype system is highly recommended in order to mature system integration and cooperative behaviors, test system limitations and determine optimal configurations. Expanding the system to include a second upgraded Spray glider is relatively inexpensive and would provide added capability to test realistic cooperative behavior and adaptive sampling strategies. Theoretical studies on adaptive sampling, autonomous responses, optimizing acoustic communications, etc., can be tested in the field generating valuable datasets that provide realistic measures of performance.

References

Baumgartner, M. F., K. M. Stafford, P. Winsor, H. Statscewich, and D. M. Fratantoni, 2014: Glider-Based Passive Acoustic Monitoring in the Arctic., *Mar. Technol. Soc. J.*, **48**, 5, 40–51.

Bingham, B., N. Kraus, B. Howe, L. Freitag, K. Ball, P. Koski, and Eric Gallimore, 2012: Passive and Active Acoustics Using an Autonomous Wave Glider., *J. Field Robot*., **29**, 6, 911–923, doi: 10.1002/rob.21424.

Howe, B. M., Y. Chao, P. Arabshahi, S. Roy, T. McGinnis, and A. Gray, 2010: A Smart Sensor Web for Ocean Observation: Fixed and Mobile Platforms, Integrated Acoustics, Satellites and Predictive Modeling., **3**, 4, 507–521.

Rudnick, D. L., R.E. Davis, C. C. Eriksen, D. M. Fratantoni, and M. J. Perry, 2004: Underwater Gliders for Ocean Research., *Mar. Technol. Soc. J.*, **38**, 2, 73–84.

NPS-N16-N463-A: Satellite Vulnerability Planning Models

Researcher(s): Dr. Luqi
Student Participation: Maj Chris Wildt USMC

Project Summary

This project seeks to assess and improve capabilities of Satellite Vulnerability (SATVUL) planning systems. The study focuses on accuracy of satellite planning predictions based on models used in current and planned systems. We are identifying differences between the Simplified General Perturbations #4 or SGP4 (USAF) and Position Partials and Time or PPT3 (USN) propagation models, and analyzing them to determine the impact of these differences on positional error in orbital determination. Results of the study will assess effectiveness of current approaches to SATVUL planning, determine the sensitivity of prediction accuracy to various model parameters, and identify affordable improvements.
Specific research objectives are to:

1) Assess the coverage of various relevant physical effects in each of the two models, and the sensitivity of model outputs to those effects.
2) Assess the accuracy of approximations used in the models.
3) Analyze the accuracy of the numerical methods used in the software implementing the models.

Background

Naval forces need prior knowledge of overflight by satellites for effective planning. This includes positions of friendly satellites that are expected to provide Intelligence, Surveillance, and Reconnaissance (ISR) and communications support to our forces as well as positions of adversary and commercial satellites that could potentially detect and report planned Navy activities via various onboard sensors.

Precisely predicting satellite motion under realistic conditions is complicated because many detailed physical effects must be taken into consideration. The classical textbook solutions that yield elliptical orbits for satellites assume that gravity comes from a single point mass and that there are no other forces acting on the satellite. The real situation is different: near-earth satellites are affected by drag from the thin vestiges of the atmosphere at their altitude, sources of gravity other than the earth (such as the sun, the moon, and other planets) affect their motion, the point mass approximation is imperfect because the earth is not perfectly spherical and the distribution of mass in the earth is not perfectly uniform, satellites are affected by light pressure from sunlight and collisions with the solar wind, and so on. While all of these effects are much smaller than the effect of the earth's gravity approximated as a point mass, over time they build up to produce perturbations of a satellite's orbit that deviate from the elliptical trajectory described by the textbook solution to the simplified orbital problem.

Although the effects listed above could be included in the differential equations describing the motion of the satellites, this complicates the equations to the point where they cannot be solved in a closed form like the textbook solution of the simplified model. The realistic equations must be solved by numerical methods which depend on discrete approximations, and are therefore not perfectly accurate.
A propagation model is a mathematical framework for extrapolating satellite position observations from a given point in time to obtain future positions of the satellite. The propagation models being considered the project, SGP4 and PPT3, use various approximations. These models and algorithms are unclassified and have been published.

The SGP4 model used by the Air Force was initially developed for North American Aerospace Defense Command (NORAD) in 1959 [1] and refined in 1966 [2]. Detailed descriptions of the models and a FORmula TRANslation (FORTRAN) IV implementation were published in 1988 [3] and a later analysis [4] determined that SGP4 has an error of about 1km at epoch which grows about 1-3km per day. Due to this error, National Aeronautics and Space Administration (NASA) and NORAD update their element set data frequently [5]. The NORAD data are called two-line element sets, and are published in a format described in [6]. These element sets are derived specifically to match assumptions in the SGP4 propagation model, and must be used together with these models to get accurate predictions [3].

Naval Network Warfare Command also distributes satellite data, using an error correction process described in [7]. This is based on a 1959 solution of orbital equations by Brouwer [8], adjusted by Lyddane [9] to avoid numerical problems for orbits with small eccentricities. This model is now known as PPT3 [10]. The study will determine the relevant differences between these two models.

Findings and Conclusions
We gathered material on the larger context for this inquiry, such as the publications cited in the reference list and the wider Navy context regarding motivations for accurate satellite tracking and prediction. The two models cited in the topic description are not the most accurate ones currently available, but they require less computation than the most accurate models, resulting in faster response times. Satellite propagation model accuracy does not appear to be the limiting factor in determining vulnerability to ISR sensors on satellites. The goal of the study is to provide analysis based on concrete data to check this perception and to provide a sound basis for characterizing the differences between the two models.

Planned actions to validate and assess differences between the models will compare model predictions to real-world satellite measurements. A high level description of the planned process follows: Obtain old satellite measurement data and executable code for the calibration and orbit prediction functions of both models. Repeatedly calibrate and run both models, calculate prediction error based on later measurements. Do statistical analysis of the results to characterize and compare errors of the two models and variation with orbit elements. Obtain information about area per mass for the satellites in the benchmark data to assess effects of differences in models of atmospheric drag, solar wind, and light pressure.

An M.S. thesis to carry out the above analysis based on measured data on satellite positions has been initiated and will be completed next year. SGP4 is currently running in our lab and we have initiated the processes to obtain PPT3 software and measured satellite position data.

Recommendations for Further Research

Future research is recommended to use the conclusions of the project at the end of the second year to determine the frequency of model parameter updates needed to support SATVUL predictions for ships. We also recommend investigating a system architecture and distributed design that would distribute model parameters to ships from a central facility and continuously update SATVUL predictions using local computations based on actual ship position and velocity.

References

Kozai, Y., "The Motion of a Close Earth Satellite", Astronomical Journal 64, 367-377, Nov. 1959.

Hilton, C. and Kuhlman, J., "Mathematical Models for the Space Defense Center", Philco-Ford Publication U-3871, 17-28, Nov. 1966.

Hoots, F. and Roehrich, R., "Spacetrack Report No. 3", http://www.celestrak.com/NORAD/documentation/spacetrk.pdf.

Vallado, D., Crawford, P. and Husak, R., "Revisiting Spacetrack Report #3: Rev 2, American Institute of Aeronautics and Astronautics, 2006, http://www.centerforspace.com/downloads/files/pubs/AIAA-2006-6753.pdf.

"Simplified Perturbation Models", Wikipedia, https://en.wikipedia.org/wiki/Simplified_perturbations_models.

NORAD Two-Line Element Set Format, http://www.celestrak.com/NORAD/documentation/tle-fmt.asp.

Danielson. D, Canwright, D., Perisi, D. and Schumacher, P., "The Naval Space Command Automatic Differential Correction Process", Paper AAS 99-366, 1999 AAS/AIAA Astrodynamics Specialist Conference, http://fas.org/spp/military/program/track/autodc.pdf.

Brouwer, D., "Solution of the Problem of Artificial Satellite Theory without Drag", the Astronomical Journal, Vol. 64, No. 1274, pp. 378-397, Nov. 1959.

Lyddane, R., "Small Eccentricities or Inclinations in the Brouwer Theory of the Artificial Satellite", the Astronomical Journal, Vol. 68, No. 8, pp. 555-558, Oct. 1963.

Hoots, F, Schumacher, P. and Glover, R., "A History Of Analytical Orbit Modeling In The United States Space Surveillance System", Journal of Guidance, Control, and Dynamics, Vol. 27, No. 2 (2004), pp. 174-185, http://aero.tamu.edu/sites/default/files/faculty/alfriend/S6.1%20Hoots.pdf

NPS-N16-N470-A: High Latitude Positioning, Navigation and Timing

Researcher(s): Dr. Luqi
Student Participation: No students participated in this research project.

Project Summary

The study seeks to improve capabilities of U.S. Navy ships for accurate positioning, navigation, and timing (PNT) in order to support operations in the high arctic region with latitude > 85 degrees. The rate of change for "North" approaches infinity at the pole. Therefore compass directions become undefined there. Shipboard gyros switch to a transverse coordinate system in which the pole becomes (latitude 0, longitude 0), and directions near the pole become stable and well defined. GPS works correctly at the poles.

Potential system difficulties are associated with transitions between the two coordinate systems. Problems manifest specifically in cases where computations combine positions obtained before the coordinate system change with others obtained after. The project is investigating impacts on shipboard PNT and combat systems when these transitions occur. We seek affordable mitigations for the effects discovered.

Keywords: Arctic Operations, Surface Ships, Navigation, Position, Timing, Systems Integration.

Background

The arctic is gaining strategic importance as climate changes are reducing arctic ice cover and opening access to ships in the high north latitudes, which contain significant reserves of oil and natural gas under the ice, and Naval focus on this area is increasing [1, 5]. This increases the importance of accurate PNT in the high arctic.

It has been established that VMS ECDIS-N works in the polar mode, after transitioning to the transverse coordinate system. VMS ECDIS-N is an electronic navigation chart system that has been certified for use on Navy surface ships [2].

It has not been established that shipboard PNT distribution systems and combat systems are able to handle switching to the transverse coordinate system. The study is investigating this issue, identifying potential problems and seeking affordable mitigations.

Since the transverse coordinate system has the same shape as the standard one and differs only in the orientation of the axes, computations depending only on current PNT data should produce correct results relative to the new axes. Potential sources of difficulty are physical effects that depend on the latitude and interfaces between subsystems that switch between the two coordinate systems when crossing between the arctic and the rest of the world, and those subsystems that do not.

Findings and Conclusions

Examples of latitude-sensitive physical effects are oblateness of the earth and acceleration due to the earth's rotation.

- The earth is not a perfect sphere: due to the rotation of the earth, there is a bulge at the equator. An observer standing at sea level on either pole is 21.36 km closer to center of the earth than if standing at sea level on the equator [3]. This difference could affect calculations involving altitudes of satellites in low earth orbit, for example.
- The Coriolis force affects motion of objects relative to a rotating coordinate system [4]. This effect is proportional to the sine of the angle between the earth's rotation axis and the direction of the object's motion. The direction of the earth's rotation axis is very different in the two coordinate systems. This difference could affect trajectory calculations for unguided ordinance such as shells from Navy guns.

Guided ordinance

Since guided ordinance uses continuous feedback rather than dead reckoning, it should be insensitive to higher order effects such as the Coriolis force. Questions to be investigated are:

- Representation of bearing used by ordinance guidance systems – will instability of direction near the pole pose problems?
- Representation of waypoints and target location transmitted to and used inside the guidance system – would preassigned routes be invalidated by transverse coordinates, and would a change to internal guidance representations be necessary to correct that?
- If the launch point is in the normal coordinate region and the target is in the transverse coordinate region, would guidance need a transition to transverse coordinates, either in flight or prior to launch, and do the systems provide such a capability?

Unguided ordinance

Since targeting occurs prior to launch for unguided ordinance, ordinance heading and waypoints are not relevant. Bearing and range of the target relative to its own ship heading are the main relevant factors, but precision and higher order effects may matter.

Proposed investigations will quantitatively characterize these conditions and determine implications for the targeting systems and the amount of redesign that is needed.
We are investigating the following questions:

- Would targeting work correctly at the pole if normal coordinates are used?
- For which types of ordinance and what conditions is the Coriolis force relevant?
- How do weapons systems determine the direction of the Earth's rotation axis?
- What coordinate system is used to represent that three dimensional direction?
- How would switching to transverse coordinates affect targeting systems?

This is the first year of a two year project. We are gathering information about PNT issues and POC's knowledgeable about the current status of ship systems with respect to arctic operations and related issues. These issues may include interoperability, the degree to which Open Systems Architectures currently accommodate transverse coordinates, and compatibility with cyber infrastructure.

Since we could not find anyone who knew how ship's systems would interact with each other at high latitudes, we started to design a simple test case to find out. Intention is to get some test time at Naval Surface Warfare Center Dahlgren Division.

Differences in test results between running the same scenario at temperate latitudes and in the high Arctic should shed light on potential trouble areas. Intent is to understand for several combat and situational awareness systems what potential trouble areas, if any, are revealed if working at high latitudes. For details see [6].

Recommendations for Further Research

In the short term, the needs are to determine whether current architectures and interfaces can successfully handle multiple/transverse coordinate systems and transitions between them. Relevant concerns for combat systems are whether latitude-dependent effects require the use of particular, absolute coordinate systems, and whether instability of absolute directions at high latitudes affect system operation.

In the longer term, a more robust solution is to adjust the open system/enterprise architectures to explicitly support extensible context as a first-class entity. Current position, heading and time are examples of system context information (situational awareness). The purpose of the proposed architecture fragment or Technical Reference Framework is to enable agile, adaptive smart system responses to unanticipated situations, thus improving Navy abilities to handle surprises such as the impending ice-free arctic as well as other changes to the world situation, and adapt to the evolving relevant subset of available context information.

References

[1]"The Nordic countries are banding together against Russia's Arctic push", Business Insider, April 23, 2015, http://www.bu offshorsinessinsider.com/nordic-countries-banding-together-against-russia-2015-4.

[2]Electronic Chart System to First U.S. Navy Ship Certified for "Paperless" Navigation, Sperry Marine, June 15, 2005, http://www.sperrymarine.com/news/electronic-chart-system-first-us-navy-ship-certified-paperless-navigation.

[3]Equatorial Bulge, Wikipedia, https://en.wikipedia.org/wiki/Equatorial_bulge.

[4]Coriolis effect, Wikipedia, https://en.wikipedia.org/wiki/Coriolis_effect.

[5]U.S. military tests Arctic operations, March 20, 2016, http://www.cnn.com/2016/03/20/politics/gallery/u-s-military-arctic-exercise-icex/index.html.

[6]"Luqi, High Latitude Positioning, Navigation and Timing, Technical Report NPS-CS-16-004R, 2016."

NPS-N16-N589-A: Big Data Architecture and Analytics for Common Tactical Air Picture – Practical Applications

Researcher(s): Dr. Ying Zhao, Ms. Bonnie Johnson, and Mr. Tony Kendall
Student Participation: LCDR Emily M. Mooren USN

Project Summary

Big data is omnipresent. The related Deep Analytics including machine learning (ML) and artificial intelligence (AI) methods and tools are abundant in the commercial world. However, they may not be appropriate to solve military applications. Data sources for the Department of Defense (DOD) applications including disparate multi-sources real-time sensors are of extremely high rates and large volumes, and the needs for information sharing and agility as well as strict security across all domains make the matter more complex.

Funded by the NPS Naval Research Program (NRP), we have identified partial needs, requirements and challenges of the Common Tactical Air Picture (CTAP) and Combat Identification (CID) in the areas of Big Data and Deep Analytics.

The current CID processes include collecting, processing, and analyzing data from a vast network of sensors, platforms, and decision makers present quite a lot of challenges. Traditional battlespace CTAP and CID data sources as well as the additional non-traditional data sources, such as temporal, spatial and organic sensor data currently collected but not used present a very difficult Big Data problem for its volume, velocity and variety. These new data sources (e.g. Aegis residual data, open source flight schedules, advanced (Electronic Warfare/Electronic Intelligence (EW/ELINT)) signature data sources, and intelligence data) could be fused and analyzed in parallel using Deep Analytics. The resulting knowledge repository, i.e., *Smart Data*, could be searched, matched, and cross-validated with real-time new data streams. For example, the cloud could send or push the smart data (e.g. early warnings or alerts) to various platforms within a battlespace. A platform with partial or uncertain sensor/track data could send a real-time query to the cloud to find a higher certainty match. The smart data push and pull would have a relatively small data size and therefore not strain current networks for transmission between platforms.

We investigated and tested the Deep Analytics applicable to transform Big Data into Smart Data in the CTAP and CID areas as follows:

- Machine vision and Deep Learning models: These algorithms have the potential to improve object recognition, classification accuracy, and probability of correctly identifying air objects by associating, correlating, and fusing heterogeneous data sources that do not share data models. This process was demonstrated with unclassified tactical data samples of infrared (IR) and Electro-optical (EO) images (Zhao, Kendall, & Johnson, 2016).
- Pattern recognition, anomaly detection, and unsupervised learning models: We developed and selected pattern recognition and anomaly detection algorithms that could be used for

identifying intent, air picture event anomalies, or launch predictions. This process was demonstrated in a use case in this project. The detailed report was given in a secret level.

- Optimization, decision making, cognitive models and deep reinforcement learning models: We investigated using the Soar cognitive architecture (Soar, 2017) to reduce mental loads of CID operations and compared it with DeepMind (Mooren, 2017). The models could not only automate many current manual CTAP and CID processes but also have the potential to be applied in other DoD applications of decision making, enhancing future CTAP capabilities such as uncooperative game theory and modeling adversaries' cognitive behaviors.

Background

The Naval Common Tactical Air Picture (CTAP) collects, processes, and analyzes data to provide situational awareness to air warfare decision makers. Accurate CID enables warfighters to locate and identify critical airborne objects as friendly, hostile or neutral with high precision. CID plays an important role in generating the CTAP and other combat systems. This knowledge would reduce the probability of fratricide.

It is self-evident that Big Data, Deep Analytics and ML/AI are critical to design futuristic combat systems such as adaptive, cooperative and learning combat systems along with authoritative data sources, standards and interoperability from sensors, platforms, and weapons for mission requirements. It is also imperative to test and adapt commercially available tools now to satisfy the ongoing needs and requirements of the CID and combat systems.

In the past, we studied how to use the advanced analytics to improve combat systems and CID applications.

Findings and Conclusions

Last year, we studied a novel approach to fuse the sample track data collected from an exercise near the Wallops Island for the Cooperative Engagement Capability (CEC) which is a core CID component. This data matched with the Federal Aviation Administration (FAA) data in the same time and locations.

Combination of the MIT Lincoln Lab track fusion tools sequentially combined with the Lexical Link Analysis (LLA), a deep learning tool, shows great promise for identifying generally "friendly" flying objects, i.e. regular commercial aircrafts. Elimination of friendly aircraft from the air picture would allow the analysts to concentrate on those remaining unidentified objects.

Recommendations for Further Research

This success is just the first step into integrating heterogeneous data besides track data for identifying friendly aircraft as well as flight behavior patterns that would improve CID. For example, other data sources could be used such as EW/ELINT/ESM to identify the type of aircraft beyond the track information. With the same analytics methods and implementation of Mode S (international) and the automatic dependent surveillance-broadcast (ADS-B) for known U.S. regions, we could identify friendly aircrafts worldwide. When the kinematic and behavior patterns discovered from historical data, the resulted models can be used as signatures to identify normal commercial aircraft behavior patterns and anomalous behavior patterns.

Big Data and Deep Learning techniques can be used although mining historical data as well as streaming real-time data.

The NPS team has worked closely together with the University Affiliated Research Centers (UARCs) and Federally Funded Research and Development Centers (FFRDCs) such as the Naval Surface Warfare Center (NSWC) Corona division, Massachusetts Institute of Technology (MIT) Lincoln Lab (LL), Johns Hopkins University Applied Physics Laboratory (JHU/APL), and NAWCWD China Lake in the past to research the needs and requirements of the CID systems.

Also in this project, we showed the success of NPS to work with the MIT Lincoln Lab as a testbed to build prototypes and demonstrations that leverages commercial ML/AI tools to the CID and combat applications. The reasons for NPS and MIT Lincoln Lab to collaborate include:

- Commercial ML/AI firms do not know the combat systems, CTAP, CID and their functions, their related Big Data systems such as radar data (raw or processed), ES data, or SIGINT data. The UARCs/FFRDCs tend to understand more about the combat systems, the related technologies, functions, and data.
- The UARCs/FFRDCs also have secure labs and clearance to work on the systems and data.
- Naval Postgraduate School (NPS) is in the unique position to involve experienced warfighter officers as thesis students. While NPS has these warfighters as students, in turn, they provide needs and requirements for these military applications. F-18 pilots, E-2D Tactical Action Officers (TAOs) were among the thesis students who participated in the research in the past.
- The MIT Lincoln Lab has expertise in sensors, information extraction (signal processing and embedded computing), communications, and integrated sensing and decision support, all supported by a broad research base in advanced electronics. The NPS team collaborated with MITLL in the past in the areas of Integrated Air and Missile Defense applications (IAMD), Homeland Security applications and High Performance Computing (HPC). Therefore, it can provide a good integration location for rapid prototyping and secure demonstrations.
- NPS is also in a position to work with small businesses for STTR/SBIR projects. Experts from the Wentworth Institute of Technology, the original developer of Soar reinforcement learning modules (Soar-RL) and a machine learning expert, helped to develop the NPS prototype.

In the near future, we want to continue the effort of prototyping and demonstrating of Big Data, Deep Learning, ML/AI that can be applied to the CID and other combat systems applications. We propose eleven projects with data sources to leverage the success of this project by continuation of the development of the testbed. The goal is to demonstrate the logical, rapid and incremental introduction of the technologies into the CID and combat systems towards improved engagement in doctrine, tracking and identification.

References
Laird, J. E. (2012). *The Soar Cognitive Architecture.* Cambridge: MIT Press.
Mooren, E. (2017). *Reinforcement Learning Applications to Combat Identification.* Monterey: Naval Postgraduate School.
Soar. (2017). Retrieved from http://soar.eecs.umich.edu/
Zhao, Y., Kendall, T., & Johnson, B. (2016). Big Data and Deep Analytics Applied to the Common tactical Air Picture (CTAP) and Combat Identification (CID). *Proceedings of the 8th International Joint Conference on Knowledge Discovery, Knowledge Engineering and Knowledge Management*, (pp. 443 – 449). Porto, Portugal.

N3/N5: Plans & Strategy

NPS-N16-N156-A: Scalable Response Prediction of Underwater Explosion Effects on Critical Infrastructure

Researcher(s): Dr. Young Kwon and Mr. Jarema Didoszak
Student Participation: ENS Jean B. Loomis USN

Project Summary
Critical port infrastructure is especially vulnerable to waterborne improvised explosive devices (IED) and other underwater explosions (UNDEX). These massive engineering structures such as bridges, tunnels and piers serve the public day in and day out providing transportation, commerce and connectivity throughout waterfront areas. In addition, they are fully integrated into society and serve as the visible backdrop for all sorts of recreational, social and ceremonial events in the port area. However this need for accessibility also makes them stand particularly vulnerable to the powerful effects of fluid structure interaction resulting from UNDEX.

In response to these growing concerns, various security measures such as structural protection against ship collisions, heightened surveillance and physical barriers in close proximity to bridge abutments has been implemented. In some instances it is unclear that these changes have improved or actually degraded the overall survivability of the structure. The goal of this investigation is to analyze the resulting potential damage to critical port infrastructure subjected to near field UNDEX. Representative of the profound importance of our nation's massive civil engineering structures, a suspension bridge is used as the object of theses analyses. Findings from physics-based modeling and simulation of the shock event reveal the damage potential of UNDEX as a function of charge weight and standoff distance, and serve as a template for future efforts for other bridge structures in direct contact with significant bodies of water.

Keywords: Critical Port Infrastructure, Mine Warfare, Waterborne IED, Fluid Structure Interaction (FSI), Underwater Explosion (UNDEX), Suspension Bridge

Background
In the event that an underwater improvised explosive device, commonly referred to as a waterborne IED, is found within the waters near critical port infrastructure, typically Explosive Ordinance Disposal (EOD) units will mitigate the threat by conducting a controlled detonation of the bomb. The controlled detonation must be executed a safe distance from the structure to ensure its survivability. This study is designed to assist in providing on scene commanders with information that could help aid them in their decision making process during such an incident.

Many types of critical port infrastructure have been studied in order to correlate charge weights, types and standoff distances with potential damage [1-3]. The current study focuses on bridges, specifically suspension type bridges and their abutments. Sample structures of this type were examined and a particular bridge chosen as an example for this analysis in order to present the proposed modeling and simulation approach.

To characterize the most critical scenario, the underwater detonation of TNT was simulated at varying horizontal standoff distances from the bridge structure at several water depths. The fluid structure interaction of the UNDEX with a bridge foundation was observed. Explosive charge weights ranging from 20 to 2000 lbs. of TNT equivalent were considered in this study. These charge weights cover the practical range of explosives that could be readily delivered within the surrounding waters of the bridge foundation.

Findings and Conclusions
In order to determine the extent of the potential damage that would be experienced by the bridge structure, it is first necessary to clearly outline how this prediction is made based on the given inputs of charge weight, charge type, geometry of the charge placement and characteristics of the structure and surrounding fluid environment.

The physics of UNDEX sees multiple competing loading phenomena that are present and at work simultaneously in the area of the blast. Direct shockwaves, bottom reflections, surface or rarefaction waves, all occur nearly instantaneously while the effects of the gas bubble oscillation can affect the late time response which occurs on the order of seconds post detonation. The surrounding depth of the water, depth of the charge, environmental materials, structural materials and geometry of the blast area all come into play and influence the structural response of the critical element under analysis.

Conducting full scale testing of bridges using UNDEX is neither practical nor desired. Additionally, live fire testing of a scaled structural model is not always feasible due to similitude requirements in materials and more importantly overall cost. However the continued development of physics-based modeling and simulation approaches such as the finite element method have allowed highly detailed simulations to be generated via high power computing resources which accurately capture the response of structures due to UNDEX loading. A detailed finite element model of the suspension bridge piers including appropriate material and dynamic load representations was generated based on construction drawings, visual inspection and other available engineering data.

The Dynamic System Mechanics Advanced Simulation (DYSMAS) [4] suite was chosen as the primary computational solver for this work. DYSMAS is a three dimensional finite element hydrocode designed to study the effects of an explosive charge on a user-defined structure. DYSMAS uses Eulerian fluid equations to conduct a finite element analysis of the water volume during an UNDEX event while Lagrangian finite element equations of motion capture the response of the structure. The program combines the data from the Eulerian and Lagrangian solutions at each time step to develop a fully coupled system solution, which is of great importance as the structure intersects a multiple fluid media.

Finite element method codes offer various options to consider while ascertaining the potential to which a particular scenario will damage the structure. Direct and derived quantiles such as pressure, stress, strain, displacement, and others relating the resulting response of the nodes and elements representing the structure offer insight into its ultimate disposition as failed or not.

Herein, the damage criteria were determined by using the following variables: a) Damage Parameter and b) Plastic Strain found in the rebar embedded into the concrete. The values were selected and outcomes assigned as presented in Table 1.

Damage Parameter	Plastic Strain in Rebar	Result
$\leq$ 0.0001 and	no	Safe
0.0001 - 0.001 and	no	Slightly Damaged
$\geq$ 0.001 or	yes	Damaged

Table 1. Description of Damage Parameter

Damage Parameter values were chosen to be conservative to account for uncertainties in the model as modeled condition of the bridge structure. Examples of this are considerations for aging of construction materials, corrosion of metals etc. Such items are more difficult to characterize yet affect the strength and therefore response of the structure.

Next damage curves, similar to the one presented in Figure 1, were generated for the specific cases which were investigated as part of this study. Various combinations of charge weight and standoff distance were directly verified by simulation using the DYSMAS suite of computer codes. Figure 1 summarizes the simulation results in a damage curve profile for a typical scenario.

As stated, this study employs modeling and simulation to characterize safe detonation distances for a given charge weight of TNT. The results of this research will allow operational commanders to anticipate the effects of UNDEX on nearby infrastructure. Full details of the completed work are provided in a MAE Department Technical report.

Recommendations for Further Research

The work presented here was based on a specific type of critical port infrastructure - suspension bridges. However, even within this single category of bridges, there are many other types of structures that could potentially exhibit different failure modes when subjected to UNDEX. Cable-stayed, beam, truss, arch, cantilever and pontoon bridges are just a few of the others. Of particular interest are bridges that incorporate multiple characteristics of these simpler structures in a complex system such as the Hood Canal floating bridge. This bridge represents a unique challenge as it is comprised of floating pontoon and fixed girder sections as well as a portion that retracts to create the passage opening. An investigation of this critical port infrastructure using the method presented here is recommended as follow on work.

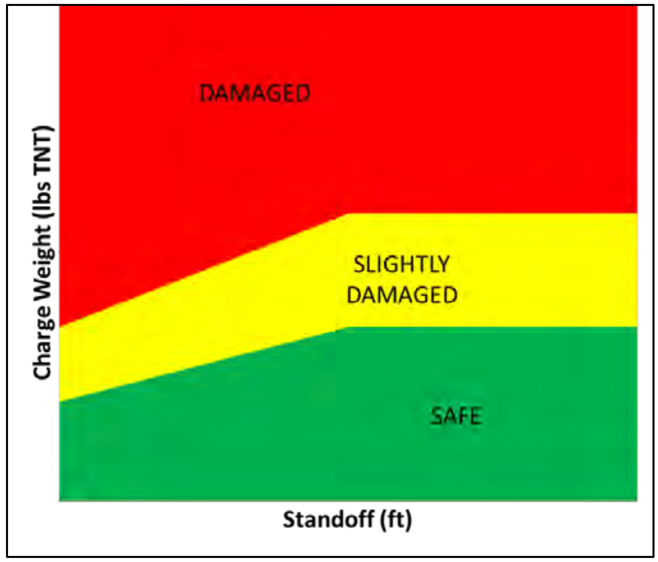


Figure 1. Damage potential as a function of charge weight and standoff

References

Bomb threat stand-off distance chart, National Counterterrorism Center, 2005, [Online] Available: https://www.nctc.gov/docs/2006_calendar_bomb_stand_chart.pdf

B. Gelfand, Translation from russian to english the book “Blast effects caused by explosions” authored by B. Gelfand and M. Silnikov, Final Technical Report, Apr. 2004

M. Marcus, S. Tidwell and G. S. Harris, “Underwater blast effects in Confined waters” NSWC IHD Report IHTR 10-30560, Jun. 2010.

Wardlaw, Jr., Luton, J.A., Renzi, J. R., Kiddy, K. C. and McKeown, R. M., “The Gemini Euler Solver for the Coupled Simulation of Underwater Explosions,” NSWC IHD Report IHTR2500, Nov. 2003.

NPS-N16-N173-A: The Nuclear Taboo and Non-Western Regional Powers

Researcher(s): Dr. Michael Malley, Dr. Paul Kapur, Mr. Feroz Khan, BG, PA (Ret.) and Dr. James Russell

Student Participation: No Students participated in this research project.

Project Summary

In the literature on nuclear weapons and international security, a strong argument has been made that a norm against the use of nuclear weapons has developed since 1945. This literature rests almost exclusively on observations of the behavior of specific states (Western ones) during a specific time period (the Cold War). However, Western ideas about the usability of nuclear weapons are likely to differ from those of newer, non-Western nuclear weapon states. Social and cultural norms, experiences with nuclear weapons, and regional security dynamics may lead newer nuclear powers to different conclusions about the circumstances under which nuclear use could be contemplated.

To assess the existence and strength of the nuclear taboo outside the Western world, this study examined three non-Western cases – India, Iran, and Pakistan – to identify their cultural, social, and experiential differences and determine how these differences influence the countries' views of the nuclear taboo. The authors found weak support for the nuclear taboo as typically defined in the literature, especially in Pakistan. Nonetheless, they found that some in Iran believe that the use of nuclear weapons would be normatively unacceptable. They also concluded that India and possibly other non-Western countries are likely to avoid using nuclear weapons in a war-fighting capacity, but will continue using them in the same way Western countries have done—as instruments of coercion that carry high but acceptable risks.

Keywords: nuclear taboo; nuclear weapons; nuclear strategy; India; Iran; Pakistan

Background

Despite significant tensions and even outright conventional military conflicts between nuclear-armed powers, nuclear war has not erupted since the dawn of the atomic age in 1945. This absence of nuclear war presents scholars and analysts with an important puzzle. Given the numerous opportunities and incentives for nuclear conflict over the decades, why has no country attacked another with nuclear weapons? The scholarly literature on international relations offers two broad sets of explanation: A realist approach, which focuses on the material effects of nuclear conflict; and an ideational approach, which focuses on nuclear conflict's normative implications.

According to realists, nuclear war has not occurred because its physical costs would be unacceptably high. In this view, no goal that a state might seek could be worth the massive death and destruction that would result from a nuclear conflict. As a result, nuclear deterrence has been extremely robust, with nuclear-armed states assiduously avoiding their use at every turn. Indeed, realists believe that astronomical material costs of nuclear war have deterred even conventional war between nuclear-armed adversaries.[2]

Ideational arguments, by contrast, emphasize the normative costs of nuclear use. They argue that the leaders of nuclear-armed states have avoided nuclear conflict because they believed

[2] See John Lewis Gaddis, "Great Illusions, the Long Peace, and the Future of the International System," in Charles Kegley (ed.) *The Long Postwar Peace* (New York: HarperCollins, 1991); Thomas Nichols, *No Use: Nuclear Weapons and U.S. National Security* (Philadelphia: University of Pennsylvania Press, 2014), 7; Kenneth Waltz, "The Spread of Nuclear Weapons: More May Be Better," in Kenneth Waltz and Scott Sagan, *The Spread of Nuclear Weapons: A Debate* (New York: W. W. Norton and Co., 1995), 1-45; and Susan Martin, "Realism and Weapons of Mass Destruction: A Consequentialist Analysis," in Sohail Hashmi and Steven Lee (eds.), *Ethics and Weapons of Mass Destruction* (Cambridge: Cambridge University Press, 2004), 96-110.

that the resulting death and damage would be morally unacceptable. Thus, even if using nuclear weapons could potentially have yielded strategic benefits, nuclear states have refused to do so. This normative prohibition against using nuclear weapons has become so powerful as to constitute an outright taboo, on par with moral prohibitions against incest and slavery.[3] Which of these explanations is correct? The stakes in correctly answering this question are high.

Our expectations regarding the dangers that nuclear weapons pose, and the policies needed to mitigate these dangers, differ significantly between the two models. If realists are correct, states' propensity for using nuclear weapons will depend on their understanding of their strategic environment, particularly their nuclear forces' susceptibility to preemption. Policy responses would focus on stabilizing the strategic environment in which nuclear-armed states operate, through measures such as the deployment of defense-dominant conventional military capabilities and the insulation of nuclear forces from preemption, both of which would reduce incentives for nuclear first use.

If proponents of nuclear-taboo arguments are correct, states' propensity for using nuclear weapons will depend on their normative views. The stronger their belief that using nuclear weapons is morally unacceptable, the less likely they will be to do so. Policy responses here would focus on socialization, rather than the stabilization of the strategic environment. Specific measures would include public and private diplomacy designed to stress the moral undesirability of nuclear weapons and their use; and example-setting by other nuclear states through revision of their force postures and doctrines in order to reduce the role of nuclear weapons.

Findings and Conclusions

This project aimed to evaluate the existence and power of the nuclear taboo outside the Western world. It did so by assessing the taboo's impact on the behavior of three countries: India, Pakistan, and Iran. It sought to determine what motives underlie these states' nuclear behavior and the extent to which the taboo might reduce their propensity to use nuclear weapons. The project examined the cases of India, Pakistan, and Iran for two main reasons. First, all three are non-Western states. This allowed the project to evaluate the taboo's effects independent of a host of cultural and experiential variables that could impact leaders in Europe and North America and that may have biased past studies of the nuclear taboo. Second, these three states are particularly conflict-prone. Indeed, South Asia is probably the world's most likely location of any future nuclear exchange. Iran, for its part, has tense relations with many of its neighbors and is, through the use of proxy forces, implicated in conflicts across the Middle East. Thus these states present significant nuclear dangers. They and the international community would benefit significantly from insights as to how these dangers might be mitigated. The author of each case study conducted his own review of the literature,

---

[3] See Nina Tannenwald, *The Nuclear Taboo: The United States and the Non-Use of Nuclear Weapons Since 1945* (Cambridge: Cambridge University Press, 2007); Steven Lee, *Morality, Prudence, and Nuclear Weapons* (Cambridge, Cambridge University Press, 1996); and John Finnis, Joseph Boyle, and Germain Grisez, *Nuclear Deterrence, Morality and Realism* (Oxford: Clarendon Press, 1998).

considering relevant country-specific and subject-specific works. In addition, each author conducted meetings with leading experts from the case study-country and surrounding region to obtain information about the view of the “nuclear taboo” in each country and about the considerations that affect nuclear decision-making in each country.

The study produced several key findings:
Familiarity with the “nuclear taboo” as conceptualized in Western scholarship is quite limited, especially in Iran and Pakistan. This is less surprising in the case of Iran, since it does not yet have nuclear weapons and therefore its strategic studies community has not had to grapple with the specific question about whether to use such weapons in an armed conflict. The same is not true of Pakistan, which has nuclear weapons and whose leaders have thought about how to use them in a conflict with India. Questions about whether to use them, and whether their use should be constrained by normative concerns, have not been widely debated because officials believe they can be used under specific conditions and because there are few experts outside government who engage in discussions and studies of these issues.

Evidence that a “nuclear taboo” would constrain these countries’ use of nuclear weapons is mixed.

- In Iran, some religious experts believe that it would be morally unacceptable to use nuclear weapons; however, the extent to which this view is shared is difficult to evaluate, and since Iran itself does not have nuclear weapons it is impossible to assess how this view would influence future Iranian leaders’ view of whether to use weapons they might one day possess.
- In Pakistan, there is little evidence that nuclear decision making has been or would be constrained by the “nuclear taboo.” Strategic concerns and an abiding fear of being defeated by overwhelming Indian conventional forces overwhelm any moral considerations about whether to use nuclear weapons.
- India provides the strongest evidence for the presence and influence of the “nuclear taboo” as that concept is understood in mainstream scholarship and as it has been used to describe the behavior of Western nuclear states. India has avoided launching nuclear attacks against its adversaries, does not appear to have ever contemplated such action, and shows no signs of wishing to do so in the future. However, like Western nuclear states, India has used and will continue to use nuclear weapons as a deterrent.

Recommendations for Further Research
Further research is required to assess the impact on the nuclear taboo of changes in non-Western countries’ nuclear arsenals, nuclear strategies, and bilateral relations. This is particularly needed in the case of India, where evidence for the presence and strength of the nuclear taboo has been greatest. India’s adherence to the nuclear taboo could be weakened by two developments. One is Pakistan’s acquisition of tactical nuclear weapons, which would lower the nuclear threshold. The other is growing rivalry between India and China, which already has led Indians to question whether their commitment to no first use has weakened the deterrent effect of their nuclear arsenal.

NPS-N16-N359-A: Deepening U.S. Partnerships in the Indian Ocean Region

Researcher(s): Dr. Michael Malley, Dr. Paul Kapur, and Mr. Ryan Jacobs
Student Participation: CDR Michael Gussenhoven USN

Project Summary
Increased naval patrols, infrastructure construction, and diplomatic visits characterize China's expanding political, economic, and military presence in the Indo-Asia-Pacific region. This expansion creates challenges and opportunities for regional states and extra-regional powers that depend on the Indian Ocean's sea-lanes. The alignment strategies undertaken by regional states in response to Chinese moves will critically influence how the region develops over the next 15 years.

This project sought to identify the alignment strategies of smaller countries in the Indian Ocean Region (IOR) in the face of increasing Chinese presence in the region as well as the emerging Sino-Indian competition (the subject of a previous study by the same PIs). The aim was to inform the development of naval strategy and policy by providing USN leaders with insights that enable them to identify the most promising opportunities for building partnerships in the IOR. Focusing mainly on Sri Lanka and Indonesia, this project gathered a wide array of qualitative data through archival research and meetings with high-level officials and experts, mainly in India, Indonesia, and Sri Lanka. In general, we found that India remains strongly inclined to balance against China and aims to strengthen its partnerships with the United States and other countries to achieve this aim. However, smaller countries in the IOR are much less inclined to balance against China. They seek to enhance their ties with the United States and China, but wish to avoid taking sides in a Sino-American contest. This calls for a high degree of sensitivity, creativity, and patience in developing maritime security partnerships in the IOR.

Keywords: China; India; Indian Ocean; Indonesia; Sri Lanka; strategy; security cooperation

Background
China's ongoing economic expansion has facilitated growth in Chinese military power, including an increase in Chinese Navy (PLAN) capabilities.[4] These capabilities and Chinese soft power will enable China to expand its reach across the Asia-Pacific and into the Indian Ocean region (IOR).[5]

---

[4]See Andrew S. Erickson, "China's Modernization of its Naval and Air Power Capabilities," In Ashley J. Tellis and Travis Tanner (eds.), *Strategic Asia 2012-13: China's Military Challenge* (Washington, DC: The National Bureau of Asian Research, 2013), 79; "China's Navy Extends its Combat Reach to the Indian Ocean," U.S.-China Economic and Security Review Commission, Staff Report, 14 March 2014, http://www.uscc.gov/Research/china %E2%80%99s-navy-extends-its-combat-reach-indian-ocean; and "China's Military Strategy," Information Office of the State Council, People's Republic of China, May 2015, http://news.usni.org/2015/05/26/document-chinas-military-strategy#BDC.

[5] See Mohan Malik, *China and India: Great Power Rivals* (Boulder: FirstForumPress, 2011), 350-1.

This is leading to rivalry with India, which aims to achieve some form of maritime dominance in the IOR.[6] Smaller regional states will face a complex set of choices about whether to balance with one power against another; whether to seek extra-regional partners to balance against India and China; and whether to bandwagon with one or both of these Asian powers. Experts are divided over the choices that these countries will make. Some predict that the opportunities for joint economic gains between China and states in the IOR, as well as the high cost of competition and conflict with an increasingly powerful and assertive China, will create strong incentives for smaller states to cooperate with the Chinese. In such a cooperative scenario, states may not simply strike economic deals with China – they may bandwagon more broadly with the Chinese, acquiescing in the rules, institutions, and military arrangements favored by Beijing for management of the Indian Ocean region.[7] Other analysts expect that these states will view an increased Chinese presence as more of a threat than an opportunity. In response, they will likely take steps to balance against the potential dangers of Chinese power, including such measures as arms racing and regional and extra-regional alliance seeking with India and others.[8]

Findings and Conclusions

To assess the current and likely future alignment choices of other countries in the Indian Ocean region, as well as the partnership opportunities that these present for the U.S. Navy, we undertook an extensive literature review, gathered public documents and secondary sources regarding the choices of each country, and conducted a series engagements with senior leaders and experts in India, Sri Lanka and Indonesia. There was very close coordination with the study's sponsor, who participated directly in the project's key events in India and Sri Lanka. Moreover, project PIs provided direct support to the sponsor during his high-level engagements with counterparts in those two countries.

The main purpose of the meetings we conducted in the partner countries was to gain insight into the strategic views of a broad range of actors who shape each country's decision about whether and how to align with China, India, and the United States. The most important engagement we conducted in the course of this project was done in collaboration with the Indian Naval War College and OPNAV N51. This event provided an unparalleled opportunity to present our hypotheses about the current and future alignment strategies of small and medium powers in the IOR and to receive immediate feedback, critiques, and input from senior scholars and officials in India. After consulting with our sponsor, we conducted similar engagements in Sri Lanka and Indonesia, which are considered crucial cases because of their strategic

---

[6] See Kanti Bajpai, "India-China: The Shadow of the Future," *Seminar* 629, January (2012); Deepak Kapoor, "India's China Concern," Strategic Analysis 36, no. 4 (2012), pp. 663, 665; and David Scott, "India's Aspirations and Strategy for the Indian Ocean – Securing the Waves," Strategic Studies 36, no. 4 (2013).

[7] See Darshana Baruah, "Modi's Trip and China's Islands: The Battle for the Indian Ocean," *The Diplomat*, 11 March 2015, http://thediplomat.com/2015/03/modis-trip-and-chinas-islands-the-battle-for-the-indian-ocean/.

[8] See Robert Kaplan, "China's Unfolding Indian Ocean Strategy – Analysis," Center for a New American Security, 11 February 2014, http://www.cnas.org/content/china%E2%80%99s-unfolding-indian-ocean-strategy-%E2%80%93-analysis#.VeZnzZ3BzGc.

geographic positions and potential to cooperate with the United States as well as U.S. allies (e.g., Australia) and partners (e.g., India).

Although this project had a sharp policy focus and provided direct analytical support to a senior Navy leader, it was based on deeper theoretical and analytical propositions and sought to answer questions of enduring importance in the field of international relations. As mentioned in the preceding section of this report, we adopted a balancing-bandwagoning approach to analyze the alignment choices of key countries in the IOR. This approach is grounded in theories of international relations but is often used by policy analysts. Therefore, it provides not just an effective analytical tool, but also a common language for communicating the study's findings to senior leaders who make strategy and policy.

This project produced three key findings:

1. Under its current leadership, India views China as a growing threat. There is a broad consensus among India's strategic thinkers and officials that China's actions present a broad challenge to India's security and to its preeminence in the Indian Ocean region. As a result, India is seeking to balance against China. Strengthening its partnership with the United States is a critical component of its balancing strategy. Less well known are its efforts to deepen and broaden maritime security cooperation with other partners, including IOR countries such as Australia and Indonesia, as well as others beyond the IOR, such as Japan and Vietnam.
2. For Sri Lanka, relations with India have always taken priority over ties with other countries. India has often been an unreliable economic partner and occasionally a military and political threat, so Sri Lanka often seeks to balance against India by forging partnerships with other powerful countries. In recent years, this has led Sri Lankan leaders to turn to China, which has offered military and economic assistance, and now ranks as Sri Lanka's second largest trading partner and largest foreign investor. Yet Sri Lanka is unlikely to provide consistent support for China, given the importance that it continues to attach to relations with India.
3. Indonesian leaders see China as a potential threat in the South China Sea, but Indonesia's interests there are quite limited. By contrast, they see many benefits from closer economic cooperation with China. As a result, few leaders are inclined to engage in explicit balancing against China. However, the current government is strongly inclined to defend the country's maritime rights, and it seeks partnerships that will strengthen its own naval and maritime enforcement capabilities. This presents significant opportunities for the United States but few for India or other countries in the IOR, which have weak ties with Indonesia.

Recommendations for Further Research

Further study would be useful in three areas.

1. Effort should be devoted to empirical investigation of the alignment choices of the region's small and medium powers. These choices, and their causes, pass largely unexamined in the scholarly literature because they have little impact on the balance of power. But these choices are critical to U.S. policymakers and USN strategists who must determine which countries are potential partners and then decide how many resources to invest in developing those partnerships.

2. Initiating and developing effective partnerships with non-traditional partners requires naval personnel with sufficient knowledge and understanding of those potential partners, especially the domestic political variables that shape partners' strategic interests and alignment choices. Such personnel appear to be in very short supply. Studies should be undertaken to assess personnel requirements and associated training and education requirements.
3. More attention should be devoted to the empirical examination of maritime security cooperation among small and medium powers in the region and to the implications of this cooperation for the United States. India's government has adopted an "Act East" policy and is pursuing naval cooperation with countries in Southeast Asia. Indonesia's government sees itself as an "axis" between those two oceans. Similar changes are occurring among other countries. These shifts in our partners' policies create new opportunities for the U.S. to strengthen maritime security cooperation among its partners and enhance regional stability.

NPS-N16-N406-A: Evolving Russian Views on Nuclear Weapons and their Significance for the US and NATO

Researcher(s): Dr. Mikhail Tsypkin and Dr. David Yost
Student Participation: No students participated in this research project.

Project Summary
The basic roles of nuclear weapons for Russia include ensuring its status as a great power and compensating for its conventional military shortcomings. Russian nuclear-related activities, including the high-level declarations, aerial intrusions, exercises, and weapons development efforts, are intended to intimidate and deter North Atlantic Treaty Organization (NATO) and other states that Moscow regards as adversaries. Russians hold that deterrence requires options for the actual employment of nuclear weapons. Russian public diplomacy remains calculated to undermine support for U.S. and NATO missile defense. The long-standing discord between NATO and Russia on missile defense continues, including Russian political warfare against NATO missile defense efforts.

Russian nuclear messaging with exercises and aerial intrusions illustrates Russia's new assertiveness and Moscow's rejection of NATO's vision of a peaceful and democratic Euro-Atlantic security order. Beyond Western recognition of a Russian sphere of influence in the post-Soviet space, Moscow's ambitions are open to debate — a new security architecture in Europe without the United States, leadership of anti-Western coalitions, or Stalin-like opportunism and autonomy. As a revanchist power oriented toward the recovery of lost territories and zones of influence, Russia sees itself in competition with the West over the future of Ukraine and other countries in the post-Soviet space. Russia may be willing to engage in risk-taking, including the "de-escalatory" use of nuclear weapons, in contingencies in which it perceives an asymmetry of stakes with the NATO countries.

Keywords: Russia, nuclear weapons, NATO

Background

This research was inspired by the work performed for the sponsor in the previous fiscal year, a research effort entitled *Responding to Russian Noncompliance with Nuclear Arms Control Agreements*.

Findings and Conclusions

Nuclear saber rattling has been characteristic of the Kremlin's conduct since at least 1999. All three versions of the official military doctrine since 1999 have warned that Russia could be the first to use nuclear weapons if the existence of the Russian state were endangered. Russia is in the midst of a significant modernization of its Strategic Nuclear Forces (SNF) and Non-Strategic Nuclear Weapons (NSNW). Moscow has also conducted exercises simulating nuclear strikes against other nations, as well as engaged in verbal threats to use nuclear weapons against some of its neighbors.

The most important leg of the Russian nuclear triad - the Intercontinental Ballistic Missiles (ICBMs) of the Strategic Rocket Forces (SRF) – has been increasing the number of mobile ICBMs, postured for launch-under-attack. Nevertheless, the SRF continues to maintain a substantial number of silo-based ICBMs, postured for launch-on-warning. The Russians plan to modernize their silo-based ICBM contingent with the introduction of a liquid propellant ICBM called Sarmat and designed to carry up to ten Multiple Independently Targetable Reentry Vehicles (MIRVs).

Russia wants a free hand in its vicinity (at least along its periphery in Europe), and regional nuclear deterrence, which includes the threat of first use of nuclear weapons, or actual use of nuclear weapons, is intended to support this policy goal. The escalatory ladder might begin with threats, continue with demonstration strikes, and then proceed to nuclear use against enemy forces.

For this mission, Russia appears to rely primarily on long-range cruise missiles, against which NATO does not have substantial defenses. The possible scenarios range from the regional nuclear deterrence posture simply preventing NATO from intervening against Russia's military action in its vicinity, to a contingency in which Russia initiates military action against one of its neighbors, suffers a defeat, possibly because of a counter-intervention by NATO, and threatens the use of, or actually uses, nuclear weapons to end the conflict on terms acceptable to Moscow.

Russia's "de-escalation" concept, sometimes dubbed "escalating to de-escalate," calls for a limited use of nuclear weapons in a confrontation to fragment the NATO Alliance and bring about an end to combat on Russian terms. One of the dangers in the "de-escalation" concept is that it might lead Russian leaders to regard nuclear strikes as instruments to reassert control over events in a crisis. Russian leaders might try to limit the potential consequences of Russian nuclear attacks by employing low-yield weapons with tailored effects.

The Russian weapons acquisition program for regional nuclear deterrence, with an emphasis on dual-capable cruise missiles, against which NATO has only limited defenses, suggests serious interest in preparedness for regional nuclear contingencies.

The use of Sea-Launched Cruise Missiles (SLCMs) and Air-Launched Cruise Missiles (ALCMs) against targets in Syria, which were not protected by air defenses, was a demonstration of the Russian capability in regional nuclear deterrence. At the same time, it appears that the Russian military has not yet developed a coherent doctrine for using nuclear weapons in regional deterrence. The most disturbing aspect of the discussions of this subject by Russian military experts is the lack of attention to the possibility that a limited use of NSNW in order to "de-escalate" a conventional conflict might result in an escalation of operations and a global nuclear war with catastrophic consequences.

Recommendations for Further Research

Future researchers should examine Russian nuclear capabilities, doctrine, professional military literature, and exercises. It is especially important to deepen understanding of all types of Russian nuclear messaging in peacetime and crisis conditions. Another topic that deserves sustained attention is the Russian concept of nuclear "de-escalation."

NPS-N16-N422-A: China's "New Asian Security Concept" and U.S. Maritime Interests in East Asia

Researcher(s): Dr. Michael A. Glosny
Student Participation: No students participated in this research project.

Project Summary

The "New Asian Security Concept" (NASC), first announced by Xi Jinping at the May 2014 Conference on Interaction and Confidence Building Measures in Asia (CICA) summit, summarizes and reflects China's strongest direct challenge since the late 1990s to U.S. regional presence, security alliances, maritime interests, and the preferred U.S. vision of regional security. This project draws on Chinese-language sources to examine the evolution of this concept, especially the envisioned role for U.S. naval presence and maritime interests, and show how this concept is influencing Chinese naval modernization and activities. The main findings are that China's NASC vision for regional security order represents a more indirect and long-term challenge to U.S. security and maritime interests. It also provides recommendations for U.S. responses to reduce the regional support for China's NASC and enhance regional support for a regional order not under Chinese domination.

Background

Many analysts have observed that China's military modernization and recent assertive behavior, especially in the maritime domain, has challenged U.S. interests in East Asia. At the April 2014 Beijing meeting of the Conference on Interaction and Confidence Building Measures in Asia (CICA), Chinese President Xi Jinping's speech directly criticized and challenged the U.S.-led regional security order and called for the establishment of a "New Asian Security Concept" (*Yazhou Xin Anquanguan*), hereafter referred to as NASC. China's NASC vision includes strong criticism of U.S. alliances and military presence in the region, and aims to fundamentally reshape the regional security order so that it favors China's interests. One of the lines that attracted the most attention in Xi's speech was the suggestion that "it is for the people of Asia to run the affairs of Asia, solve the problems of Asia and uphold the security of Asia."[9] Xi's speech and subsequent official discussions of NASC have criticized the recent strengthening of U.S. alliances, "zero-sum mentality," "Cold War mentality," and attempts by the U.S. to dominate regional affairs as the outdated thinking and the source of regional instability and increased difficulties in China's security environment. Xi's discussion of common security, as opposed to absolute security which he argues the U.S. advocates, included several attacks on the current U.S.-led regional security order. According to Xi's speech, "To beef up and entrench a military alliance targeted at a third party is not conducive to maintaining common security." President Xi argued further that "no country should attempt to dominate regional security affairs or infringe upon the legitimate rights and interests of other countries." Many Western analysts have suggested that the NASC and new regional initiatives represent a new broad-based Chinese attempt to establish a sphere of influence in East Asia in a new "Monroe Doctrine" that includes pushing the U.S. out of the region, eliminating U.S. alliances, and ending the U.S. military presence in East Asia.[10]

Although Western analysts have focused on the "Asia for the Asians" aspect of the NASC, Chinese officials have emphasized how the new concept can transcend past competition and achieve win-win cooperation and regional security.[11] In language repeated by Chinese official subsequently, Xi summarized the task and vision of NASC in his CICA speech: "It is necessary to advocate common, comprehensive, cooperative and sustainable security in Asia. We need to innovate our security concept, establish a new regional security cooperation architecture, and jointly build a road for security of Asia that is shared by and win-win to all." Common security (*gongtong anquan*) refers to "respecting and ensuring the security of each and every country." Comprehensive security (*zonghe anquan*) includes "upholding security in both traditional and

---

[9] Xi Jinping, "Remarks at the Fourth Summit of the Conference on Interaction and Confidence Building Measures in Asia," May 21, 2014, available at http://www.china.org.cn/world/2014-05/28/content_32511846.htm

[10] Shannon Tiezzi, "At CICA, Xi Calls for New Regional Security Architecture," *The Diplomat*, May 22, 2014; David Cohen, "'A Clash of Security Concepts': China's Effort to Redefine Security," *China Brief*, June 4, 2014; and Joel Wuthnow, "What to Make of Xi Jinping's Vision for Asian Security?" Asan Forum, August 11, 2014.

[11] For other official discussions of NASC, in addition to Xi's CICA speech, see Cheng Guoping, "Yazhou Anquanguan: Yinling Yazhou Anquan Hezuo Xin Fangxiang," *Qiushi*, July, 16, 2014; and Liu Zhenmin, "Jianchi Hezuo Gongying: Xieshou Dazao Yazhou Mingyun Gongtongti" [Uphold Win-Win Cooperation: Cooperate in Forging Asian Community of Common Destiny], *Guoji Wenti Yanjiu*, No. 2 (2014), pp. 1-10.

non-traditional fields." Cooperative security *(hezuo anquan*) means "promoting the security of both individual countries and the region as a whole through dialogue and cooperation." In this context, Xi noted, "we should bear in mind the common security interests of all countries." Lastly, sustainable security (*kechixu anquan*) requires a "need to focus on both development and security so that security would be durable." According to this vision, the essence of security is that it should be universal (*pubianxing*), equal (*pingdengxing*), and inclusive (*baorongxing*).

Findings and Conclusions

As this project is still ongoing (completion date is projected as 6/30/2017), this section will present interim Findings and Conclusions based on the research to date, which has mostly included a thorough analysis of Chinese-language writings. These efforts are the foundation for my planned research trip to China, the most important part of my research. I will conduct discussions with Chinese government officials, military officers, and civilian experts to obtain a deeper view of their understanding of this "New Asian Security Concept" and China's visions for regional and maritime order in East Asia. After completing this research, I will provide a complete written report and complete NRP progress report, in addition to providing briefings on the main findings of the project.

First, China's decision to propose and promote the NASC and attempt to reshape the regional security architecture is driven by dissatisfaction with several aspects of the U.S.-led regional security order established at the end of World War II. Although recognizing that U.S. presence in Asia and the U.S.-led regional order have been helpful for China's sustained economic rise, Chinese officials and experts are disappointed and dissatisfied that as the regional balance of power has shifted, the regional security order has not also adjusted to reflect these changing power realities. Despite the balance of power shifting to Asia, and to China within Asia, the United States remains dominant. Chinese experts hoped that the regional security order would adjust to accommodate China's interests, but the U.S. "rebalance to Asia," and deeper involvement in Asia by other "non-Asian" powers has led to greater challenges to China's interests.

Second, China's shift to more actively shape the regional security order and propose an alternative conception of regional security is part of China's overall shift towards greater activism in foreign and security policy. China has become more active in economic statecraft, using its advantages and resources in economics, to reassure countries about the rise of China and show how other countries can benefit through a peaceful, stable, and friendly relationship with China. The promotion of NASC shows that China has both expanded its activism into the realm of security, and is trying to integrate economics and security in ways that will use its economic advantages to reshape the regional security order.

Third, the potential threat of the NASC to U.S. regional interests and U.S. Navy maritime interests is a more indirect, subtle, and long-term challenge than Chinese assertiveness in maritime disputes and challenges to U.S. Navy operations. The NASC vision is critical of U.S. alliances and concerned that U.S. domination of the regional security architecture will damage Chinese interests and constrain its rise and the exercise of its influence. However, Chinese experts are conscious to not be seen as directly challenging U.S. alliances or the U.S.-led order, recognizing that such an offensive would likely backfire. China is pointing to shortcomings and problems in the existing order that can be reformed and improved on, rather than trying to overturn the regional order, destroy U.S. alliances, or propose an alternative vision. Although its vision would definitely weaken U.S. alliances and reduce U.S. dominance and influence in the region, its attempts to emphasize cooperation and the connections between economics and security are difficult to reject or dismiss outright. Moreover, China recognizes that the move from a U.S.-led regional order to an order consistent with its NASC is likely to be a slow and gradual process, making this a long-term and more subtle threat than other aspects of Chinese assertiveness. However, as countries gradually adopt or endorse China's NASC, this would produce a fundamental transformation of the region, weaken U.S. alliances, and severely limit cooperation with potential regional partners.

Fourth, the United States should not directly criticize all aspects of China's NASC vision, but should respond to the long-term indirect challenge with a similar long-term subtle approach that will reassure the region of the need and benefits of a continued U.S.-led order. Although the "Asia for the Asians" aspects of NASC suggest that China might want to exclude the United States from the region. However, NASC also clearly welcomes constructive contributions of non-regional powers, which is how Chinese experts refer to the United States. As NASC clearly expresses an open and welcoming attitude to the United States, as long as it behaves in ways that China finds constructive, simply criticizing or dismissing it as a way to push the U.S. out of the region is unlikely to be satisfying to the region, and provides China with an easy response. Instead, the United States should recognize that many of the ideas in NASC, such as the importance of economics and dialogue, are supported by the region. Instead of focusing on criticizing China and its NASC vision, the United States needs to take actions to demonstrate how the U.S. is also promoting regional economic growth and demonstrate to the region that it is the U.S. military and U.S. Navy that provides global and regional security goods and should be the partner of choice for the region.

Recommendations for Further Research

Although the final report will highlight additional areas of further research, at this point in the project, there are two important areas of further research. First, as Chinese official statements and experts emphasize the "inclusive" nature of the NASC, and how U.S. regional presence is welcome, further research of which American activities and actions China sees as constructive would be helpful and highlight areas for potential cooperation. Second, future research is needed on how regional countries are understanding and responding to China's NASC vision. This research would help inform and shape U.S. policy to ensure continued support from the region for U.S. presence and a U.S.-led regional security architecture.

References
Cheng, Guoping. "Yazhou Anquanguan: Yinling Yazhou Anquan Hezuo Xin Fangxiang," *Qiushi*, July, 16, 2014.
Cohen, David. "'A Clash of Security Concepts': China's Effort to Redefine Security," *China Brief*, June 4, 2014.
Liu, Zhenmin. "Jianchi Hezuo Gongying: Xieshou Dazao Yazhou Mingyun Gongtongti" [Uphold Win-Win Cooperation: Cooperate in Forging Asian Community of Common Destiny], *Guoji Wenti Yanjiu*, No. 2 (2014), pp. 1-10.
Tiezzi, Shannon. "At CICA, Xi Calls for New Regional Security Architecture," *The Diplomat*, May 22, 2014.
Wuthnow, Joel. "What to Make of Xi Jinping's Vision for Asian Security?" Asan Forum, August 11, 2014.
Xi, Jinping. "Remarks at the Fourth Summit of the Conference on Interaction and Confidence Building Measures in Asia," May 21, 2014, available at http://www.china.org.cn/world/2014-05/28/content_32511846.htm.

NPS-N16-N577-A: Strategic Stability in Sino-American Nuclear Relations, the Maritime Dimension

Researcher(s): Dr. Christopher Twomey
Student Participation: No students participated in this research project.

Project Summary

Given the centrality of "strategic stability" to U.S. declaratory policy, this study proposes to engage Chinese interlocutors to identify published understandings of the concept as they pertain to the maritime sphere, and the degree to which it faces challenges. Chinese writings and research on the subject have surged given recent U.S. emphasis on the concept. Evaluating and disseminating this is of interest to policy makers and scholars alike. This study proposes engaging with Chinese sources on the topic to deepen U.S. understanding of the Chinese views on the topic and the ways such stability might be challenged in the future with a particular eye towards developments in the maritime sphere.

Background

Strategic stability is an important, stated goal for U.S. policy toward China. In order to advance that, it is important to understand what China views the term to signify and what factors influence it. The maritime dimension, so central to U.S. - Soviet dynamics, warrants particular attention.

Findings and Conclusions

Core findings that reside at the center of most international relations syllabi have not been applied to nuclear affairs in East Asia. The shift from bipolarity to multipolarity in the nuclear arena is a major change, and one that the international relations canon of Rosencrance, Waltz, and Mearsheimer can speak to. But no one has systematically done so. This project identifies the implications from the theoretical literature and performs simple tests—perhaps just plausibility probes—of these in contemporary East Asian politics.

Whether we learn about the Cold War from a historian like Gaddis or a political scientist like Waltz, nuclear weapons were seen as stabilizing elements, at least in the second half of that epoch.

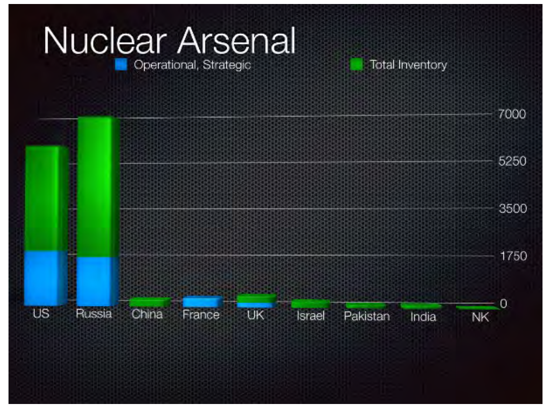


Figure 1. Nuclear powers in Asia.

A number of studies have suggested nuclear weapons can provide grounds for optimism. There is an active debate between proliferation optimists and pessimists, both in the quantitative and qualitative literature. Separately, that multipolarity in Asia than nuclear weapons stabilizing a dangerous multipolarity in Asia, we have nuclear multipolarity worsening that already dangerous situation. This depended on a range of context specific factors that have changed today. Three new, or at least worsened kinds of in the nuclear instability: truel instability, alliance dilemma instability, and tangled redline instability.

A second, very distinct set of challenges is posed by the complexity of the strategic environment today. First, states think about nuclear weapons utility and role in very different ways in the second nuclear age. Second, identifying what exactly is a "strategic" weapon has gotten more difficult.

Perceptions on the Utility of Nuclear Weapons in Asia

	Russia	United States	China	Pakistan	India	North Korea	Japan
Expected role							
Deter nuclear threat to cities	X	X	X	X	X	X	
Deter nuclear escalation	X	X	?				
Deter major conventional defeat	X		?	X		X	
Extended deterrence of nuclear threat		X					X
Extended deterrence of conventional threat		X					X
Compellent power		X				X	
Arsenal needs							
Existential				X	X	?	Virtual?
Robust second strike			X				
Advanced	X	X					

Table 1. Perceptions on the utility of nuclear weapons in Asia.

Asia illustrates these problems. In several cases, the truel instability manifests and poses pressure on arsenal sizes and weapons development. The existence of nuclear multipolarity in Asia is straightforward; as shown in Figure 1 there are six nuclear powers in the region. At least four of them, China, India, Pakistan, and North Korea, are currently growing their arsenals.

Asia also exhibits the complexity of strategic affairs described above. One element of this is the diversity of views about the role of weapons. There is also significant variation in the way weapons are postured and the role weapons are thought to play. Drawing on my previous work, Table 1 highlights that diversity. This raises problems distinct from that posed by multipolarity, but also means that comparing across nuclear powers is difficult.

Recommendations for Further Research

Further work in this area is warranted. A few areas merit particular attention. Might one characterize triangles in different ways? Perhaps some are tightly coupled in crises (severe trilateral crisis instability) and others are more tightly coupled in posture/arsenal size (arms race instability). Second, how can we manage to assess the instability of crises or intense diplomatic engagement? Thankfully the data set of nuclear use is small, but it does complicate the assessment of more or less dangerous nuclear crises.

Contrary to characterizations of nuclear weapons having a stabilizing effect on Asian politics today, the distinctive elements of the second nuclear age mean that nuclear weapons in the context of a complex, multipolar environment exacerbate the dangers of an already volatile region. Optimists regarding either proliferation or the potential for avoiding a Thucydides trap because of the existence of nuclear weapons are ignoring important differences between the contemporary environment and previous experience.

None of this depends on specific crises in the South China Sea, East China Sea, over Taiwan, or North Korea. All of those are pretty easy to imagine, however. While wargaming each has its limitations for predictive power, it is clear that such conflicts would develop in the context of this looming nuclear shadow. This shadow or backdrop will loom over any of these other conflicts, amplifying their scale.

References

Rovner, Joshua. “Two Kinds of Catastrophe: Nuclear Escalation and Protracted War in Asia.” *Journal of Strategic Studies*, 2017, 1–35.

Logan, David. “PLA Reforms and China’s Nuclear Forces.” *National Defense University Press*. Accessed March 7, 2017. http://ndupress.ndu.edu/Media/News/Article/969665/pla-reforms-and-chinas-nuclear-forces/.

Chase, Michael S., and Cristina L. Garafola. “China’s Search for a ‘Strategic Air Force.’” *Journal of Strategic Studies* 39, no. 1 (January 2, 2016): 4–28. doi:10.1080/01402390.2015.1068165.

Chase, Michael S., and Arthur Chan. “China’s Evolving Strategic Deterrence Concepts and Capabilities.” *The Washington Quarterly* 39, no. 1 (January 2, 2016): 117–36. doi:10.1080/0163660X.2016.1170484.

Biddle, Stephen, and Ivan Oelrich. “Future Warfare in the Western Pacific: Chinese Antiaccess/Area Denial, U.S. AirSea Battle, and Command of the Commons in East Asia.” *International Security* 41, no. 1 (July 2016): 7–48. doi:10.1162/ISEC_a_00249.

Wu, Riqiang Q. “Chinas Anxiety About US Missile Defence: A Solution.” *Survival* 55, no. 5 (2013): 29–52.

Tellis, Ashley J., Abraham Denmark, and Travis Tanner, eds. “Asia in the Second Nuclear Age.” Seattle; Washington, D.C.: National Bureau of Asian Research, 2013.

Khan, Zafar. “The Arrival of Tactical Nuclear Weapons in South Asia: Deterrent Stability or Instability?” *Comparative Strategy* 32, no. 5 (2013): 402–417. doi:10.1080/01495933.2013.840205.

Morgan, Patrick M. “The State of Deterrence in International Politics Today.” *Contemporary Security Policy* 33, no. 1 (2012): 85–107. doi:10.1080/13523260.2012.659589.

N4: Material Readiness & Logistics

NPS-N16-N169-A: CAD Interoperability for Navy Reuse in Additive Manufacturing (AM), 3D Printing, Maintenance and Training

Researcher(s): Dr. Amela Sadagic and Dr. Don Brutzman
Student Participation: Capt Matthew Friedell USMC

Project Summary
Additive Manufacturing (AM) technology has a potential to affect and change everything in all services: logistics, repair, warfighting along with training, simulation, education and support. Additive Manufacturing (AM), 3D printing and Computer-Aided Design (CAD) export are also critical for Navy maintenance. Rapid change continues to occur across the design, engineering, manufacturing, and production processes - many products can now be fabricated using AM methods. Iterative design processes require close collaboration of all entities involved from design to production; with AM, the lines between these previously stovepipe steps become blurred. A need to design, test, and adopt different maintenance workflow becomes a necessity in cases of preventive and corrective maintenance of mechanical components on Navy ships and aircrafts where such operations have major impact on operational readiness. This project proposed to study and test elements that were identified as critical for effective deployment of AM in Navy operations, with specific emphasis on maintenance operations, while remaining sensitive to other Navy domains and activities where the use of AM could bring significant value. Our overarching goal was to provide a comprehensive approach that would lead towards reduction of energy costs, as well as reduction of materials and human resources engaged in that process.

Keywords: shipboard maintenance operations, 3D printing, 3D scanning, virtual training, energy savings, stereoscopic display, X3D

Background
Additive Manufacturing (AM) technology has a potential to affect and change everything in all services: logistics, repair, warfighting along with training, simulation, education and support. The landscape of technology innovations is moving so fast that the opportunities to capture full potential for game-changing capabilities may easily get lost. With the emergence of low cost commercial-off-the-shelf solutions and high power computing, the current military acquisition system and infrastructure needed for rapid setup and large-scale adoption of new technologies may not be best suited for more recent waves of digital innovations. The example domain that has been addressed in this project includes preventive and corrective maintenance of mechanical components on Navy resources like ships and aircrafts – this domain can have major impacts on operational readiness. Corrective maintenance itself is characterized by an

added level of complexity: given the nature of physical resources used in Navy domain that is reflected in the age and uniqueness of many components currently in use on the ships, the availability of needed parts and components further reduces the service flexibility. The characteristics and constraints of this domain space served as the ultimate motivation for our research efforts; our overall project objective is to provide a comprehensive approach that would lead towards reduction of energy costs, as well as reduction of materials and human resources engaged in that process. The objectives of this type are at the center of attention of the project topic sponsor OPNAV, N41.

The main objective for the part of the project that is focused on adoption of novel technologies, in our case Additive Manufacturing, is in acquiring more detailed understanding about the current practices, processes, global domain conditions, the existence of elements of supportive environment (physical infrastructure, expertise), current and projected promotion efforts and communication, user attitudes and parameters that can positively or adversely influence adoption of this technology in the Navy and military domain in general. The characteristics of the innovation and benefits it brings to its users are important elements that influence adoption of that innovation among its intended users [Rogers-1995]. Additional elements that significantly impact the rate of adoption are user-perceived usefulness of innovation, its ease of use and final user acceptance - these types of characteristics were studied and incorporated in Technology Acceptance Model (TAM) introduced and expanded in Davis (1986), Davis (1989), and Davis (1993), as well as by Venkatesh et al. (2000). A new theory - Unified Theory of Acceptance and Use of Technology or UTAUT also incorporate this type of considerations by Venkatesh et al. (2003). Discussions that we had with multiple institutions and individuals engaged in AM domain, generated a great interest for issues directly related to Protection of Intellectual Property Rights (IPR) associated with 3D models generated and maintained in support of AM activities. The issues in this domain have been addressed by several technical research teams for quite some time, especially the techniques commonly called 3D Watermarking in Ohbuchi et al. (1998), Praun et al. (1999), Benedens (1999), Harte and Bors (2002), Macq et al. (2015). However, the policies that would address this space are yet to be fully formulated.

Findings and Conclusions

Two domains with multiple issues were addressed in this work on additive manufacturing (AM): technology adoption studies and 3D model interoperability. Technology adoption study efforts included a Master's thesis on large-scale adoption of AM in expeditionary missions by Friedell (2016), which included a formal study of the AM domain for naval use. Additional research explored effective use of stereoscopic displays for training on corrective and preventative equipment maintenance, producing a novel commercial-off-the-shelf (COTS) hardware/software solution for conducting and evaluating virtual assembly tasks.

3D model interoperability activities were focused around the Extensible 3D (X3D) Graphics International Standard (Brutzman and Daly (2007)). Lengthy ascertainment in concert with partners in the Web3D Consortium determined that common technical characteristics are found between Computer Aided Design (CAD) models, 3D printing, and 3D scanning. A shared strategy is now being pursued for an addition of CAD-model export conversion, compatibly combined encryption/authentication/compression. These conclusions and activities were further verified by emergent work by International Standards Organization (ISO) Joint Technical Committee (JTC-1) on 3D Printing and 3D Scanning across 20 different international standards. Additional synergies have emerged that demonstrate direct usefulness to model exchange between Navy and Marine Corps stakeholders. The SPIDERS3D program for Web-based visualization of ships, ports and piers uses database-driven models using compatible X3D models. Interestingly these same characteristics are shared with 3D-printable medical models found on the National Institutes of Health (NIH) Model Exchange.

As part of our work with the topic sponsor, groups and individuals who have been actively working in this domain, an information meeting titled "Naval Web-Based Collaboration and Model Exchanges using X3D" has been organized in February 2017. This meeting gave opportunity to review our work with the sponsor and discuss future agenda and collaborations with colleagues. NPS AM Wiki is an additional resource that has been created to house a diverse set of materials, data and documents created by NPS faculty and students who have been working on AM related topics, and to instigate collaboration with other colleagues (note: wiki page is publicly visible).

These results have the potential for broad impacts across the naval enterprise, both deployed and ashore. Allowing operators to view printed objects, collaboratively work over the Web and print/scan/modify 3D models brings multiple benefits to long-standing logistics challenges such as diagnosis of materiel failures and confirmation of part correctness. A partnered approach between user-centered requirements and technical capabilities has been fundamentally productive. Project results show the potential for improved processes and capabilities across the Navy and Marine Corps.

Recommendations for Future Research

The nature of technology adoption process dictates that it has to be studied over longer period of time. It is recommended that the future studies in this domain acknowledge service needs as they are identified in this domain, and focus on likely conduits of adoption of AM system and technologies.

Viewability, interoperability, sharing and collaboration are driving forces for applying technical capabilities. Data-centric approaches for metadata information along with data authentication, compression and encryption can augment contracted products to protect the government's intellectual investments and paid-for assets.

In the naval domain, for both Navy and USMC, Fabrication Laboratories (FABLABs) are now becoming our partners of choice for exploring the role of technology and innovation catalysts that Additive Manufacturing (AM) brings. NPS faculty and students will continue to work on these worthy challenges for the broader benefit that occurs.

References

Benedens, Oliver (1999). Geometry-Based Watermarking of 3D Models, IEEE Computer Graphics and Applications, Jan/Feb 1999.

Brutzman, D.P. and Daly, L. (2007). Extensible 3D Graphics for Web Authors, Morgan Kaufmann Publishing, 2007. 468 pages, http://x3dGraphics.com

Davis, F. D. (1986). Technology acceptance model for empirically testing new end-user information systems: theory and results (MIT PhD Thesis) 1986

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly*, Volume 13 Issue 3, p. 319–339.

Davis, F. D. (1993). User Acceptance of Information Technology: System Characteristics, User Perceptions and Behavioral Impacts, *Int J. Man-Machine Studies*, 38, p. 475-487.

Friedell, M. (2016). Additive Manufacturing (AM) in Expeditionary Operations: Current Needs, Technical Challenges and Opportunities, Master Thesis, Modeling Virtual Environments and Simulation (MOVES), Naval Postgraduate School, Monterey, CA, June 2016.

Harte, Thomas and Bors, Adrian G. (2002). Watermarking 3D Models, IEEE International Conference on Image Processing, Volume: vol. III, pp. 661-664.

Macq, Benoît; Sales, Mireia M.; and Alface, Patrice R. (2015). Applicability of Watermarking for Intellectual Property Rights Protection in a 3D Printing Scenario, Web3D conference, Heraklion, Crete, 2015.

NPS AM Wiki (n. d.), https://wiki.nps.edu/display/ADDM/Additive+Manufacturing

Ohbuchi, R., Masuda, H., Aono, M. (1998). Watermarking three-dimensional polygon models through geometric and topological modifications, IEEE Journal on Selected Areas in Communications, Vol. 16, No. 4, May, 1998, pp. 551-559.

Praun, E., Hoppe, H., Finkelstein, A. (1998). Robust Mesh Watermarking, Proc. SIGGRAPH '99 (Los Angeles, August 8-13, 1999). In Computer Graphics Proceedings, Annual Conference Series, 1999, ACM SIGGRAPH, pp. 49-56.

Rogers, E. M. (1995). *Diffusion of Innovations*. New York, NY: Free Press, 4th edition

Sadagic, A., and Yates, Floy A. (2015). Large Scale Adoption of Training Simulations: Are We There Yet?, accepted for publication in proceedings for I/ITSEC 2015.

Venkatesh, V., and Davis, F. D. 2000. A Theoretical Extension of the Technology Acceptance Model: Four Longitudinal Field Studies. *Management Science*, 46, p. 186–204.

Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. 2003. User Acceptance of Information Technology: Toward a Unified View. *MIS Quarterly, 27*, p. 425–478.

Yates, F. (2013). Diffusion and Large-scale Adoption of Computer-supported Training Simulations in the Military Domain, NPS Master Thesis, Sep 2013.

NPS-N16-N169-B: Microstructural Analysis and Comparative Study of Powders Used in 3D Metal Printing

Researcher(s): Dr. Claudia Luhrs
Student Participation: LT Cody Colyer, USN and LT David Buitrago, USN

Unclassified Project Summary:
The primary objective of this research was to perform a failure analysis on fatigue fractured Ti-6Al-4V coupons fabricated using additive manufacturing (AM), namely, selective laser sintering (SLS). Additionally, this study aimed to analyze and characterize the powders used to fabricate the coupons through each step of the additive manufacturing process up to printed parts. Microstructural features in both the fracture surface and base material were analyzed using optical and electron microscopy. The coupons were further analyzed with Energy Dispersive X-ray Spectroscopy (EDS) techniques and mechanical properties were measured. The powder used to fabricate the coupons was analyzed by optical and electron microscopy/EDS techniques to determine size, shape, elemental composition, and microstructure. Additionally, the powder was characterized through X-ray Diffraction (XRD) as well as Thermogravimetric Analysis (TGA) and Differential Scanning Calorimetry (DSC). The merit of the work relies on gaining a better understanding of the evolution of the material characteristics, from raw powders to printed parts, to help reduce the risks associated with the use of the new AM fabrication techniques and aid the decision making process regarding material selection and processing parameters.

NPS-N16-N169-C: Additive Manufacturing Novel Metal Particle Technology

Researcher(s): Dr. Jonathan Phillips
Student Participation: LT Karima Greenaway USCG and LT Chris Pelar USCG

Project Summary
In this program we developed a novel method for making metal thin films, particularly Ni, but likely to work for all base metals. The method consists of creating a paste consisting of a physical mixture of urea and metal in an oxide state, either metal oxide particles or molecular species such as chloride and nitrides, spreading on a surface, and heating in an inert atmosphere. The successful development of this technique is the first step in the larger goal: apply a form of Reduction Expansion Synthesis (RES), a technique developed by an NPS team, to improve Metal Additive Manufacturing (M-AM). This goal was based on an analysis of the current fundamental problems with M-AM technology. These can be distilled to the following: i) The large size and high temperature (>1500 C) of the laser heated zone currently employed to sinter metal particles together, and ii) the size of the metal particles available to create metal

objects. This leads to the production of objects in which the 'roughness' is of the order of particle/melting method size, ca. 50 micron. The ability demonstrated in the present work to create metallic films using a modified RES process in which crystallite size and thickness is of the order of 1 micron indicates a path forward for solution to the fundamental problems with current M-AM technology. Proposition: Deploy the modified RES process in existing 'writing' style plastic AM devices. The pastes, for example a physical mixture of urea and NiCl, should be 'drop in' replacements for plastic precursor pastes currently used. Heat the resulting written pattern with either a laser, or in an inert atmosphere furnace. Metal layers, of a micron scale, will form that reliably follows deposited pattern. Repeat for additional layers, as per standard AM protocols.

Background

Current Technology- Virtually all M-AM is based on laying down a layer of metal particles, then selective heating the layer to melt the particles, where desired, using computer-aided manufacturing (CAM) type software controls. This create a 'thin' sintered layer of relatively precise geometry, sintered to the one below. The excess powder is removed and the process is repeated until a full part is created.

The process M-AM process does not produce a perfectly precise, smooth object. The ultimate limit of precision of parts is limited by two physical aspects of this process: particle size and laser heating zone. First, the precision of the part is limited by the size of the metal precursor particles: no smaller than 10 microns, and generally closer to 50 micron. This particle size reflects the primary source of metal particles, 'atomization'. This standard commercial process creates near spherical shaped particles with an average size close to 50 microns in most cases. Smaller particles, far more expensive, can be culled by filtering, etc. from the output of the atomization process. Indeed, grinding, 'atomization' and other particle production techniques are inherently limited to the production of particles 10 micron or larger. Alternative processes can be used to make nanoparticles, but, perhaps surprisingly, there is no commercial process for making particles between 10 microns and nanoscale. Precision of the M-AM manufactured part is also limited by the heat source, generally laser, but sometime electric arc. The heated spot is generally at least 50 microns in size.

There are a few 'outliers' to the above description of M-AM. There are firms in Switzerland that place metal particles where desired, still of order 50 microns, and 'paste' them in place chemically using modified printing type technology. The particles are not sintered layer-by-layer, but rather the entire part is sintered after the M-AM build. The final sintering process does have a significant impact on the shape of the object, although this is sometimes understood with a precision that permits proper initial structural design.

Finer precision of the 'surface' of the part is often achieved by the use 'post build' of standard metal 'removal' technologies. Using 'preening', 'blasting' and 'tumbling' technologies on the completed part it is possible to achieve a surface (only) precision on the order of a few microns.

Proposed Improved Technology- In this work, a new 'chemistry' was postulated, and initial testing completed, for the M-AM process, one that if successful will enable finer parts. The Chemical Metal Additive Manufacturing (CM-AM) postulate in brief: The material deposited in the new CM-AM will be a physical mixture of a metal in an oxidized state (i.e., missing electrons) and a solid reducing agent. The mixture can be deposited as a 'paste' using the same type of equipment employed in Plastic based AM. That is, the paste will be deposited, layer by layer, in the desired part geometry. Post deposition the paste will be heated in an inert atmosphere to a relatively low temperature (ca. 800 C) causing the solid reductant to decompose, releasing reducing species that will convert the metal in an oxide state to zero valent metal.

The chemical component of this proposal, that metal in an oxide state can be reduced via the thermal decomposition of a solid reductant, is based on a new technology, called Reduction Expansion Synthesis (RES) introduced by the PI and collaborators at NPS for making sub-micron particles from various metal precursors (1-6). In particular, it has been shown that sub-micron scale iron, nickel and iron nickel particles can be made rapidly by heating physical mixtures of metal oxide particles, or metal nitrates, and urea (solid reductant) in inert gas environments (3-5). The underlying basis of the CM-AM postulate is that variation on the RES particle production process can produce metal films in-place, rather than particles.

It is clear CM-AM if perfected will have significant advantages relative to current technology. The primary advantage of the new Chemical M-AM (CM-AM) will be greater precision throughout, ca. 1 micron, with no need for post-process preening, etc. Other potential advantages: i) CM-AM may reduce capital cost as the power required for a heating device will be lower as the temperature to be reached is far lower, ca. 800 C vs. 1600 C, ii) materials waste will be reduced, even eliminated, iii) reduction of the void space in the final product and iv) performance closer to bulk produced materials. The last two advantages are related. If void space is reduced strength and other properties, including corrosion resistance, will better track bulk materials. This raises the question: Why might void space be reduced using CM-AM? It is postulated, more below, that CM-AM will produce average particles more than 10^5 times smaller, on average, than those employed in standard commercial practice. Concomitantly, this will reduce average void size by the same factor. Smaller voids fill more quickly via sintering than do very large pores. Also, the high power applied by lasers, necessary to melt metal (generally >1500 C) in present technology leads to unanticipated void formation processes, such as 'keyhole' voids forming below the surface.

Findings and Conclusions

Experiments were designed to answer fundamental questions related to using a modified RES to create metal films in precise positions. Specific questions asked included: i) What metals can be reduced using this technology? Thermodynamics alone clearly indicate that refractory metal oxides such as alumina, silica and titania cannot. Experience indicates base metal oxides such as iron oxide and nickel oxide can. Some oxides appear to be 'borderline' such as chrome oxide. ii) Is it better to employ metal in 'molecular' form such as nitrates and chlorides rather than metal oxides? 'Better' as a metric includes production of smaller metal particles, and reduction at lower temperature. As a first step in this process many experiments were conducted to produce metallic chrome particles, and thin films. This was selected as the first effort because of the need for a replacement for the current chrome electrolytic plating process. The current method produced highly carcinogenic Cr(VI) and is restricted. The US DoD officially called for a replacement more than a decade ago. Yet, chrome coating remains an important means of creating corrosion resistance in critical parts such as landing gear of carrier based airplanes, components of pneumatic systems aboard ships, etc.

The sum of the many months of effort to create chrome metal particles or films using the modified RES process: Null. This led to the conclusion that the RES process is excellent for base metal reductive processes, but not capable of positive outcome for many other metal reduction processes, including chrome.

The second effort was designed to determine if thin films of a base metal could be produced using variations of the RES process. Two positive outcomes, that is outcomes that produced rough Ni films on an iron foil substrate, are briefly described below.

EXPERIMENT 1: A paste created by hand grinding ~30 micron sized NiO particles and urea, in a 1:3 weight ratio, was roughly spread on the surface of a metal foil (Sigma Aldrich) of size 1cm X 2cm. The foil was placed in an alumina boat (1cm x 5 cm), and the boat + foil positioned at the center of a quartz tube, fitted for controlled gas flow. After thorough flushing of the tube with N2 gas, the quartz tube, nitrogen gas still flowing, was placed in a pre-heated tube furnace (1000 C) such that the foil was at the very center of the furnace. The tube was removed after 300 seconds and allowed to cool to ambient. Subsequent analysis using scanning electron microscopy (SEM), equipped with Energy Dispersive X-Ray Analysis (EDAX), indicated that the NiO was reduced to Ni metal and that virtually no carbon was incorporated (Figures 1 and 2).

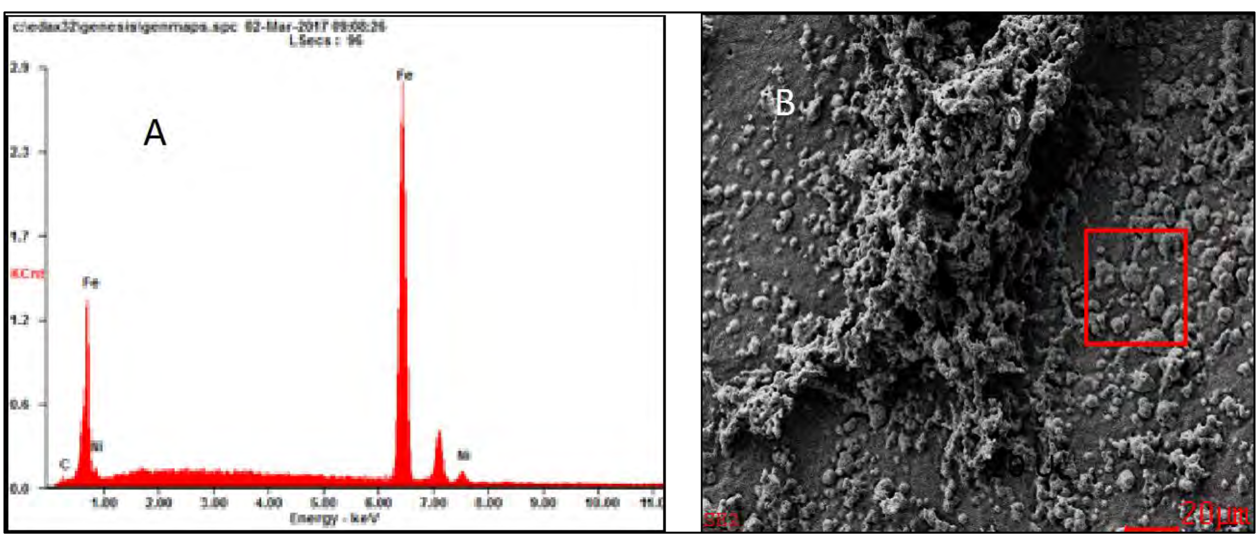


Figure 1. Chemistry and Morphology of Ni film formed on Fe Foil, thin coat area.

The EDAX results show only Fe and Ni present in the film, no evidence of carbon or oxygen. The results show an uneven distribution of Ni particles on the surface. Where the coat is thin, the underlying iron signal dominates. The results also clearly show that the Ni film that forms is uneven, and very porous. This result suggests that the use of metal oxide precursors requires great attention to the initial distribution of paste. There is no evidence that it will naturally flow over the surface to create an even film.

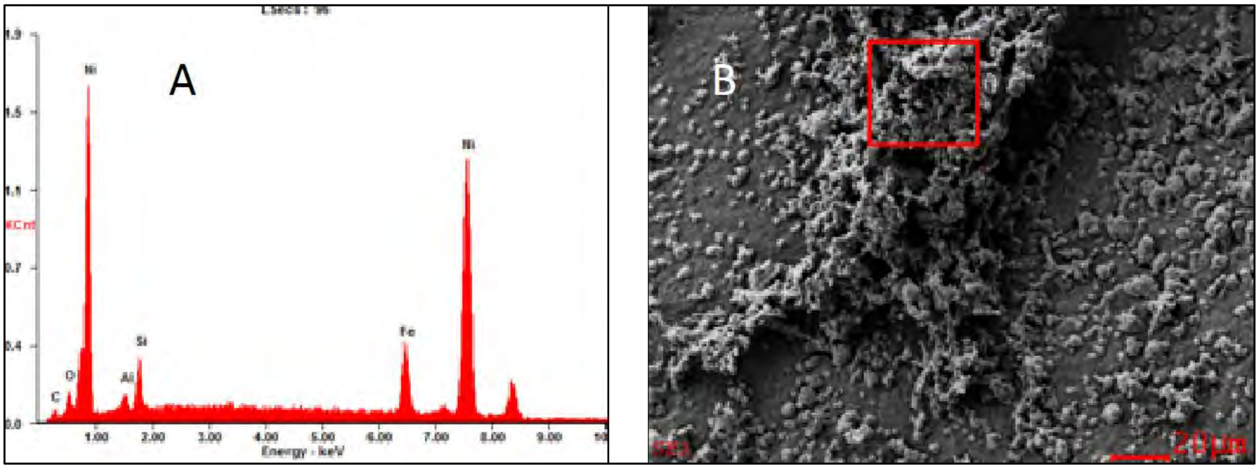


Figure 2. Chemistry and Morphology of Ni film formed on Fe Foil, thick coat area.

The EDAX results show only Fe and Ni present in the film, no evidence of carbon or oxygen. Where the Ni coat is thick, the underlying iron signal is largely blocked by the nickel. Consideration of Fig 1 and 2 showing different relative signal strengths as a function of particle layer thickness suggests little alloy formation.

In sum, films made from Ni oxide particle/urea paste show promise as the Ni is fully reduced, and no carbon is incorporated. However, as seen in Figure.3 there is a tendency of the created films to be uneven, that is the Ni tends to bunch rather than spread and large pores (ca. 3 micron) are found. Still, the size of the primary particles, order 1 micron, and even the pore size, is far smaller than that found in films generated using current technology. The preliminary results justify further research on this approach.

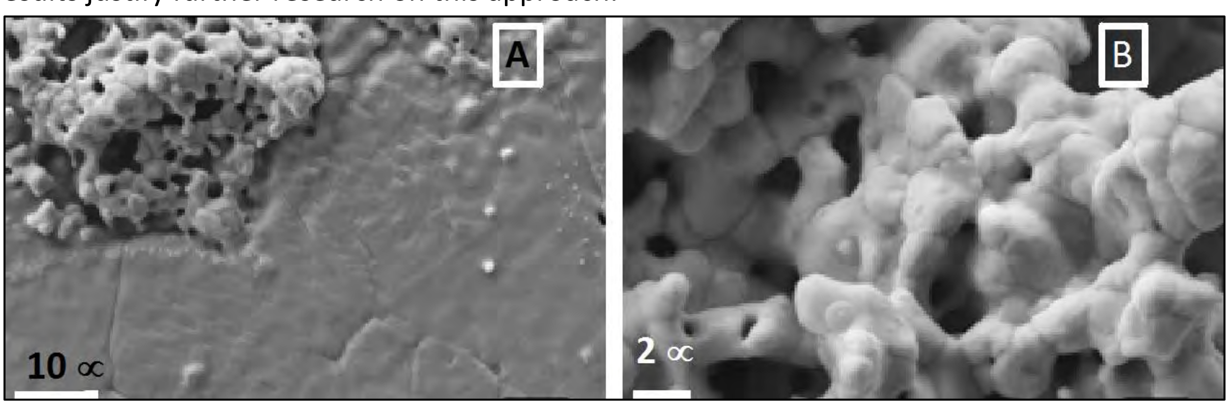


Figure 3. Morphology of Ni films formed on Fe foil using NiO particle/urea paste. A) The Ni tends to form islands on top of the Fe foil, rather than spreading evenly over the surface. B) The 'primary' particles are of the order 2 □, thousands of tim
current M-AM technology. The pores, of the same size as the primary particles, are also smaller than those formed using current technology.

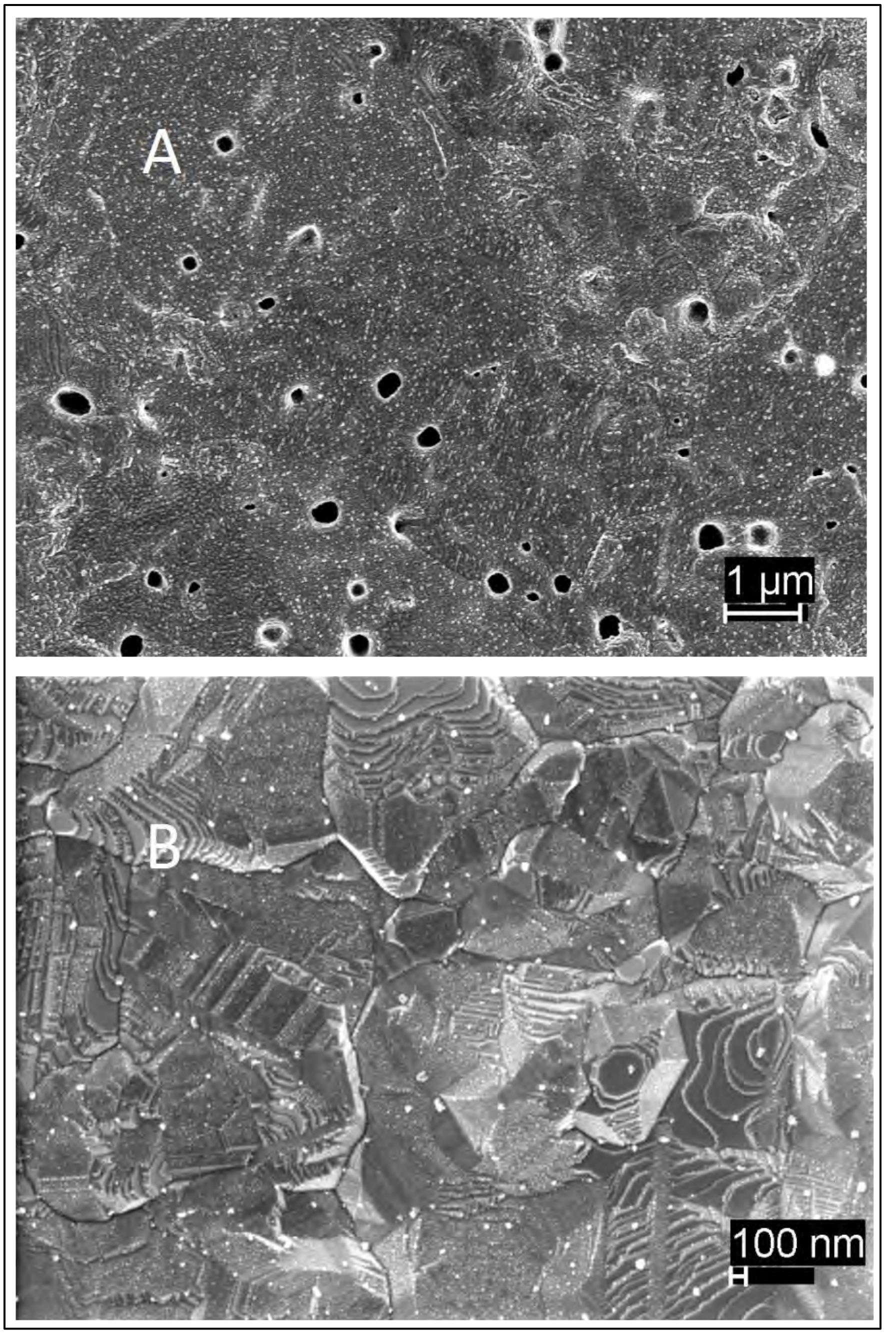


Figure 4. SEM Image of Metallic Ni Film on Fe Foil formed by Heat Treatment of Physical Mixture of NiCl and Urea. A) At high magnification the film appears to consist of a Ni film and round pores about 500 nm across. B) At even higher magnification it is clear the Ni metal film consists of crystallites of Ni.

EXPERIMENT 2:
Experiment 2 used nearly the same method employed in Experiment 1. The only change was the composition of the paste. For Experiment 2, the paste was a hand ground mixture of NiCl and urea in a 1:4 weight ratio.

EDAX results showed once again that only metallic Ni is present, very similar to Figures 1 and 2 above. There is no evidence of carbon or oxygen. In contrast, in earlier efforts to produce metallic chrome films, oxygen was clearly present, as well as significant carbon impurity. The morphological difference is significant. Over a large area, approximately 1 cm X 1 cm a thin film, less than 1 micron thick formed. The film was composed of very small crystallites, ca. 500 nm, sintered together to form a nearly continuous surface, except for a relatively small number of pores also about 500 nm in size (Figure 4).

There are two primary conclusions. First, the modified RES process can be developed as a means to make metal thin films of the order of a micron thick. Second, there is a strong basis in preliminary work for efforts to develop modified RES processes for use in M-AD. Success would lead to a process that produces metal parts of far higher precision (ca. 1 micron) than those produced with todays' technology (>10 micron). The modified RES process also may lead to faster, simpler, cheaper forms of M-AD.

Recommendations for Further Research

The immediate focus of further research should be on production of metallic thin films on a variety of substrates using RES with 'molecular' metal precursors. For example iron films should be produced on Ni and Fe foils using FeCl and $Fe(NO_3)_3$, similarly nickel and cobalt nitrates should be used as precursors to form films on iron, nickel and cobalt foils. The effect of parameter variation, such as the relative amounts of urea and metal precursor, and temperature, should be studied systematically. As part of this research, the effect of the original distribution of the precursor pastes (metal precursor ground with urea) on the regularity of the film should be carefully monitored. Methods should be developed to make the dimensions of the final film align with the geometry of the paste as deposited.

After a methodology has been developed to create very fine (ca. 1 micron) scale metallic films that follow precisely the geometry of the deposited paste, an effort to create multi-level structures should be carried out. Success should lead to collaboration with expert in current M-AD to organize full scale tests of the modified RES technique as a means to create M-AD generated objects of very fine and precise build dimensions. These should then be thoroughly characterized for bulk properties.

References

Luhrs, C.C. and J. Phillips, 'Reductive/Expansion Synthesis of Graphene', US Patent 8,894,886 (2014).

Elbaz, L., J Phillips, K. Artyushkova, K. More, E.L. Brosha. 2015. 'Evidence of High Electrocatalytic Activity of Molybdenum Carbide Supported Platinum Nanorafts', Journal of The Electrochemical Society 162 (9), H681-H685.

Zea,H., CC Luhrs, J Phillips, 'Reductive/expansion synthesis of zero valent submicron and nanometal particles', Journal of Materials Research 26, 672-681(2014).

Luhrs, C.C., M. Kane, Z. Leseman and J. Phillips, 'Novel Process for Solid State Reduction of Metal Oxides and Hydroxides', Metal. And Mater. Trans B 44, 115-122 (2013).

Luhrs, C.C., Z. Leseman, J. Phillips, H. R. Zea, 'Generation of Metal and Alloy Micron, Submicron or Nano Particles in Simple, Rapid Process', U.S. Patent 8,709,126 (2014).

Greenaway, Karima A. 'A novel nonelectrolytic process for chromium and nickel coating'. Diss. Monterey, California: Naval Postgraduate School, 2015.

NPS-N16-N240: Modeling and Analysis of Surface Navy Availability Maintenance Processes

Researcher(s): Mr. Perry McDowell
Student Participation: LT Megan Jamison USN

Project Summary

The goal of this project is to analyze available data kept by various parts of the Navy for insights into the causes of Navy ships incurring cost overruns and delayed completion of shipyard overhauls. The intention is to create predictors for the causes of overruns and delays so that they can be discovered earlier, which would allow maintenance planners to take steps to either prevent their occurrence or minimize their size and effects.

Keywords: surface, maintenance, navy, ship, repairs, SHIPALTS

Background

Maintenance forms the basis of everything the Navy surface ships do; without proper maintenance, the ships cannot perform as expected to carry out their missions. The Commander, Naval Surface Forces (CNSF) has indicated that improving maintenance is one of his highest priorities.

Currently, the Navy is experimenting with several new models that have affected how maintenance is performed on surface ships, such as modified manning, reduced funding for depot level maintenance availabilities, and modifications to training. The effects of these changes are not fully understood and have the capacity to negatively affect the readiness of the fleet.

In order to ensure that the Navy is using its maintenance funds is the most effective manner, we intend to evaluate available data on surface ship maintenance to determine whether any trends appear that might indicate ways to improve how the Navy approaches both shipboard and depot level maintenance.

Findings and Conclusions

There's an old saying in the Navy: go to sea with one or three clocks, but not two. The meaning is that when two clocks disagree, you cannot tell which is correct, and the hope is that two of the three clocks will agree on the correct time. However, if all three disagree, the navigator is in the same situation of not knowing the ship's position.

The same may be said for databases containing supposedly equivalent information – it is impossible to determine the correct implications of the data. That is the position we have found ourselves during much of this research. While we have located several databases containing information about ship availabilities, often the information in one contradicts the information in another. There does not seem to be a master database including all the information that may be relied upon as correct.

To date, we have located the following databases containing information on ship availabilities:

- Navy Data Environment (NDE)
- Maintenance Resource System (MRE)
- Navy Maintenance Database (NMD)
- Open Architecture Retrieval System (OARS)

We have conducted initial analyses on these and found the discrepancies mentioned above. We paused this research to conduct other projects, but are on the point of resuming it in May of 2017. When we resume it, we will apply techniques to try and account for the discrepancies in the databases and determine whether it is possible to draw any conclusions from the data as to the underlying causes of delays and overruns in major availabilities of Navy surface ships.

Recommendations for Further Research

As discussed in the Findings and Conclusions section, the data was located in multiple databases, had significant amounts of data missing, and often different databases did not agree. This makes truly significant analysis difficult. It also increases the number of assumptions and/or corrections analysts must make, which reduces the confidence in the results. Therefore, one early recommendation is that all data from availabilities be consolidated into one master database. Additionally, the entry of data into the database must be a high priority for personnel, and it must be rigorously inspected for correctness after each availability.

NPS-N16-N259-A: Viability of Waste to Energy Technologies for Naval Facilities

Researcher(s): Dr. Alejandro S. Hernandez and Mr. Matthew Boensel
Student Participation: LT Adam Haag USN

Project Summary

This research was requested from N46 to determine the viability of Waste-To-Energy (WTE) technology at existing facilities. This research project has created an additional module to an existing in-use tool. The new module allows a user to determine whether investment for implementing one of three types of WTE in a facility is warranted.

Background

In an effort to diversify the Department of Defense's (DOD) energy sources, there has been an increase in studies about renewable energy. There are many sources of power generation that do not involve fossil or nuclear fuels. Adding these sources to the grid decreases reliance on any single type of energy production. Of the recent renewable energy projects, a great majority have involved solar power and wind power, despite their reliance on the weather conditions and time for their power production. Waste-to-Energy (WTE) is a potential boon to the DOD. WTE has been largely untapped. As such developing basic estimation tools for decision makers to better assess the utility of a WTE facility is the primary goal of this project.

Findings and Conclusion

In this research, we examined three different WTE technologies which have the potential to fit the needs of the military. Detailed study of theoretical and historical cost data resulted in developing basic cost models for both technologies. Research included the construction and maintenance costs of WTE facilities based on user-provided data. The cost models estimate the capital investment required, the time period for return on investment, annual costs (including labor), and potential input and output streams required. Use of this cost model will help decision makers select DOD sites for further study that currently have the required local assets that would make WTE investments worthwhile. The team will demonstrate the tool in Washington, DC, November 2016.

This research has:

- Developed a new module for an existing DOD cost model for examining potential WTE facilities,
- Postured a data analysis tool to support selection of potential locations with advantageous cost-benefit values, and
- Developed supporting documentation for the cost models to ensure they are properly understood by intended users

Recommendations for Further Research

Further research to refine the tool with respect to accuracy of estimation is recommended. Empirical data for this project was scarce. As data becomes available, test the model against existing facilities.

References

Brown, Jim. *Web EROI Project Development User Manual*. CNIC Navy Shore Energy Program Development, 2015.

“Moore, Mary K., and Elmer B. Ledesma. *Academia and Industrial Pilot Plant Operations and Safety*.

"Energy from Waste." IBA. Accessed May 01, 2016. http://www.esauk.org/energy_recovery/iba_-_incinerator_bottom_ash.html.

Incineration Example. May 11, 2016. Accessed May 1, 2016. https://www.e-education.psu.edu/egee110/sites/www.e-education.psu.edu.egee110/files/lesson09/waste_energy_plant_diagram.jpg.

"Negative Impacts of Incineration-based Waste-to-Energy Technology." AENews. Accessed May 01, 2016. http://www.alternative-energy-news.info/negative-impacts-waste-to-energy/.

"The Gasification and Syngas Technologies Council." The Gasification & Syngas Technologies Council » GSTC. Accessed May 01, 2016. http://www.gasification-syngas.org/.

"Pyrolysis Oil Gets More Practical Refining." Pyrolysis Oil Gets More Practical Refining. Accessed May 01, 2016. http://newenergyandfuel.com/http:/newenergyandfuel/com/2010/12/03/pyrolysis-oil-gets-more-practical-refining/.

HowStuffWorks. Accessed May 01, 2016.

http://science.howstuffworks.com/environmental/energy/plasma-converter.htm.
"The Anaerobic Digestion Process - NEO Energy." Neo Energy. Accessed May 01, 2016. http://www.neoenergyusa.com/biogas-process/.

Athanasiou, C., D. Tsalkidis, E. Kalogirou, and E. Voudrias. "Feasibility Analysis of Municipal Solid Waste Mass Burning in the Region of East Macedonia - Thrace in Greece." *Waste Management & Research* 33, no. 6 (2015): 561-69. doi:10.1177/0734242x15587368.

Clark, Bruce J., P.E, and Marc J. Rogoff, Ph.D. "Economic Feasibility of a Plasma ARC Gasification Plant ..." April 17, 2014. Accessed August 01, 2016. http://www.seas.columbia.edu/earth/wtert/sofos/nawtec/nawtec18/nawtec18-3502.pdf.

GRN. "Enviros RIS in Global Recycling Network." Global Recycling Network. Accessed August 01, 2016. http://www.grn.com/equip/aa022839.html.

Perry, Robert H., and Don W. Green. *Perry's Chemical Engineers' Handbook*. New York: McGraw-Hill, 2008.

Whyte, Rob, and Guy Perry. "A Rough Guide to Anaerobic Digestion Costs And MSW Diversion." January 06, 2009. Accessed August 01, 2016. http://infohouse.p2ric.org/ref/44/43217.pdf.

NPS-N16-N574-A: New Paradigm Supercapacitors for Energy Storage

Researcher(s): Dr. Jonathan Phillips
Student Participant(s): LCDR Jonathan Gandy USN, LT Natalie Jenkins USN, CDR David Backer USN, LT Steve Lombardo USN, and EN Clay Petty USN

Project Summary

Super dielectric materials potentially can have a game changing impact on the U.S. Navy, enabling electric based weapons systems. During the past year our team, largely funded by NRP, has made significant progress toward creating Super Dielectric Materials (SDM) based capacitors which advance this goal. Working with five NPS students, significant progress was made in building, testing, and characterizing several types of Super Dielectric Materials (SDM), and additionally inventing two new categories of SDM. Papers were written and published in peer reviewed journals regarding improved characterization of power, energy, dielectric constants of capacitors based on two previously invented SDM category materials: particle based SDM (P-SDM), and anodized titania based SDM (Tube or T-SDM). The published papers included, for the first time, systematic study of the impact of frequency on SDM performance. A U.S. patent was issued for P-SDM and T-SDM. Two entirely new categories of SDM were invented, fabric based SDM (F-SDM) and, thin plastic sheet based SDM (PL-SDM), and appropriate patents filed. Initial studies of the newly invented PL-SDM, based on the use of very thin hydrophobic plastic with mechanically created macro scale holes, suggests a potential '*game changing'* technology. Specifically, we have now repeatedly created capacitors based on this inexpensive, simple to construct, technology with a delivered energy of between 65 and 75 J/cm^3 of dielectric. Notably, two students completed MS degrees based

on their work with SDM during the grant period, and three students are making excellent progress toward completing MS thesis work on the topic.

Background

The U.S. Navy is involved in converting many ships to an 'all electric' configuration. In order to enable this transformation, capacitors with energy density superior to those presently commercially available are required. Moreover; the leading candidate for this role, graphene based supercapacitors, are prohibitively expensive. This project was designed to develop a novel type of capacitor, Novel Paradigm Supercapacitors, which employ super dielectric materials (SDM), a class of materials invented at the Naval Postgraduate School (1-9), that are even lower cost than current commercial supercapacitors, yet far higher in energy density. The final version developed, Plastic SDM (PL-SDM) appear to have all the qualities required, particularly high energy density, and low cost. The patents for all the SDM are now licensed, and capacitors based on them under development commercially.

Findings

This report is divided into five sections: I.) P-SDM, II.) T-SDM, III.) work done with one newly invented category of SDM, fabric based SDM, IV.) work done with the second newly invented form of SDM, PL-SDM and V.) a brief review of work in progress.

I. Particle Super Dielectric Materials:

Below, a very brief summary of three publication (1-3) on PSDM is presented. The most important findings from work on this topic were i) further demonstration of the generality of the SDM hypothesis, ii) the finding of the highest dielectric constants ever recorded, and iii) the first reports on the trends in dielectric constant, energy density, etc. as a function of discharge time.

Regarding the generalization of the SDM hypothesis: For the first time a high surface area ceramic other than alumina was thoroughly investigated as the insulating matrix phase of SDM. Working with fumed silica saturated with aqueous NaCl solutions our team further demonstrated the validity of the general form of the underlying SDM hypothesis: Any non-conductive porous solid in which the pores are filled with a liquid with a sufficient concentration of dissolved ions will have a high dielectric constant. The concept underlying this hypothesis is that dissolved ions will migrate to form giant dipoles in the presence of an applied field. These dipoles will partially cancel the field created by charged species on the electrode plate, thus allowing more charge to collect on the plate at any given voltage than is possible with any other type of dielectric. The hypothesis and the underlying physics are described in far more detail elsewhere (4-6).

Using the RC time constant method, the highest dielectric constants ever were recorded for this form of SDM (Figure 1). The values obtained, $>10^{11}$, are particularly spectacular considering that before the invention of SDM, the highest claimed dielectric values were $<10^5$.

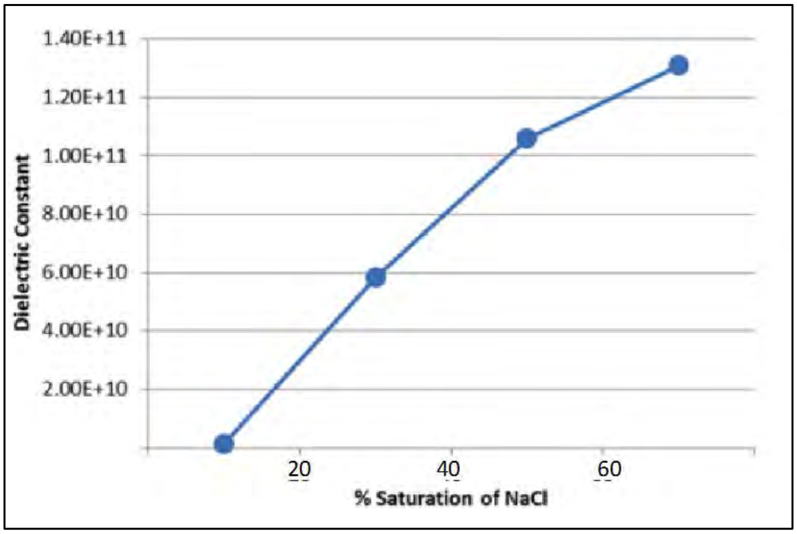


Figure 1. The RC time constant was employed to study the dielectric constant of aqueous NaCl solution filled fumed silica. The data shows that the higher the salt concentration, the higher the dielectric constant. This data is found in two published works (1,2).

As noted, the third significant aspect of the work was that it constituted the first systematic study of the behavior of SDM as a function of frequency. Indeed, it was found, as expected for all dielectrics, that the energy density, dielectric constant (Figure 2) and power density fell monotonously as discharge time was shortened.

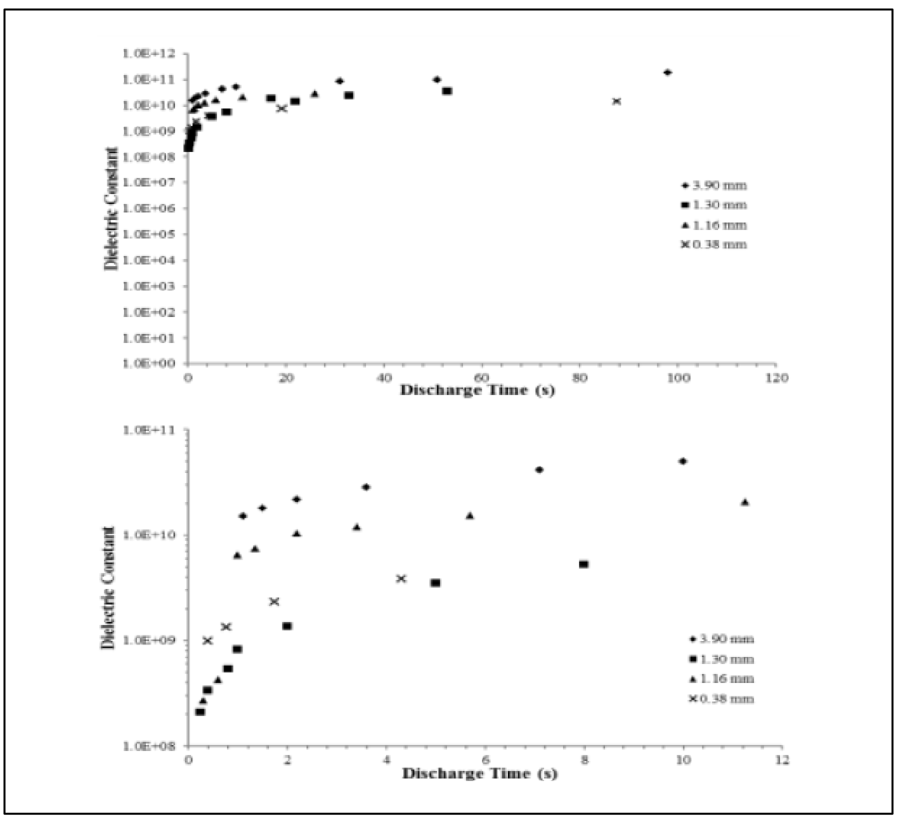


Figure 2. Dielectric constants decrease as discharge time is shortened. TOP- At very long discharge times, >100 seconds, the dielectric constants measured using a galvanostat are nearly equal those recorded with the RC time constant method (Figure 1). BOTTOM- As the discharge time is shortened (ca. <1 second) the dielectric values fall steadily, but even at very short discharge times are still >108. The values of dielectric constants, etc. fall monotonically as discharge time is

II. Tube Super Dielectric Materials-

The most significant aspects of work done with these materials (Figure 3) was the finding that the energy density is a function of the identity of the aqueous salt solution (7,8). In the first report on these materials $NaNO_3$ was the salt dissolved and the highest energy density obtained was about 220 J/cm^3. In the work conducted during the period of this study NaCl was the dissolved salts and repeatedly energy density of the order of 400 J/cm^3 (Figure 4). The best prototype supercapacitors reportedly have an energy density of about 450 J/cm^3 (4). The finding of this study that salt identity can impact energy density significantly, suggests that an optimum design T-SDM with the best salt, best pore structure, etc., all to be determined empirically, might surpass the best supercapacitors in energy density.

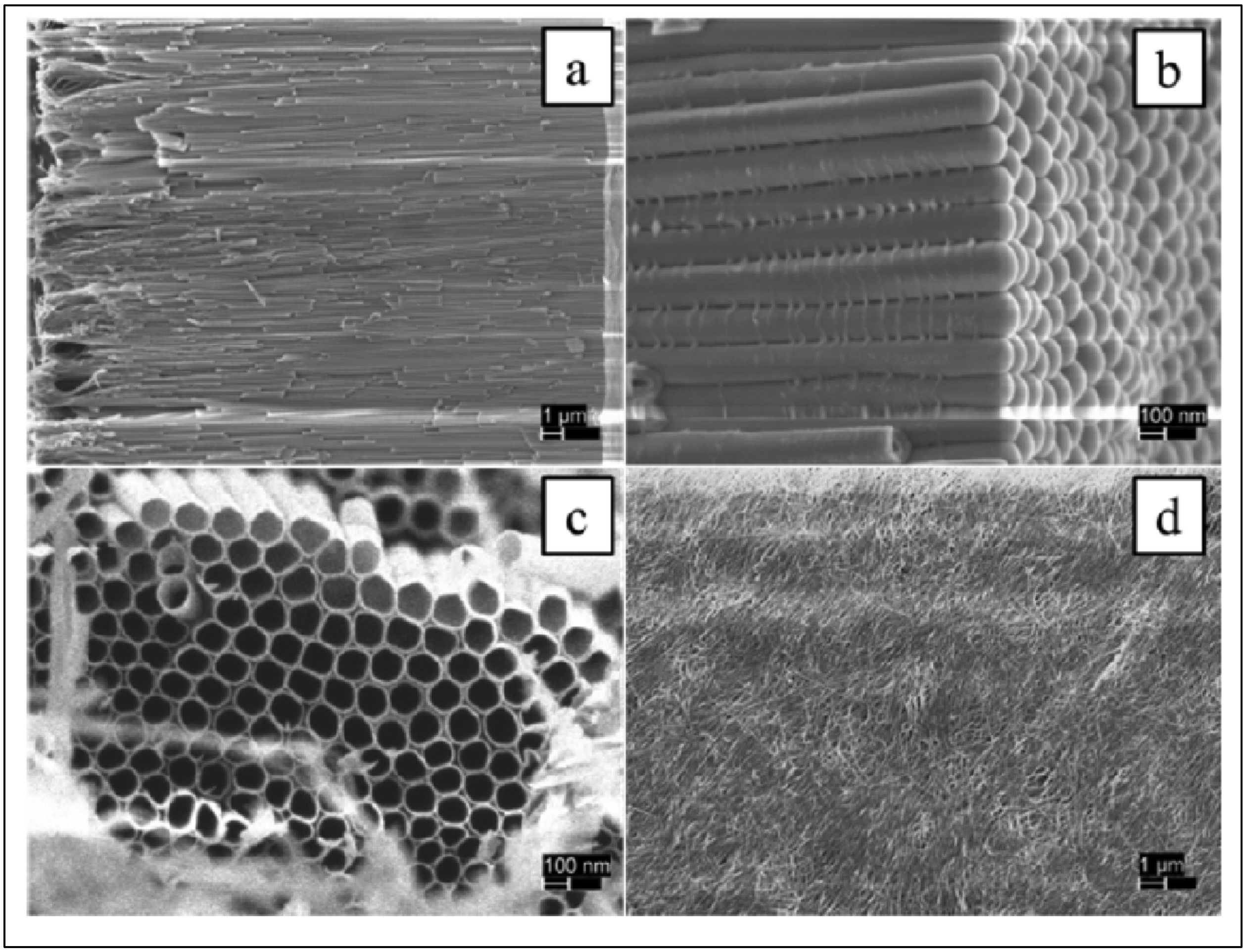


Figure 3. Various views of the titania nanotubes formed on titania surfaces via anodization. A) Side view showing tubes about 15 nm in length. B) Side view showing ends of tube adjacent to metallic titania are closed. C) Top end of tubes open, thus can be filled with aqueous salt solutions. D) Very long tubes 'collapse' to form irregular 'grass' structures (7,8).

The study also confirmed that the energy density of T-SDM is nearly independent of the length of the tubes formed. This constitutes an important demonstration of the basic SDM hypothesis (Figure 4).

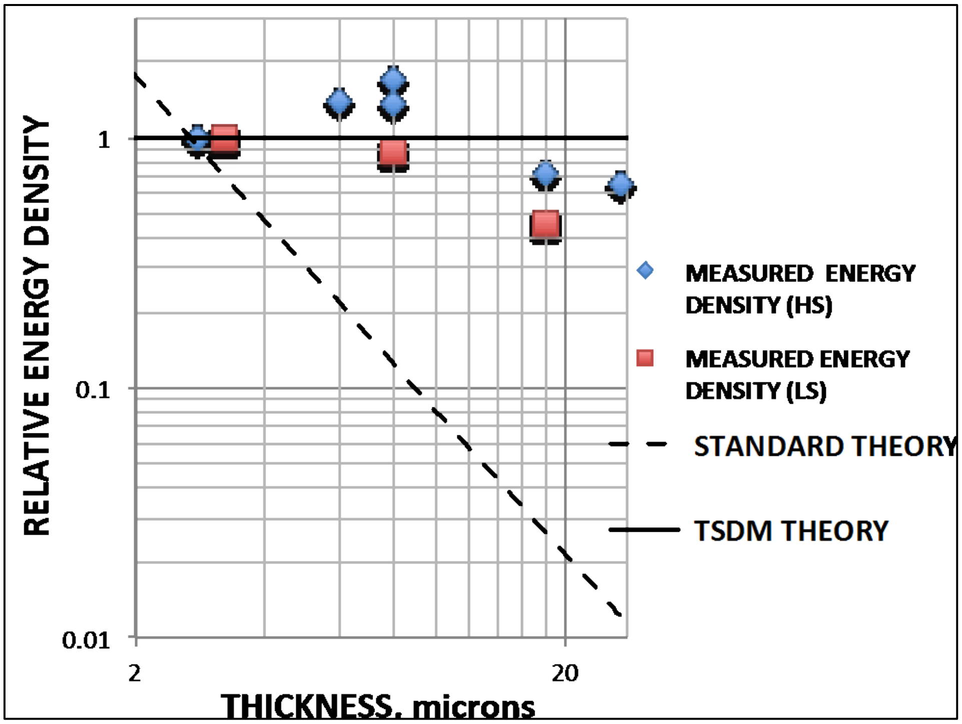


Figure 4. Energy Density as a Function of Tube Length. The graph indicates that the energy density is nearly independent of tube lengths until tubes reach about 20 microns in length. The loss in fidelity to the model at >20 micron length may result from the loss of integrity of tube structure with tube length (Figure 3D, above). (7,8)

III. Fabric Super Dielectric Materials-

This category of super dielectric material was invented less than a year ago based on a logical extrapolation of the SDM hypothesis (9). According to this hypothesis any non-electrically conducting, 'porous' material can serve as the matrix material in an SDM. A clear example of this is a fabric created by weaving together threads of any material. Such a material contains open spaces between threads that constitute large pores which can be filled with the dipole forming, ion containing, liquid phase. Specifically, in this study a fabric composed of a weave of nylon, with approximately 50% void volume was employed as the matrix material, and the ion containing phase of the SDM, which filled the void volume, was an aqueous NaCl solution.

There were two major findings reported in this study. First, the results once again support the general SDM hypothesis. That is, the results show that any electrically insulating matrix material that has 'pores' capable of holding solutions with dissolved ions should work as an SDM. It should be noted that an empirical extrapolation of the early results of the SDM work would have led solely to the study of Powder type SDM. It is only because of the general SDM hypothesis proposed at the beginning of the work on SDM that T-SDM, F-SDM and finally PL-SDM were studied at all (5). This is a good example of a general model leading to a wide range of particular 'discoveries'. Second, this report provides the first detailed report on capacitance, dielectric constant, energy density and power density as a function of discharge time.

The study of ‘time dependence’ of parameters produced quite plausible results. In all cases, capacitance, dielectric constant (Figure 5), and energy density (Figure 6) decreased as the discharge time decreased. Moreover, the reported power law behavior is entirely plausible. In contrast, other groups, generally using Impedance Spectroscopy show trends that stretch credibility with parameters such as dielectric constant increasing, then decreasing as frequency is increased. The data in these reports clearly cannot be fit by any simple mathematical formula.

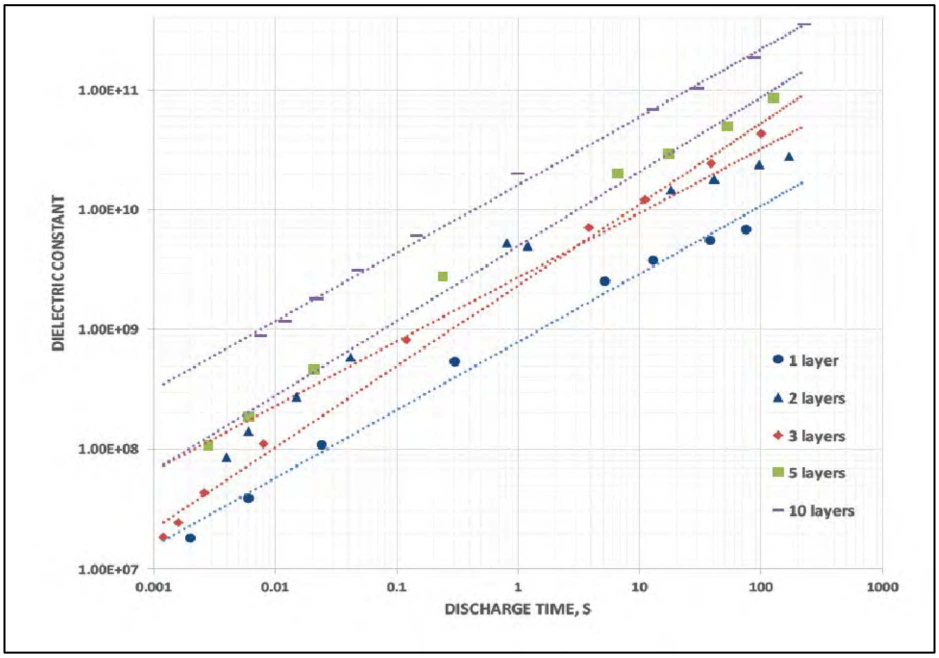


Figure 5. Dielectric Constant vs. Discharge Time. Five distinct capacitors were made, identical but for number of layers of nylon employed in the construction. In all cases a simple power law accurately describes the decrease in dielectric constant with more rapid discharge (9).

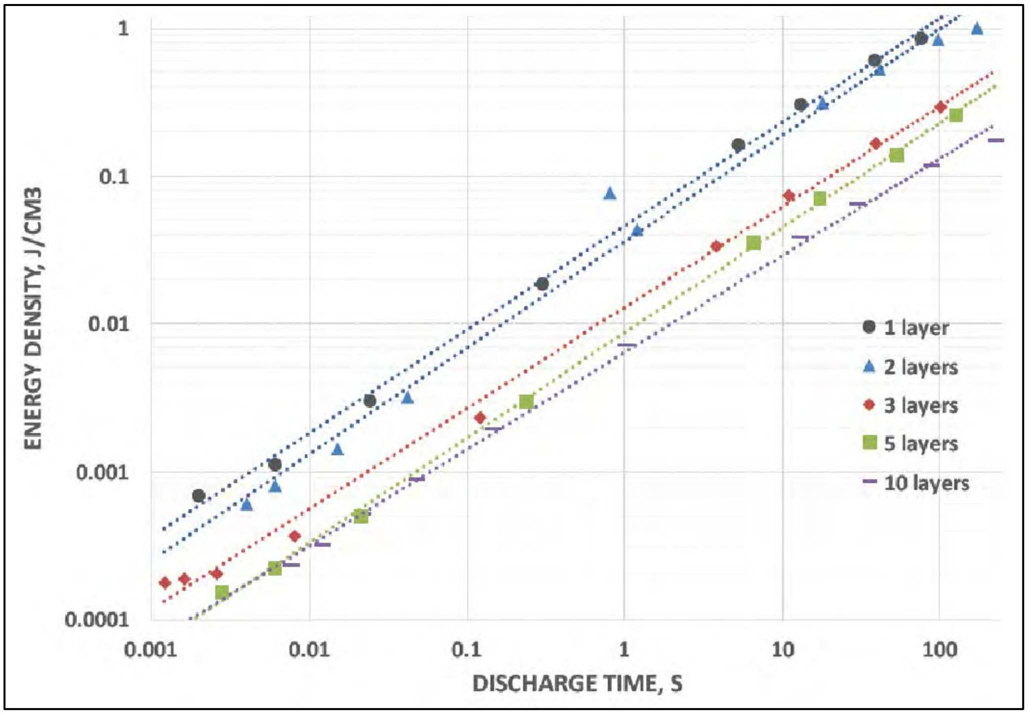


Figure 6. Energy Density vs. Discharge Time. Simple power laws fit the empirically determined energy density of all five unique capacitors studied. As expected for capacitors, the thinner the dielectric, the larger the energy density (9).

IV. Plastic Super Dielectric Materials

A capacitor with energy density of ~ 75 J/cm^3 of dielectric material was made using a unique form of super dielectric material. It is notable in this regard that the best commercial supercapacitors have an energy density of approximately 30 J/cm^3. The novel super dielectric, herein called D-1, consisted of a piece of hydrophobic polypropylene plastic sheet (Celgard PP1516), 2.5 cm x 2.5 cm x 16 micron (thickness), into which 325 holes (~50 holes/cm^2) were through punched with a pin of diameter 0.6 mm, placed on top of a commercial 'sheet carbon' (Grafoil) electrode, then smeared with a solution of 30wt% NaCl in distilled, de-ionized water. 'Salt Water' placed on the hydrophobic plastic beads up. Excess water was physically squeezed out by compressing (lightly) a second electrode onto the plastic. It was found that the capacitor thus constructed, constant current cycled between 2.3 and 0 volts, showed virtually no change in behavior over 30 cycles using charge and discharge times of about 300 seconds.

Additional experiments were conducted to test this hypothesis: The high dielectric value and energy density observed for the capacitor constructed with D-1 results from the large induced electric dipoles that are created in the 'salt water' columns that form in the holes punched through the plastic with the pin. This hypothesis is completely consistent with the SDM hypothesis described in the scientific literature (1-9). In brief, the longer the dipoles in the dielectric and the higher the density of dipoles, the greater the maximum energy density and dielectric value. Relative to solid dielectrics in which the dipole length is a maximum of 0.1 Å, the dipoles formed via field induced ionic migration (Na + toward negative electrode, Cl- toward positive electrode) in the salt water columns of D-1 are enormous.

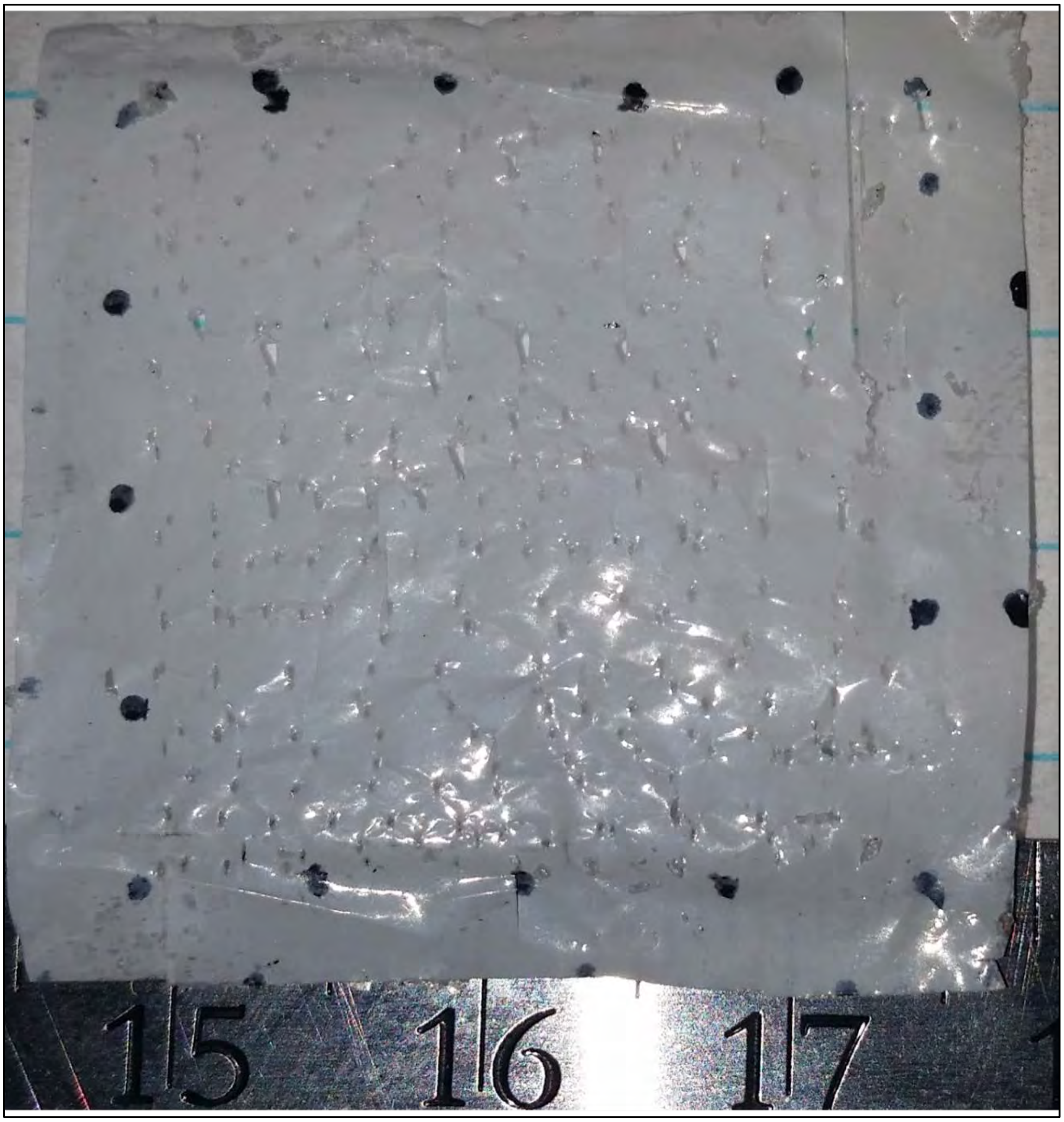


Figure 7. PL-SDM. Shown, one of the three layers in the multi-layer capacitor described below, above ruler marked in mm. Two hundred and fifty holes were hand-punched into a hydrophobic, 16 micron thick plastic in an area 2.5 cm x 2.5 cm. Once filled with an aqueous solution, 30% NaCl by weight, these proved to be extraordinary dielectric materials. Note: The edges, no holes, prevent electric contact between Grafoil squares (electrodes) that measure 2.5 x 2.5 mm.

The hypothesis suggests that the net energy density that a capacitor made from a plastic through which holes have been punched and then filled with aqueous salt solution, should increase with the number of holes punched. For this reason, experiments were conducted to study the impact of hole density on energy density. In each case, a capacitor of the same dimensions as above included a dielectric made in the same fashion as D1. That is, it was made from the same plastic, using the same punch and same salt water solution, but with one major difference: in each case a different number of holes were punched. In the first experiment, a single hole was punched at the center (D-2). A third capacitor (D-3) was made using an identical dielectric but with ~10 holes/cm^2, and a fourth with ~15 holes/cm^2. The outcome predicted by the SDM model, the measured energy density should increase with the number of holes punched, is consistent with the values obtained.

Punched Holes/cm^2	Measured Energy Density, J/cm^3	Discharge Time, sec
0.016 (one hole, center)	<0.01	<0.1 sec, maximum
3	0.3	30
15	24	~200
56	76	~300

Table 1. Preliminary results from measured energy density study.

A second type of study was designed to test for ease of creating multi-layer capacitors using PL-SDM. In this test a capacitor consisting of three sheets of the same material employed above, each with a hole density of 40 holes/cm^2, employing Grafoil electrodes of the same dimensions as above (2.5 cm x 2.5 cm). The structure consisted of seven layers: Electrode 1, P-SDM 1, Electrode 2, P-SDM 2, Electrode 3, P-SDM 3, and Electrode 4. Electrodes 1 and 3 were electrically connected as were Electrodes 2 and 4, effectively creating three capacitors in parallel. It was repeatedly shown this multilayer capacitor had energy density of >65 J/cm^3 of P-SDM dielectric.

The outcome of this study is significant as it suggests an inexpensive, simple design for high energy density capacitors. That is, it is easy to imagine a simple process for commercial production of the dielectric materials from punched plastic sheets. Indeed, plastic sheet is very inexpensive, punching holes in thin plastic sheet easily and inexpensively organized (e.g. rapidly passing sheet between rotating cylinders containing properly positioned pins), and soaking with ‘salt water’ also remarkably inexpensive. Moreover, the energy density measured in this ‘first effort’ is more than double the value available in the current commercial supercapacitor market. Commercial processes could be designed to yield far higher energy density via optimization of the salt solution employed, including organic electrolytes, the hole density, the number of holes, the thickness of the plastic, the identity of the plastic, etc.

V. Testing Novel Electrolytes on T-SDM:

CMDR David Backer and LT Steve Lombardo continue to test the effect of a variety of electrolytes on the performance of T-SDM capacitors. The electrolytes are made from a matrix of polar organic solvents and salts. Preliminary results based on non-aqueous solvents with different salts are shown in Table 2.

Solvent	Salt	Highest ED (J/cm^3)
NMP	NaCl	Not tested
NMP	KNO3	25
NMP	NaNO3	66
NMP	Boric Acid	Not tested
DMSO	NaCl	21
DMSO	KNO3	26
DMSO	NaNO3	57
DMSO	Boric Acid	21
PC	Di Water/NaCl	Various Concentrations

Table 2- Preliminary results for tests of organic solvents/salts in 8 micron high tubes of anodized titania.

Solvent	Salt	Highest ED (J/cm^3)
Charge (Various) = Discharge		
DI	NH_4Cl (10%)	41.12
DI	NH_4Cl (20%)	27.83
DI	NH_4Cl (30%)	34.62
DI	$NaNO_3$ (10%)	1.75
DI	$NaNO_3$ (20%)	6.69
DI	$NaNO_3$ (30%)	6.39
DI	KOH (10%)	17.64
DI	KOH (20%)	14.79
DI	KOH (30%)	59.18
Charge (10mA) ≠ Discharge Rate		
DI	NH_4Cl (10%)	28.61
DI	NH_4Cl (20%)	22.16
DI	NH_4Cl (30%)	7.44
DI	$NaNO_3$ (10%)	1.32
DI	$NaNO_3$ (20%)	3.13
DI	$NaNO_3$ (30%)	3.45
DI	KOH (10%)	3.35
DI	KOH (20%)	7.66
DI	KOH (30%)	25.84
Control	Di Water (100%)	Not Analyzed Yet

Table 3. The near final results from tests in which the electrolyte was distilled/de-ionized water into which salts other than NaCl were added.

Findings and Conclusions

PL-SDM are viable for near term use by the U.S. Navy for the following reasons:

I. It has been demonstrated with non-optimized, preliminary designs, that capacitors in this category have >2.5 X the energy density of the best commercial super capacitors.

II. The materials (thin plastic, salt water and conductive electrodes) required for PL SDM are very inexpensive.
III. The processing required to create PS SDM; punch holes in plastic, add water, cover with conductive electrodes, package, are very simple, and easily instituted commercially. In sum, the research conducted can be an enabler to a significant proposed transformation: all electric ships.

Recommendations for Future Research

Before SDM were discovered at NPS the highest dielectric constants reliably reported were $\sim 10^{4}$, that is seven orders of magnitude smaller in value than the best SDM, $\sim 10^{11}$. The finding that there are four classes of SDM- Particle SDM, Tube SDM, Fabric SDM and Plastic SDM indicates that the discovery of SDM is in fact the discovery of a large and totally unexplored fertile field of engineering and science. Although we have done much to explore the breadth of that world, and some 'engineering' including direct demonstration of remarkable energy densities and demonstration of low cost versions, we have done very little to study this vast field in depth, and have not developed a true mathematical explanation of the mechanism of super dielectric behavior.

In order to achieve optimum performance, a true need of the U.S. Navy, we recommend further research into the effects of variations in the parameters of construction of all SDM classes including, salt identity, polar electrolyte identity, fabric identity, electrode identity, etc. We also recommend more work be done to explain and model the observed behavior. Finally, we urge additional collaboration with industry to accelerate the commercial availability of novel paradigm supercapacitors based on SDM.

References

Jenkins, N.; Petty, C.; Phillips, J., 'Investigation of Fumed Aqueous NaCl Super Dielectric Material'. *Materials* 2016, 9, 118.

Jenkins, N., 'Optimal Super Dielectric Material', M.S. Thesis Naval Postgraduate School URI http://hdl.handle.net/10945/47280 2015.

Phillips, J. and S. Fromille, 'Super Dielectric Materials' *U.S. Patent* 9530574, 2016.

Quintero, F.; Phillips, J., 'Tube-Super Dielectric Materials: Electrostatic Capacitors with Energy Density Greater than 200 J·cm−3'. *Materials* 2015, 8, 6208–6227.

Fromille, S.; Phillips, J., 'Super Dielectric Materials'. *Materials* 2014, *7*, 8197–8212.

Quintero, F.; Phillips, J., 'Super Dielectrics Composed of NaCl and H_2O and Porous Alumina'. *J. Electron. Mater.* 2015, 44, 1367.

Gandy, J.; Quintero, F.; Phillips, J., 'Testing the Tube Super Dielectric Material Hypothesis: Increased Energy Density Using NaCl.' *J. Electron. Mater*. 2016, 45, 5499-5506.

Gandy, J.; 'Characterization of Micron-scale Nanotubular Super Dielectric Materials' M.S. Thesis Naval Postgraduate School URI ttp://hdl.handle.net/10945/47260 (2015).

Phillips, J., Novel Superdielectric Materials: Aqueous Salt Solution Saturated Fabric, *Materials* 2016, 9, 918.

N8: Integration of Capabilities & Resources

NPS-N16-N168-A: ASW USV EMPLOYMENT

Researcher(s): Dr. Luqi
Student Participant(s): LT Steven Fahey USN, Capt Anthony Ambriz USMC, LT2 Warren Barksdale USA, LCDR Andrew Belding USN, Capt Victor Castro USMC, Capt Boulat Chainourov USMC, LT Justin Downs USN, Maj Paul Haagenson USMC, LT Raven Holm USCG, LT Daniel Lukaszewski USN, Capt Taylor Paul USMC, LT Alexis Pospischil USN, LT Marsha Rowell USN, Maj Devin Smiley USMC, Maj Steven Thompson USMC, and Maj Oleksandr Tytarenko ZSU

Project Summary
This project investigated details of Undersea Warfare **(**USV) Anti-Submarine Warfare (ASW) Employment, with focus on strike group protection in the context of Concepts of Operations (CONOPS)“Maritime Shield” and “Protected Passage.” Communication and coordination needs among swarms of USVs and other platforms were analyzed in the context of ASW. Preliminary risk analysis indicates that solutions involving large numbers of small inexpensive USVs are likely to be most effective with minimized cost. Proposed work is leveraging previously developed requirements, system, and context models for ASW USVs. The objective of the study is to answer the following questions:

1) What USV employment approaches best support ASW CONOPS "Maritime Shield" and "Protected Passage?"
2) What are the USV speed requirements for each approach, and how are they affected by protection zone size, sensor range, sensor motion limits, and strike group motion? How many USVs, sensors and other resources are needed for each scenario?
3) What kind of interactions will the USVs need to have with other platforms in these contexts, and what degree of human operator control will they need? What kind of decisions will have to be made, and which aspects of these missions could the USVs carry out autonomously?

The motivation for the study is to explore whether USVs can effectively augment the capabilities of the relatively small number of surface platforms currently available to focus on ASW; if so, in what capacity can they best contribute and what areas of the ASW trade space would USVs best fill?

The study completed four team projects on analyzing requirements for ASW USVs, with attention to which capabilities need to be autonomous. An MS thesis is in progress on how to measure/evaluate the contributions of autonomous capabilities.

Keywords: Strike Group Protection, Anti-Submarine Warfare, Unmanned Surface Vehicles, Autonomous Systems.

Background
The purpose of frigates is to protect other ships — mainly ASW and air defense, while the new Littoral Combat Ship (LCS) also has an optional mine sweeping mission package [1]. The last of the 51 Oliver Hazard Perry-class frigates is due to be decommissioned by October 2015 [2], and the LCS ships that are supposed to replace them are slow in arriving — only 4 have been commissioned as of September 2014 [3], 32 are planned, and plans for the future LCS fleet are under review for possible adjustment [4]. Other platforms that can perform ASW include destroyers and submarines, which are very expensive and needed for other missions, and aircraft, which have short endurance.

Past approaches to anti-submarine warfare (ASW) include the shore-based Sound Surveillance System (SOSUS) and the Integrated Undersea Surveillance System (IUSS), which includes manned ships carrying the Surveillance Towed Array Sensor System (SURTASS). SURTASS is an aging system which is due for replacement soon. One of the options for its replacement is some as yet undetermined type of unmanned surface vehicle (USV). The current study will investigate alternatives for this option to inform future decisions.

Findings and Conclusions
This is the first year of a two-year project. Further theoretical analysis of search patterns, methods for reducing high speed requirements for Protected Passage ASW USVs, determining how USV speed requirements vary with respect to changes in variables such as sensor range, strike group transit speed, number of USVs employed, and number of buoys employed, as well as validation of models via simulation are planned for the second year. An MS thesis aimed at determining the value of autonomy and which aspects of ASW benefit most from automation is under way [9].

Defense Advanced Research Projects Agency (DARPA) has been concerned that an adversary could take over an autonomous vehicle or an entire fleet of such vehicles. For example, Iran landed a U.S. drone on one of their airbases by jamming its communications and spoofing its GPS to make it believe it was over a U.S. airbase in Afghanistan [5]. There are two main components to hardening systems against such threats: partitioning and verification. Partitioning is a way to build strong walls that separate the non-critical parts of the software from the critical parts, so that in case the non-critical parts get hacked, it does not leak across the partitioning barrier. This requires finding a good architecture that enables such strong partitioning. Verification checks that the critical parts do not have vulnerabilities such as buffer overflows that enable attackers to inject malicious code into the system. This process is not tractable in the general case. Specially designed languages that prevent programmers from writing code that contains buffer overflows and enable formal verification, such as the Ivory language developed by Galois Inc. are being explored as a means to overcome this problem.

A Google autonomous car had a crash this year [6], and so did a Tesla car on autopilot [7]. Even in the absence of attacks, software designed for safe and effective autonomous control has to be very precise, based on valid models of the system's environment that span the full range of possibilities. The full range is possibilities is very difficult to determine – not only can sensors fail, but the characteristics of the world change also, with corresponding changes in the probability distributions for sensor readings. Processing of sensor data can therefore only characterize the past, and is not always sufficient to predict the future, which can be affected by unexpected external events that can lead to unprecedented situations. Robust software control should combine analysis of the past with constructive reasoning that applies to the future in the absence of guidance from similar past situations. The challenge is to find ways to leverage sensor data processing to guide such reasoning, enable such reasoning to be completed within reasonable time bounds, and determine when it is necessary by recognizing unanticipated situations. Initial steps in this direction can be found in [8]. A complete solution to this problem is difficult and requires substantial advances to the state of the art.

In the near term, we recommend keeping USVs under the control of a human operator, and developing higher level concepts of control that will enable a single operator to control multiple vehicles, rather than needing one or more operators for each vehicle. We also recommend requirements for runtime monitoring of the software infrastructure to detect cyber-attacks and resilient designs that recover from attacks, or if that fails, bring the vehicles into a safe state if possible and self-destruct otherwise.

Recommendations for Further Research

We further recommend investigation of the potential benefits of renewable sonobuoy technology for mitigating the difficultly of small USVs keeping up with a transiting strike group in high sea states. The most effective way to retrieve the buoys at the trailing edge of the strike group would appear to be best done by a manned platform, autonomously by a large USV, a large USV carrying a small temporary crew, or by some as yet defined other method.

References

[1]LCS Mission Packages: The Basics, USNI News, Aug. 21, 2013, http://news.usni.org/2013/08/21/lcs-mission-packages-the-basics.

[2]FFG-7 OLIVER HAZARD PERRY-class, http://www.globalsecurity.org/military/systems/ship/ffg-7.htm.

[3]LCS: The USA's Littoral Combat Ships, Defense Industry Daily, Sep. 3, 2014, http://www.defenseindustrydaily.com/the-usas-new-littoral-combat-ships-updated-01343/.

[4]After 32 Ships, Future of LCS Program Unclear, Defense News, Mar. 2, 2014, http://www.defensenews.com/article/20140302/DEFREG02/303020016/After-32-Ships-Future-LCS-Program-Unclear/.

[5]SOUNDBYTE, University of Minnesota, Spring 2016, p.1.

[6]C. Ziegler, "A Google self-driving car caused a crash for the first time", The Verge, Feb. 29, 2016, http://www.theverge.com/2016/2/29/11134344/google-self-driving-car-crash-report.

[7]"Inside the Self-Driving Tesla Fatal Accident", NY Times, July 1, 2016, http://www.nytimes.com/interactive/2016/07/01/business/inside-tesla-accident.html.

[8]Luqi, D. Lange, "Schema Changes and Historical Information in Conceptual Models in Support of Adaptive Systems", Springer LNCS 4512, 2008, pp. 112-121, ISBN 978-3-540-77502-7.

[9] Fahey, "USV ASW Employment", NPS Thesis, in progress.

N9: WARFARE SYSTEMS

NPS-N16-N022: Traceability of Funding Lifecycle

Researcher(s): Dr. Gary Langford and Dr. Robert Eger III
Student Participation: LCDR Manny Lamberty USN, LT Patrick Stone USN, LT Gilberto Viera USN and LCDR William Harley USN

Project Summary

Traceability of lifecycle funding is premised on a formal approach that mathematically models the use of money to fund tasks, meet schedules, and produce expected results in terms of functionality, performances, and quality. An approach based on principles of systems engineering results in a standardized set of measures of effectiveness. An operative theory for traceability is derived from the general theory of systems integration from which ten propositions. These propositions derive from a set of definitions and axioms. This research affirms there is a proper insight into the concept of effectiveness that rests firmly on an appropriate, repeatable method. Measures of effectiveness are standardized when viewed within the proper formulation of an evaluative framework based on physical objects mapped to processes.

Background

Under a $75,000, 21-month research project funded by OPNAV N1 under the auspices of the Naval Postgraduate School (NPS) Naval Research Program, NPS developed measures of effectiveness (MOEs) to further the work of OPNAV N91 (Office of the Chief of Naval Operations - Warfare Systems) for integrating alternatives to improve disposition and use of funds in carrying out their responsibilities related to sustainment of warfare systems over their lifecycle (Program Objective Memorandum (POM/SPP through transition and execution). This research formulated a standardized, systematic means for measuring effectiveness of funds throughout the funding lifecycle. Findings can be used to leverage existing methodologies to lay out the foundation for a standardized framework for MOEs that reflects the various stakeholder perspectives, provides the requisite structure, tools, and techniques to determine the level of assurance that objectives will be met. It is assumed that the integration of a MOE-based strategy with necessary traceability and transparency provides better assurance than without standardized MOEs for satisfying requirements through full systems and system of systems integration.

Findings and Conclusion

This research examined new methods to improve traceability and transparency throughout the funding lifecycle for projects, contracts, and tasks. The tenets of lifecycle systems engineering integration were enacted to determine the allowable interactions with regards to effectiveness of traceability and transparency. The method used was developed under a framework that was structured on formal logic, after the work of Leśniewski (1984). The work of developing the artifacts related to funding, tasking deliverables, and period of performance was premised on determining the measures of effectiveness (MOEs) of tracing the use of funds. A preliminary model for complete compliance in capturing the lifecycle issues was developed. Then in contrast, a non-perfect traceability model was developed to provide a best case/less than best case comparison so that one could estimate the impacts of the lifecycle model on the traceability and transparency of use of budgets.

Developing a standardized, quantifiable set of measures of effectiveness (MOEs) that reflect the various stakeholder perspectives was accomplished by showing an example of physical security (deterrence). This example was then generalized to show the types of measures of effectiveness that could be used with the structure and implementation posed by the models. The goal was is to manage and improve the fidelity of the lifecycle model and its analyses for development, delivery, sustainment, and operations.

The effectiveness of traceability and transparency depends on the (1) identification of the significant measures of causality that drive the uses of appropriated funds, (2) interpretation of the measurements of traceability and transparency, and (3) perspective from which the measures and measurements are observed. These three factors reveal the functions and processes of traceability and transparency that determine the degree of influence of syphonage, misuse of funds, malfeasance, and misfeasance. From a functional and process perspective of the social and psychological issues (i.e., mechanisms) pertaining to these three factors, a warning (perceived or real) of a problem with traceability or transparency will be invariably linked through these social and psychological mechanisms. That warning may be general in nature, resulting in a need for a sustained level of vigilance or be quite specific, resulting in heightened awareness or the enactment of additional measures to track and evaluate. It is through the analysis of functions and processes that the harbingers of misuse can be observed.

Recommendations for Further Research

There are five steps to implement traceability for lifecycle funding. The first step is to build the foundation for sound lifecycle traceability in a theory that is validated with a formal model. The second step is to architect a preliminary model that encapsulates the degree of transparency, traceability, and compliance that is deemed necessary and sufficient to satisfy the purposes and intent to monitor and predict effectiveness. The third step is to establish procedures to implement a funding lifecycle effort built on a manual process to identify problems and encumbrances. The fourth step is to release a computerized traceability system. The fifth step is to mold individual and organizational behaviors into an operational model that is efficient in carrying out tasks and effective in delivering on-time, on-budget, on-time, on performance products and services.

The objective for this research work was to satisfy the requirements for the first step outlined above. However, during the development of the methodology for a standardized set of measures of effectiveness, it was noted that the traditional DOD concept of determining risk could be extended into the same integrative framework. Therefore, there is also a standard, quantifiable means of determining risk that builds on the structures of Leśniewski's formal model and is a natural consequence of organizing risk through functional and process domains.

References

Leśniewski's Systems. (1984). Leśniewski's Systems: Ontology and Mereology. ed. By J.T.J. Srzednicki, V.F. Rickey, and J. Czelakowski. Martinus, Nijhoff Publishers, Kluwer Academic Publishers Group, London.

NPS-N16-N155-A: Development of Non-Traditional Detection Algorithms for Undersea Warfare (USW)

Researcher(s): Associate Professor Timour Radko and John Joseph
Student Participation: LCDR Christopher Merriam, LT Troy Benbow USN, LT Michael Martin USN and LT Zachary Moody USN

Project Summary

This study addresses the problem of hydrodynamically-based detection of the surface and subsurface wakes generated by transiting submersibles. Our primary objective is to investigate the wake intensity, its thermal signatures and detection potential. Research activities involved numerical, laboratory and field experiments. Our work was aimed at providing a comprehensive and systematic analysis of stratified wakes in a realistic oceanic environment and will offer valuable operational guidance in this regard. This project is most timely since numerical modelling capabilities, and understanding of environmental influences, have only recently reached the level at which all key physical components can be fully represented. The identification of detection vulnerabilities will affect the tactics of undersea warfare by narrowing search areas for USW. These techniques became particularly appealing in view of continuous technological advances in remote sensing methods, which have dramatically improved the accuracy of measurements in the submarine wake.

Keywords: Non-traditional detection; Undersea Warfare; Battlespace environment; Submarine search, detection and avoidance

Background

Research into non-acoustic submarine detection methods, mainly supported in the US by the Office of Naval Research, has been ongoing since the 1960s. Several promising methods have been considered for airborne and submarine-based detection of the thermal and velocity signatures of submarine wakes. However, attempts to consistently implement non-acoustic methods on the operational level have yielded mixed results. The interest in hydrodynamically-based detection systems has been recently invigorated by: (i) continuous technological advances in remote sensing methods, which have dramatically improved the accuracy of measurements in submarine wakes and (ii) the proliferation of ultra-quiet air-independent propulsion submarines whose signal-to-noise levels fall significantly below the threshold of passive acoustic detection systems.

Findings and Conclusions

Since this project is directly based on student research activities, we summarize our key findings by referring to thesis projects supported by this NRP:

LCDR Merriam: The wake of a propagating, submerged body in a stratified fluid is fundamentally different from that of the same body in a homogenous fluid due to modification by buoyancy and gravity. The size of the wake, especially its vertical extent, is dependent upon the body's momentum and diameter and the stratification of the water. These parameters are captured by the Froude number which is the ratio of the inertial forces of a wake to the buoyancy forces. In a thermally stratified fluid it is possible to detect the wake of a submerged object by perturbations in temperature. This thesis identifies an additional parameter, the depth ratio, for the prediction of wakes that will reach the surface. Through laboratory experiments and numerical simulations we show that, for a given depth ratio, there exists a critical Froude number above which the wake can be detected at the surface by infrared (IR) camera. A field study conducted in Monterey Bay shows that it is also possible to detect such wakes below the surface using a unmanned underwater vehicle (UUV) and looking for a warming of the temperature profile. (Merriam, 2015)

LT Benbow: A numerical study has been performed to investigate the feasibility of hydro-dynamically based detection of propagating submersibles. Of particular concern is the possibility of utilizing microstructure measurements as a means of wake identification. The simulations are based on the Massachusetts Institute of Technology General Circulation Model (MITgcm), which has been modified for wake analysis. The dissipation of a turbulent wake produced by a sphere uniformly propagating in a doubly stratified environment is examined for three scenarios: (i) quiescent regime, (ii) double-diffusive regime, and (iii) a flow with pre-existing turbulence. The analysis of the numerical models was based on two quantities, the dissipation of turbulent kinetic energy (ε), and the dissipation of thermal variance (χ). This analysis indicates that wake signatures generated by a 1-meter wide object are detectable for 0.4 and 1.2 hours, depending on regime, and the detection interval is not strongly sensitive to the density ratio. Double-diffusive convection plays a significant role in the duration of submarine wakes. The extrapolation of the simulations to objects of ~10m propagating with speeds ~10m/s suggests that microstructure-based detection is feasible for at least two hours after the passage of a submersible and significantly longer outside the double-diffusive regime. These results indicate that microstructure-based observations of stratified wakes offer a viable method for the non-acoustic detection of submerged objects. (Benbow, 2016)

LT Martin: Submerged bodies propagating in stratified fluids frequently create disturbances in temperature, salinity, and momentum that are detectable at the air-sea interface. This project includes the addition of momentum excess in order to model the fundamental differences between signatures generated by towed and self-propelled bodies in various ocean states. In cases where the body forces, form drag and thrust were balanced, fewer and less expansive surface signatures were observed. In cases where the balance was disturbed by either lack or excess of self-propulsion, a greater perturbation was achieved, particularly in the ocean interior. Discovering the significance of the internal, intermediate-range wakes has transformed the focus of the entire study. With the increasing employment of unmanned underwater vehicles, it is equally imperative to research the internal ocean dynamics as it is to study the physics at the surface. This study was focused on direct numerical simulations. However, the data collected in this investigation have produced new insights into the dynamics of stratified wakes, which can be used on the operational level for developing and improving algorithms for non-acoustic signature prediction and detection. (Martin, 2016)

LT Moody: A hydrodynamically-based predictive model for the detectability of submarines will greatly enhance the U.S. naval advantage over adversaries within the battlespace environment. The ability to detect a thermal wake at depth using an autonomous underwater vehicle (AUV) is tested. Primary investigation consisted of real-world ocean experiments using a scaled towed body to mimic a self-propelled submerged body (SB). The impacts and bias from a tow ship on the thermal signature are considered. Direct numerical simulations (DNS) and laboratory experiments are used to complement field work findings. Similar thermal deviations were found between applied ocean observations and theoretical research. Two measurement methods were used to discern water column regions that had experienced the passage of a submerged body. This thesis concludes that thermal wake detection at depth in a stratified fluid is very possible, and an AUV is well suited for employment as a measurement platform. Additional research is necessary in order to capture different SB and environmental parameters, along with the testing of various sensors. (Moody, 2016)

Recommendations for Further Research

The project can and should be further developed in several directions. Additional experiments are necessary in order to explore different submerged body characteristics and environmental parameters which will ultimately lead to development of a general predictive algorithm. The maneuvering and acceleration of the submerged body was not taken into consideration, but would most likely result in the amplification of both interior and surface signatures of the wake. Extending the period of observation into the late wake regime, while continuing to monitor the interior thermal signal, will make it possible to quantify the decay rates of turbulent patches – an important problem of general oceanographic significance. The proposed critical conditions for the surfacing of a wake need further refinement and inter-comparison between numerical, observational and laboratory analogues. Nevertheless, even our preliminary results indicate that detection based on thermal wake signatures is highly promising as a means of non-acoustic target recognition.

References

Benbow, T. (2016). *The effects of double-diffusion and Background turbulence on the persistence of submarine wakes.* Monterey: NPS, thesis.

Martin, M. (2016). *Influence of the momentum excess on the pattern and dynamics of intermediate-range stratified wakes.* Monterey: NPS, thesis.

Merriam, C. (2015). *Laboratory experiments on stratified wakes.* Monterey: NPS, thesis.

Moody, Z. (2016). *Stratified wakes induced by submerged propagating objects: detection using UUVs.* Monterey: NPS, thesis.

NPS-N16-N206-A: Propagating Uncertainty in Hierarchical Combat Models

Researcher(s): Dr. Thomas W. Lucas and Dr. Paul J. Sanchez
Student Participation: Capt Salih Ilaslan, TAF

Project Summary
The Office of the Chief of Naval Operations (OPNAV) uses a hierarchy of simulation models as part of scenario-based planning to help decide how the Navy should be equipped, organized, and employed. Simulation is used throughout the acquisition process, from platform design to force structure analysis. In hierarchical combat modeling, the mean outputs of lower-level, higher-resolution models are typically used as inputs to higher-level, lower-resolution models. The objective of this process is to inform Navy leadership on how detailed design changes ultimately impact campaign effectiveness. Unfortunately, by ignoring variability in linkages between layers in the hierarchy, the results may bias campaign-level outcomes or understate the final variability (or risk) estimated by the campaign-level model. The primary goal of this research was to design and run experiments to better understand the impacts on the hierarchical modeling process associated with error propagation methods and design of experiments techniques. Another objective was to developed new algorithms that improve upon our ability to explore high-dimensional combat models.

To empirically explore a host of different error propagation approaches, this research conducted thousands of experiments using a two-model hierarchical structure in an air-to-air warfare setting. The results indicate that the manner in which the engagement and campaign models are linked significantly affects the estimates of operational effectiveness and risk. In addition, this research advanced our ability to explore combat models and fit response surfaces through the development and testing of new metamodeling approaches and sequential Latin hypercube methods.

Keywords: Design of experiments, hierarchical models, error propagation, combat modeling, response surface.

Background
The Navy uses families of models of varying detail to analyze forces and operational concepts. The information gleaned in these model-supported studies helps shape the composition of the future Navy and how it will fight. The current practice in the higher-to-lower-fidelity sequence of modeling is to use point estimates of more focused higher-fidelity model outputs as the inputs for the broader lower-fidelity models. It is vitally important to understand how these lower-level model errors are propagated through the series of models, and consequently how decisions are affected. This research built on previous efforts related to propagating errors in hierarchical models and empirically explored the effects of multiple approaches. The research was guided by an application of air-to-air warfare.

Findings and Conclusions

In this research period, an engagement-level model for a two-versus-two air engagement between jet fighters was developed in the stochastic, agent-based Map Aware Non-uniform Automata (MANA) simulation environment. The inputs to this mission-level MANA model include the jet fighters' characteristics such as speed, range, and weapon effectiveness. The output measures of effectiveness (MOEs) are losses, time of battle, and the probability each side wins. Variability in the inputs is induced and explored using two different design of experiment (DOE) techniques, nearly orthogonal Latin hypercubes (NOLHs) and resolution V fractional factorials (R5FFs). The MANA runs yield a library of outputs that can be accessed as needed by the campaign model.

Our campaign-level model is a stochastic Lanchester linear law simulation. Each campaign simulates four discrete engagements of 25 versus 25 jet fighters, and each engagement utilizes a breakpoint such that the engagement is terminated as soon as one side is depleted to a quarter of their original strength. The attrition coefficients for the stochastic Lanchester campaign model are determined by the losses and time of battle obtained from the engagement-level MANA model. Because MANA is stochastic, many replications are run, producing a distribution of outcomes. However, the campaign-level model takes scalars as input. Thus, the research question is how best can we link these two models to account for the variability? Several methods for using the engagement-level results as inputs to the campaign-level simulation were assessed and compared in this effort. The campaign-level outcomes are total losses and probability of win. Generally, we find that linking the campaign model to mission-level output is a more effective approach for quantifying risk than the use of a deterministic embedded meta-model. However, much more research is needed.

Naval Postgraduate School faculty also continue with their research in developing design of experiment algorithms that improve upon our ability to explore high dimensional models of combat (and beyond). This past year, we performed a large-scale empirical study of several Gaussian process (GP) software packages, and found differences in their suitability for creating meta-models of high-dimensional behavior (Erickson, Ankenman, & Sanchez 2016). This is a first step toward enhancing recent work on sequential methods (Duan, Ankenman, Sanchez, & Sanchez 2017) in order to develop adaptive methods that update meta-models to dynamically focus on interesting parts of the trade space as experiments are executed and evaluated.

Recommendations for Further Research

The models employed in this research were developed to explore error propagation in hierarchical combat models. As such, they were much simpler than the models that are actually used by OPNAV analysts. Nevertheless, they provided useful insight into the practice of hierarchical combat modeling. Constructing and examining other variants (e.g., land combat) may be useful in establishing the robustness of these findings. In addition, numerous other experiments could be done exploring many other design of experiment approaches. Ultimately, these simple experiments should be repeated using the more complicated simulations actually used in OPNAV's studies.

References

Ilaslan, S. (2016). Analysis of error propagation within hierarchical air combat models. M.S. in Operations Research, Naval Postgraduate School, Monterey CA.

Duan, W., Ankenman, B.E., Sanchez, S.M., & Sanchez, P.J. (2017). Sliced full factorial-based Latin Hypercube designs as a framework for a batch sequential design algorithm. Forthcoming in *Technometrics*.

Erickson, C., Ankenman, B.E., & Sanchez, S.M. (2016). Comparison of Gaussian process modeling software, *Proceedings of the 2016 Winter Simulation Conference,* Institute of Electrical and Electronic Engineers: Piscataway, NJ, 3692-3693.

NPS-N16-N264-A: Application of Model-Based Systems Engineering (MBSE) to Compare Legacy and Future Systems in Mine Warfare (MIW) Missions

Researcher(s): Eugene P. Paulo and Paul Beery
Student Participation: Mr. Chadwick Cummings, LT William Davidson USN, LT Shawn Hoch USN, Mr. John Kady, Mr. Raymond Tagulao, and LT Philip Wicker USN.

Project Summary

This research analyzes the expected mine countermeasures (MCM) performance of legacy and emerging mine neutralization systems on multiple platforms. The systems evaluated are the SLQ-48 “Mine Neutralizing System (MNS)”, the SLQ-60 “SeaFox”, AN/AQS-235 “Airborne Mine Neutralization System (AMNS)/ Archerfish”, and the “Improved Mine Neutralization System - Barracuda” currently being developed by Raytheon. The platforms in which these systems are to be supported on are the Avenger MCM ship, the MH60S “Knighthawk” helicopter, and the littoral combat ship (LCS). The study focused on three measures of effectiveness (MOEs): mission time, weapon expenditures, and mission effectiveness. Using an operational simulation, the team determined which configuration variations of these systems on supported platforms appeared to be the most effective. The study found that the performance of the “Improved Mine Neutralization System – Barracuda” presented an increase in capability over legacy systems. In addition, the simulation analysis results depicted a significant performance increase from aerial-deployed neutralizers and neutralizers deployed simultaneously in parallel configurations. This report suggests that, when possible, mine neutralization should be conducted in a parallel configuration from multiple platforms with the most capable neutralizer available.

Keywords: Model-Based Systems engineering, mine warfare, unmanned underwater vehicles

Background

This study built on previous MCM research conducted by two NPS systems engineering student teams and led by the principle investigator, which examined mine detection and classification concerns. The purpose of this study was to focus on the Localization, Identification, and Neutralization (L-I-N) segment of the mine neutralization continuum (see figure 1) for current platform/system configurations, and also for proposed combinations, under a range of field configuration and environmental conditions to investigate the following study questions:

- What configurations, using current neutralization systems and platforms, are most effective (fastest) in clearing a minefield?
- What configurations, using current and/or proposed neutralization systems and platforms, are most effective (fastest) in clearing a minefield?
- What individual platform or neutralization system performance parameters (i.e. range, speed, probability of kill, etc.) have the greatest impact on the efficacy of current or proposed operational scenarios?

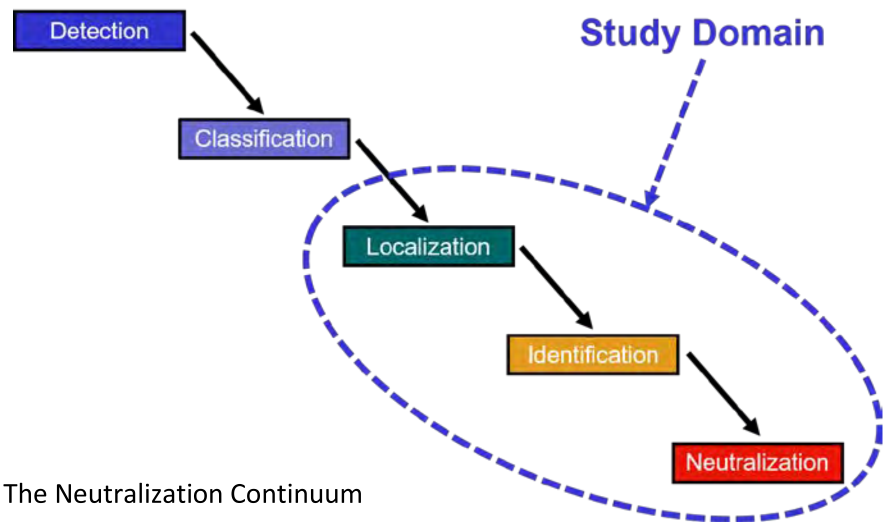


Figure 1: The Neutralization Continuum

Findings and Conclusions

Through stakeholder solicitation and other research methods, the analysis team identified three currently fielded, and one proposed platform, to support the current Naval MNS mission, along with four currently fielded, and one proposed Naval MNS for mission evaluation as indicated in Table 1. Demonstrated performance characteristics, or notional performance characteristics for Naval MNS in development, were determined for these systems.

Table 1. Platforms and MNS under study.

Platform	Mine Neutralization System (MNS)
MCM-1 Avenger Class Ship	AN/SLQ-48 Mine Neutralization System
MH-53E “Sea Dragon” Helicopter	AN/SLQ-60 Sea Fox
Littoral Combat Ship (LCS)	AN/ASQ-235 AMNS Archerfish
MH-60S "Knight Hawk" Helicopter	AMNS Barracuda *(Future System)*

Using a simulation built with the Python programing language (Python Software Foundation, https://www.python.org), models representing mine fields of varying target density, depth, type, and environmental conditions were created to test each operational combinational variant of the platform and MNS. This analysis allowed for determination of the efficacy of each type of operational scenario as illustrated in Table 2 and Figure 2. Table 2 shows Mission Time in hours and Mission Effectiveness as a ratio mines/weapon expenditure.

System	Configuration 1 1 Neutralizer		Configuration 2 2 Neutralizers		Configuration 3 4 Neutralizers	
	Mission Time	Mission Effectiveness	Mission Time	Mission Effectiveness	Mission Time	Mission Effectiveness
SLQ-48	98.27	0.671	52.68	0.673	31.41	0.672
SLQ-60(1)	78.58	0.775	42.24	0.772	25.21	0.776
SLQ-60(2)	88.53	0.773	47.52	0.778	28.48	0.776
AMNS	65.77	0.915	34.92	0.914	20.71	0.912
Barracuda	52.97	0.958	28.02	0.959	16.49	0.957

Table 2. Neutralizer performance.

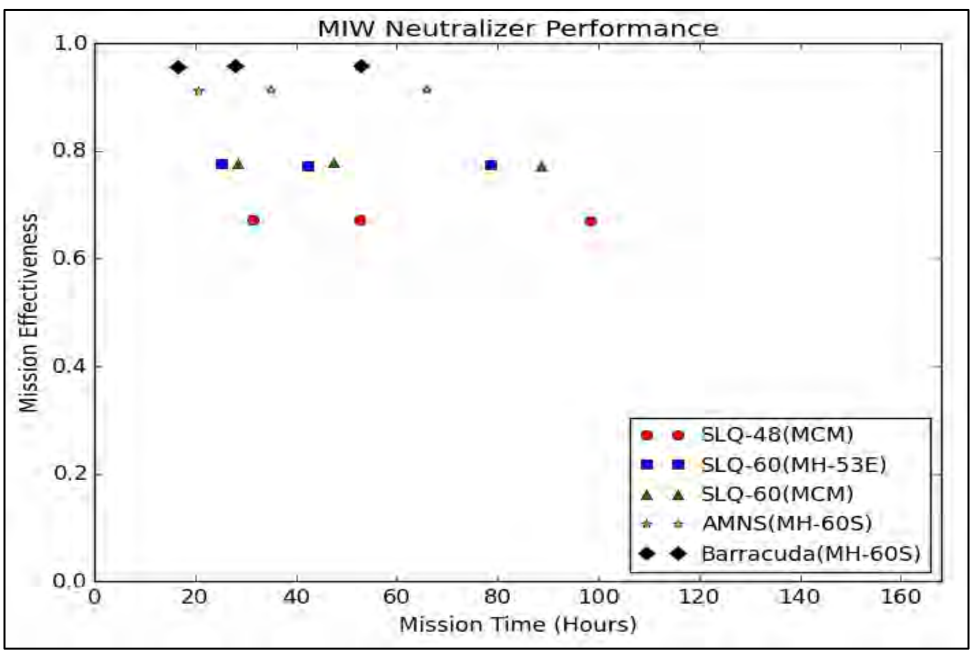


Figure 2. MIW Neutralizer Performance

Additionally, through the use of regression analysis, the relative importance of each individual platform and MNS performance characteristic's impact on overall scenario efficacy was determined. An overall relationship between the primary independent variables, Probability of Malfunction (pM) and Probability of Misidentification (pMID), and the combined dependent variables, Mission Effectiveness / Time, showed a higher effect from pM – as pM decreases, Mission Effectiveness / Time increases substantially. The equivalent type of effect from pMID is significantly less substantial, as seen by the slopes indicated in Figure 3.

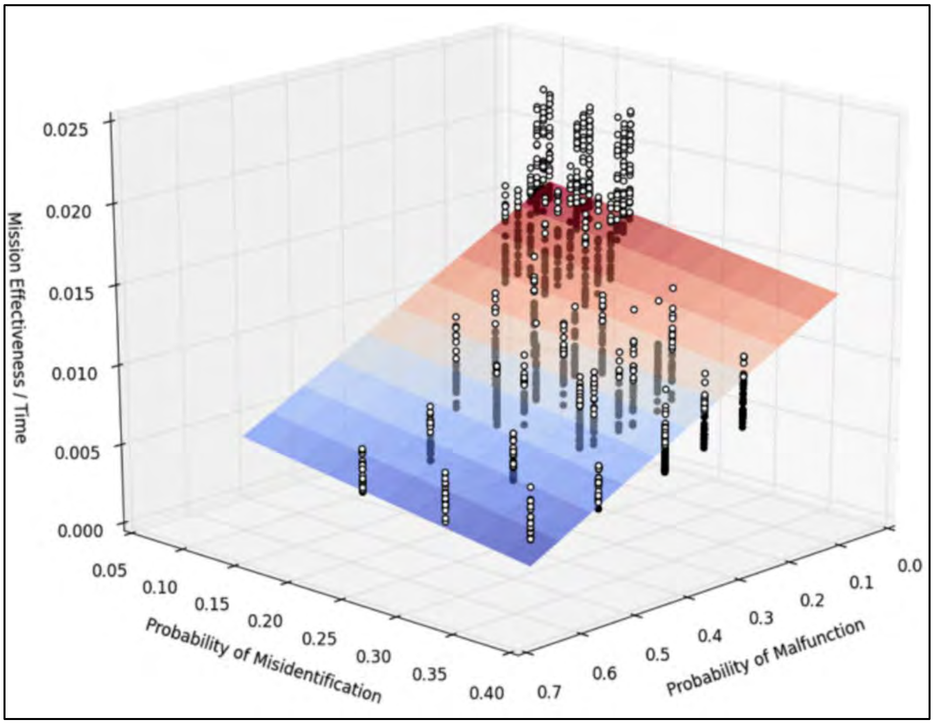


Figure 3. Overall performance effects.

Overall, the performance of the AMNS systems (both Archerfish and Barracuda) present an increase in capability over Legacy systems. In addition, model analysis shows a significant performance increase from aerial-deployed neutralizers and neutralizers deployed simultaneously in parallel configurations due to the decreased mission time required to clear a given minefield.

This report suggests that, when possible, mine neutralization should be conducted in a parallel configuration from multiple platforms with the most capable neutralizer available. It is accepted, however, that operational limits may present an obstacle to the use of multiple MIW platforms simultaneously and the increased presence of platforms may provide diminishing results as the number is increased.

Recommendations for Further Research

Recommendations for further study and improvement include the expansion of this model and its associated input variables to account for more MOEs that can be specified by future MNS acquisitions teams. To accurately account for the MOEs used in this model, it is recommended that the input variables used to represent neutralizer and platform capabilities be set as constants representing the actual capabilities of the neutralization systems reviewed in this report. This information and the associated result would, however, require a classified environment.

References

BAE Archerfish Mine Neutralization System. In Laststandonzombieisland. March 4, 2016. Accessed November 3, 2016. https://laststandonzombieisland.com/2016/03/04/navy-to-get-more-archerfish/.

Cummings, Chadwick, et al. *Efficacy of Current and Future U.S. Navy Mine Neutralization Systems*. Capstone Project Report, Monterey, California: Naval Postgraduate School, 2016.

Frank, David, et al. *Application of Model-Based Systems Engineering (MBSE) to compare legacy and future forces in Mine Warfare (MIW) missions.* Capstone Project Report, Monterey, California: Naval Postgraduate School, 2014.

Furey, Sean, Mass Communication Specialist 2nd Class. MH-60S Sea Hawk Helicopter Equipped with the Airborne Laser Mine Detection System (ALMDS). August 4, 2014. U.S. Navy, ID: 140804-N-WX059-219.

Gatley, Eric, et al. *Scenario-Based Systems Engineering Application to Mine Warfare.* Capstone Project Report, Monterey, California: Naval Postgraduate School, 2015.

Hammond, Michelle R., Photographer's Mate 1st Class. The Mine Countermeasure Ship USS Avenger (MCM-1) Operates off the Coast of Hawaii during Exercise Rim of the Pacific (RIMPAC) 2004. July 10, 2004. U.S. Navy, ID: 040710-N-6551H-229.

SeaFox Mine Neutralization System. In ATLAS North America SeaFox. November 3, 2016. Accessed November 3, 2016. http://www.marinelink.com/news/america-seafox-atlas347530.

SLQ-48(V) Mine Neutralization System (MNS). In 21st Century U.S. Navy Mine Warfare. Washington, DC: Program Executive Office Littoral and Mine Warfare, 2009.

NPS-N16-N354: Comprehensive Aerial Logistics Management for the Sea Base

Researcher(s): Dr. Kyle Lin and Dr. Michael Atkinson
Student Participation: LT Samuel Chen USN

Project Summary

Carrier onboard delivery (COD) is the use of aircraft to transport people and cargo from a forward logistics site (FLS) to a carrier strike group (CSG). The goal of this project is to study how a real-time cargo tracking capability can reduce the delay of high-priority cargo while increasing that of low-priority cargo. To do so, we analyze data from COD operations between 2010 and 2015 to develop a simulation model, and use those data to infer model parameters.

Our simulation results indicate that, with two C-2A aircraft currently used by the Navy, real-time cargo tracking can reduce the delay of high-priority cargo by more than 50%, while increasing that of low-priority cargo by about 25%. The Navy plans to replace C-2A with a variant of V-22 Osprey for COD operations in the near future, and is conducting cargo space studies to facilitate this transition. By testing a few different model parameters based on studies available for V-22, our simulation results indicate a similar observation of delay tradeoff between high-priority cargo and low-priority cargo, although the tradeoff is less pronounced, mainly because three V-22 will be stationed at the FLS.

Background

Carrier Onboard Delivery (COD) is the transport of high priority cargo, mail, and passengers between carriers and shore bases. COD operations are accomplished with airplanes with the ability to land onboard aircraft carriers. These airplanes fly from Forward Logistics Sites (FLS) to the carrier to supply items critical to the entire Carrier Strike Group (CSG), as well as the carrier itself.

The Navy currently uses C-2A Greyhound aircraft to support the COD operations, but lacks a comprehensive method of tracking and prioritizing cargo shipped to the CSG. Consequently, limited aircraft shipping space/weight is often allocated to low priority items while high priority items are left behind. As the Navy will soon replace the C-2A with CMV-22B—a Navy variant of the V-22 Osprey—to support the COD mission, the goal of this project is to assess the value of near real-time end-to-end tracking of individual cargo items for both C-2A and CMV-22B in the COD mission.

Finding and Conclusions

The Fleet Logistics Support Squadron 30 (VRC-30) provides data on COD operations between 2010 and 2015. The data set contains the COD sorties, the number of passengers transported, and the amount of cargo delivered. We work with VRC-30 to develop a simulation model for the COD operations, and use these data set to infer model parameters.

Our simulation model is flexible to account for different operational scenarios and different aircraft types. The model accounts for four priority levels for cargo, two types of passengers (distinguished visitors and regular visitors), and one type of large items that take up the entire cargo space (such as F-18 engine). We adopt a priority-based policy to decide what to load into the aircraft's cargo space based on each item's priority level and waiting time at the FLS. The model also accounts for regular aircraft maintenance cycles and occasional breakdowns. By running the simulation model, we estimate the delays of passengers and cargo when the FLS does not have real-time cargo tracking capability, as well as the delays when the FLS has real-time cargo tracking capability.

For an FLS with two standard C-2A Greyhound, our simulation results indicate that a cargo tracking system can reduce the delay of high-priority cargo by more than 50%, while increasing the delay of low-priority cargo by 25%. When the payload on C-2A drops, either when the CSG sits at a farther distance or when the temperature rises, this tradeoff is even more pronounced.

It is more difficult to run our simulation model for an FLS with CMV-22B Osprey, since there are ongoing studies on its cargo space configuration. We use the numbers from a cargo study carried out by Naval Air Station Patuxent River in November 2014 as our baseline, and test additional numbers in the same range. In those simulation experiments, our results indicate that a cargo-tracking system can reduce the delay of high-priority cargo delivered by CMV-22B by 17–35%, while increasing the delay of low-priority cargo by 8–17%.

Recommendations for Future Research

Our simulation results depend heavily on model parameters, which can be fine-tuned and adjusted if further studies are available. Since there is no data on the volume and frequency of cargo and passengers arriving at the FLS, we make a few assumptions in our model via educated guesses.

We do take into account the fact that aircraft go through breakdown and repair cycles, and assume different aircraft act independently through their individual cycles. This assumption may not hold in practice, if the parts of a broken aircraft can be used to repair another aircraft of the same type, in which case the breakdown of one aircraft actually makes the others more likely to remain operational. Another interesting research question is how cargo tracking can help alleviate the added delay of high-priority cargo when a surge of demand arrives at the FLS. The answers to these questions require further research.

NPS-N16-N365-A: Determine a Shannon-Entropy-Based Decision Making Process to use in Launching a Weapon Autonomously from an Unmanned Vehicle

Researcher(s): Joseph W. Sweeney III, and Gary W. Parker
Student Participation: LT Bradley Johnson USN

Project Summary

Following conversations with the N98 sponsor's representative, a decision was made to alter the line of research to include two topics.

The first research project developed and analyzed the functional architecture for an "autonomous" unmanned aerial system performing an Intelligence, Surveillance, and Reconnaissance (ISR) mission without a continuous communication link to human operators for trust needs. The factors that affect human trust were developed from a literature review covering theory and empirical studies that have investigated the importance of human trust in human-automation interactions. The identified factors were applied to the functional architecture, and the system functions were categorized as reasoning functions and non-reasoning functions. Each functional category was analyzed for trust needs by describing how the function's purpose, process, and performance link to human knowledge, perception and beliefs. From the analysis, automation design requirements that link to the identified trust needs were developed. This work highlighted the importance of applying human factors analyses in the early stages of the Systems Engineering process for "autonomous" systems.

The second line of research focused on the introduction of autonomous weapon systems (AWSs) capable of selecting and lethally engaging targets without human intervention. This research used a system engineering approach to identifying the informational requirements of a decision maker making an AWS activation decision.

Keywords: autonomy, autonomous, trust, decision-making, weapon system

Background

The driving factor for this research originates from a Defense Science Board (DSB) task report of 2012. In the man-machine systems being devised and implemented, there needs to be a level of trust on the part of the human to allow a synergistic cooperation. The human operator must have confidence that the machine will follow a specified set of behaviors on a routine basis so the operator can expect consistent actions to be carried out in expected scenarios. This trust in the machine's behaviors develops a more productive relationship and increases the capability of the combined man-machine system.

A significant problem in weapon-carrying is that autonomy technology is being underutilized. The initial use of Unmanned Vehicles (UXVs), particularly aerial and space, concentrated on conducting non-lethal missions such as communications relay and intelligence, surveillance, and reconnaissance (ISR). The introduction of weapon carry and fire capability on UXVs raised concerns of ensuring the appropriate target is attacked using an appropriate level of force changes the nature of potential UXV implementation. Allowing an UXV to independently release weapons at a target has not been accepted by societal constraints to date. Current strategies require positive identification by some informed person(s) in the chain of command to proceed to the point of releasing weapons. Before any Force Commander will allow a UVX to fire a weapon at a target, a satisfactory method must be developed to provide the required level of confidence in the identification of the target as well as an estimate of potential collateral damage that will be affected. There is no method in place to quantify this process yet.

Findings and Conclusions

The key finding from LT Johnson's thesis is that an analysis performed on the functional architecture of an "autonomous" system linking human psychological factors that influence trust to the system's functional purpose, process, and performance (Lee and See 2004) can aid in developing system design requirements that directly trace to trust calibration and correct reliance in the system. This thesis focused on the steps required to be carried out to convert a currently manned operation to a combination of manned and unmanned efforts.

First, an operational scenario was developed to describe what actions must be completed to meet the capability needs and provide a solution to the problem. The actions, or functions, described in the scenario were then used to create the system's functional architecture; typically, the architecture is modeled-based. Architecture modeling methods such as Function Flow Block Diagrams (FFBDs) use a top down approach decomposing high-level functions into sub-functions to describe the sequential relationship of the functions.

For this research, an existing capability was chosen: the ability to perform an ISR mission without constant communication with a controlling station. The capability is currently met with a manned aerial system. However, recent developments in automation technology indicate that an advanced unmanned system, or combination of advanced systems, could feasibly be used instead of the manned system to meet the same capability.

If an advanced unmanned system, described in this research as the aerial vehicle with automated cognitive capability (AVACC), were to replace a manned system for the ISR mission, the actions needed for mission accomplishment do not change very much. However, the functional allocation is completely different. Functions that were allocated to a human operator must now be assigned to software in the AVACC. In addition to function allocation, human-system interaction changes. With humans removed from the vehicle, the primary operational human-system interaction occurs when the AVACC provides a Contact Report to the humans on the ship. For the Contact Report to be properly accepted and used in any further ship mission decisions, the human must have calibrated trust in the AVACC and its ability meet the ISR capability. Thus, an investigation into trust in automation is needed to ensure the correct system is designed to meet capability needs.

This work developed the series of steps that can be followed to incorporate unmanned capabilities into the battlefield solutions to provide increased operational capability along with reduced exposure of crew members to potentially fatal situations. The results aligned with expectations, with more clearly defined incremental steps to assist in developing the process required to implement unmanned capabilities.

Although there are many feasible military scenarios in which an AWS might be operationally employed, the informational needs of the activation authority fall into two categories: the information needed to maximize the probability the AWS selects to engage an allowable target, and the information needed to minimize the probability that the AWS will engage a target in a manner inconsistent with legal, policy, or operational restrictions. The decision authority must understand the conditions in which the AWS will be operating and their effect on sensors the AWS uses to determine an allowable target. The decision authority must also have information about the location and behaviour of potential targets to determine target “windows of vulnerability” during which lethal engagement by the AWS is consistent with law, policy, rules of engagement, and operational restrictions.

Recommendations for Further Research

Expanding the trust analysis to a complete functional architecture would be the next step for continuing this research. Then, with trust needs identified and initial trust requirements written, measures of effectiveness and measures of performance used for testing the system for calibrated trust would be developed.

Unfortunately, clear measures of effectiveness and measures of performance for trust calibration cannot be adequately developed until an initial interface design is considered. The trust analysis performed in this work identifies what information must be provided by the

AVACCC in the Contact Report based on human knowledge, beliefs and perception of the AVACC purpose, process and performance. It does not address how the information in the Contact Report will be put together at the human-AVACC interface. Once these items are clearly defined, the next steps can be addressed.

References

Defense Science Board. 2012. *Task Force Report: The Role of Autonomy in DOD Systems*. Department of Defense, Defense Science Board Office of the Under Secretary of Defense for Acquisition, Technology and Logistics. July 2012. Washington, DC, http://www.acq.osd.mil/dsb/reports/AutonomyReport.pdf.

Lee, John D. and Katrina A. See. 2004. "Trust in Automation: Designing for Appropriate Reliance." *Human Factors*, Vol. 46, No. 1, Spring: 50–80. http://dx.doi.org/10.1518/hfes.46.1.50_30392.

Lockett III, John F. and Jeffrey Powers. 2003. "Human Factors Engineering Methods and Tools." In *Handbook of Human System Integration*, edited by Harold R. Booher, 463–496. New Jersey: John Wiley and Sons, Inc.

NPS-N16-N495-A: Air Combat Analytic Model

Researcher(s): Dr. Michael Atkinson, Dr. Moshe Kress, and Dr. Roberto Szechtman
Student Participation: CPT Jason Gay RSA

Project Summary

The U.S. Navy has an existing procurement and retirement plan for aircraft that is part of a complicated DOD budget planning process. With an evolving global strategic environment that is becoming more volatile and complex, budget analysts are pressured to continually respond quickly to scenarios that may surface from emergent world events and domestic politics. The daunting task of this procurement process lies in the partial responsibility of the Office of the Chief of Naval Operations (OPNAV).

This project focuses on naval fighter aircraft, in both air-to-air and air-to-ground specifications. These fighter aircraft includes the F35-C Lightning II, the F/A-18C Hornet, and the F/A-18E/F Super Hornet. Understanding which capabilities and characteristics of the aircraft are most important will help OPNAV make cost-effective procurement decisions in the future. We develop lower resolution analytically tractable models that can provide "first" order results regarding in-context operational effectiveness of certain mixes of physical characteristics and capabilities. More specifically, for the design of fighter aircraft, the balance between the design attributes; such as maneuverability, stealth, velocity, survivability, and onboard weapon effectiveness; mission demands; and budget constraints poses great challenges to both planners and decision-makers.

The study uses Stochastic Duel and Markov chain machinery to evaluate the Measure of Effectiveness (MOEs) of naval fighter aircraft. We start with one-on-one interactions between aircraft and then expand to incorporate multiple fighter aircraft on each side. The main beneficiary of this study will be the Office of Chief Naval Operations (OPNAV). Specifically, the Air Warfare Division (N98) will be able will be able to leverage our results to conduct low cost, time efficient, first order analysis of alternatives in their future procurement of naval fighter aircraft.

Keywords: air combat, stochastic duel, pursuer-evader, Markov chains

Background

The U.S. Navy operates 104 aircraft types, which are grouped and assigned into 22 mission sets (Zabinski, 2015). The assignment is unique; each aircraft type is associated with a single mission set. The physical and operational characteristics of each aircraft type are tuned according to the tactical and operational requirements generated by the mission set. As aircraft age and mission sets evolve, new aircraft need to be developed, produced, and procured. In particular, there is a continuous need to examine and analyze the match between existing and evolving requirements in mission sets and the physical and operational characteristics of aircraft.

The common practice for analyzing this match is through detailed computer simulations. The benefits of such simulations are clear; they emulate physical and behavioral realities and often generate valuable insights regarding relations between operational requirements and physical and behavioral capabilities. The downsides of computer simulations are lack of transparency – their “engines” are typically black boxes, which are difficult to verify and validate – and most of all they are costly in terms of time and money. Notwithstanding these limitations, simulations are indispensable at advanced R&D stages when fine-tuning of characteristics are crucial. However, lower resolution analytically tractable models at the early stages of weapons’ R&D process, and perhaps even in Analysis of Alternatives (AoA) studies, can be beneficial due to their lower development costs and the ability to produce analytical insights. Such models can provide “first-order” results regarding in-context operational effectiveness of certain mixes of physical characteristics and capabilities, and complement the more higher-granularity simulation models.

In this project we develop lower resolution models to evaluate the tradeoffs between maneuverability, stealth, velocity, survivability, on-board weapons’ effectiveness, etc. This type of analysis can be addressed by models such as many-on-many stochastic duels (Kress, 1992). The concept of the stochastic duel was studied extensively by Williams and Ancker (1963), where the fundamental framework stemmed from the one-on-one duel with differing initial conditions. We also use the one-on-one interaction as the key building block in our analysis.

Findings and Conclusions

This project was initially scheduled for FY16 and part of FY17. However, the project was postponed until FY17, and thus we have just started working on the project. We recruited CPT Jason Gay, Singapore Army, to work on this project as part of his thesis project. CPT Gay is scheduled to graduate in September 2017. We have only worked on the project for two months, but we have developed an initial model, which we describe below.

The final model will be based on a many-on-many stochastic duel that capture both force-on-force attritions and the uncertainty inherent therein. Relations among sensors' range and reliability, weapons' effectiveness, platform maneuverability, and stealth, as well as other attributes such as endurance and tactics, will be captured within this framework of stochastic duel models. The effect of modern technologies (e.g., autonomous aircraft) will also be represented in the proposed analytic framework.

While we eventually will consider multiple aircraft on each side, we first examine the one-on-one scenario using a continuous time Markov chain model. We initially assume both aircraft are beyond visual range, but each has detection-beyond-visual range capabilities. Once one aircraft has identified the adversary, it can fire a missile. One of the aspects about our model different from most duels is the ability of one side to recognize it has been fired on and to take countermeasures, including returning fire. The interaction will proceed rapidly. If neither side is destroyed by the adversary's missile, then the two aircraft will quickly be within very close range of each other. At this point one aircraft will become the *pursuer* and the other aircraft is the *evader*. The pursuer may eventually shoot down the evader, or the evader may break away from the pursuit and the roles of the two planes will switch. The key characteristics of this interaction include on-board detection and acquisition, maneuverability, offensive weapons, and defensive systems.

Recommendations for Further Research

As we just started working on this topic, the project's evolution in the coming months will dictate potential future work. Stochastic Duels are inherently strategic and thus require some game theory machinery. If the interaction also involves multiple waves of fighter aircraft, the problem becomes even more complex as there may be decisions about when to send another wave and what aircraft to send in a given wave. Berkovitz and Dresher (1959) examined a related problem and building upon that work may be a fruitful future path.

References

Berkovitz, L. D., & Dresher, M. (1959). A game-theory analysis of tactical air war. *Operations Research*, 7(5), 599-620.

Feigin, P. D., Pinkas, O., & Shinar, J. (1984). A simple Markov model for the analysis of multiple air combat. *Naval Research Logistics*, 31(3), 413-429.

Kress, M. (1992). A many-on-many stochastic duel model for a mountain battle. *Naval Research Logistics*, 39(4), 437-446.

Williams, T., & Ancker Jr, C. J. (1963). Stochastic duels. *Operations Research*, 11(5), 803-817.

Zabinski, H. (2015). Capital Investment Planning Aid for Naval Aircraft (Master's thesis, Monterey, California: Naval Postgraduate School).

ASN (RDA): Research, Development & Acquisition

NPS-N16-N112-A: Novel Power Supply for Pulsed Power Application

Researcher(s): Dr. Giovanna Oriti
Student Participation: LT Mitchell Stewart USN

Project Summary
Railgun muzzle flash, or post-fire arcing, is a major concern to the Navy because of the potential thermal stress associated with post-fire arcing. In this project a new railgun power supply was compared to the thyristor-based one, which is the state of the art. Quantification of the post-fire rail energy reveals that the proposed buck-boost converter topology is better suited for the railgun than the thyristor-based one, particularly at minimizing the post-fire muzzle energy. The minimization of the post-fire energy allows for an extended rail life and potentially longer usage.

Keywords: railgun power supply, post-fire energy, thyristor-based converter

Background
A significant part of the railgun is the power supply that delivers high current from a capacitive source. This is the largest component in the railgun system and includes solid state thyristors and diodes as described in [1] through [3]. Railgun muzzle flash, or post-fire arcing, is a major concern to the Navy because of the potential thermal stresses associated with post-fire arcing. When the armature exits the rails, a finite energy from the railgun pulsed-power supply is inductively stored in the rails and discharges at the muzzle. This energy, which is due to the loss of the low-voltage electrical contact that is ordinarily between the armature and the rail, is forced by the system inductance to flow as an electrical discharge, creating a muzzle flash. Alternative power supply architectures that reduce the size of the railgun system and the post-fire energy are very attractive to the U.S. Navy [4].

Findings and Conclusions
The goal of this project was to predict the behavior of an alternative power supply for the railgun. Such behavior was compared to that of the existing thyristor-based power supply with respect to the post fire energy at the end of the barrel.
Physics based equations were derived to model the power supply and the railgun. Features of the model include; circuit current characteristics, energy to the rails, armature velocity, post-fire arcing and post-fire energy into a resistor. The Matlab/Simulink software was used to perform several simulations of the behavior of the buck-boost converter and the thyristor-based power supply (baseline).

The performance of the proposed power supply was compared to that of baseline system. The results of the simulations show that the buck-boost converter and thyristor-based converter transfer energy to the rails with the same level of efficiency. The armature velocity and calculated kinetic energy plots for both circuits show relative similarities. From the results of the simulations it can be concluded that the buck-boost converter could replace the current railgun power supply topology. Both circuits deliver similar current levels to the rails given the same initial input energy. The area where the buck-boost converter shows promise over the thyristor is in post-fire arcing.

Analysis of the railgun post-fire energy and post-fire arc demonstrated that the thyristor railgun power supply delivers 0.123 MJ more than the proposed buck-boost power supply architecture to the rail in the form of an arc after the armature had exited the rails. This is because the thyristor-based power supply delivers more current to the rails than the buck-boost converter circuit after the projectile has exited the rails. This continued supply of current was discharged into the rails at the muzzle, producing high temperature arcs. On the other hand, the buck-boost converter topology allows control of the rail current. Therefore current delivery to the rails can be stopped when the armature exits the rails. This minimizes the discharge of high-energy arcs at the muzzle, therefore diminishing thermal damage to the rails.

This work was performed with the contribution of LT Stewart as part of his MSEE thesis [5].

Recommendations for Further Research

The inductors and capacitors should be designed and sized. Also the minimum switching speed of the power devices should be determined and compared to what is commercially available. A prototype of the proposed power supply should be tested in the laboratory to validate the simulations.

References

A. L. Julian, J. H. Black and W. B. Maier II, "Power supply design for high voltage capacitor discharge railgun supply using thyristors," in Electromagnetic Launch Technology, 2008 14th Symposium On, 2008, pp. 1-5.

J. Bernardes, S. Swindler, “Modeling and Analysis of Thyristor and Diode Reverse Recovery in Railgun Pulsed Power Circuits”, in Proc. of IEEE Pulsed Power Conference, June 2005, pages 79–82.

Jack S. Bernardes, Michael F. Stumborg, Thomas E. Jean, “Analysis of a Capacitor-Based Pulsed-Power System for Driving Long-Range Electromagnetic Guns”, IEEE Trans. on Magnetics, Jan. 2003, Vol. 39, Issue 1, Part 1, pages 486–490.

C. Martino, “Theory and design of medium voltage pulsed current supply using wide band gap solid state device,” Ph.D. dissertation, Dept. Elect. Eng., Naval Postgraduate School, Monterey, CA, 2015.

LT Mitchell Stewart, “Comparison of two railgun power supply architectures to quantify the energy dissipated after the projectile leaves the railgun”, NPS MSEE Thesis, September 2016.

NPS-N16-N116-A: Cybersecurity Figure of Merit (CFOM) Cyber Readiness Assessment

Researcher(s): Dr. R. William Maule
Student Participation: CDR Eric Perle USN, Capt Nicholas Bakewell USMC, and LT Keith Nelson USN

Project Summary
Cybersecurity Figure of Merit (CFOM) methodology for tactical cyber assessment extended systems integration test results from FORCEnet and Sea Trial naval and joint forces exercises to address secure next-generation architecture. Adaptive complexity was advanced as the theoretical basis for understanding complex cyber engagements. Cyber events were recreated in laboratory simulations to understand adversary cyber capabilities and effects, and to emulate countermeasures.
Metrics to produce a systems cyber readiness coefficient were advanced, and within context and mission a confidence level for that coefficient. Analysis considered dynamic variables in complex systems, both unintentional such as latent data that leads to inaccurate decisions, and intentional such as control actions by cyber adversaries. Adaptation addressed the capacity for a system or process to automatically respond to dynamic variables—as may be encountered in a cyberattack progression.
CFOM was advanced as a method to address performance and cyber gaps, evaluate cyber adversary impact, and integrate systems to automate ship cyber defense. The methodology can provide quantitative measurement for system functional, performance and cyber readiness assessment.

Keywords: Cyber, cybersecurity, cyberattack, modeling, simulation, measurement

Background
Cyber modeling and analysis were advanced within the context of complexity science, with technical and human phenomena that interface to determine systems readiness and operational effectiveness. Evidence of complexity in naval systems is evident in multi-layered communication architecture; multiple organizational structures to provide mission capabilities; and multiple routes for media and data from sources to users (Maule, 2016).

The methodology advances multi-disciplinary research techniques to assess naval systems readiness for, and effectiveness in, cyber warfare. This includes evaluation of variables we have found to impact data validity in naval and joint forces exercises (Maule, 2013; Maule, 2014).

Complexity theory was advanced as a technique to investigate how subcomponents of a system integrate to produce a collective behavior (Ladyman, 2013; Du, 2014). Analysis was introduced within the technical, operational and environmental conditions required for high-performance communications in cyber-challenged environments. Absent system synchronization the data relied upon for mission decisions may be latent, corrupt, or compromised (Maule, 2011).

Adaptive systems are a subset of complexity science characterized by the capability to change and learn from experience (Forrest, 2016). We measure adaptive behaviors in naval exercises through our instrumentation on ship networks and systems to assess data flows across diverse layers of satellite and terrestrial communications (Maule, 2013; Maule, 2014). Equipment casualties and failovers, and human behaviors that impact cyber infrastructure are additional factors. The components of systems interact, with the result of those interactions dependent on dynamic contextual variables.

While it is possible to establish linear relationships between system variables, these relationships tend to no longer be relevant when the system is integrated into a dynamic architecture—therein requiring probabilistic interpretation (McMullen, 2015). This requires assessment over time within the full range of technical, operational and environmental contexts that a system is expected to operate. An example would be a naval systems-of-systems architecture in a cyber engagement in an Anti-Access/Area Denial (A2AD) environment. The number of dynamic variables in warfare, together with the number of possible technical, operational and environmental contexts to be assessed in an engagement, render deterministic analysis impractical. CFOM advances probabilistic approaches to address complexity, and automated solutions for cyber resolution.

Findings and Conclusions

CFOM methodology integrated best practices from industry and government, extending analysis from cyber experiments conducted in naval exercises from 2000 to 2015. The focus was on cyber infrastructure and security technologies for forward-deployed, tactical forces in A2AD environments. The assumption was that warfighters in future cyber conflicts will be under simultaneous cyber and electronic attack from sophisticated cyber adversaries and without shore reach-back for technical support. The methodology advanced technical and operational means to address platform and warfighter tactical cyber risk through complex systems analysis methodology supported by instrumentation for cybersecurity automation.

Analysis included threat and security models, analytics workflows, cyber measurement techniques, and cyber assessment methodology for tooling, cyber event simulation, and cyberattack emulation. The research methodology was applied in a process for systems cyberattack assessment through quantitative readiness coefficients, and the rendering of confidence levels for those coefficients based on mission technical, operational and environmental contexts.

Recommendations for Further Research

Options for continuation of this research include application of the tools and techniques to specific systems within defined cyber or A2AD contexts. Extension of this research may address organizational variables that we found to impact tactical cyber readiness. New research may advance Artificial Intelligence (AI)-based machine learning and cognitive predictive algorithms for cybersecurity automation.

References
Du, D., and Ko, K. (2014). Theory of Computational Complexity. NY: Wiley.
Forrest, S., and Mitchell, M. (2016). Adaptive Computation: The Multidisciplinary Legacy of John Holland. *Communications of the ACM*, 58-63.
Ladyman, J. Lambert, J., and Wiesner, K. (2013). What is a complex system? *European Journal for Philosophy of Science*, 33–67.
Maule, R. (2016). Complex Quality of Service Lifecycle Assessment Methodology. *IEEE 5th International Conference on Big Data*, San Francisco, CA.
Maule, R., and Lewis, W. (2011). Performance and QoS in Service-Based Systems. *IEEE World Congress on Services Computing*. Washington, DC.
Maule, R. Jensen, J., and Gallup, S. (2013). *Trident Warrior 2012 Analysis Reports.* Monterey, CA: Naval Postgraduate School.
Maule, R. Jensen, J., and Gallup, S. (2014). *Trident Warrior 2013 Analysis Reports.* Monterey, CA: Naval Postgraduate School.
McMullen, T. (2015). It Probably Works. *Communications of the ACM*, 50-54.

NPS-N16-N143-A: Broadband Metamaterial Structure for Shielding Against CDEW

Researcher(s): Dr. Dragoslav Grbovic and Dr. James Luscombe
Student Participation: LT Chester Hewitt USN and LT Edward Wulff USN

Project Summary

This project accomplished building and testing several generations of broadband metamaterials. These are the materials with tailored optical properties, not found in any naturally occurring materials. The goal of this project was to test the viability of designing and building broadband metamaterials that could serve as a shield against microwave directed energy attack.

Keywords: metamaterials (MMs), microwave, directed energy weapon (DEW)s, shielding, counter-directed energy weapons (CDEW)

Background

Continuing advances in directed energy weapons (DEW) by our adversaries put electronic components of Navy combat systems at increased risk. The effects of DEW can cause burnout, upset, jamming and deception. Whatever the mode of attack, electromagnetic energy can reach the target system's internal electronics. Once radiation penetrates into the interior of a target system, several failure regimes are possible. We have shown that narrow-band metamaterials (MMs) with a tunable frequency response in the microwave portion of the spectrum can be fabricated. By "stacking" such structures into a laminate, one could build composite structures with a wideband frequency response [1, 2]. Since the actual frequency spectrum of DEW is often unknown, having broadband MMs is desirable to protect combat systems against a wide range of weapons.

Findings and Conclusions

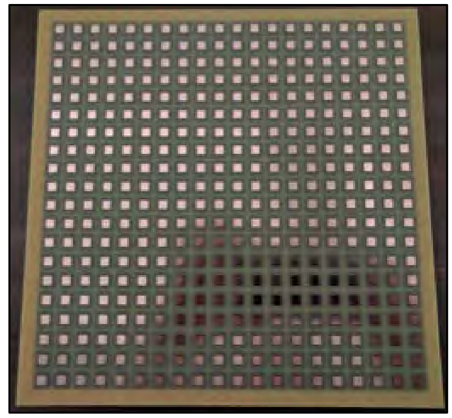


Figure 1. Example of metamaterial produced during the study.

We have successfully produced several generations of rigid and flexible metamaterials. These consist of alternating layers of metal and dielectric with the bottom being a solid metal layer and subsequent metal layers being 2-dimensional arrays of patterned squares (Figure 1). We have also experimentally verified that they observed nearly perfect absorption in certain regions of microwave spectrum (Figure 2). We have also developed and refined the finite element model that could be used to design and optimize such metamaterials in the future (Figures 2 and 3). This study has developed both the method of design and testing of such metamaterials to be used as a shielding. It has tested the hypothesis that using multi-layered, multimaterial metamaterials, we can design and fine-tune optical properties of metamaterials to be broad band and absorbent to a wide range of frequencies.

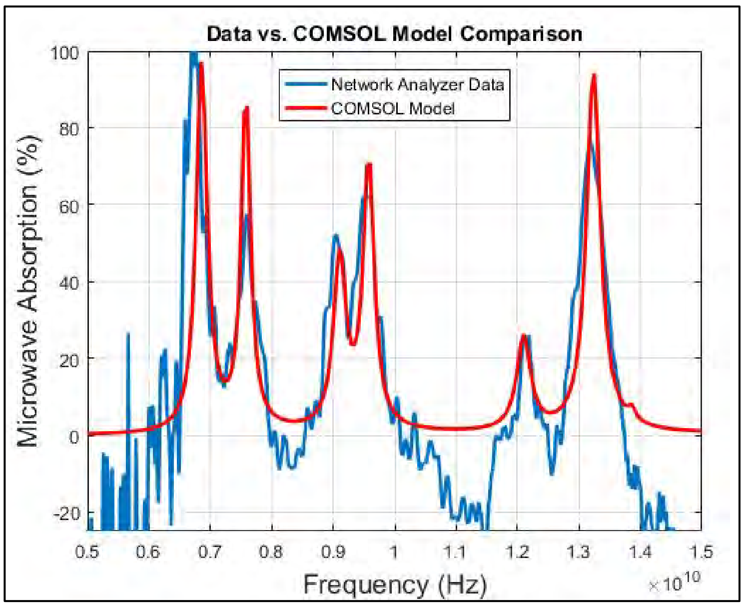


Figure 2. Experimentally obtained absorption spectrum along with the result using our finite element model.

We have used sources and detectors along with spectrum analyzers and network analyzers available at NPS (Figure 3). This has presented certain limitations. In particular, energy levels available to us for testing are limited and these metamaterials are supposed to operate at (protect from) much higher level of microwave radiation. For this, we will have to partner with collaborators at other institutions, such as universities or warfare centers. We have established contacts with researchers both at Johns Hopkins University (JHU) and Naval Surface Warfare Center Dahlgren Division (NSWCDD.

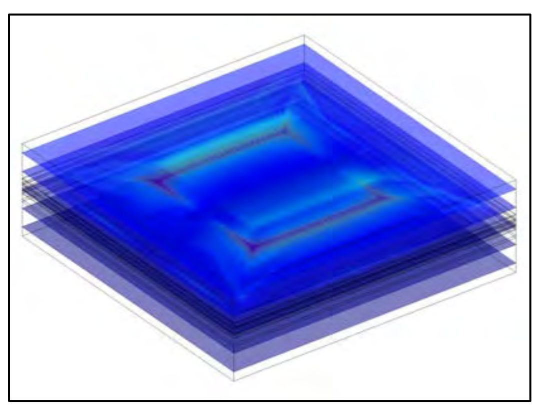


Figure 3. Electric field strength obtained through finite element model.

Another issue, or a shortcoming, of these first-generation metamaterials is that they are completely passive. This means that they may protect against a wider range of weapons but have no capability of detecting or reporting the exact spectral signature of the weapon in question for forensic purposes. We have identified a way, using our finite element model, to capture the spectral signature of these weapons.

Finally, as can be seen in Figure 1, the metamaterials created so far have absorption peaks that are spread apart and our goal would be a more constant high absorption coefficient over a broad range. This can be easily achieved by patterning squares in metal layers in these metamaterials layers to have sizes grow in smaller increments.

Recommendations for Further Research

Exposing our metamaterials to much higher energy levels will provide us with data that will mimic more closely the performance of our metamaterials at much higher energy levels. This data could be used to verify and further refine our finite element models. We hope to have an opportunity to partner with JHU and NSWC Dahlgren to obtain this data.

A new feature that could further enhance a MM used as shielding would be detection spectral signature of incoming radiation. With appropriate sensors, MM structures could capture the spectral signature of incoming radiation, and help identify the type of directed energy weapon involved and potentially identify its source.

References

Li, Xinwang, et al. "Ultra-broadband and polarization-insensitive wide-angle terahertz metamaterial absorber." *Photonics and Nanostructures-Fundamentals and Applications* 15 (2015): 81-88.

Ding, Fei, et al. "Ultra-broadband microwave metamaterial absorber." *Applied Physics Letters* 100.10 (2012): 103506.

NPS-N16-N179-A: Extending the Endurance and Capabilities of the Raven/Puma UAVs Using Advanced Flexible Solar Cells

Researcher(s): Dr. Sherif Michael

Student Participation: CAPT Michael Billings USMC

Project Summary

Uncertainty and chaos are inherent in all combat operations. In an effort to reduce the uncertainty and improve situational awareness of ground forces, Small Unmanned Aerial Systems (SUAS) have been employed to provide real-time video and images of the battlefield. A major limitation of SUAS is the limited flight endurance provided by the air vehicles (AV) battery. In this research, investigation of extending the flight endurance by augmenting the AV power supply with single junction Photovoltaic (PV) cells is conducted. The fully integrated system was experimentally tested to show the feasibility and limitations of augmenting the AV power supply with a PV array. The integrated Raven AV was successful in significantly extending the endurance in spite of non-ideal test conditions and limitation in PV array assembly; the AV endurance was more than doubled producing an increased flight time of 125.6%.

Background

Unmanned systems have become increasingly popular among each of the military services [1]. SUAS allows the rapid and relatively safe employment of Intelligence, Surveillance, and Reconnaissance (ISR) assets to provide information to unit leaders. The need for increased flight duration SUAS is present in a wide range of mission sets. With extended flight endurance, ground forces can reduce the weight of batteries carried. Another added benefit is that we can reduce coverage gaps in surveillance by reducing the amount of battery replacement cycles when monitoring a target set.

Research Process

The goal of this research was to determine the feasibility of integrating low- cost PV cells to augment the internal battery supply of an SUAS in order to increase the flight duration. One of the major contributions to this research was baseline power consumption during typical missions. Using the Raven RQ- 11B, as the testing platform [2] as shown in Figure 1, we were successfully able to determine how the AV is typically controlled and operated during flight.

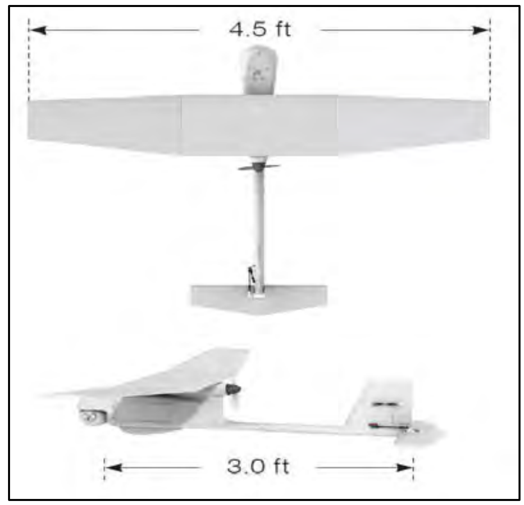


Figure 1. The RQ-11B Raven

With certified Raven operators, we were able to conduct field-testing of performance metrics in environmental conditions that operating forces would experience [3]. By comparing multiple in-flight parameters, we were able to determine the power consumed by the AV to maintain altitude and conduct typical mission sets. Analyzing the throttle percentage and current draw of the motor, as depicted in Figure 2, we were successfully able to determine that the Raven typically consumed an average between 41.3 and 56.6 W of power, with the overall average power consumed by the AV of 51.3 W.

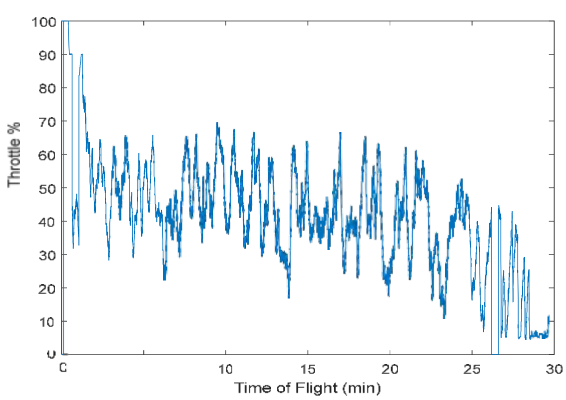
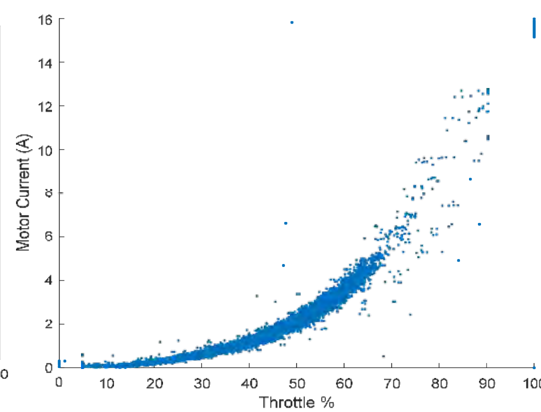


Figure 2. Typical throttle percentage of RQ-11B



Raven Current/Throttle Relationship

Investigation of available solar cells to be utilized on the Raven wing was then conducted. To maximize the photovoltaic power generated by the limited wing area, a different type of solar cells were considered as compared to the cells used in previous research [4]. The PV cells used in this project were the Sunpower Interdigitated Back Contact (IBC) silicon cells [5]. These cells enjoy about 22% conversion efficiency as compared to the 12% cells utilized in the previous research, which will result in a sizable increase in produced power. See Figure 3 for comparison of the two cells.

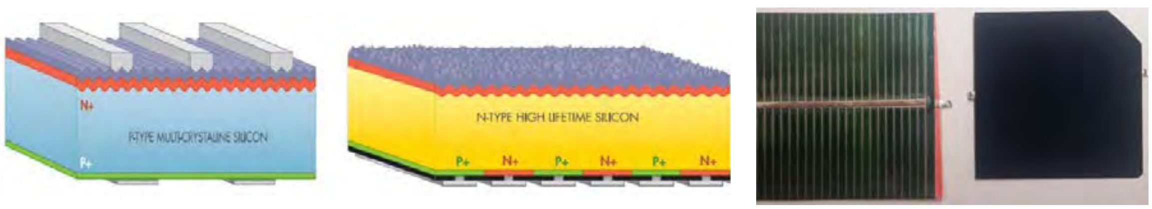


Figure. 3. Conventional Cell Design (left) and IBC Cell (right)

The solar design utilizing IBC PV cells was able to produce 33.7 W of power at its maximum power point as shown in Figure 4a. The solar wing was then integrated with the Raven vehicle through a Maximum Power Tracking circuit (MPT) and a dc/dc converter to further maximize the power output under different sun conditions as demonstrated in Figure 4b. The power supplied from the PV array was transferred to the Raven during simulations to experimentally determine the increased flight duration.

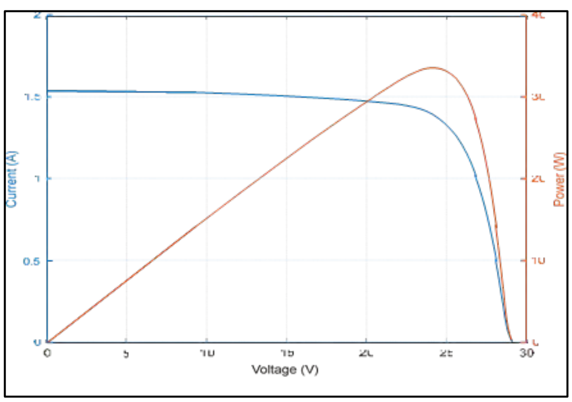


Figure 4a. I-V and Power Curve of PV Array.

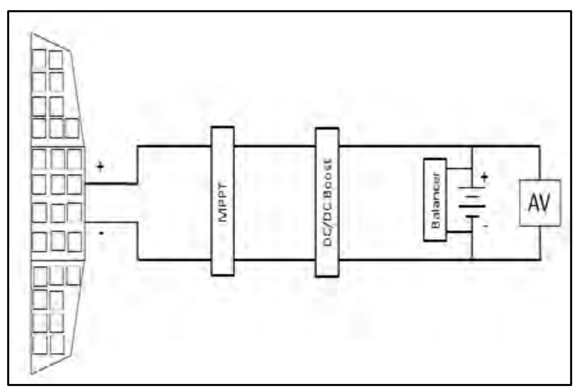
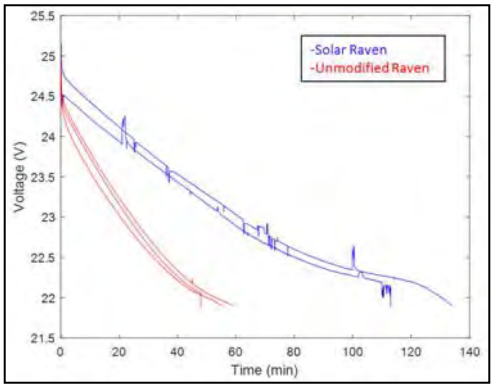


Figure 4b. Solar and Air Vehicle static flight.

Overall, we were able to increase the flight duration by 125.6%, more than doubling the original capability, Figure 5a., successfully proving the feasibility to significantly extend the endurance of the Raven during daytime operations. A photo of the solar Raven designed and tested for this project is shown in Figure 5b.



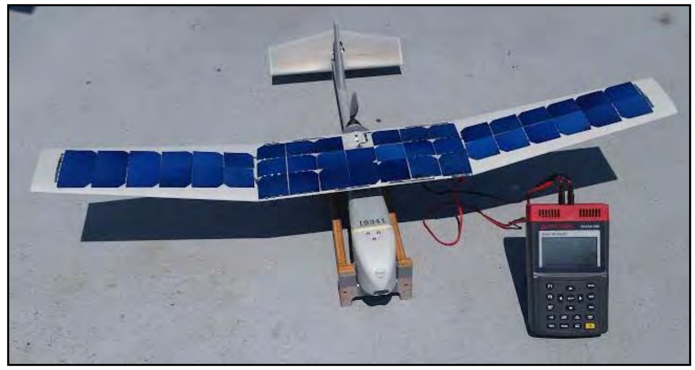


Figure 5a. Extended Endurance Comparison. Figure 5b. Testing of the Solar Raven UAS.

Findings and Conclusions

In conclusion, research objectives were met and the feasibility of augmenting the AV battery supply by integrating IBC PV cells was confirmed. The design showed a significant improvement to the flight endurance under certain atmospheric conditions. The solar powered Raven wing designed and tested in this research was found to experimentally increase the simulated flight time of a conventional Raven UAS by more than two and a half times of a regular mission endurance. The PV array was robust and durable enough to withstand the rigors of flight operations and transportation. Finally, the increased capability was gained with a minimal additional cost incurred.

Recommendations for Further Research:

- Implementation on other group 1 air vehicles: Incorporating the design on other group 1 AVS could provide an increased capability to flight duration. The RQ-20A puma has nearly double the surface area available to place a PV array along the wing. Depending on the power consumption of the RQ-20A puma it is feasible that increased performance can be achieved by augmenting the power supply with solar.
- Utilize multiple MPTS in design: The three-piece raven wing is not planar when assembled, as the wing tips are at a different angel. Only one MPT is used to optimize the power output of the wing was investigated. Additionally, airborne maneuvering of the AV will cause uneven sun distribution on the wing. Incorporating three MPTS, one for each wing section should increase the power output when conducting flight operations.
- Explore battery technologies: Increased flight endurance could also be achieved by replacing the current LI-ION rechargeable battery with a more capable battery. Investigating new battery technologies, one might be able to find a battery that has a higher energy density to replace the current AV battery.

References:

Unmanned Systems Integrated Roadmap FY 2013–2028, DOD, Washington, DC Reference Number 14-S-0553

AeroVironmnet. (2016). Raven RQ-11A/B [Online]. Available: https://www.avinc.com/images/uploads/product_docs/Raven_Datasheet_v1.1.pdf

Raven B Small Unmanned Aircraft System with Digital Data Link Operator's Manual, Rev. B., DOD, Washington, DC, Reference Number60707_A1.,2012.

S. Carey, "Increasing the endurance and payload capacity of unmanned aerial vehicles with thin-film photovoltaics" M.S. thesis, Dept. of ECE, Naval Postgraduate School, Monterey, CA, 2014.

SunPower Datasheet C60 Solar Cell Mono Crystalline Silicon. (2010). SunPower Corp. [Online]. Available: http://eshop.terms.eu/_data/s_3386/files/1379942540-sunpower_c60_bin_ghi.pdf

AeroVironment. (2016). Puma AE RQ-20A [Online]. Available: https://www.avinc.com/images/uploads/product_docs/WaspAE_Datasheet_v1.1.pdf

NPS-N16-N242: Surface Combatant High Energy Laser Weapon Viability

Researcher(s): Dr. Keith Cohn and Dr. Joseph Blau
Student Participation: LT Rene Martin USN, LT Herbert Heaney USN, LT Joseph Collins USN, LT Joshua Valiani USN and ENS Donald Puent USN

Project Summary

Continuing our past research into directed energy (DE) weapons and modeling, we will analyze the performance of a notional 30 kW to 400 kW laser weapon integrated onto a surface combatant. This analysis will model the laser from the source, through a turbulent atmosphere, toward a target at various ranges and altitudes using the laser performance tool Atmospheric NPS Code for High Energy Laser Optical Propagation or ANCHOR (developed by the Physics Department) integrated with the optical turbulence model called Navy Atmospheric Vertical Surface Layer Model or NAVSLaM (developed by the Meteorological Department). This study will focus on validating the turbulence model using experimental and climatological datasets and diffraction codes, investigating the interplay between turbulence and thermal blooming on laser performance, and estimating the potential benefits of atmospheric compensation.

Keywords: directed energy weapons, high energy lasers, atmosphere propagation, surface combatant, turbulence, atmospheric compensation, adaptive optics.

Background

The feasibility of using High Energy Lasers (HELs) in a maritime environment against relevant asymmetric targets has recently been demonstrated aboard the USS Ponce using the 30 kW, fiber-based Laser Weapon System. The Navy has funded HEL research over several decades, including the Free Electron Laser Innovative Naval Prototype (FEL-INP) and the ongoing Solid State Laser Technology Maturation (SSL-TM) project. As all-electric weapons, HELs have deep magazines, and their precise, rapid delivery of energy onto targets makes them advantageous over kinetic weapons in many instances. However, the operational parameters where HELs hold the advantage over their kinetic counterparts are not well defined when considering the physics of delivering lethal energy (both hard and soft kills) to the target. For example, atmospheric considerations (wind, turbulence, scattering, absorption, thermal blooming, etc.) affect how much light from an HEL can be focused onto the target. One prominent concern is the turbulence generated by strong thermal gradients above the deck of a ship, since this turbulence in near the source of the lasers. The overall scope of this project is severalfold: estimate the performance of HELs in realistic weather conditions, focusing especially on quantifying the ambient environmental turbulence as well as turbulence near the ship; incorporate additional improvements into ANCHOR; and evaluate the benefits of atmospheric compensation. The results of this study will aid our sponsor, Assistant Secretary of the Navy for Research, Development and Acquisition (ASN(RDA)), in evaluating the relative merits of atmospheric compensation, especially considering the additional substantial cost and system complexity required by such compensation.

Findings and Conclusions

This study is comprised of several projects. We will discuss the progress of each one separately.

Project 1: Characterize Turbulence Profiles for Potential Theaters (In Progress)

Turbulence in potential theaters was estimated using climatological data from the Climate Forecast System Re-analysis database and NAVSLaM (a turbulence model developed at NPS). This information, which is critical for estimating HEL performance, was generated over a wide geographical area for different times of the day, seasons, and altitudes above the water. An example of such output is provided in Figure 1. Furthermore, percentile plots were produced that characterize mean turbulence values and likely spreads in those values over the course of the day and year.

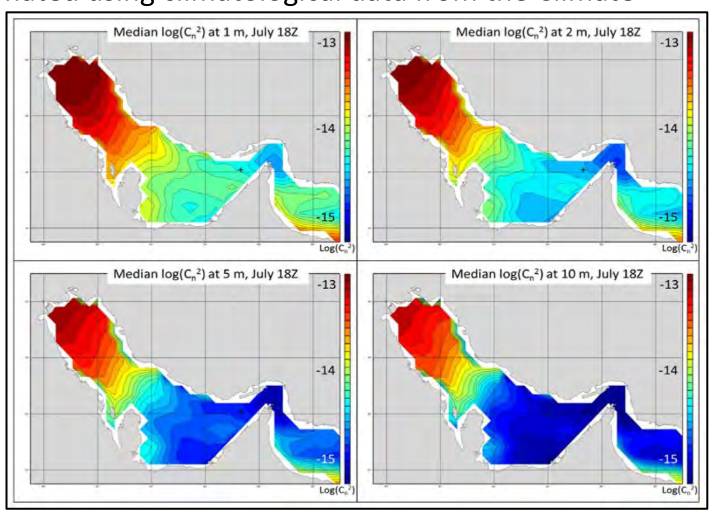


Figure 1: Turbulence profiles at different altitudes above the water's surface

Additionally, we have measured turbulence profiles aboard the Self-Defense Test Ship (SDTS), where the Navy's Laser Weapon System Demonstrator (LWSD) will be installed in 2018. The analysis of this data is ongoing with an anticipated completion date by the summer of FY2017.

Project 2: Implement New Thermal Blooming Model into ANCHOR (Completed)

ANCHOR is a high-performance laser performance scaling code developed at NPS. The interplay between turbulence, thermal blooming, and platform/target geometry is a difficult effect to predict. We used a self-consistent diffraction code to iterate over many thousands of atmospheric conditions and laser/target configurations. We then fit simple analytical models to these thermal blooming results to capture the overall correlation within this parameter space between all of the variables. Finally, we incorporated these models into ANCHOR.

Project 3: Evaluate Laser Performance Using ANCHOR (In Progress) Using the climatological studies from Task 1, we have evaluated HEL performance in potential operational theaters for a wide variety of likely weather conditions and laser configurations. Additionally, we will use the turbulence data collected aboard the SDTS to estimate the impact of ship-induced turbulence on performance of the LSWD. The estimated completion date for this task is by the summer of FY2017.

Project 4: Incorporate Atmospheric Compensation into ANCHOR (In Progress)
Atmospheric compensation techniques may be implemented to mitigate the harmful the effects of turbulence on laser propagation. However, these techniques are expensive and may be difficult to field. Therefore, it is imported to establish (1) whether atmospheric compensation will be necessary for realistic engagement scenarios, and (2) to what extent will it improve performance. We will use the modeling and measurements from project 1 as a basis for establishing realistic turbulence profiles, and then proceed to study the impact of atmospheric compensation. Anticipated completion of this part is by the end of FY2017.

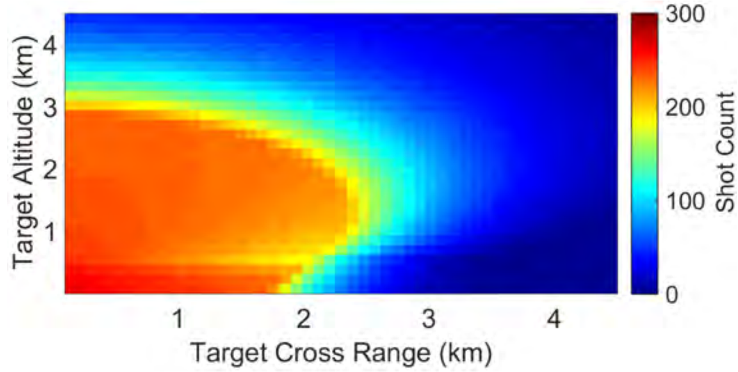


Figure 2: Number of shots available from a notional 500 kW laser with a lithium ion battery energy storage device. The laser platform is located at the origin of the plot, and the color represent the number target kills before the battery requires recharging.

Student Thesis Involvement

LT Joseph Collins, USN, Applied Physics (June 2016), “An improved thermal blooming model for the laser performance code ANCHOR.”

LT Joshua Valiani, USN, Applied Physics (June 2016), “Power and energy storage requirements for ship integration of solid-state lasers on naval platforms.”

LT Herbert Heaney, USN, Applied Physics (June 2017), “Investigation of ship-induced turbulence effects for the laser weapons system demonstrator,” (in progress).

LT Rene Martin, USN, Applied Physics (June 2017), “High energy laser performance based on ship-induced turbulence effects,” (in progress).

ENS Donald Puent, USN, Applied Physics (June 2017), “Integration of adaptive optics into high energy laser modeling and simulation,” (in progress).

Recommendations for Further Research

This research can be expanded to include results from full diffraction codes to augment the results from ANCHOR. Furthermore, the measurements conducted aboard the SDTS were constrained by time and expense to a period of only two days. Due to the direct relevance of this information to the LWSD program, we strongly recommended further investigation of this topic, including measurements at different times of the year, different locations on the ship, and on different platforms.

NPS-N16-N282-B: Cybersecurity Framework for Ship Industrial Control Systems

Researcher(s): Dr. R. William Maule
Student Participation: LCDR Joseph Hake USN

Project Summary

Ship mechanical and electrical control systems, and the communications grid through which these devices operate, are a high priority concern for Navy leadership. Ship systems use microprocessor-based controls to interface with physical objects, and Programmable Logic Controllers (PLCs) to automate ship electromechanical processes. Ship operations are completely dependent on these devices. The commercial security products upon which ships depend do not work on Industrial Control Systems (ICS), leaving ships vulnerable.

The ICS research framework advanced in this project provide metrics for ship ICS cyber-physical infrastructure evaluation, and analytic techniques based on industry best practices. Component test and measurement workflows were developed to apply test procedures and metrics to ship industrial controls. Ship ICS audit processes and decision support workflows will help watchstanders address and counter cyber-physical infrastructure vulnerabilities.

Keywords: Cybersecurity, cyber-physical infrastructure, industrial control systems, supervisory control and data acquisition, programmable logic controllers

Background

Modern warship designs have evolved toward distributed, network-enabled automation architecture to improve operational awareness for Hull, Mechanical and Electrical (HM&E) systems. Automation enhances battlespace awareness and mission-readiness, and supports systems designed for reliability under random failure (e.g., link outages) or correlated failure under duress (e.g., fire, physical damage). HM&E and Machinery Control Systems (MCS) engineering has not prioritized cybersecurity, leaving ships in a vulnerable cyber posture.

Some work has been devoted to clean-slate design approaches for control systems (Velagapalli, 2011; Hieb, 2009; Chavez, 2009) but to date these and similar efforts have not been implemented in a manner sufficient to address Navy security needs. Nor does this approach address the large installed base of legacy control systems (Lindqvist, 1998; Federal Times, 2014) which may be subject to compromise during original equipment manufacturing, systems integration, daily operations or maintenance (Collado, 2016; DuHarte, 2016).

There are over 250 industrial control technologies, with most using protocols not detected by legacy ship cybersecurity. These devices and their controls are the target of cyberattacks since security is minimal and they provide access to infrastructure (Sands, 2016). These devices control ship mechanical, electrical and power systems—which are additionally subject to component-specific attacks against embedded devices, such as electrical relays or gates (Bruggermann, 2016). Vulnerabilities exist in end-point devices such as sensor interfaces, analog to digital conversion gates, and motor controls and actuators (Grow, 2008).

Programmable Logic Controllers (PLCs) are embedded within MCS to automate processes. Supervisory Control and Data Acquisition (SCADA) controls supervise the PLCs. Both can be exploited by adversaries seeking to disrupt electrical or mechanical operations, or control cyber-physical infrastructure (Koscher, 2015). Fault handlers neither protect systems whose control logic has been compromised, nor protect against attacks where damage is caused in aggregate—not detected from the perspective of any single system. Ship Electric Management Systems (EMS), Distribution Control Systems (DCS), and Process Control Systems (PCS) are impacted (Duggan, 2005). Cyber intrusion of mission critical controls may impact command decisions (Maule, 2015).

Findings and Conclusions

This report developed research frameworks, metrics and workflows for the analysis of ship ICS infrastructure to help assess the degree to which ship cyber-physical systems can be protected from cyberattacks and external control. This included a discussion of methods through which adversaries can enter cyber-physical infrastructure through conventional cyberattacks, and conversely compromise ship systems and networks through ICS devices and controls.

Discussion of ICS cyberattack methods that may impact ship cyber-physical infrastructure were integrated with analysis metrics, supporting audit processes and decision workflows. Research frameworks to assess ICS infrastructure included a discussion of ICS devices, their protocols and metrics, and interfaces to legacy information technology (IT)/network security systems.

In addition to traditional IT and network cybersecurity, successful ICS defense requires familiarity with the specialized equipment that will be attacked, and with the cybersecurity tooling required to assess that equipment. This includes proprietary integrated circuits and firmware. The auditor needs to be versed in traditional IT/network cybersecurity and tooling, and in the engineering specializations required for assessment of the specialized ICS components. The learning curve and tooling requirements are significant.

Recommendations for Further Research

Future research may apply the ICS research frameworks, audit processes and decision workflows for ship ICS cyber assessment and defense. ICS cybersecurity audits require up-to-date reference databases to adequately protect ICS infrastructure. Future research may develop databases which contain component specifications, ship architecture models, control and device measurement results, and vulnerability maps for ship ICS configurations.

In a prolonged cyber conflict ship watchstanders may be overwhelmed with ICS problems, and in Anti-Access/Area Denial (A2AD) and Disrupted, Disconnected, Intermittent and Limited bandwidth (D-DIL) conditions without reach-back for technical support. Future research may develop architecture for ICS cybersecurity automation to help protect ship cyber-physical infrastructure. New advances in artificial intelligence, cognitive computing, and machine learning provide viable options for ship ICS cybersecurity automation.

References

Bruggermann, M., Schwartke, H., and Spenneberg, R. (2016). PLC-Blaster: A Worm Living in your PLC," *BlackHat USA 2016*, Las Vegas, NV: Blackhat.

Chavez, A. (2009). Protecting Process Control Systems Against Lifecycle Attacks Using Trust Anchors. *DHS Workshop on Future Directions in Cyber-Physical Systems Security,* Washington, DC: Department of Homeland Security.

Collado, E. (2016). Reversing and Exploiting Embedded Devices. *DEFCON 24.* Las Vegas, NV: DEFCON.

Duggan, D. (2005). *Penetration Testing of Industrial Control Systems.* Albuquerque, NM: Sandia National Laboratories.

DuHarte, M. (2016). Basic Firmware Extraction. *DEFCON 24.* Las Vegas, NV: DEFCON.

Federal Times. (2014, January 29). How COTS Endangers National Security. *Federal Times*.

Grow, B., Tschang, C., Edwards, C., and Burnsed, B. (2008, October 1). Dangerous Fakes: How Counterfeit, Defective Computer Components from China are getting into U.S. Warplanes and Ships. *Business Week*.

Hieb, J., and Graham, J. (2009). Designing Security-Hardened Microkernels for Field Devices. *Critical Infrastructure Protection II* (pp. 129–140). NY: Springer.

Koscher, K. (2015). Sniffing SCADA. *DEFCON 23.* Las Vegas, NV: DEFCON.

Lindqvist, U., and Jonsson, E. (1998). A Map of Security Risk Associated with Using COTS. *IEEE Computer, Vol. 31, No. 6*, 60-66.

Maule, R., Goldberg, J., Baker, B., McElvain, L., and Sinopoli, J. (2015). Integrated Air and Missile Defense (IAMD) Multi-Tactical Data Link (M-TDL) Network (MTN). *Valiant Shield 2014 Analysis Report*, Norfolk, VA: Navy Warfare Development Command.

Sands, F., and Gorenc, B. (2016). Hacker-Machine Interface. *DEFCON 24.* Las Vegas, NV: DEFCON.

Velagapalli, A., and Ramkumar, M. (2011). Minimizing the TCB for Securing SCADA Systems. *Seventh Annual Workshop on Cyber Security and Information Intelligence Research.* Oakridge, TN: Oakridge National Laboratory.

NPS-N16-N460-A: Agile, Hovering AUVs for Naval Special Warfare Operations

Researcher(s): Dr. Douglas Horner
Student Participation: LT Ian Taylor USN

Project Summary

Historically, maritime Autonomous Underwater Vehicle (AUV) development has focused on long-range, open-ocean applications. However, a large number of applications, particularly for Naval Special Warfare (NSW) missions, require operation close to objects (e.g., the seafloor, ships, submarines, submerged structures, other AUVs, and even divers). This study investigated the use of agile, hover-capable AUVs during NSW operations. Ongoing research at the Naval Postgraduate School (NPS) is focused on developing an agile, hover-capable AUV that is suitable for operations in close proximity to any or all of the above (close quarters operations). Continued research is required in precise platform control and dynamic stabilization, precision terrain-relative navigation, 3D mapping and obstacle avoidance, joint diver-robot operations with autonomous and semi-autonomous modes of operation, and autonomous intervention. Building on ongoing efforts, this effort will specifically investigate the use of an AUV in support of NSW missions. Through this program, students will have the opportunity to research the challenges associated with proximal AUV operations, including control, terrain-relative navigation, 3D mapping and obstacle avoidance, and intervention.

Background

A variety of naval commands would benefit from precise AUV control and navigation in cluttered dynamic undersea environment. It requires a leap in current AUV/ROV (remotely operated vehicle) autonomy technology that includes improvements in hydrodynamic modeling, adaptive control and exteroceptive sensor feedback.

An accurate hydrodynamic model can help in the development of precise AUV control and navigation in two ways. First, it can be used for conducting simulation. This can determine initial performance without taking the AUV out to sea. Second, the dynamic model can be used to improve controller performance. Past research emphasized hydro-dynamical modeling of the REMUS 100 vehicle but it didn’t consider cross tunnel thrusters and assumed a fixed velocity.

One mission area that requires variable speed consideration is autonomous underwater docking. It is an important capability for AUVs. It permits the vehicles to recharge its battery and communicate mission results and receive additional new tasking. Previous approaches assume a fixed speed into the docking station. This can damage the AUV and docking station. The fixed velocity during terminal homing was required since the control fin requires flow over the surfaces to maneuver the AUV. An AUV with cross tunnel thrusters can hover in front of the docking station and potentially provide a more robust, safer solution.

Findings and Conclusions

A successful, three-degree of freedom (3DOF), variable speed, hydrodynamic model was created for the NPS REMUS 100 cross tunnel thruster AUV. The model was validated against actual NPS REMUS 100 operations conducted in Monterey Bay, CA. When a variable depth standard mission was compared with the model, the mean error was -12.8 cm with a standard deviation of 34.4 cm. A second test confirmed the performance of the REMUS cross tunnel thrusters. It again compared the REMUS real world mission versus the model behavior. Again the results were very good. The mean error was 8.8 cm with a standard deviation of 43.4 cm.

In summary, the 3DOF model provided an accurate variable speed model of the REMUS AUV with cross tunnel thrusters in the X and Z planes. The assumptions made in this model did not impact its fidelity dramatically and allows for a simulated prediction of the REMUS vehicle’s behavior in the field. With the development of the 3DOF model, a better understanding of the capabilities of a REMUS vehicle with cross-tunnel thrusters has been accomplished. The 3DOF model can simulate a REMUS vehicle's cross-tunnel thruster and variable speed behavior during docking missions, mimic the vehicle's depth control, and revolutions per minute (RPM) capabilities, and can be consulted when designing future REMUS docking stations.

Recommendations for Further Research

The following goals can be pursued in future work:

1) Calculation and verification of the minor coefficients used in the 3DOF model.
2) Expansion of the 3DOF model to a 6DOF model.
3) Create a 3DOF model that can accept environmental inputs such as wave action and currents.
4) Create a virtual simulation to display the REMUS vehicle's behavior.
5) Design a better proportional–integral–derivative (PID) controller to minimize the REMUS vehicle's behavioral errors during the initialization period of the model.
6) Integration of the 3DOF model into the REMUS vehicle's secondary controller.
7) Implementation of a neural network to learn and predict the REMUS vehicle's behavior.

References

Bermudez. (2016). Terminal homing for autonomous underwater vehicle. Naval Postgraduate School, Mechanical and Aerospace Engineering. Monterey: NPGS.

Healey, D. B. (2001). Command, control, and navigation experimental results with the nps aries auv. IEEE Journal of Oceanic Engineering, 26 (4), 10.

Prestero, T. (2001). Verification of a six-degree of freedom simulation model for the REMUS autonomous underwater vehicle. Massachusetts Institute of Technology, Mechanical Engineering. Boston: MIT.

Sgarioto, D. E. (2007). Control system design and development for the remus autonomous underwater vehicle. Australia Defense Technology Agency. Sydney: DTA.

NPS-N16-N475-A: Multiphase Combustion and Lethality Model for High Density Reactive Materials

Researcher(s): Dr. Joseph P. Hooper
Student Participation: LCDR Tabitha Booth-Seay USN and LT Tina Pryne USN

Project Summary

We develop an analytic model for the multiphase combustion of a reactive material debris cloud inside an enclosed target. Starting metal, product oxides, and gases are tracked explicitly but mass and energy equations are solved by homogenizing the mixture into a single fluid. A single Arrhenius term is used to describe the combustion process. Model calculations for an aluminum dust cloud show good agreement with pressure rise times, but over predict peak overpressures inside the target. Though it lacks the complexity of full flow simulations, this fast calculation could be used to quickly analyze experimental pig data and use it to fit an improved combustion rate term. Comparison with much smaller targets relative to the reactive fragments

Background

The Navy's High-Density Reactive Material (HDRM) program is currently focused on developing and transitioning metal-based composites that provide enhanced lethality to traditional warheads. Metals such as aluminum and zirconium have extremely high enthalpies of combustion, and on a volumetric basis contain nearly one order of magnitude more energy when burned than high-performance explosives. However, they tend to release this energy slowly via deflagration, as compared to the supersonic nature of an organic high explosive's detonation. However, there are a number of critical DOD applications where large energy release over a slower timeframe is more desirable than maximizing primarily blast damage or fragment velocity. Reactive materials (RMs) being developed under the HDRM program are designed to enhance this form of lethality. References cover much of the (sparse) open literature on these materials, but the majority of work most relevant to the Navy (including past NPS theses in this area) has remained FOUO and is not openly citable.

The Navy currently has a semi-standardized test to measure the overpressure of a reactive fragment. Colloquially referred to as the "pig test," this involves a sabot launch of a reactive fragment through a standard aluminum or steel plate and into a closed pressure vessel (the "pig"). The fragments strike a thick mild steel anvil and combust. The situation inside the pig is quite complex, with many shock reflections, a traveling deflagration wave from the burning metal, and turbulent flow effects which affect the mixing of the burning metals with their oxidizer (the air). A few groups have been working on full numerical simulations of these tests using continuum level simulations, but these frequently require significant empirical parameterization for the fragment cloud and the burning process. Our goal in this NRP program was to develop a simple analytic model that can predict the slow pressure due to overall combustion inside the chamber.

Findings and Conclusions

In the course of this program we developed a multiphase combustion model for the processes inside the pig following impact of a reactive fragment. A schematic of the model is given in Figure 1. The system is reduced to a single dimension, taken to be out from the point of impact (the pig anvil) and zero-flux boundary conditions are imposed on both sides. The species Al, N_2, Al_2O_3, and O_2 are tracked explicitly in this model. The multiphase nature of the mixture is handled by taking an average of the local density, velocity, temperature, etc. to create a homogenized fluid. The pressure is assumed to be constant throughout the pig (a low Mach number assumption), but its scalar value will change as the material combusts. Differential equations for continuity, energy, and species diffusion/evolution are solved numerically via a MATLAB script. The most challenging element is

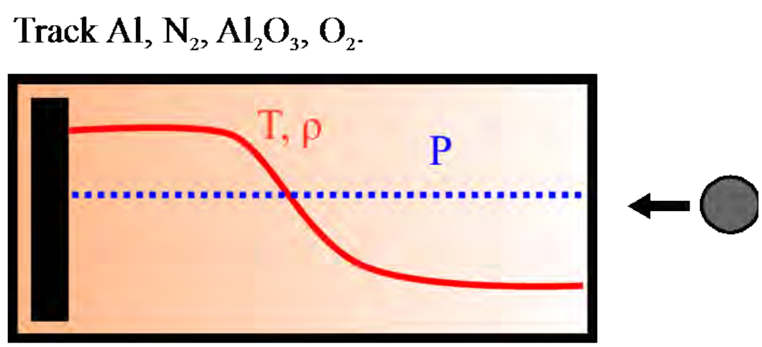
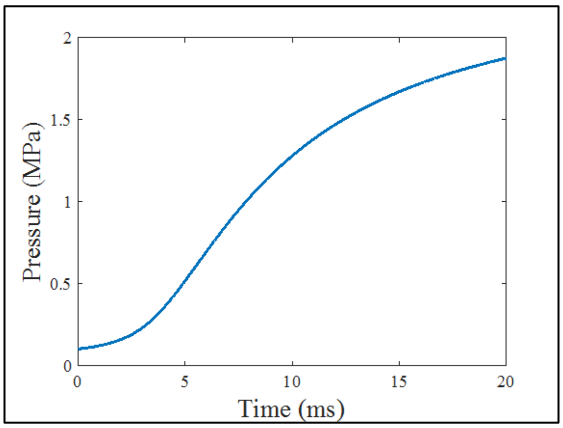


Figure 1: Schematic of the developed model.

a reaction rate model for the reactive material (during this project we consider only basic aluminum). We assume a single global Arrhenius rate describes the transformation to oxidized products, with parameters taken from Bind and Co.[4]

Example model output is shown in Figure 2 for the overpressure inside a 20 L spherical pig. While this is a slightly different configuration than that used for RM testing, there is accurate data for aluminum dust explosions from Ogle and Co. that we can use to validate the approach.[5] While we accurately predicted the sigmoidal rise to pressure and the overall timescale, we over predicted the peak pressure in the chamber. The model is very sensitive to the Arrhenius parameters, and in the future we plan specific experiments to fit a pig-specific rate model to be used in our general framework. Overall however, our results indicate that a simple, nearly analytic multiphase model with a single global rate can provide a reasonable estimate of the peak pressure inside a target that has been struck by a reactive fragment.



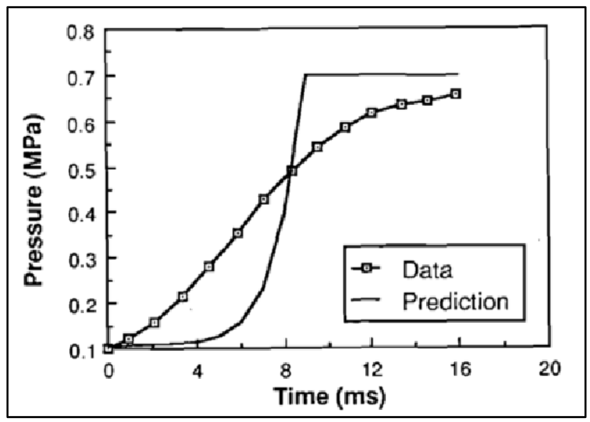


Figure 2: Predicted overpressure from the model (left frame) versus previous experimental overpressure data from Ogle et al.

Recommendations for Further Research

One of the key assumptions our model makes is that the pressure is nearly constant inside the target. For the full-scale Navy pig shots, we know that is generally not the case. Recommended future work would be study of small enclosed targets struck by explosively-launched RM fragments. We can use this data to fit a combustion rate model specific to the Navy materials in an environment that better matches our assumptions.

References

Ames. R, Mater. Res. Soc. Pro., 896, 78-83, (2006).

Ames. R and Waggener. S, Proc., 32nd International Pyrotechnics Seminar, 180-1-180-9, (2005).

Ferranti. L and Thadhani. N, Metal. Mat. Trans. A, 38 [11], 2697-2715, (2007).

V. K. Bind, S. Roy, and C. Rajagopal. Can. J. Chem. Eng. 89, 663-670 (2011).

R. A. Ogle et al. Com. Sci. Tech. 61, 75-99 (1988).

NPS-N16-N483-A: Operational Impacts on ASW by South China Sea Sand Dunes

Researcher(s): Dr. Ben Reeder
Student Participation: Students in Tactical Oceanography Course (OC4270) winter and summer of 2016. LT Michael Beall USN, LCDR Guy Carlsward USN, Maj Liam Doyle USAF, LT Geoffry Eberle USN, LCDR Stephen Fleet USN, LTJG Suleyman Gurbuz TNF, LCDR Ho-Chun Huang ROCN, LCDR Richard Ilczuk USN, LTJG Murat Kucukosmanoglu TNF, LT Zachary Lukens USN, LCDR Colleen McDonald USN, LCDR Matthew O'Brian USN, LT David Price USN, LT Albert Yudono TNI–AL, LT Kristine Bench USN, LCDR Brian Breshears USN, LCDR Alexander Cullen USN, LT Henry Flores USN, LCDR Jeremy Hankins USN, LCDR Jennifer McNitt USN, LT Guy Molina USN, LT Zachary Moody USN, LT Mitchell Nelson USN, LT Jonathan Park USN, LT Richard Rainer USN, LT DyAnna Rodriguez USN, LCDR Cassandra Sisti USN, LCDR Kevin Solem USN and LT Aaron Willmarth USN

Project Summary

Very large subaqueous sand dunes were discovered on the upper continental slope of the northern South China Sea (SCS) in the spring of 2007 in water depths of 160 m to 600 m. While subaqueous dunes are found in many locations throughout the world's oceans and coastal zones, these particular dunes appear to be unique for two principal reasons: their location on the upper continental slope and their distinctive formation mechanism (approximately 30 episodic, extremely energetic, large amplitude, high frequency, trans-basin non-linear internal wave (NLIW) events each lunar cycle). These NLIWs and sand dunes are important acoustical features, as they will cause operationally significant anomalies in the acoustical field, which will impact the performance of both active and passive sonar systems. The acoustical impact is a function of frequency, source/receiver depth, NLIW and sand dune amplitude, and source-receiver azimuth relative to the wave fronts and dune crests. At propagation angles nearly parallel to the NLIWs, short time scale transmission loss anomalies are as high as 10 dB; at propagation angles perpendicular to the sand dune crests, short time scale transmission loss anomalies are as high as 8 dB. These anomalies are significant enough to impact sonar system performance, and knowledge of these NLIWs and dunes inform Anti-Submarine Warfare (ASW) asset placement and performance assessment.

Keywords: South China Sea, acoustic propagation, internal waves, sand dunes

Background

Research into the acoustic propagation characteristics of the South China Sea began with the Asian Seas International Acoustics Experiment (ASIAEX) in 2001, funded primarily by Taiwan's National Science Council and the U.S. Office of Naval Research, and originally focused on the shelf/slope front in the northeastern SCS. During the field experiment, what are now known to be the world's largest observed high frequency nonlinear internal waves (NLIW) were discovered (Ramp & Tang, 2001). Since ASIAEX, a number of other research programs followed, including WISE/VANS, NLIWI/SCOPE , QPE, IWISE, and ITOP. The current sand dunes effort is focused on the same area as ASIAEX, with the scientific goals of ascertaining the acoustical impacts of the combined effects of the large NLIWs and sand dunes (the existence of which were unknown during ASIAEX). The NLIWs have been observed to scatter acoustic energy from a deep source below the thermocline to depths throughout the water column, due to its large perturbation of the depth-dependent sound speed field (Chiu et al., 2004). The ambient noise field in the deep basin has been correlated to the seasonal variation of the SCS environment over a period of one year (Chiu et al., 2012). Trains of high-frequency elevation waves are produced on the continental shelf by the shoaling trans-basin NLIWs; these elevation waves draw relatively cooler water up from the seabed and create acoustics ducts, which generate 10 dB anomalies in the acoustic field along propagation paths nearly parallel to the wave fronts (Duda et al., 2011).

Findings and Conclusions

This effort is focused on the data collected during the most recent field experiment over the sand dune field in 2014. Four environmental moorings and six acoustic moorings were deployed in the sand dune field. The instruments on the environmental moorings monitored temperature, salinity, pressure and current velocity; the instruments on the acoustic moorings monitored all of these parameters in addition to the acoustic signals. From this very large dataset, the present effort focused on a four-hour period during which an acoustic source, lowered from the ship to a nominal depth of 250 m, transmitted 100 sec. long linear frequency modulated (LFM) signals between 700 and 1200 Hz. The signals were observed by three hydrophones at depths of 117, 199 and 281 m on an acoustic mooring at a range of 3.2 km from the source. During this four-hour period, three large trans-basin NLIWs passed between source and receiver, causing fluctuations in the acoustic field. These time-dependent fluctuations resulted from the NLIW-induced acoustic sound speed field perturbations in the water column and the NLIW-induced variation in bottom interaction of the signals. Through data analysis and associated acoustic propagation modeling of these broadband signals, the broadband transmission loss anomalies between 850 and 1150 Hz were observed and modeled to be as high as 8 dB. The variance was depth dependent, with the mid-water phone experiencing the greatest overall variance and the phone closest to the thermocline observing the largest short time scale fluctuations. These results confirm the expected impact of the NLIWs and sand dunes on acoustic propagation at low-to-mid-frequencies. These fluctuations in the acoustic field drive down acoustic field coherence, which negatively impacts a sonar system’s ability to detect and track a contact. Based upon their operational experience, students in the Tactical Oceanography course (OC4270) contributed to the conclusion that sonar assets should be placed at depths and orientations relative to the contact which minimize variance in the signal.

Recommendations for Further Research

The present study is limited to a single geometry; the larger dataset addresses other geometries and frequencies. Future research should include further data collection at greater source/receiver ranges, a variety of source depths and at lower frequencies; these future efforts would contribute to a more complete understanding of the acoustical impacts of the NLIWs and sand dunes.

References

Chiu, C-S, S.R. Ramp, C.W. Miller, J.F. Lynch, T.F. Duda and T.Y. Tang (2004). "Acoustic intensity fluctuations induced by South China Sea internal tides and solitons," IEEE J. Oc. Eng., v29(4), 1249-1263.

Chiu, C-S, C.W. Miller and J.E. Joseph (2012). "Low-frequency ambient noise characteristics and budget in the South China Sea basin", J. Ac. Soc. Am., 132, 2057.

Duda, T.F., Y.T. Lin and D.B. Reeder (2011). "Observationally constrained modeling of sound in curved ocean internal waves: Examination of deep ducting and surface ducting at short range", J. Ac. Soc. Am., 130(3), 1173-1187.

Ramp, S.R., and T.Y. Tang. 2011. A history of Taiwan/US oceanographic research in the South China Sea. Oceanography, 24(4), 16–23.

NPS-N16-N515-A: Shipboard Deployable Expendable Environmental Sensing System

Researcher(s): Dr. Qing Wang and Mr. Ryan Yamaguchi

Student Participation: LT Andrew Sweeney USN

Project Summary

This project intends to design and test an environment sensing system deployable from the shipboard in response to the Navy's need of obtaining in situ data for operation and research applications related to Electromagnetic (EM) and Electro-optical (EO) propagation in the atmosphere. The objectives of the sensing system development are: 1) low-cost and eventually expendable that is suitable for operational application; 2) easy deployment and non-interfering with other deck operations; and 3) measurements in the vicinity of the ship in uncontaminated air/water and real time data transmission. The first year's work included research on various available sensor components, basic design of the system, assembly of the system, float test at the dock, and at-sea testing and preliminary data analyses. We have developed a prototype of the buoy system and made at-sea testing. The system includes a sensor package, a floating platform, and a data acquisition and transmission package. All sensors and communication units are affixed to a small float to keep them from salt water damage/contamination. Initial data analyses also provided a good understanding of the measurement data quality of the buoy system.

Keywords: METOC Sensing; Battle Space Characterization; EMMW; Air-Sea Interaction; Meteorology; EM/EO

Background

The lowest 100 m of the atmospheric layer, termed as the marine atmospheric surface layer (MASL), exhibits significant vertical gradients in temperature and humidity (Fairall *et al.* 1996, Edson *et al.* 2004). These gradients result in corresponding gradient in the atmospheric index of refraction, which often lead to the bending of the radar and communication links toward the

Earth's surface and the subsequent trapping of the electromagnetic wave (EM) energy within a thin layer of a few to 30 meters above the surface (Babin et al. 1997). This thin trapping layer is called the Evaporative Duct (ED). The depth and strength of this duct have significant impact on the EM propagation in the atmosphere and cause adverse consequence if their characteristics are not adequately characterized (Paulus 1985). Unfortunately, the mesoscale forecasts, targeting on prediction of weather, are incapable of producing adequate forecasts for ED due to the coarse grid resolution and inherent deficiencies in physics models. The assessment of the ED properties around the battle space environment is generally achieved through a MASL model that requires input of the basic air/ocean parameters such as wind, air temperature, water vapor specific humidity, sea surface temperature, and pressure. However, these basic parameters around the ship environment are not available. With the termination of the Navy's upper-air radiosonde measurement program, there is essentially no in situ data in the theatre region to help validate forecast models or for EM prediction purposes. The most ideal platform for this purpose is measurements from a small buoy that introduces minimum flow distortion to the immediate environment.

Findings and Conclusions

The general approach to develop the Sea and Air Expandable (SNAX) buoy system is to utilize existing sensor packages on the commercial-off-the-shelf (COTS) market and perform system integration and testing. Major considerations during the development of the SNAX are described below.

1. **Sensor identification and testing and sensor integration**

The sensor package we initially evaluated and integrated was based on commercial rawinsonde packages, such as the iMet-1-RS. This package is designed for integration with other sensors, allowing us to integrate sensors such as a cup anemometer and a water thermometer to allow sampling of wind speed and sea surface temperature in addition to temperature, humidity, and pressure. The choice of wind finding mechanism required some research. A cup anemometer is one of the choices along with other choices such, as a 2-D sonic anemometer that can be potentially used without moving parts. To test their accuracy, both potential sensors were integrated to the prototype of the SNAX that was tested at sea. The final choice of sensors will be based on their measurement accuracy and precision, power consumption, physical size, as well as their compatibility with other sensors and the data acquisition system.

2. **Floating system design and fabrication**

The floating system required extensive water tank and dock side testing in various stages. We used a spar buoy float with minimum above-the-water component to minimize platform induced disturbance to the air and to the water. The material and the geometry of the float were determined during the development of the SNAX.

The under-water section of the floating system required careful design to be water tight if additional batteries are needed for extended deployment, in which case the compartment below the water can serve as a balancing weight and a container for additional batteries.

3. **Communication protocol design and integration**
Two data transmission links were considered for SNAX, the existing 400 MHz very high frequency (VHF) transmitter that the radiosonde uses or Iridium SBD (Short Burst Data) service via Defense Information Systems Agency (DISA) EMSS (Enhanced Mobile Satellite Services). Both transmission links afford certain advantages and disadvantages. The 400-406 MHz band is allocated for meteorological use and SNAX would appropriately utilize this band for surface met measurements. It was however not selected due to various reasons such as the requirement of a new receiving systems and the need of data encryption methods, and the need of line-of-sight data transmission. The other communication link that was considered and ultimately chosen was Iridium SBD service. The Iridium provides a well-documented ICD [model] for interfacing data acquisitions systems to the Iridium SBD 9602 SIM-less modem via serial Universal Asynchronous Receiver/Transmitter (UART). Iridium SBD provides beyond-line-of-sight data transmission and data can be distributed among pre-determined data terminals including other Iridium SBD modems, servers on NIPR/SIPR Nets, and email. This allows the flexibility to offload calculation and model runs on shore-based computation clusters and those results would be disseminated among Navy vessels. With Iridium SBD, data streams cannot be easily eavesdropped and decrypted, providing some level of information assurance (IA). Also, using Iridium SBD services offloads encryption and IA techniques onto Iridium developers to methods to secure data transmission via VHF. One disadvantage of SBD is that data cannot be sent at relatively high rates. Transmitted data packets cannot exceed 270 bytes and can be only transmitted at the most roughly every 30 secs. However, data can be averaged on board the data acquisition system. The current SNAX prototype transmits 5 minutes averages every 5 minutes via Iridium SBD. This data frequency provides enough data for model simulations.

4. **System integration of all components, and bench testing**
This task mainly involved the engineering work for sensor and system integration to turn ideas into a functioning system. The integrated SNAX system is shown in Figure 1.

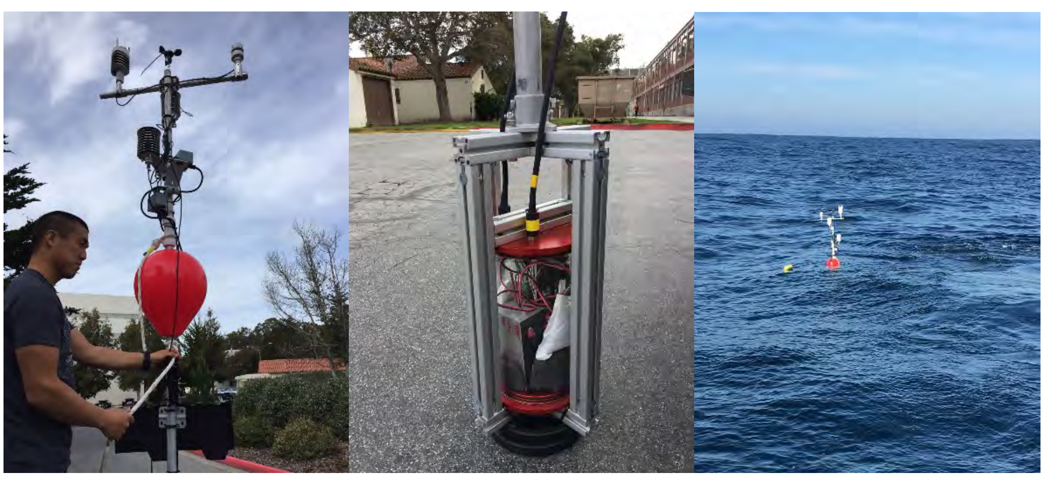


Figure 1. (left) The integrated SNAX system with redundant sensors. (middle) the underwater component of the SNAX with the water proof compartment hosting the data acquisition system. (right) SNAX test deployed at sea.

5. **At-Sea system testing and evaluation**
Although extensive sensor and float component testing were done at various stages of the system development, the at-sea testing on the overall performance of the system is crucial to ensure a functional system in a majority of weather conditions. At-sea testing was performed offshore of Monterey Bay using the R/V John Martin, a research vessel operated by the Moss Landing Marine Laboratory on November 9, 2016 and again on March 7, 2017.

Recommendations for Further Research
We have developed a small buoy system for measurements at the air-sea interface to support EM/EO research. The system in its current form includes redundant sensors for inter-comparison purposes. Further research will include determining appropriate sensors for various applications, transferring data acquisition and Iridium modem interface to low-cost and easily programmable microcontroller (e.g. Arduino), designing and constructing data server systems to securely store, process and distribute multiple SNAX Iridium data streams, and inputting SNAX surface parameters into weather forecast and electromagnetic ducting models.

References

Babin, S. M., G. S. Young, and J. A. Carton, 1997: A new model of the oceanic evaporation duct. *J. Appl. Meteor*., 36, 193–204.
Edson, J.B., C.J. Zappa, J.A. Ware, and W.R. McGillis, 2004: Scalar flux profile relationship over the open ocean, *J. Geophy. Res.*, 109, C08S09, doi:10.1029/2003JC001960.
Fairall, C. W., E. F. Bradley, D. P. Rogers, J. B. Edson, and G. S. Young, 1996a: Bulk parameterization of air–sea fluxes in TOGA COARE. *J. Geophys. Res.*, 101, 3747–3767.
Paulus, R. A., 1985: Practical application of an evaporation duct model. *Radio Sci.,* 20, 887–896.

NPS-N16-N515-B: Navy Atmospheric Measurements for EM Propagation Modeling

Researcher(s): Mr. Paul Frederickson

Student Participation: No students participated in this research project.

Project Summary

The ultimate goal of this project has been to improve characterizations of the battlespace environment for operational U.S. Navy electromagnetic (EM) system performance prediction tools. New and past marine surface layer measurements have been used to test, validate and improve models for characterizing near-surface refractivity and the evaporation duct. The analyses performed during this project have led to demonstrated improvements in the performance of the NPS-developed Navy Atmospheric Vertical Surface Layer Model (NAVSLaM), which characterizes the evaporation duct for EM system prediction models, through the use of new dimensionless profile functions for both unstable and stable conditions. The improved performance was validated by systematic comparisons between NAVLSaM-modeled and

measured propagation data (Frederickson 2017a and 2017b). The NPS Vertical Refractivity Profile Blending Algorithm (VRPBA) has also been improved as part of this project (Cherrett et al. 2016 and Frederickson et al. 2016) with capabilities to handle new environmental situations. Lastly, in collaboration with Jon Pozderac of the Ohio State University (OSU), the NAVSLaM model has been used to validate and improve the OSU X-band evaporation duct height estimation algorithm (Pozderac et al. 2017). In the month remaining before this project is completed, further analyses and validations will be performed with newly available experimental data from the Coupled Air Sea Processes and EM-ducting Research (CASPER) project. The modeling improvements resulting from this project will lead to more accurate EM system (radar, electronic attack, surveillance, communications, etc.) performance predictions for U.S. Navy warfighters.

Keywords: electromagnetic (EM) propagation, radar performance, evaporation duct, refractivity, Navy Atmospheric Vertical Surface Layer Model (NAVSLaM)

Background

Due to the persistence and critical impact of the oceanic evaporation duct on the propagation of radio waves, great effort has been made by U.S. Navy researchers over the past several decades to accurately model this refractivity feature in order to predict its impact on the performance of radars and other EM systems. The Navy Atmospheric Vertical Surface Layer Model (NAVSLaM), developed at NPS by this PI, is the U.S. Navy standard evaporation duct model and, like many other models, it employs Monin-Obukhov similarity theory (MOST). MOST depends upon empirically-determined functions and physical assumptions that may not always be valid, therefore these functions and assumptions require extensive validation with actual experimental data.

The U.S. Navy is also increasingly relying upon numerical weather prediction (NWP) models, such as the Coupled Ocean-Atmospheric Mesoscale Prediction System (COAMPS), to characterize the refractivity environment for EM system performance predictions. It is currently not practicable for models such as COAMPS to have the required vertical resolution to characterize the evaporation duct with sufficient fidelity for EM propagation modeling purposes, nor is it clear that these mesoscale models have sufficient surface layer physics for this purpose. For these reasons, it is necessary to predict the evaporation duct using models such as NAVSLaM with input data from COAMPS, and then to realistically blend this near-surface refractivity profile onto the bottom of the COAMPS upper-air refractivity profile. NPS has developed the Vertical Refractivity Profile Blending Algorithm (VRPBA) with this goal in mind. An objective of this effort is to evaluate and compare different blending approaches using the combined marine surface layer measurements from multiple experiments.

Findings and Conclusions

The area with the most potential for improving the performance of evaporation duct models such as NAVSLaM is to incorporate improved dimensionless profile functions, especially for humidity and temperature, due to the model's high sensitivity to the form of these functions. Several different sets of empirical functions (i.e. Beljaars and Holtslag 1991, Grachev et al. 2000, Cheng and Brutsaert 2005, Grachev et al. 2007) have been evaluated, as well as modifications to these published forms. Comparisons were made between NAVSLaM-modeled data using the different profile functions and propagation data from the Roughness and Evaporation Duct (RED) Experiment conducted off Hawaii in 2001 and the Wallops 2000 Experiment. Based on these evaluations it is clear that the blended functions presented by Grachev et al. and used in the well-known Coupled Ocean-Atmosphere Response Experiment (COARE) model (Fairall et al. 1996), are not the best choices. The standard 'Kansas' type Businger-Dyer functions (Businger et al. 1971, Dyer 1974) with no blending clearly performed better than the blended Grachev et al. (2000) approaches in unstable conditions, as seen in Figure 1, with significantly lower mean and RMS differences between the modeled and measured data for NAVSLaM when using the Kansas functions. For stable conditions (not shown here) the use of a modified form of the Grachev et al. (2007) profile functions in NAVSLaM performed better than the original published functions, or the Beljaars and Holtslag (1991) or Cheng and Brutsaert (2005) funcitons. These improved functions have been incorporated into NAVSLaM Version 1.2, which has recently been accepted as the U.S. Navy standard evaporation duct model in the Commander Navy Meteorology and Oceanography Command (CNMOC) Oceanic and

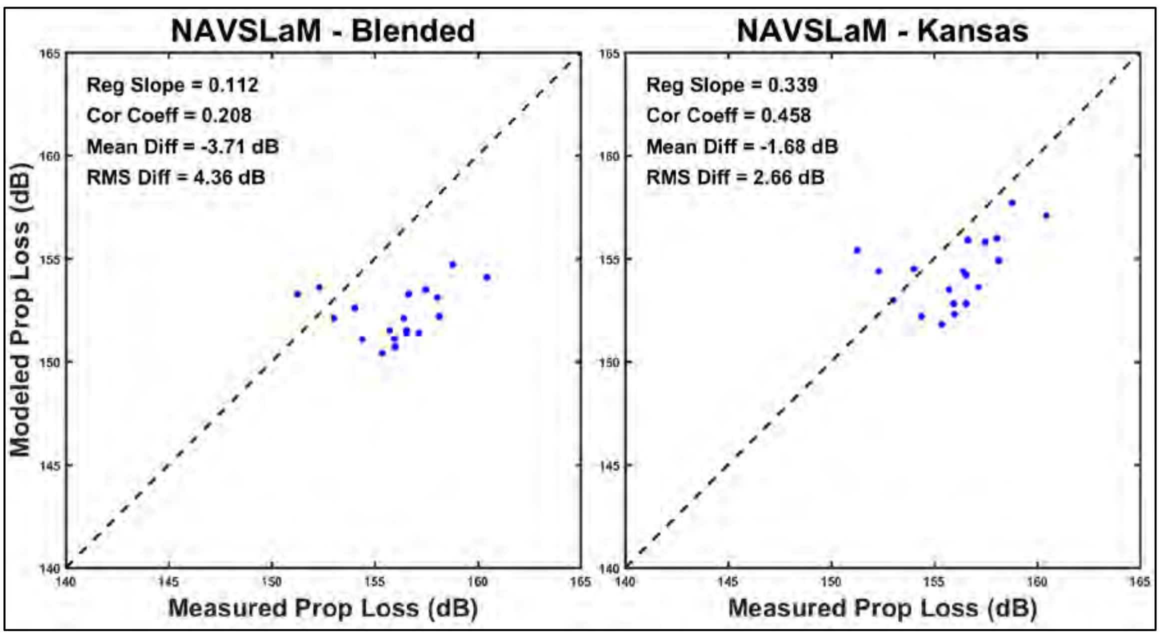


Figure 1. Scatter plot of modeled versus measured propagation loss in dB from the RED Experiment of 2001 with unstable conditions, for NAVSLaM using the Grachev et al. (2000) blended profile functions in the panel on the left, and the 'Kansas'-type functions of Dyer 1974 on the right.

Atmospheric Master Library (OAML).

The Vertical Refractivity Profile Blending Algorithm (VRPBA), developed by this PI, is currently used in operational U.S. Navy EM prediction systems. A study of data from the Wallops 2000 Experiment indicated that the blending algorithm should give more precedence to the COAMPS refractivity profiles in cases when COAMPS predicted a deep surface-based trapping layer. A parameter was introduced into the VRPBA to allow the user to set how much precedence to be given to NAVSLaM or to COAMPS, and recommended values for this parameter were established. Figure 2 shows an example in which COAMPS predicts a deep surface-based trapping layer, whereas the NAVSLaM refractivity profile computed from the lowest level COAMPS data predicts a much lower evaporation duct height (EDH). In such cases, blending with an EDH-based blending interval produced a refractivity profile which is judged to depart too significantly from the COAMPS prediction, and thus a much lower blending interval was used to preserve the original COAMPS profile more, while importantly eliminating the sharp

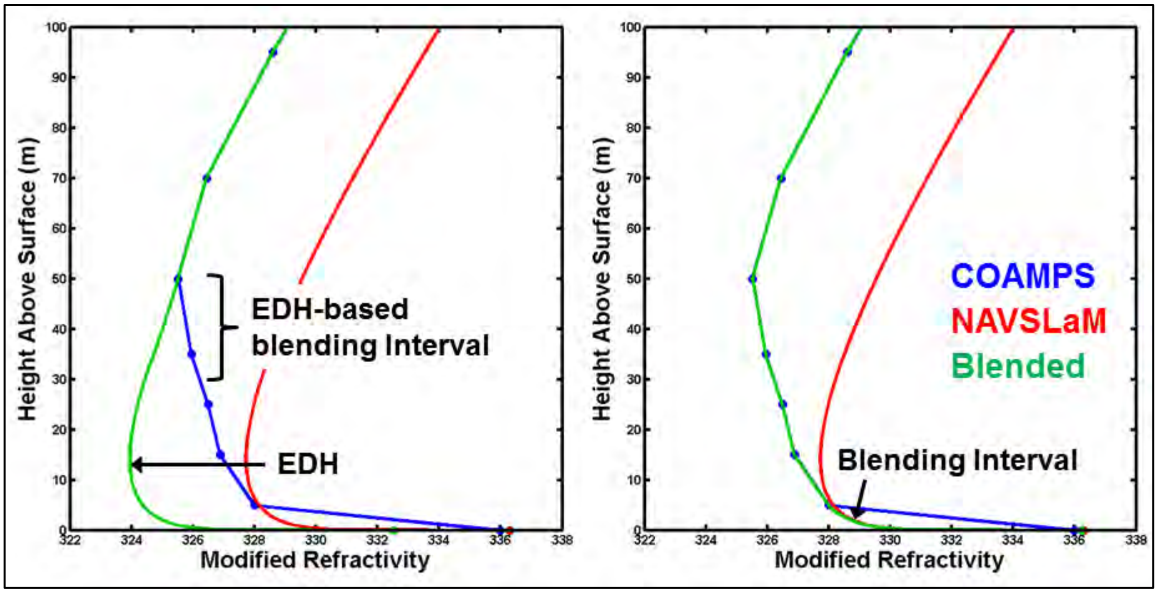


Figure 2. Examples of blended vertical modified refractivity profiles (green) produced from blending the COAMPS (blue) and NAVSLaM (red) predicted profiles. The new VRPBA produces blended profiles that more closely follow the original COAMPS profiles in situations when COAMPS predicts a much deeper surface-based trapping layer than indicated by NAVSLaM, as shown in the right panel.

near-surface 'kink' at the lowest COAMPS model level.

In conclusion, the demonstrated improvements in the operational NAVSLaM and VRPBA models made possible through this study will lead to more accurate EM system performance predictions being provided to U.S. Navy warfighters, which will enable the warfighters to more effectively employ their sensors and weapons systems in the current or predicted environmental conditions.

Recommendations for Further Research

New data being collected as part of the ongoing Coupled Air Sea Processes and EM-ducting Research (CASPER) project, directed by Professor Qing Wang of the NPS Department of Meteorology, represent a promising source of experimental data for further model improvement and validation, which should be vigorously exploited. Further evaluations with this new data will continue over the month remaining in this project, and it is hoped further model improvements will result.

References

Beljaars, A. C. M., and A. A. M. Holtslag, 1991: Flux parameterization over land surfaces for atmospheric models. *J. Appl. Meteor.*, **30**, 327-341.

Businger, J., J. Wyngaard, Y. Izumi, E. Bradley, 1971: Flux-profile relationships in the atmospheric surface layer. *J. Atmos. Sci*., **28**, 181-189.

Cheng, Y., and W. Brutsaert, 2005: Flux-profile relationships for wind speed and temperature in the stable atmospheric boundary layer. *Bound.-Layer Meteor.*, **114**, 519-538.

Cherrett, Robin, Qing Wang, Hway-Jen Chen, and Paul Frederickson, 2016: A new blending algorithm for evaporation duct and mesoscale model profiles. *2016 USNC-URSI National Radio Science Meeting*, Boulder, CO, 6 January 2016.

Dyer, A., 1974: A review of flux-profile relationships. *Bound.-Layer Meteor*., **7**, 363-372.

Fairall, C., E. F. Bradley, D. P. Rogers, J. B. Edson and G. S. Young, 1996: Bulk parameterization of air-sea fluxes for Tropical Ocean-Global Atmosphere Coupled-Ocean Atmosphere Response Experiment. *J. Geophys. Res.*, **101**, 3747-3764.

Frederickson, P., and T. Haack, 2016: Evaluation of Vertical Refractivity Profile Blending Schemes. *USNC-URSI National Radio Science Meeting*, Boulder, CO, 6 January 2016.

Frederickson, Paul, 2017a: Updates and Validation for the Navy Atmospheric Vertical Surface Layer Model (NAVSLaM). *2017 USNC-URSI National Radio Science Meeting*, Boulder, CO, 4 January 2016.

Frederickson, Paul, 2017b: Potential Improvements and Validation for the Navy Atmospheric Vertical Surface Layer Model (NAVSLaM) from the CASPER Project. *CASPER Three Year Review & Planning Meeting*, Arlington, VA, 9-11 January 2017.

Grachev, A. A., C. W. Fairall, and E. F. Bradley, 2000: Convective profile constants revisited. *Bound.-Layer Meteorol.*, **94**, 495-515.

______, E. L. Andreas, C. W. Fairall, P. S. Guest, and P. O. G. Persson, 2007: SHEBA flux-profile relationships in the stable atmospheric boundary layer. *Boundary-Layer Meteorol*., **124**, 315-333.

Pozderac, J., J. Johnson, C. Yardim, C. Merrill, T. Cook, T. de Paolo, E. Terrill, F. Ryan and P. Frederickson, 2017: Further studies of the X-band beacon-receiver phased array and evaporation duct height estimation. *2017 USNC-URSI National Radio Science Meeting*, Boulder, CO, 4 January 2016.

NPS-N16-N590: Education for Energy Culture Change

Researcher(s): Dr. Susan Higgins and Dr. Erik Jansen
Student Participation: No students participated in this research project.

Project Summary

This paper explores culture change through the lenses of an organizational design model, frameworks that describe stages of skill acquisition and the relationship of moods to learning. We wanted to understand how these models and frameworks might inform and enhance each other. We reviewed publications and had conversations with researchers, developers, practitioners and users/recipients. We evaluated and synthesized what we learned. Our goal was to initiate a conversation with Navy leaders who want to drive culture change in their organizations. We found that there is still much to be discovered.

We explored how informal learning might be a powerful component of changing culture in the Navy. We evaluated online learning technologies and developed online modules about energy.

Keywords: culture change, learning, training, education, Massive Open Online Course (MOOC)

Background

The Navy would like to develop a new shared value among its more than half million members: that energy is a warfighting enabler. Navy leaders would also like to instill an ethos that conserving energy where possible adds value to the warfighter. Sometimes that value is direct: as in a ship that can stay on station longer without refueling. Ashore conservation saves money which can be used elsewhere.

Changing culture is a challenging and lengthy effort. Jay Galbraiths's Star Model for Organizational Design is useful for simplifying the complexity when leaders try to drive culture change (Galbraith, 1995.) This project integrates this model of organizational design with stages of skill acquisition (Dreyfus, 2001), innovation (Denning, 2010), moods and learning (Flores, 2016) and conversations (Flores 2012) to explore how leaders might drive and even accelerate culture change in their organizations.

A change of topic sponsor redirected the work to emphasize culture change instead of developing specific online modules that could be incorporated into a Massive Open Online Course (MOOC). At the request of the sponsor, Professor Erik Jansen expanded certain areas of our 2015 paper.

Findings and Conclusions

1. Leaders can set conditions that enable a new organizational culture to emerge via their involvement in five domains: strategy and goals, organizational structure, rewards and incentives, tasks and practices, and learning.
2. Learning significantly affects organizational culture change; however, learning in isolation of the other domains is insufficient. Leaders need to address multiple domains simultaneously. New behaviors need to be seen as valued and rewarded if they are to grow and sustain across the organization.
3. The ability for individuals to learn new behaviors is impacted by their own mood and the collective mood of the organization. Individual moods of frustration, resignation, arrogance, boredom, fear, overwhelm and lack of confidence impedes learning. Moods of trust, resolution, ambition and confidence are conducive to learning. (Flores 2016)
4. As rates of change accelerate in areas that impact the Navy's mission (maritime systems, global information systems and technology), the value of continuous learning increases. Leaders need to show that learning is valued, that strategy structure, practices, rewards, and learning are aligned, and that questions are encouraged.

5. Massive Open Online Courses (MOOCs) and other online learning technology platforms are rapidly evolving. MOOCs on energy, organizational change and leadership are available for free from many global universities. Entire courses (or parts of courses) can be leveraged by those creating Navy training and education to blend with Navy-specific content. However, simply developing and making MOOCs available to Navy personnel will have little impact on culture change without the accompanying attention on other domains including rewards, strategy and practices.

The Chief of Naval Operations' *Design for Maintaining Maritime Superiority* highlights the need to reexamine approaches in every aspect of the Navy's operations. Culture will need to be examined to accommodate these new forces. At a minimum, continuous learning will need to be highly valued and rewarded.

Leaders in all organizations can play key roles in cultivating moods conducive to learning if they understand their importance. This expanded understanding of how new culture can emerge is important to the Navy as it contends with accelerated rates of change in the global environment. In today's Navy, learning is no longer the purview of the schoolhouses and formal training and education organizations. Continuous learning is the new norm.

Recommendations for Further Research

Future work should include is encouraged about the relationship between culture, organizational change, learning, moods and leadership.

References

Chief of Naval Operations (2016). A Design for Maintaining Maritime Superiority. http://www.navy.mil/cno/docs/cno_stg.pdf

Denning, P.J. (2010). The Innovator's Way, Cambridge, MA: MIT Press.

Denning, P.J, Higgins, S.L (2015). Being in Uncertainty: Cultivating a New Sensibility in Miltary Education, chapter in Innovative Learning: A Key to National Security, Doughty, R., Wells, L., Hailes,T. ed. Ft Levinworth: Army Press.

Dreyfus, H.L. (2001) On the Internet London, Routledge.

Flores. G. P. (2016). Learning to Learn and the Navigation of Moods: The Meta-Skill for the Acquisition of Skills. Self-Published.

Flores, F., (2012). Conversations for Action and Collected Essays: Instilling a culture of Commitment in Working Relationships. Self-published.

Galbraith, J.R. (1995). Designing Organizations: An Executive Briefing on Strategy, Structure, and Process. San Francisco: Jossey-Bass Publishers.

Jansen, E., Gallenson, A.C., Higgins, S.L. (2015). An Organizational Design Approach to Culture Change, Training and Education: Integrating Energy Conservation into Navy Culture. Monterey: Naval Postgraduate School. http://calhoun.nps.edu/handle/10945/48170

NPS-N16-N596-A: Precision Control of Agile Underwater Vehicles

Researcher(s): Dr. Douglas Horner
Student Participation: Mr. Mkuseli Mqana

Project Summary

Precision control of underwater vehicles is complicated by the lack of accurate dynamic models, changing vehicle configurations (including mid-mission changes), and large environmental disturbances. Yet, close-proximity Autonomous Underwater Vehicle (AUV) operations are required for a variety of missions, including operations close to other objects (e.g., ships, submarines, divers, etc.), docking, and high-resolution underwater Intelligence, Surveillance, and Reconnaissance (ISR) missions. This study investigated the use of advanced control and navigation techniques for the control of agile, hover-capable AUVs.

This effort builds on the platform development effort, as well as ongoing student research on detailed 3-D mapping of the operating environment and accurate terrain-relative navigation. Students developed and implemented planning and control concepts on the existing physical platform and tested the approaches during frequent ocean-based experiments. Students were able to explore applications of precisely controlled agile platforms appropriate to support of a variety of naval commands, including Undersea Warfare (USW), Naval Special Warfare (NSW), Explosive Ordinance Disposal (EOD), and Salvage.

The report includes research accomplished by students and faculty with the Center for Autonomous Vehicle Research (CAVR). Part of this research was conducted in conjunction with the National Aeronautics and Space Administration (NASA) Extreme Environment Mission Objective (NEEMO) Experiment conducted at the Florida International University (FIU) Aquarius undersea habitat in Key Largo, FL.

Background

This research is aimed at developing a robust and flexible planning and control architecture for a hovering-class AUV in support of NSW operations. The control architecture must be able to handle mid-mission configuration changes, as well as poor prior information about the vehicle dynamics. Furthermore, a planning approach is desired for deployment in environments for which little prior information exists.

One area that highlights the need for precision control of agile underwater vehicles is terminal homing to an undersea docking station. The ability to reliably dock to an undersea dock provides persistence for AUV monitoring that can be important for littoral missions. Past research includes McEwen et al. presented a docking control system for the Monterey Bay Aquarium Research Institute (MARI) Dorado AUV (R. S. McEwen, 2008). Using the same vehicle, Hobson et al. describe Dorado docking results in Monterey Bay, CA (B. W. Hobson, 2007).

Ben Allen et al. described a REMUS docking station similar to the docking station presented in this paper (B. Allen, 2006). More recently, Li et al. presented results for AUV docking using a combination of cameras and light-emitting diode (LED) lighting on the docking station for docking approaches (Y. Li, 2015). A combination of ultra-short baseline (USBL) and cameras for far and near control provide a potentially robust solution to docking. Additionally, San-Muntadas et al. discuss AUV docking using a USBL. It includes the ability to calculate in real time, the probability of successful docking (Sans-Muntadas, 2015).

These approaches use an AUV with a single aft thruster such that control is only possible with significant flow over the AUV body. This resultant velocity potentially results in the AUV and docking station incurring damage from the collision. Instead, with an AUV that had forward and aft cross tunnel thrusters, a more deliberate, slower and safer approach is possible. Additionally, another novel aspect of this research is that it implicitly considers the sparse nature of the USBL measurements and introduces a novel filtering methodology for handling these observations.

Findings and Conclusions

The focus of the research was the development of a technique for position estimation for handling sparse, error prone and unpredictable USBL sensor observations that are common with AUV terminal homing. The ability to more accurately estimate position is part of an overall guidance, navigation and control (GNC) approach to make AUV docking more robust.

After comparing more standard filtering approaches, the Moving Horizon Estimation (MHE) filter was selected. This approach uses a non-linear least squares smoothing approach over a past window of measurements to produce an accurate position of the vehicle.

Using data from docking missions conducted in Monterey Bay, CA. It showed that the MHE approach can produce a more accurate solution by considering the short term accuracies of the AUVs dead reckoning and combining it with the USBL measurements. Over a total of 16 docking station runs the MHE filter consistently provided better estimates of the AUV position than either the Extended Kalman Filter or Unscented Kalman Filter.

References

B. Allen, T. A. (2006). Autonomous docking demonstrations with enhanced remus technology. IEEE/MTS OCEANS.

B. W. Hobson, R. S. (2007). The development and ocean testing of an auv docking station for a 21” auv. IEEE/MTS OCEANS, 1-6.

R. S. McEwen, B. W. (2008). Docking control system for a 54-cm-diameter (21-in) auv. IEEE Journal of Oceanic Engineering, 33 (4), 550–562.

Sans-Muntadas, A. (2015). Navigation and probability assessment for successful auv docking using usbl. IFAC-PapersOnLine, 48 (16), 204-209.

Y. Li, Y. J. (2015). Auv docking experiments based on vision positioning using two cameras. Ocean Engineering.

Fleet Forces Command

NPS-N16-N233-A: Creating a Simulation Model to Assess Options for Distributed Lethality

Researcher(s): Mr. Jeff Kline, CAPT, USN (ret) and Dr. Thomas Lucas
Student Participation: LT Kristen Ericksen USN

Project Summary
This research project created, developed and then assessed an agent based model within Naval Surface Warfare Center Dahlgren Division's (NSWCDD's) Orchestrated Simulation Model (OSM) to represent naval surface to surface engagements in order to aid in the development of the distributed lethality concept. The Distributed Lethality OSM (DL-OSM) simulation was assessed through wargaming, a fleet exercise, and using advanced experimental design to explored best tactics for organic helicopters, emission control, and formations during surface to surface engagements. The simulation was determined to be satisfactory to explore tactical variables in the distributed lethality concept.

Keywords: combat modeling, distributed lethality, tactical development.

Background
As potential adversaries develop naval capabilities to challenge the United States' sea control, new technologies and maritime tactics need to be conceived, developed, assessed, and introduced through fleet tactical training. Simulation, combined with advance design of experiments and analysis, can make cost-effective contributions in each of these steps. The Naval Postgraduate School's tactic development team and Simulation Experiments Efficient Designs (SEED) Center partnered with Naval Surface Warfare Center Dahlgren (NSWCDD) modeling team to create an agent-based model within the Orchestrated Simulation Modeling (OSM) framework that mimics important variables in naval surface to surface engagements. The simulation, Distributed Lethality in OSM, was created specifically to aid in develop the distributed lethality concept introduced by VADM Thomas Rowden in January 2015.

Findings and Conclusions
Distributed Lethality in OSM (DL-OSM) was created in coordination with NSWCDD modeling and simulation team. In addition to providing subject matter expertise advice to NSWCDD programmers, NPS SEEDs' contribution to this initial development effort included developing software that allowed to automatically run multiple simulations varying specific parameters to enable the efficient use of the DL-OSM in experimental design. The original DL-OSM prototype beta version was tested in a classified NPS Distributed Lethality wargame with a team of officers from all U.S. military services, including LT Ericksen, USN who would later use the program for distributed lethality tactical development. Recommended changes were provided

to the DL-OSM programming team and modifications were made. A version of this program was used during Valiant Shield 2016 as a decision support tool, with additional changes provided to the programming team.

The updated DL-OSM beta version was then used by LT Kristen Ericksen to explore surface on surface engagements as part of Distributed Lethality tactical development. Her primary thesis question was “Can DL-OSM be used to develop tactics associated with distributed lethality?” She answered this question by creating and executing a design of experiments which focused on surface to surface tactical engagements. She varied tactical formations, emission controls on specific platforms, helicopter tactics, and weapon performance using DL-OSM as the simulation to conduct over 200,000 tactic engagements. Although her exact findings are classified, she demonstrated the importance of helicopter tactics, emission control, and certain formations to make a positive effect on the ability to fire missiles before an adversary can fire their missiles. By doing so, we assess that although some improvements can be made to the simulation, DL-OSM is capable of being used as a surface tactical development aide. This allows NSWCDD to offer their modeling and simulation services to the surface community. LT Ericksen briefed her tactical lessons learned to VADM Rowden and others on Commander Naval Surface Force (COMNAVSURFOR) staff. Her final thesis was provided to COMNAVSURFOR staff as a final deliverable.

Recommendations for Further Research

DL-OSM can now be used for further research related to surface navy tactics and technologies. For example, the contribution of a large surface unmanned vessel as a sensor, decoy, and/or weapons delivery platform in a surface engagement may be assessed and tactics developed for its employment. Further, DL-OSM may be modified to understand the impact of multi-domain contributions to surface engagements, such as the use of a P-8 or shore based anti-ship cruise missile battery.

A major change to DL-OSM will allow it to be used as a wargaming tool. Currently, DL-OSM is a closed loop simulation. However, if given the ability for user input during a simulation (man-in-the-loop) given certain events occurring, DL-OSM may be used as a training tool as well as a tactics development tool.

NPS-N16-N233-B: Applying Systems Engineering and Architecting to the Application of Distributed Lethality to the Operational Navy Surface Forces

Researcher(s): Dr. Eugene P. Paulo and Dr. Paul Beery
Student Participation: LCDR Clay Johnson USN

Project Summary
Distributed Lethality is a new concept in Surface Warfare that involves using small groups of surface combatants to go on the offensive against the enemy. This new concept requires structure and definition, and building a systems architecture for it is an effective way to provide both. This research investigates and defines the core requirements of Distributed Lethality and the capabilities that are necessary to meet these requirements. It builds an example mission flow for a Distributed Lethality scenario, and then defines the functions necessary to implement this flow. Finally, the model includes the components that perform the identified functions. The systems architecture for operational Distributed Lethality clearly demonstrates the connections and relationships between each element of the model, allowing for clear traceability from the smallest component to the originating requirement. This systems architecture for operational Distributed Lethality builds the foundation for future Distributed Lethality research and will power operational simulations and wargames.

Keywords: Model-Based Systems Engineering, Distributed Lethality

Background
Potential adversaries to the United States seek to deny the U.S. Navy the ability to freely operate with high-speed and highly accurate weapons. This denial of access significantly impacts the Navy's traditional carrier strike group operations paradigm, as now the limited number of high value assets are becoming increasingly vulnerable to this new threat.

To answer this danger to the Navy's dominance at sea, the surface navy is rapidly developing and fielding a new concept called Distributed Lethality. The goal is straightforward: take the fight to the enemy with small groups of powerful surface combatants. The implementation of the Distributed Lethality concept, though, is much more complicated. As a brand new idea, Distributed Lethality presents a unique opportunity for the application of systems architecture concepts with the goal of better understanding what it will take to make Distributed Lethality work.

Systems architecting is the science and art of building and connecting all of the different ideas and components that are necessary for a system to operate. The output of this architecting is a model capable of better explaining the elements and interactions of the parts of the system. As a form of model based systems engineering (MBSE), the model developed by the architecting process can act as a foundation for more detailed simulation work.

The process for developing the systems architecture for the operational section of Distributed Lethality is based on general system architecting concepts and the Department of Defense Architecture Framework (DODAF). The process is dependent upon each element in the architecture being easily traceable to every other part of the model. The first step is to develop Requirements that are linked to Capabilities. Capabilities are the basis of Operational Activities that are implemented by Functions. Finally, Functions are allocated to the Components that perform them (see Figure 1).

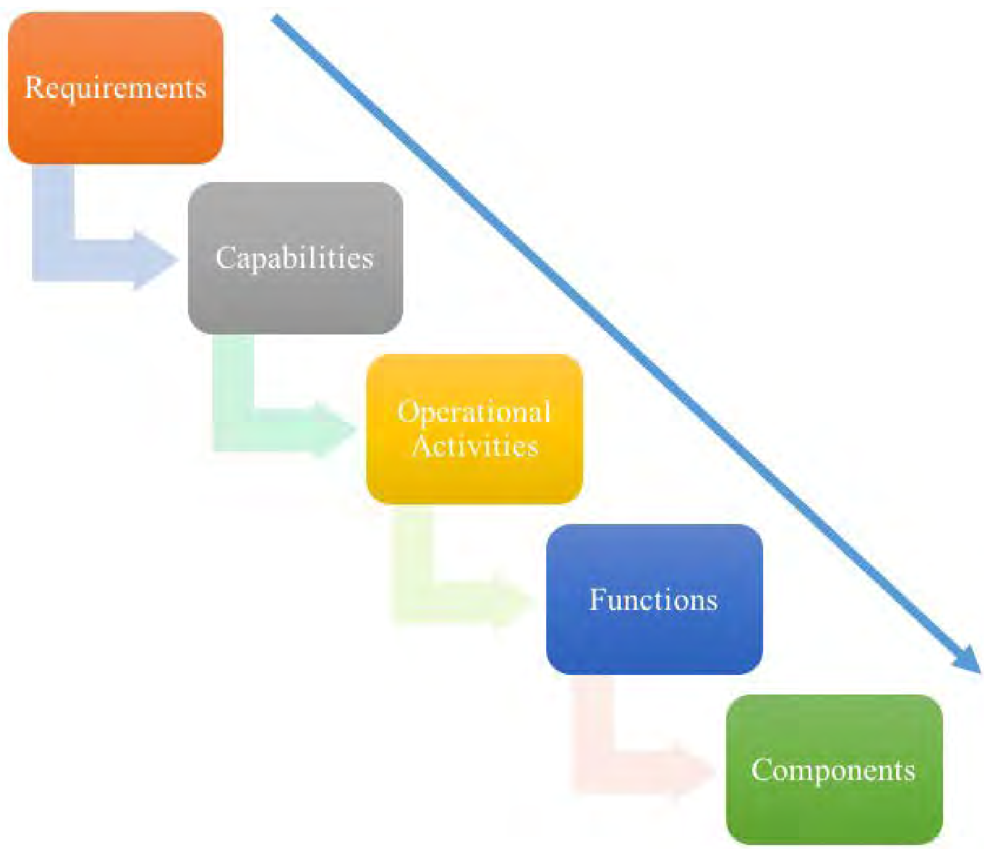


Figure 1. Systems architecting approach for distributed lethality. Adapted from Giachetti (2015).

This research focuses on building the systems architecture for operational Distributed Lethality. It identifies and explores the Requirements and Capabilities of Distributed Lethality. There are 11 of these Requirements, including Localized Sea Control, Offensive in nature, and Rapid Adaptive Force Package (AFP) Turnaround (see figure 2). These Requirements then implement the various Capabilities of Distributed Lethality, including Amphibious Operations Support, Anti-Surface Warfare, and Strike Operations. From there, the entire model is built for one of the eight sub-Capabilities, Anti-Surface Warfare (ASW). This detailed model includes the mission flow of the Capability, the Functions required to execute the mission flow, and the Components that execute the Functions. The end result is a clear path between the physical systems through the model all the way to the Requirements for which the physical systems are necessary.

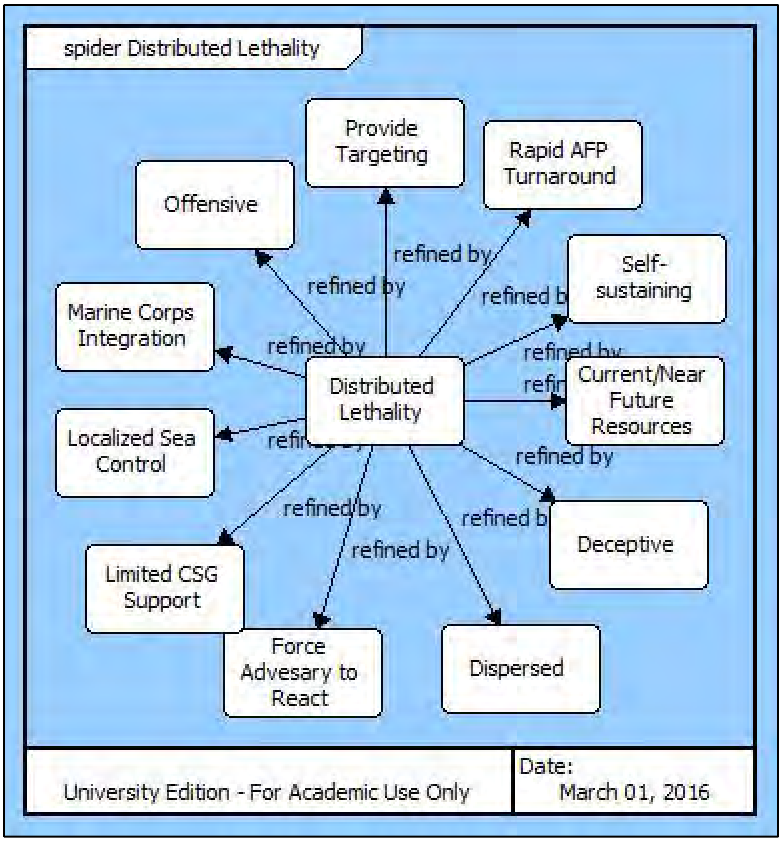


Figure 2. Distributed lethality's requirements.

The functional flow block diagram (FFBD) for the operational activity (OA) "Conduct ASUW" is shown below as an example (figure 3). All OAs are numbered for organizational purposes. The main path through the Conduct ASW Operational Activity starts in OA.2.4.2 Deploy AFP. The trigger Intelligence on mission objective dictates how the commander deploys the AFP. The next set of elements involve searching for enemy naval vessels. This search could happen in four different ways that could all be taking place simultaneously and are therefore represented by branches from an "AND" block. The AFP could search the battlespace with embarked helicopters, unmanned aerial systems, or organic sensors such as radars or electronic surveillance. Additionally, the location of targets could be pushed to the AFP from an external asset, represented by a trigger in the FFBD. OA.2.4.3 through 2.4.6 represent these different search methods.

Each of the search Operational Activities produce the output Operational Item Objective location and composition, assuming that the search is successful. This output then becomes an input for the next several Operational Activities in the FFBD. In OA.2.4.7 the AFP evaluates the input Objective location and composition to determine whether or not the search revealed enough information to proceed to OA.2.4.8 Targeting. The Targeting Operational Activity once again takes the input Objective location and composition to develop a targeting solution for the enemy ships. This input is used again in OA.2.4.9 Weapons pairing as the AFP's commander decides what system to use to engage the enemy warships.

After the commander has determined which of the AFP's weapon systems are capable of engaging the enemy ships, the FFBD moves into a decision "OR" block. The AFP can use any one of or a combination of the five branches of this "OR" block to engage the enemy, assuming that the AFP is equipped with each of the weapons. OA.2.4.10 Long-range ASCM, OA.2.4.11 Short-range Anti-Ship Cruise Missiles (ASCM), and OA.2.4.12 Naval gunfire are each dependent upon the trigger Range of target. If the target is over the horizon, then a short-range ASCM and naval gunfire might not be able to engage it. At the same, the commander also has the options of OA.2.4.13 Helicopter attack and OA.2.4.14 UAS attack.

With the attack completed, the AFP then conducts a battle damage assessment (BDA) in order to determine if the attack was successful. OA.2.4.15 BDA then leads into a “LP” block, representing a loop. If the BDA reveals that some of the enemy warships survived the attack, then the loop allows for the FFBD to cycle back to the beginning so that the entire process can play out again. If the BDA results in all enemy targets being destroyed or neutralized, then the FFBD for OA.2.4 Conduct ASUW concludes. At this point in the Perform ASUW Mission Operational Activity, the AFP has completed its assigned mission and the FFBD moves on to OA.2.5 Transit out of Area of Operation (AOR).

Findings and Conclusions
From flow of the functions required to execute the ASUW mission, a physical architecture was built that describes how the system components that execute the Functions. An example of this addresses the “Airborne search” function, as it is allocated to the MH-60R sensors (see Figure 4). The MH-60R helicopter uses three main sensors as it searches for the enemy ships, so the Component MH-60R sensors is “built from” three sub-components. These sensors are the AAS-44 Forward-Looking Infrared (FLIR) system, the ALQ-210 Electronic Support Measures system for passive surveillance, and the APS-147 surface search radar.

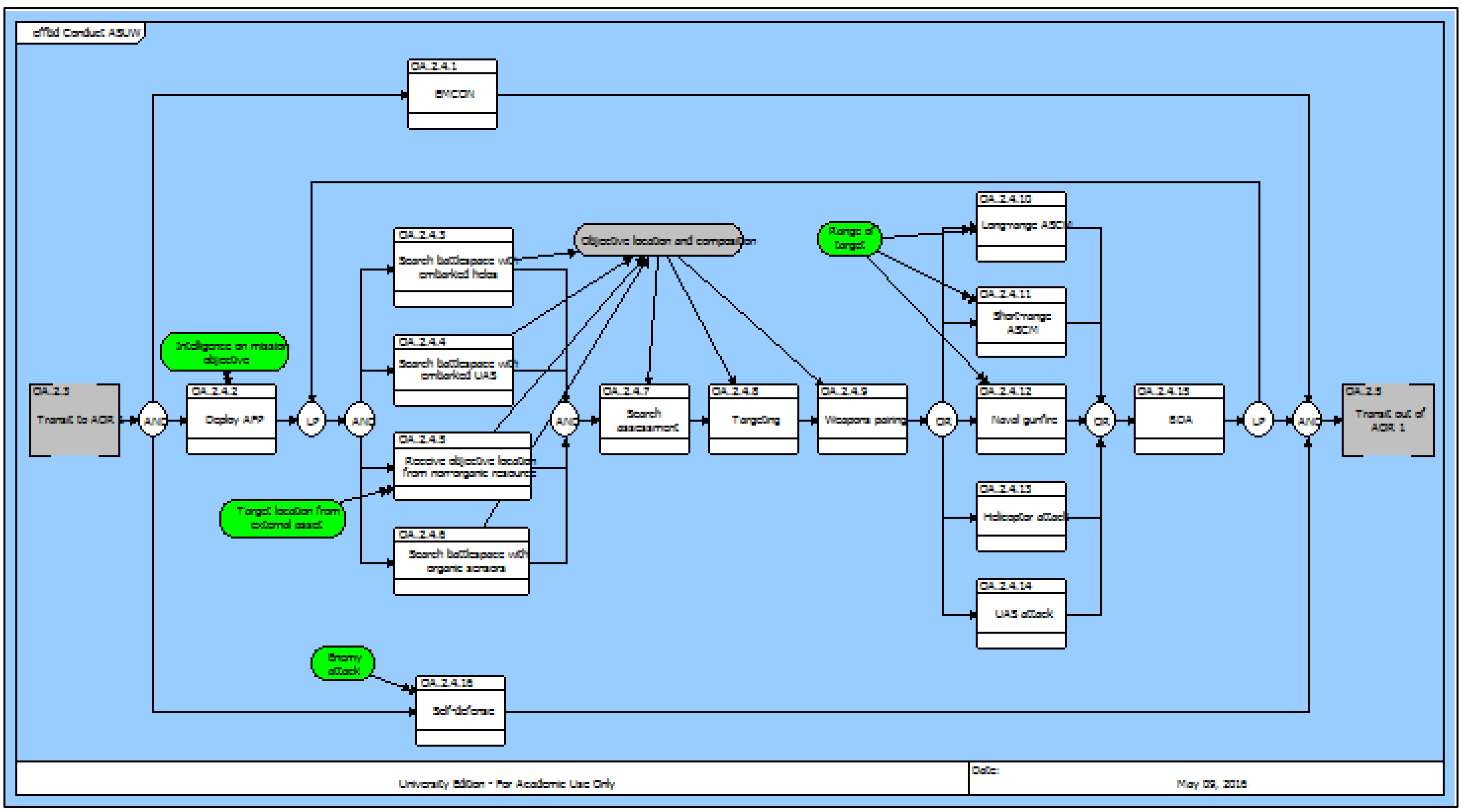


Figure 3. FFBD for conduct ASUW.

This example of the complete end results shows a clear path between the physical systems through the model all the way to the requirements for which the physical systems are necessary.

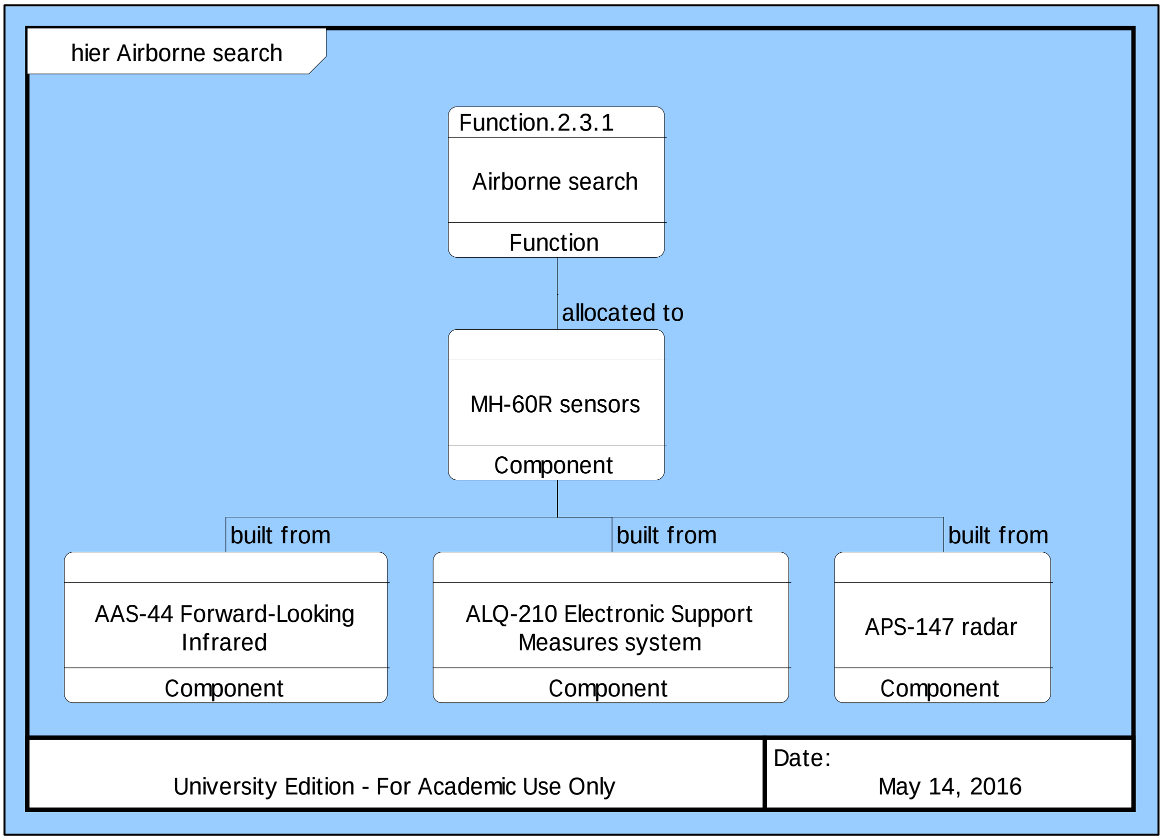


Figure 4. Components that perform airborne search function.

Recommendations for Further Research

1. Model Expansion

The architecture built for this research only fully develops a model for one of the eight sub-Capabilities. Each of the eight sub-Capabilities is essentially a mission area, and the architecture for each should include a detailed flow of Operational Activities, the Functions that implement the Operational Activities, and the Components that perform the Functions. If each of these models were fully built, then all of the Components could be compared for redundancies. Additionally, if each of the sub-Capabilities were fully built through the Components then the Components could be organized into the units that contain them. For example, an Arleigh Burke class destroyer contains Components that perform Functions across multiple sub-Capabilities, but this physical modeling of each type of ship is not yet built into the architecture and would be a valuable tool.

The entire architecture is open, meaning that elements can be added as desired. This feature becomes useful if future study shows that additional Requirements or Capabilities should be included in the Distributed Lethality concept. A proficient Common Operational Research Environment (CORE) operator would have no problem modifying the model in order to accommodate additions or changes.

2. Support to Simulations

The systems architecture of Distributed Lethality is useful on its own as a detailed description of the system and its internal interactions, but it could also be used to power simulations. A more detailed system is necessary to accurately model the complexities of a Distributed Lethality scenario. A systems such as Paul Beery's methodology for employing architecture in system analysis (MEASA) could be useful in converting the CORE model of Distributed Lethality into a more usable simulation that could be used for more in depth analysis and potentially aid in wargaming Distributed Lethality (Beery 2016).

References

Anderson, Helene. "System Engineering Challenges in Naval System of Systems." December 8, 2010.

Beery, Paul. "A Model Based Systems Engineering Methodology for Employing Architecture in System Analysis: Developing Simulation Models Using Systems Modeling Language Products to Link Architecture and Analysis." March 2016.

Defense Industry Daily Staff. Next-Gen Naval Gunfire Support: The USA's AGS & LRLAP. February 23, 2014. http://www.defenseindustrydaily.com/next-gen-naval-gunfire-support-the-usas-ags-lrlap-07171/ (accessed April 20, 2016).

Department of Defense. "DoD Architecture Framework ." Vers. 2.02. January 31, 2015.

Eckstein, Megan. Navy Studying Implications of Distributed Lethality in Wargames Series. July 9, 2015. https://news.usni.org/2015/07/09/navy-studying-implications-of-distributed-lethality-in-wargames-series (accessed April 11, 2016).

Fanta, Gumataotao, Rowden. "Distributed Lethality." U.S. Naval Institute. January 1, 2015. http://www.usni.org/magazines/proceedings/2015-01/distributed-lethality (accessed August 1, 2015).

Filipoff, Dmitry. Distributed Lethality and Concepts of Future War. January 4, 2016. http://cimsec.org/tactical-doctrine-distributed-lethality/22286 (accessed April 15, 2016).

Giachetti, Ronald. "Systems Architecuture." Class Notes. April 26, 2015.

Ho, Ben. Fixing the US Navy's Anti-Surface Warfare Shortfall. March 10, 2016. http://thediplomat.com/2016/03/fixing-the-us-navys-anti-surface-warfare-shortfall/ (accessed April 20, 2016).

Johnson, Clay. A Systems Architecture for Operational Distributed Lethality. Master's Thesis. Monterey, California: Naval Postgraduate School, June 2016.

Kline, Jeffrey E. A Tactical Doctrine for Distributed Lethality. February 22, 2016. http://cimsec.org/tactical-doctrine-distributed-lethality/22286 (accessed April 13, 2016).

—. The U.S. Navy's Surface Force Just Got a Lot Deadlier. February 4, 2016. http://warontherocks.com/2016/02/the-u-s-navys-surface-force-just-got-a-lot-deadlier/ (accessed April 11, 2016).

Vitech Corporation. Core Architecture Definition Guide (DoDAF v2.02). Blacksburg, Virginia, June 2013.

Wills, Steven. LCS: The Distributed Lethality Flottila Combatant. July 9, 2015. http://cimsec.org/lcs-distributed-lethality-flotilla-combatant/17097 (accessed August 30, 2015).

NPS-N16-N235-A: Applying Systems Engineering and Architecting to the Logistics and Support of the Fleet’s Distributed Lethality Concept

Researcher(s): Dr. Eugene P. Paulo and Dr. Paul Beery
Student Participation: LT Travis Harlow USN

Project Summary
The U.S. Navy is committed to conducting offensive operations via a new warfighting concept known as Distributed Lethality. This research examines the logistical component of Distributed Lethality and provides structure to the concept via the creation of an architectural framework. The methodology for creating this architecture included portions of the traditional systems engineering process along with model based systems engineering (MBSE) and the Department of Defense Architectural Framework (DODAF) v2.0 schema. Requirements are derived from the stakeholder analysis and then connected to the necessary capabilities to fulfill those requirements. From the capabilities, a variety of operational vignettes focused on logistical support, are used to identify the necessary operational architecture to support a distributed force. Finally, the operational architecture is decomposed to the underwriting functions that are connected to components and performers for mission execution. In conclusion, the stakeholder is provided with a fully traceable, flexible, and scalable architecture to aid in codifying the Distributed Lethality concept.

Keywords: Model-Based Systems Engineering, Distributed Lethality, Logistics

Background
In early 2015, an article in *Proceedings* magazine authored by three prominent U.S. Navy surface force admirals sparked a sense of urgency, felt throughout the fleet, to make drastic changes to the surface force’s warfighting doctrine. The admirals named this concept “Distributed Lethality”, wherein small groups of ships, referred to as adaptive force packages (AFPs), would deploy and conduct offensive operations inside contested areas to force the enemy to react to the offensive thrusts. This concept is in stark contrast to the current defensive posture the U.S. Navy employs, focusing of protection of the aircraft carrier (CVN) and commitment to the air power provided by CVN based aircraft. Several outlets within the U.S. Navy are attempting to codify the Distributed Lethality concept, the focus of this research is to create an architectural framework to serve as the backbone of the logistical component of Distributed Lethality.

The issue with the logistical support system required to support a distributed force is that it is simply a concept that many entities refer to but none have codified. Providing the U.S. Navy’s surface force and logisticians an architecture to serve as the shared understanding of what a system that could support a distributed surface force would look like to aid in the further development of this warfare concept is the key to translating the concept into reality.

Research questions guiding the study included:

- What would a proposed DODAF-like system architecture require to sustain a distributed force?
- How might one develop this system architectural framework to support a range of Distributed Lethality tactics in a range of operations areas?
- What are the current methods employed by the U.S. Navy surface force to sustain underway operations? How might these methods be redefined to support the force operating under the Distributed Lethality concept?
- Does the current logistical model employed by the force allow the Distributed Lethality concept to be executed? If not, how might the framework of the existing model be modified to support these new requirements?
- What measures of performance and effectiveness related to logistical support are the most impactful when sustained in a distributed force?

Findings and Conclusions

In order to provide structure to Distributed Logistics architectural framework, we leveraged portions of several systems engineering methodologies to harness the uniqueness of this concept. Initially, the systems engineering Vee model (shown in Figure 1) is used to gain traction and identify a launching point for the architectural construction. On the left hand side of the Vee model, the author considered the feasibility of the study and concept exploration. From this step, the use of the Vitech Core software package and the Department of Defense Architectural Framework (DODAF) v2.0 schema was chosen to capture the architecture. Moreover, model based systems engineering (MBSE) practices are also used to aid in maintaining the collaborative and traceability components of the architecture that are necessary in a dynamic concept like Distributed Logistics.

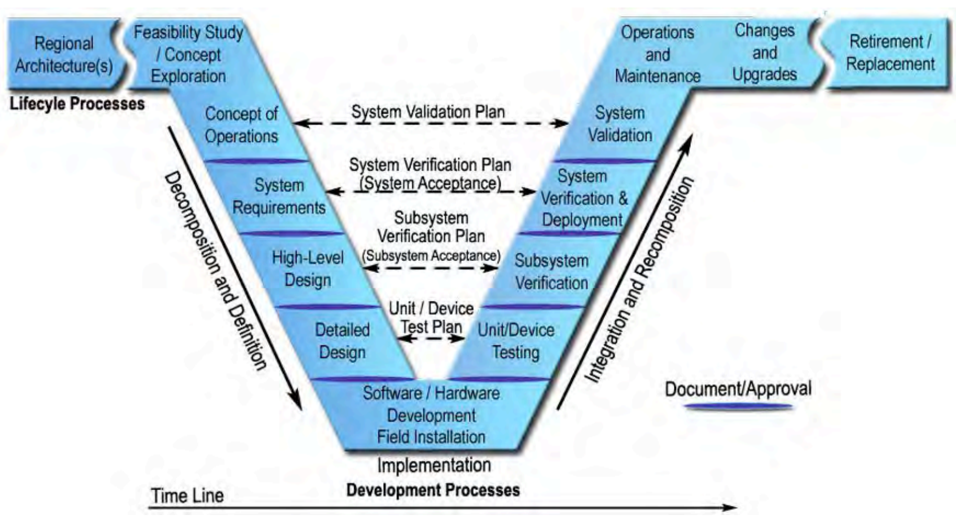


Figure 1. Systems engineering "Vee" model. Source: U.S. department of transportation, office of operations (2007).

From the previously described blended approach, a schema developed solely for use in this study was used to provide visually traceable architectural framework. Moreover, while using this schema the author created the architecture so that it is easily manipulated using the Vitech CORE software package. The final blended schema the author used for the architectural framework is depicted in the figure below.

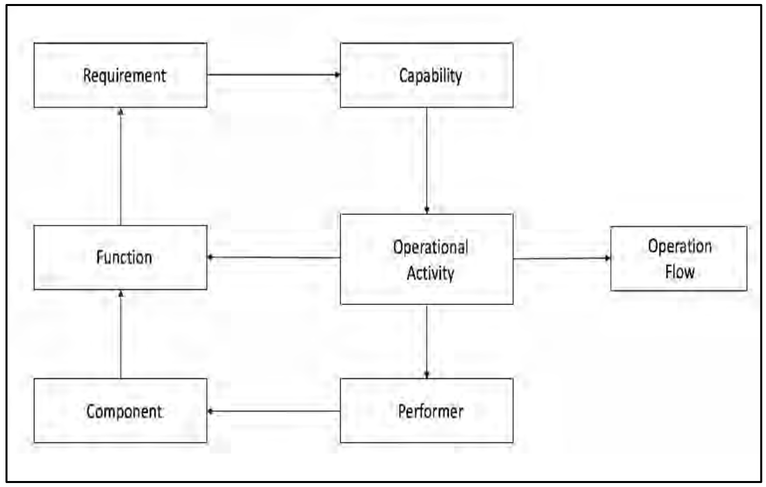


Figure 2. Adapted MBSE Approach Schema for Distributed Logistics.

Based on the available literature on the topic of Distributed Lethality a set of baseline requirements were developed (see figure below). From this set of requirements, a concept of operations (CONOPS) that led to a set of vignettes were created. Using the vignettes as a baseline, the capabilities needed to meet the requirements were written. The specific requirement "Sustainment Agility" was chosen, to be decomposed and ran through the entirety of the schema in Figure 2, this serves as an example of the end to end steps needed to execute the author's methodology.

The chosen requirement, "Sustainment Agility", is then tied to the capability "Multi-Faceted Support" (see figure 4). That capability is the basis of the operational activity "Fuel Support" to illustrate the architecture necessary to execute the "Fuel Support" vignettes. The "Fuel Support" operational activity is expanded to show its operational flow including triggers and exit conditions (see figure 5). This provides the stakeholder with a visual functional flow diagram that captures the necessary actions to execute an operational activity. Following the operational flow is the functional decomposition needed to conduct that operational flow. From that functional decomposition components, followed by performers, are assigned to carry out those functions. The resulting product is a fully traceable architecture for the parent requirement "Sustainment Agility." Although not exhaustive, this study provides an example of an effective

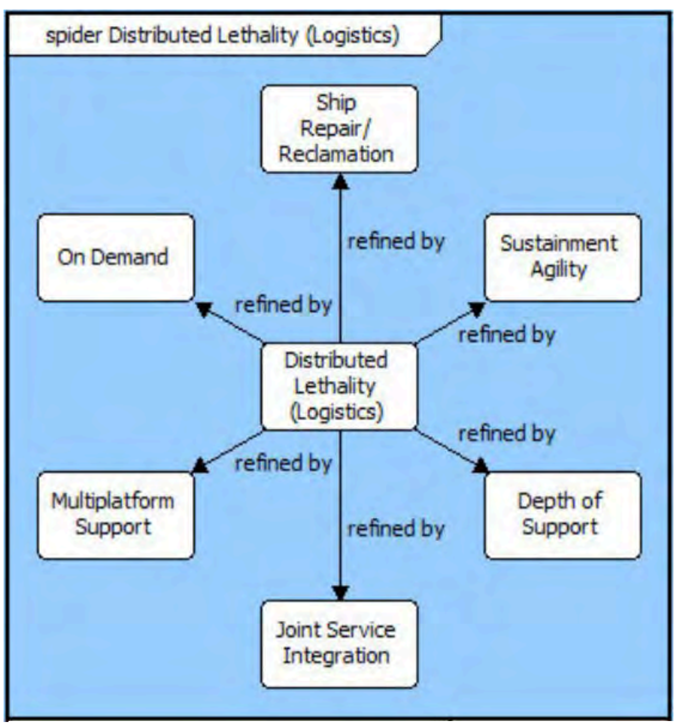


Figure 3: Requirements for Distributed Lethality.

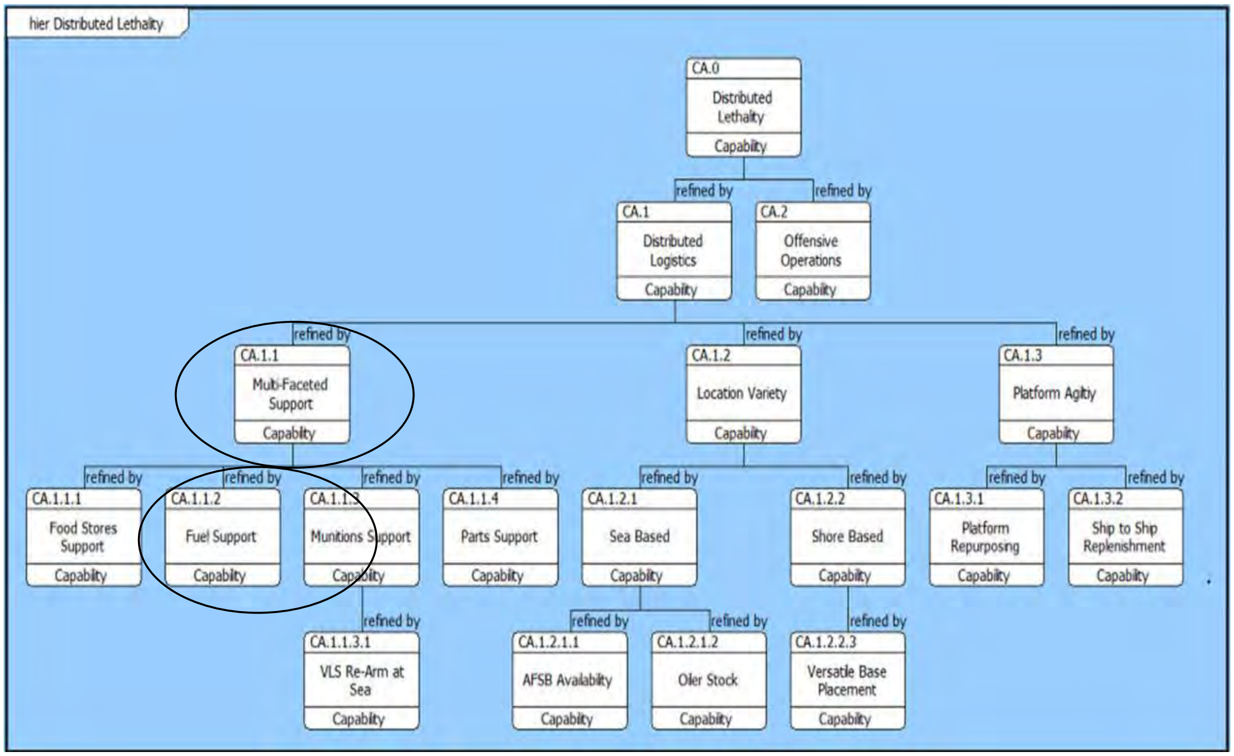


Figure 4: Decomposition of top-level capabilities

methodology for creating a complete Distributed Logistics architectural framework. We conclude that developing a baseline architectural framework that decomposes a high level requirement down to specific units or resources is necessary to capture the complexity of Distributed Logistics. Additionally, the collaboration required to create the architecture is easily implemented using the tools and methods presented here.

Recommendations for Further Research

Follow on research should focus on linking this architecture to a model for simulation. From this simulation, U.S. Navy leadership can extract measures of performance and effectiveness to ensure that the deployed surface forces are supported effectively while conducting distributed operations.

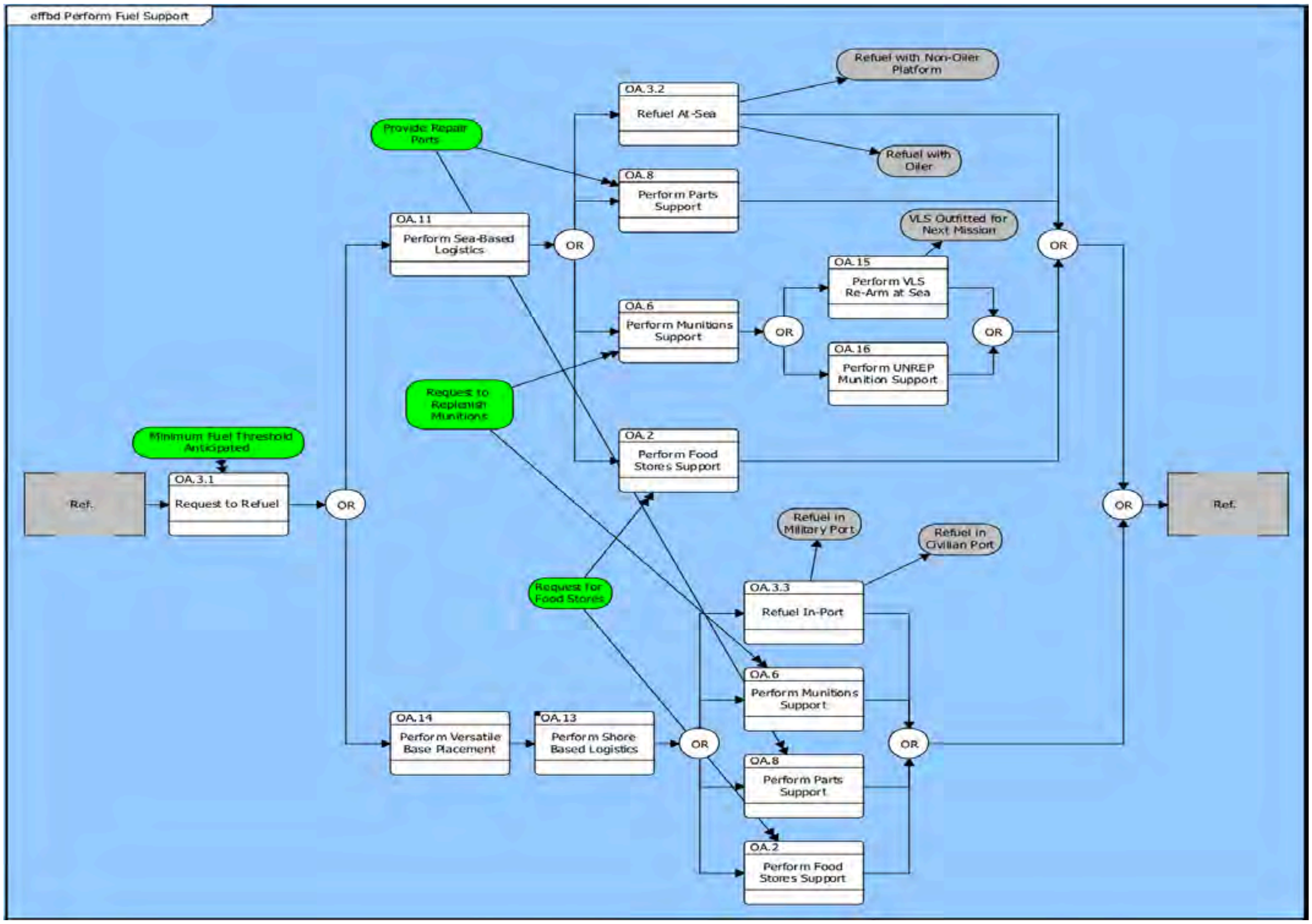


Figure 5: Operational Flow from Minimum Fuel Threshold Trigger

References

Chief Information Officer, U.S. Department of Defense. *DoDAF: DoD Architecture Framework Version 2.02.* August 1, 2010. http://dodcio.defense.gov/Library/DoDArchitectureFramework/dodaf20_arch_development.aspx (accessed January 17, 2016).

Fanta, Peter, Peter Gumataotao, and Thomas Rowden. "Distributed Lethality." *U.S. Naval Institute.* January 1, 2015. http://www.usni.org/magazines/proceedings (accessed June 8, 2015).

Harlow, Travis. *System Architecture for Logistics of a Distributed Naval Surface Force*. Master's Thesis. Monterey, California: Naval Postgraduate School, 2016

U.S. Department of Transportation, Office of Operations. "Systems Engineering for Intelligent Transportation Systems." *Federal Highway Administration.* January 2007. http://ops.fhwa.dot.gov/publications/seitsguide/section3.htm (accessed March 7, 2016).

Vitech Corporation. *Core 8: Architecture Definition Guide.* Blacksburg, VA: Vitech Corporation, 2011.

NPS-N16-N235-B: Logistic Network Model for Distributed Lethality

Researcher(s): Dr. Michael P. Atkinson, Dr. Moshe Kress and Dr. Roberto Szechtman
Student Participation: No students participated in this research project.

Project Summary

In this study we evaluate a Gas Station resupply method for Distributed Lethality (DL) scenarios, and obtain some insights about the interplay among spatial, temporal and capacity parameters related to this mode of resupply. Our motivating questions are: What is the effect of the ratio between supply ship capacity and combat ship on-board capacity on logistic responsiveness? How does the location of the Gas Station affect that responsiveness? What is the impact of the number of Adaptive Force Packages (AFPs) served by the Gas Station? Shall the Gas Station be a shuttle (i.e., a ship that goes back and forth to port to replenish) or a delivery ship that is being resupplied by a separate shuttle? Our results do not necessarily establish a specific blueprint for logistic planning, but rather point out at key factors and considerations.

Background

Changes in the global political and strategic environments have resulted in some modifications in U.S. defense strategies. In particular, these changes have led to the emergence of a new naval operational concept: Distributed Lethality (DL) [1]. From the force-employment point of view, the DL concept calls for fragmenting the traditional naval battle/strike groups into smaller, more agile and lethal Surface Action Groups (SAGs) or Adaptive Force Packages (AFP) comprising a small number of surface vessels. The SAGs and AFPs operate in a distributed manner over a relatively large area of operations. Tactical implications of the DL concept have been studied by the Commander, Naval Surface Forces, Surface and Mine War-fighting Development Center Command, and Naval War College (NWC). The studies are based on a Distributed Lethality Task Force and war games conducted at the NWC. The DL concept brings about a serious logistic challenge: how to effectively and efficiently satisfy logistic demands at different times and many locations dispersed over a large area. A fundamental dilemma in this context is choosing between two logistic principles: flexibility, derived from concentrating resources, and attainability obtained from distributing them [2]. Concentrating resources at the operational level, either on land or afloat, enhances logistic flexibility by directing resources only to areas of need. This principle has two important benefits. First, similarly to the inventory-pooling principle in commercial supply chain management [3], operational flexibility saves resources and enhances efficiency. Second, holding resources in a central location at the back of the area of interest (AOI) minimizes the logistic tail of the forward deployed AFPs, and thus reduces the AFPs' signature as targets, and make them more tactically agile. Third, keeping the inventories afloat in the relatively safe communication zone, beyond the threat area, enhances the survivability of the supplies. However, these positive features of concentrating logistics at the communication zone come at the cost of timeliness; the lead time required for shipping supplies from a central theater source at the back of the theater to the DL tactical units may be long.

SAGs or AFPs are small and agile; they may find it difficult to “drag" a logistic tail and protect it. Thus, the DL concept implies the transition from the traditional shuttle ship/ delivery ship setup, typical to CVN battle groups, where a delivery ship is attached to the battle group and a shuttle ship resupplies it with resources pulled from the theater logistic base, to a new approach that we denote the *Gas Station* setup. In the Gas Station approach, the AFPs need to travel back from the combat zone to meet a resupply source, e.g., an AOE or T-AO ship, in the communication zone. The objective of this study is to evaluate the Gas Station resupply method for DL scenarios and obtain some insights regarding the interplay among spatial, temporal and capacity parameters related to this mode of resupply.

Findings and Conclusions

Distributed lethality is an operational concept that embodies significant logistic implications. The existing logistic system supporting carrier battle group, where the logistic tail is an integral part of the tactical force – the shuttle-delivery ship setup – will clearly be inappropriate when the force structure is fragmented into small AFPs. Attaching a logistic tail to each such AFP is neither economically viable nor operationally feasible. A new logistic structure is required that adequately responds to the new naval force layout.

In this report, we model and analyze the Gas Station setup where an AOE is deployed at a certain resupply point in the communication zone and AFPs travel from their stations to that point to be resupplied. We define the utilization rate - the fraction of time the AFP is on station - as a measure of effectiveness. From a relatively simple model, with only one AFP, we see that for resupply points relatively far away from the AFP stations, the utilization rate is insensitive to the capacity of the AOE; the dominant factor is the travel time of the AFP to the resupply point. If the AOE is deployed closer to the combat area we see some differences in utilization rates for different capacities; for high capacities the utility is monotone increasing as the AOE gets closer to the combat zone but for low capacities there is an optimal resupply point closer to port. In the more realistic, and relevant, case when there are multiple AFPs we see that the utilization rate, as well as the probability an AFP has to wait for the AOE, are sensitive to the size of the operating force in the theater, but only when the force is relatively large. For any distance of the resupply point, the utilization rate is very similar when the force size is between one and four AFPs.

Recommendations for Further Research

The work in this project can be extended in several directions. The linear situation described in this report (optimizing the value of the resupply point on a line) can be extended to a two-dimensional situation, taking into account spatial considerations, as well as variable demand scenarios. Also, the underlying queuing problem may be addressed with more rigorous mathematical tools. Finally, while our research did address attritional aspects embedding the logistic model in a combat one may produce additional insights.

References
Rowden, T., Gumatautau, P. and Fanta, P., "Distributed Lethality", *Proceedings Magazine*, V. 141/1/1, 343. 2015.
Kress, M., *Operational Logistics – the Art and Science of Sustaining Military Operations*", Second Edition, Springer, 2016.
Kim, J-S and Benjaafar, S., "On the Benefits of Inventory-Pooling in Production Inventory Systems", *Manufacturing & Service Operations Management,* V. 4, No. 1, 2002.

NPS-N16-N235-C: Big Data and Deep Learning (BDDL) for Logistics in Support of the Fleet's Distributed Lethality Concept

Researcher(s): Dr. Ying Zhao, Dr. Shelley Gallup and Mr. Tony Kendall
Student Participation: Maj Kyle Opel USMC

Project Summary
The Distributed Lethality (DL) concept seeks to capitalize on the mobility and dispersed presence of naval forces, e.g., Surface Action Groups (SAGs), through increased lethality over an extended geographic area. Distributed Lethality presents challenges in logistics resource support needed specifically for distributed forces. These resources could potentially be provided by a diverse set of countries especially from the Western Pacific, if information driven reports and analytics were available to the logistics facilitators. Big Data and Deep Learning (BDDL) could be the means to provide that fusion, visualization, and analytic/reporting capabilities.

We investigated the BDDL concepts for resource management. We first worked with the sponsor to identify business and logistical operations the core business processes and databases that could support the DL concept. We then showed the potential benefits of using sample Big Data from the relevant current logistics databases and analyzing them using the state-of-the-art Deep Learning models.

Background
According to the Chief of Naval Operations (Distributed Lethality, 2015) , the so called *Distributed Lethality (DL) Concept* seeks to capitalize on the mobility and dispersed presence of naval forces (e.g., SAGs) through increased lethality over an extended geographic area. A distributed force as envisioned by the DL concept presents a logistics challenge that could potentially be met by a diverse set of countries in the Western Pacific if the information could be provided to the decision makes through Big Data. The DL concept requires new ways of organizing, training, programming, maintaining, equipping, and operating the surface force for combat readiness, material and personal readiness as well as new ways in managing logistics and the supporting information sources.

Project Scope and Objective

The goal of this project was to investigate the feasibility of applying Big Data and Deep Learning (BDDL) models to support the logistics of the DL concept. To apply the BDDL concept, the related databases, tools, systems and typical mission requirements for globally distributed geographical regions would be constantly fused, indexed, cataloged, visualized, analyzed, learned and compared without required standard data attributes.

Specifically, we developed the concepts of using BDDL models which include tools and databases to match the DL warfighting concept and requirements, i.e.:

- Globally distributed resources in geographical regions need to be constantly fused, indexed, cataloged, visualized and analyzed.
- The fused data are used for building BDDL models towards the capability of search, match and optimize the logistics requirements in real-time for the DL concept.

Findings and Conclusions

We first worked with the sponsor in order to understand the requirements of the DL warfighting concept and current logistics processes. The findings are summarized as follows:

The DL Warfighting Concept:

We studied the core DL concept which involves moving offensive capabilities in distributed locations and weaponizing new platforms that previously had no weapons. Related fighting forces include SAGs and Adaptive Force Packages (AFPs, 2015), where offensive forces are distributed and assembled according to the dynamic needs of the threats. One of the team members participated in the Valiant Shield 16 (VS16) exercise when the DL concept and the related force packages were experimented on. VS16 provided insight into the challenges of distributed combat operations at sea. A computer simulation, OSM (Orchestrated Simulation Modeling) developed by NSWC Dahlgren provided fidelity to the adjudication of the engagements. Though there were no combat logistics support vessels in the exercise, the weapons expenditures data, fuel use by the DL force, and ground truth data provided the basis for creation of multiple scenarios which can be run, with the addition of combat logistics.

Logistics Requirements for the DL Concept:

Distributed lethality means distributed vulnerability. The DL warfighting concept requires support of food, fuel, munitions, parts and platforms. The DL requirements include the following:

- The numbers and types of tactical players, e.g., SAGs or (AFPs) that can be used
- The spatial deployment of these assets
- The types of potential engagements they may be involved in

The DL concept addresses increasing the offensive firepower and lethality of the entire surface fleet—cruisers, destroyers, LCSs, future frigates, amphibious ships, and even replenishment ships (AFPs, 2015). A typical DL mission may need logistics to support the platforms, munitions, parts for the capabilities such as LCS, DDG, LHA, JHSVS, PBFM and P8. Can they be supported from the current sea based and shore based logistics operations? The DL concept may also require relocating logistics sources that are not usually in the current logistics resources, for example, partner nations and remote islands (e.g., the Wake Island).

The DL concept requires new ways of organizing, training, programming, maintaining, equipping, and operating the surface force for combat readiness, material and personal readiness. New combat conditions such as the Anti-Access/Area Denial (A2AD) environment which challenges the current logistics systems and they are addressed in the DL concept (Armstrong, B.J., 2016).

The Current Logistics Support Concept:

The current Navy's logistics support concept is based on defending a carrier centered strike group. There are ten of such carrier groups for U.S. However, in a DL concept, weaponized smaller and distributed forces can be hundreds even thousands. We studied the current logistics processes to support carrier groups including dimensions such as food, fuel, munitions, parts and platforms summarized in Table 1.

	Supply Sources	**Managed by Databases**	**Mechanisms**
Food	US sourced food services, foreign certified contractors for market ready, local fruit & vegetable	ShipCLIP, BirdTrack	
Fuel	Defense Logistics Agency (DLA), Military Sealift Command (MSC)	Replenishment at Sea Planner (RASP)	
Munitions	Ashore bases or Vertical Launching System	OIS, SIPR LOGCOP	
Parts	MSC ships	BirdTrack	Casualty Reports (CASREP)
Platforms	ShipCLIP	SIPR LOGCOP	Five Centralized Logistics Office (CLO), i.e. Norfolk, 3rd , 7th ,5th and 6th fleets

Table 1. Current logistics concept.

Navy's logistics force includes N.40, N.41, N.42 and N.43. The sea basing assets include so-called floating warehouses managed by Combat Logistics Force (CLF) and Military Sealift Command (MSC). Table 1 shows a list of current logistics databases used.

The BDDL models for supporting the DL concept:
We extracted three years (8/2013 to 8/2016) of 84 Aegis ships about 1 million requisition documents from the BirdTrack or Average Customer Wait Time (ACWT) to demonstrate that incorporating the BDDL models is critical and feasible for the Logistics Innovation for the DL concept. The following capabilities are critical for a BDDL to support:

- Data visualization tools, e.g., geospatial displays such as Google earth in Logistics Common Operational Picture (LOGCOP) to locate goods and materials in real-time.
- Data fusion including data strategies and database tools that combine the structured and unstructured data sources virtually and possible physically, therefore relevant data can be indexed, cataloged and searched in a one-stop shop. For example, BirdTrack (BirdTrack, 2005) or Average Customer Wait Time (InforM-21 ACWT) and other tools hosted at Naval Supply Systems Command (NAVSUP) InforM-21 run on commercial-off-the-shelf hardware and software. The infrastructure is flexible and can be enhanced it as-required basis.
- Data analysis tools including machine learning and data mining from historical data, pattern recognition, association and optimization tools that datamine relevant heterogeneous data sources first, and then apply patterns and associations to optimize the logistics metrics for the DL concept, e.g., Deep Learning algorithms like Lexical Link Analysis (LLA).

Recommendations for Further Research
There are tremendous challenges in the conceptual level to leverage and transform the current Navy's logistics concept summarized as follows:

- The current logistics systems and processes were designed to support the defense of strike groups. They may not be able to support the requirements from the DL concept, for example, can they support replenishment at sea.
- Logistics data models that are needed to be specifically designed to meet the requirements of the DL concept, therefore relevant data can be indexed, cataloged and searched in a one-stop shop.
- Current logistics tools hosted at NAVSUP InforM-21 is flexible but needs innovation to incorporate the BDDL tools and analytics that are needed for the DL concept such as machine learning and data mining from historical data; apply pattern recognition, association and optimization for real-time logistics management.
- The Navy's logistics innovation concept (Logistics Innovation, 2017; LOGCELL, 2016) can be used as venues and platforms to implement the BDDL models and support futuristic warfighting concepts.

Firstly, we recommend designing the DL logistics support data models using LOGCOP together with BirdTrack which already contain many relevant data feeds. The data models need to gradually to expand to include MSC, OIS, FIMARS, FSM & Navy ERP to address the needs of the DL scenarios.

Secondly, we recommend extending the existing analytic capabilities such as the Google earth interface and real-time reports in the current logistics tools to include the new web based BDDL models such as Data-Driven Documents (D3) and Deep Learning such as Lexical Link Analysis (LLA).

Thirdly, we recommend researching on how the results from the BDDL, e.g., patterns, associations, correlations and trends that are discovered in the historical data, can be applied to optimize the real-time DL logistics support, with respect to the current logistic measures. The measures may include cost, agility, efficiency including ACWT (average customer wait time), SCOR (supply chain operations reference) model, on-time delivery and receipt, order cycle time, variability and response time, supply chain responsiveness, average order fulfillment cycle time, lead time against benchmarks, and efficiency of "purchase" order cycle time.

References

AFPs. (2015). Retrieved from http://breakingdefense.com/2015/10/navys-distributed- lethality-will-reshape-fleet/

Armstrong, B.J. (2016, October 5). Retrieved from "The Shadow of Air-Sea Battle and the Sinking of A2AD." War on the Rocks: https://warontherocks.com/2016/10/the- shadow-of-air-sea-battle-and-the-sinking-of-a2ad/

BirdTrack. (2005). Retrieved from http://www.doncio.navy.mil/CHIPS/ArticleDetails.aspx?ID=3179

Distributed Lethality. (2015). Retrieved from http://news.usni.org/2015/07/09/navy- studying-implications-of-distributed-lethality-in-wargames-seriesME

DL and Ship Repair. (2017). Retrieved from http://www.realcleardefense.com/articles/2017/02/16/distributed_lethality_and_the_importance_of_ship_repair_110814.html

LOGCELL. (2016). Retrieved from http://onenavsup.navylive.dodlive.mil/2016/04/20/innovation-continues-at- naval-supply-systems-command-business-systems-center/

Logistics Innovation. (2017). Retrieved from http://scnewsltr.dodlive.mil/2016/06/03/navsup-logistics-Innovation/

NPS-N16-N568-A: Integration of Airborne ELINT/EW Collection Systems

Researcher(s): Mr. Tony Kendall and Dr. Arkady Godin
Student Participation: No students participated in this research project.

Project Summary

The researchers investigated the feasibility of a single, compatible system architecture for processing, exploitation, and dissemination (PED) of Electronic Warfare/Electronic Intelligence (EW/ELINT) data from multiple airborne systems for ingestion into existing Gale Lite analytics. The goal is to achieve a "NIFC-EW" or symbolically similar to NIFC-CA (Naval Integrated Fire Control – Counter Air). The basic idea behind NIFC-CA is to expand situational awareness until every unit within the carrier strike group—in the air, on the surface, or under water—can be networked through a series datalinks to show a common tactical picture and to aid in targeting. The EW version would add the capability to integrate non-real time airborne EW/ELINT data and eventually real Time (RT) data for inclusion into the repository for existing analytics.

Currently, airborne EW/ELINT collection systems generate and store EW/ELINT data in numerous data format transformations. The sequence of formats should be such that the final format in the transformation would be process-able by a new repository (near real time or NRT data) or the existing GALE-Lite repository for non NRT.

The basic research question then is how can the collection capabilities from a myriad of airborne collection methods be effectively and efficiently utilized in order to prevent good intelligence from being lost or not accessible for analysis? A secondary research question is, how can a unified system be developed to process, exploit, and disseminate those data for the battlegroup?

Background

The Joint Operational Access Concept (JOAC) describes in broad terms how forces will operate in response to emerging anti-access and area-denial (A2/AD). The JOAC A2/AD concept requires detailed intelligence integration across all security domains and requires a reexamination of the current classification, access to data, and toward integration as the key to countering A2/AD. Our focus is on EW/ELINT and integrating GENSER EW/ELINT and Sensitive Compartmented Information (SCI) sensor data which presents challenges in security, integration, and the "need to know".

Findings and Conclusions

Our investigation concluded that current technology used in the commercial world can provide a number of solutions for accessing and integrating disparate data formats in near real time (NRT) to be exploited by the existing GALE-Lite analytics.

There are three basic tasks that need to be accomplished for success:

- Near Real Time data needs connectivity back to CVN.
  NPS Research concluded that the network and its capabilities are the biggest impediment to the research problem. "Transmit" capability is required for airborne platforms and an ad-hoc airborne network for Beyond-Line-of-Sight (BLOS) connecting EW/ELINT airborne platforms with CVN CDC EWMOD, NPS researchers concluded combination of TTNT (Tactical Targeting Network Technology*)* and CDL/NTCDL (Common Data Links/ Network Tactical Command Data Links) may deliver EW/ELINT on board CVN CDC EWMOD. For BLOS relay nodes such as using an airborne asset like the E-2C/D may be required. Alternatively, the airborne ELINT data could be stored in NTC (Navy Tactical Cloud) or alternative cloud if one gets established. However, refreshing the new repository may be problematical as network access cannot always be guaranteed. NTC is still a work in progress.
- Data must be integrated and ingested into the data repository for use by the analytics.
  GALE-Lite uses an Oracle relational database so there are many standard tools to load the data into the database (ingestion) for use by the analytics. Most of the formats are text based (XML or CSV) and therefore an adapter can easily be created to transform XML or CSV based into the tables that are used by the analytics.
- Data management must be able to process NRT streaming data.

The current database management system may not be able to handle “hot” near real-time and “live” real-time streaming data. To handle the demands of both velocities the In-Memory Data Base (IMDB) class of databases is required. SAP’s HANA IMDB offers support of the concept of “dynamic tiering” to organize the database architecture for EW/ELINT (and beyond) as a stack of databases operating at different speeds. Having IMDB EW-ELINT near real-time/real-time repository in CVN CDC EWMOD operating at GENSER security domain seamlessly integrated with existing Oracle relational database as a GALE-Lite non-real-time repository in CVN CIC SESS/SUPPLOT operation at JWICS is expected to handle existing and future EW/ELINT repository requirements for Intelligence and Operational EW/ES missions.

Recommendations for Further Research

1. EW/ELINT INTEGRATION PROOF OF CONCEPT - Test the concept of importing non-real-time, NRT and “live” real-time streaming data for ingestion and integration into GALE-Lite analytics.
2. EW/ELINT INTEGRATION PROOF OF CONCEPT - Investigate airborne network emulation/T&E (Testing and Evaluation) in support of EW/ELINT integration.
3. INTEGRATION WITH BIG DATA ECOSYSTEM - Existing GALE analytics were developed prior to Big Data requiring a transformation of existing Distributed Database Systems to Big Data Ecosystems. It has been realized that moving data to the computations is inefficient from as limited network bandwidth continues to remain as a constraining factor. What is becoming prevalent now is embedding analytics into Distributed Databases. A pluggable capability creates an ecosystem comprised of Big Data Computational Storage Platforms.
4. REQUIREMENTS FOR RUNNING BIG DATA ANALYTICS - Some types of Big Data Computational Storage Platforms support plugging in analytics developed in high-performance languages (e.g. C++, Java, etc.). Distributed Database Systems, which were designed prior to the Big Data revolution, have been offering a mechanism of stored procedures programmed in proprietary languages which are unique to each of the Distributed Database Systems. The ability of novel Big Data Platforms to run analytics programmed in high-performance language with awareness of heterogeneous hardware underneath improves speed, scalability and reusability of the analytics executed in Polystore’s heterogeneous Big Data Computational Storage Platforms. Each of the platforms uses its own type of the data model representation.
5. NEW ANALYTICS DEVELOPER TO LEVERAGE BIG DATA ADVANCES - The future of the integration of existing analytics developed for ELINT would include two kinds of ports of the analytics to those platforms: (a) port of the analytics to the Big Data platform which supports Relational Data Model Representation (DMR), it’s not that difficult; and (b) port to different DMR platforms, which may be tricky to do. The latter may be needed whenever ELINT application requires Exascale Graph analysis. The NPS research team envisions a future need of “correlation and fusion analytics” where a Relational Data Model representation may not work due to its sheer focus on sparse data. Future storage must be flexible to support sparse and dense data.

References

F Dunford, J W Greenert, and P F Zukunft, "A Cooperative Strategy for 21st Century Seapower: Forward, Engaged, Ready" [CS21R], March 2015, available at www navymil/

Central Intelligence Agency, "ELINT: A Scientific Intelligence System", 22 Sep 1993, https://www.cia.gov/library/center-for-the-study-of-intelligence/kent-csi/vol2no1/html/v02i1a06p_0001.htm

Tactical SIGINT Data Format Overview, TE2 Mission System Engineering, Jul 2016.

Doug Henschen, "In-Memory Databases", Information Week, March 2014, http://dc.ubm-us.com/i/268861-informationweek-2014-03-03

Doug Henschen, "Two Approaches to In-Memory Database Battle", Information Week, March 2014, http://www.informationweek.com/software/information-management/two-approaches-to-in-memory-database-battle/d/d-id/1114088

"SAP HANA Defining Capabilities", SAP White Paper, Database Trends and Applications, November 2013, http://www.dbta.com/DBTA-Downloads/WhitePapers/SAP-HANAs-Defining-Capabilities-4805.aspx

"Antiaccess / Area-Denial: Old Concepts, New Frontiers", A Monograph by LCDR William F. Cunningham, USN, School of Advanced Military Studies, United States Army Command and General Staff College, Fort Leavenworth, Kansas, 2015-01

Cliff et al., Entering the Dragon's Lair, 54, 56; *Tol, Jan Van. AirSea battle, 27; Secretary of Defense, "China Military and Security Development 2014," 32.*

Cliff et al., Entering the Dragon's Lair, 76;

Secretary of Defense, Annual Report to Congress – Military and Security Developments Involving the People's Republic of China (Washington, DC: Government Printing Office, 2011), 29; Robert haddock, "China's Most Dangerous Missile (So Far),", War on the Rocks, last modified July 2, 2014, http://warontherocks.com/2014/07/chinas-most-dangerous-missile-so-far/

Kraska, How the United States Lost the Naval War of 2015, 44.

Tol, Jan Van. AirSea battle, 71.

Tim Mattson, Intel PI for the Big Data "Intel Science and Technology Center", www.clsac.org/uploads/5/0/6/3/50633811/mattson.pdf

NPS-N16-N572-A: Reduce Single Point of Failures for a Ship's System

Researcher(s): Mr. Arijit Das and Dr. Man-Tak Shing
Student Participation: LTJG Kadir Deniz Elmas TNF and Maj Roy Agila USMC

Project Summary
The project aimed to look at various ways to alleviate the failure points in a ship's network. The sponsor gave several options and the NPS team focused on 2 challenges, namely Database (DB) failover, and the use of virtualization for mobile device use.

Keywords: Database Failover, virtual pc, mobile devices.

Background
A ship has a full-fledged IT (information technology) infrastructure that needs to be updated and maintained. While land based systems are well connected to high speed networks, the ship has to rely on slower speed satellite networks. When a ship is out in the sea for months land based systems get constant software updates and security patches, thus managing to stay current. Replacing hardware on a ship is far more challenging given its deployment away from land. In spite of these limitations a ship has to be fully functional (always) and needs to meet the challenges of its designated role. Several NPS student theses focused on the use of technology to keep the ship's IT infrastructure up and running, while requiring minimal human intervention.

Findings and Conclusions
Navy has a software license for the Oracle Database and uses it extensively to conduct its IT business. Every ship's network and IT infrastructure includes a DB at the very least. If the DB fails then key functions are disrupted. The first thesis topic focus was on Oracle Data Guard (vendor solution) to ensure uptime even when there is a failure, and the ability to recover seamlessly. The fundamental aspect of the technology uses two or more DBs that are always mirror of each other. The thesis showed that it is possible for an IT professional to setup this technology, and maintain it for support of IT systems. A few tests were implemented to mimic real world scenarios. The DB Thesis showed that the vendor technology does work and is not out of the realm of a Navy tech professional to support and maintain. This gives the Navy some confidence to try it on a ship on a test basis.

The next thesis focus was the use of mobile devices for online training requirements. Normally training is done using dedicated desktops, this puts a limit on the efficient usage of resource and time, while most sailors have their own mobile devices, using it for training poses a security challenge. The thesis looked at technology from VMWare know as Horizon View that lets one create a secure virtualized Personal Computer (PC) that resides on the ship's network, which can be accessed via a thin client from a Common Access Card (CAC) enabled mobile device. The ideas from this thesis were also applied to a Marine Net eLearning study.

The thesis looked at various mobile devices using cost as a factor and tested the effectiveness of using a mobile device for training. Network speeds were measured using tools to provide a basis of comparison. The results did show the efficacy of using CAC enabled devices with the virtual PC technology, thus meeting the security and lower costs goal.

Recommendations for Further Research

There were many questions at the outset and only two were researched, so as a next step researchers can consider the other questions also. The suggested solutions from the two theses would gain validity if tested in a real ship's network. Technology is in a constant state of flux and these very same questions could be researched with newer hardware and software.

NPS-N16-N576-A: Unclassified Maritime Domain Awareness

Researcher(s): Dr. Dan Boger and Mr. Scot Miller
Student Participation: CDR Erik Lavoie USN and LCDR Erin Wreski USN

Project Summary

The maritime domain is an area of significant strategic concern to the United States and its allies. When the need arises, U.S. forces are able to detect and monitor vessels of interest (VOIs) in support of maritime interests throughout the world. However, current maritime domain awareness (MDA) processes lack the ability to provide actionable information in a timely and usable manner. Advances in intelligence, surveillance and reconnaissance (ISR) technology—particularly unclassified data sources, analytical processes and tools—available in the commercial sector could be leveraged to make MDA data more accessible and productive.

The purpose of this research is to establish a concept of operations (CONOPS) that will provide an unclassified maritime common operational picture (COP) with the capability to produce near-real-time shareable information from which all authorized interested parties can benefit. The research focuses on utilizing available unclassified commercial-off-the-shelf (COTS) capabilities to create a scalable and extensible platform that provides intelligence analysts and decision makers the ability to gain additional situational awareness and gather actionable information which can be quickly and easily shared with other service and international partners. Additionally, in an effort to prove the proposed CONOPS will work, the process was attempted utilizing some of these technologies.

Keywords: Maritime domain awareness, feature recognition, EO satellite imagery, concept of operations, SPOTR, commercial satellite imagery, SeaVision

Background

The Naval Postgraduate School Information Science Department has proposed a two-year campaign of integrated thesis research designed to explore and develop ideas relating to the development of an unclassified maritime domain awareness (MDA) concept of operations

(CONOPS). U.S. forces are able to detect and monitor the maritime domain in support of maritime interests around the world, but often lack the ability to provide actionable information in a shareable, useable manner. This issue, in particular, is an ongoing Commander Seventh Fleet (C7F) topic of interest due to the complex MDA issues present in their area of responsibility (AOR). The intent of this thesis is to take the first step in the development of a fully implementable CONOPS that leverages recent developments in unclassified commercial-off-the-shelf (COTS) intelligence, surveillance and reconnaissance (ISR) capabilities to build a comprehensive common operational picture (COP). The overarching goal of the COP is to provide the who, when, what and where for maritime vessels of interest (VOIs) adaptable to specific areas of interest (AOIs) so that operators and intelligence analysts, who will infer the why and how, can make informed actionable decisions and/or share data with interested parties.

MDA is defined as "the effective understanding of anything associated with the maritime domain that could impact the security, safety, economy, or environment of the United States" (White House, 2013, p. 2). It encompasses "all areas and things of, on, under, relating to, adjacent to, or bordering on a sea, ocean, or other navigable waterway, including all maritime-related activities, infrastructure, people, cargo, vessels, and other conveyances" (White House, 2013, p. 2). What is happening in the waterways around the world is becoming an increasing concern. Technological advances in recent decades have provided an environment that has allowed the global capital market to grow and open new economic opportunities via complex commerce pathways. The global supply chain is becoming increasingly dependent on interconnected waterways to support these expanding opportunities and, as a result, they have become essential to the United States' national economy, commerce and security. However, the increasing number of countries and vessels moving freely through these waterways is creating complex security issues. Harmful and unlawful acts within this increasingly important domain can cause the disruption or destruction of a physical and economic nature to the United States and its partners (White House, 2012). There is no shortage of these threats to national security and economic interests. These include terrorism, criminal activities, piracy, environmental destruction, illegal immigration, and human and drug trafficking to name a few (White House, 2013). The core principles of effective MDA promote a unity of effort through proper information sharing and safeguarding in order to facilitate informed decision making to ensure the safe and timely movements of legitimate commerce (White House, 2013).

When the need arises, U.S. forces are able to identify and track VOIs in support of these maritime interests. However, the means by which this data is collected and processed often does not result in information quickly or in a form that is easily shareable, which can result in lost opportunities. The data often comes from classified sources. Additionally, data persistence is difficult to maintain because it is either too expensive to sustain continuous operation of the sensor and/or there are too few personnel or resources to commit to data and information gathering objectives. This creates a reactionary environment for data analysts and decision makers who would prefer to know and act on the threat before the damage is done.

Findings and Conclusions

The goal of this thesis was to construct an unclassified CONOPS strategy to meet the evolving needs of fleet and operational commanders in the execution of MDA. The CONOPS presented is the result of extensive research into current operational MDA methods and requirements and new or improved ISR technologies. Those findings were used to develop a CONOPS that could produce unclassified data fused from numerous input sources that is low-cost, low bandwidth and easy to use. Having developed a CONOPS that met those requirements in theory, it was tested to validate its feasibility and flush out the initial imperfections.

The testing methods simulated the recommended process by utilizing the same technologies for data retrieval, processing and display suggested in the CONOPS, DigitalGlobe, SPOTR and SeaVision respectively. The concept behind the initial attempt was to detect, classify and identify a set of non-cooperative vessels using only the unclassified technologies suggested. Due to time and access constraints, however, a complete test of the CONOPS was not possible. The classification, identification and data input steps of testing via the automated system was not completed. The manual method and automated detection results received did expose multiple strengths and weakness of the three subsystems used and the overall CONOPS processes that can be improved upon in future attempts to test and refine the process.

New and evolving maritime threats and concerns require new and creative ways to conduct MDA. The CONOPS presented in this thesis is a simple yet powerful tool that creates a collaborative platform for all concerned entities to share information. It combines cooperative vessel tracking systems already in place with processed data derived from high-resolution commercial satellite imagery to provide data on vessel movements all over the world. Initial testing demonstrated that together these systems can provide a wealth of information in a fraction of the time and cost required by the cumbersome methods used currently. Further development will be required to move the CONOPS from theory to reality, but the capabilities to make the transition exist. Additionally, beyond the new and expanding COTS technologies suggested, the CONOPS provides an avenue for future growth because of its inherent flexibility, scalability and extensibility. Changes in the input sources to SeaVision, a service-orientated application, rarely affect the user. As long as the changes present the user with added benefits and remain easy to use, adoptability and acceptability will not be a concern.

As with any new information platform utilized by operators and analysts, especially one which provides valuable information on the movements of national and foreign assets, there will be some pushback. This will arise from concerns as to the level of information the system provides and who has access to it. This CONOPS provides a means to gather and share public information via a platform that is unclassified from source to display. As long as the information presented in this platform remains of common interest to all users, such as securing borders and the freedom of movement, classification concerns should be minimal. It simply provides a single comprehensive capability that could allow the flow of useful unclassified information between agencies and allies to enable an effective MDA environment beneficial to all.

Recommendations for Further Research

More effort needs to be made to integrate the various technologies together to form the complete COP. The next steps should include importing the imagery-based SPOTR derived track data into SeaVision and maturing the SeaVision application as future capabilities become available.

Import Imagery Data into SeaVision: The most significant hurdle to making the COP a reality is transforming SPOTR derived track data into an acceptable message format for input into SeaVision real time. Certain steps are required to import the current SPOTR contact and tracking information to the SeaVision COP. Along with using the correct image download format, National Imagery Transmission Format Standard (NITFS), the speed of data acquisition and transfer must be increased.

The next challenge to overcome is displaying the SPOTR data on the SeaVision COP. This will require the data to be input into the proper message format. One of the primary reasons SeaVision was selected for the COP display is because it is already built to allow National Information Exchange Model (NIEM) conformant exchanges (Department of Transportation, n.d.). This means that SeaVision can quickly assimilate new data sources, including those from new services, other agencies and foreign partners.

Transition to Future Capabilities: This CONOPS is meant to allow for future growth and expansion providing capabilities beyond data display and correlation if desired. With the proper tools in place, it could be leveraged for social network analysis along with big data analytics and dynamic logic to go beyond the who, what, where and when, but start to answer the why and how. Most COPs in existence today fail to provide information beyond answering the questions of who and where (Arciszewski & De Greef, 2011). Recent advances in big data analytics could provide new ways to further exploit the information this COP provides. With high-level data abstractions and advanced fusion techniques, detection of VOI operating patterns may be detected. With a big data approach, the sources of the unclassified COP could be ingested into a distributed file system to derive big data solutions that recognize such patterns. Analysis of these patterns and social networks can provide suggestions on how monitored vessels match planned or predicted movements or actions. These patterns of life could aid in the determination of activity and intent which would be a breakthrough in data exploitation.

References

Arciszewski, H. F. & De Greef, T. E. (2011). *A smarter common operational picture: The application of abstraction hierarchies to naval command and control*, Presented at the 16th International Command and Control Research and Technology Symposium, Quebec City, 2011. The Hague, The Netherlands: TNO Defense. Retrieved from https://www.researchgate.net/publication/235039633

Boraz, S. C. (2009). Maritime domain awareness: Myths and realities. *Naval War College Review*, *62*(3), 137.

Chinese naval bases. (n.d.). Retrieved February 21, 2017, from http://www.globalsecurity.org/military/world/china/ports.htm

DigitalGlobe. (2014, June 11). U.S. department of commerce relaxes resolution restrictions digitalglobe extends lead in image quality [Press Release]. Retrieved from http://investor.digitalglobe.com/phoenix.zhtml?c=70788&p=irol-newsArticle&ID=1939027

Digital Globe. (2016, 05 February). EV-WHS Desktop user manual. Retrieved from https://evwhs.digitalglobe.com/myDigitalGlobe/login homepage

Digital Globe fact sheet. (2017, January 19). Retrieved from

https://evwhs.digitalglobe.com/myDigitalGlobe/login

Faltemier, T., Steinhaeuser, K., Miller, D., & Paradis, L. (2016, June 20). Computer vision for maritime domain awareness [PowerPoint]. Manassas, VA: Progeny Systems Corporation.

Seavision. (n.d.a). FAQ webpage. Retrieved on January 17, 2017 from http://seavision.mda.gov/faq

SeaVision (n.d.b). What is seavision. Retrieved on September 10th, 2016 from http://seavision.mda.gov/about-seavision

Steinhaeuser, K. (2016). SPOTR operational view [Power Point Slides]. Manassas, VA: Progeny Systems Corporation.

U.S. Department of Transportation. (n.d.). Seavision information sheet, version 5.0. Retrieved on 17 February 2017 from http://ec2-107-22-98-244.compute-1.amazonaws.com/sites/default/files/2016-03/SeaVision_v5.06%20(glossy)_0.pdf

Volpe Center. (n.d.) Maritime safety and security information system (MSSIS). Retrieved on 17 February

2017 from https://www.volpe.dot.gov/infrastructure-systems-and-technology/situational-awareness-and-logistics/maritime-safety-and

White House. (2012). *National strategy for global supply chain security (NSGSCS)*. Executive Summary. Washington, DC: The White House. Retrieved from https://obamawhitehouse.archives.gov/sites/default/files/national_strategy_for_global_supply_chain_security.pdf

White House. (2013, December). *National maritime domain awareness plan for the national strategy for maritime security*. Washington, DC: The White House. Retrieved from https://obamawhitehouse.archives.gov/sites/default/files/docs/national_maritime_domain_awareness_plan.pdf

United States Marine Corps

Marine Corps Combat Development Command (MCCDC)

NPS-N16-M163: Exploring Potential Alternatives Using Simulation and Evolutionary Algorithms

Researcher(s): Dr. Susan Sanchez, Dr. Thomas Lucas, Ms. Mary McDonald and Mr. Stephen Upton
Student Participation: No students participated in this research project.

Project Summary
The NPS SEED Center has teamed with the Marine Corps Combat Development Command (MCCDC) Operations Analysis Division (OAD) to research, develop, and design methods and software tools that enable broad-scale search for viable, effective solutions for prosecuting a maritime campaign. Elements of the problem domain are represented in an agent-based simulation model, and the search for solutions exploits the power of evolutionary algorithms (EA). An EA is a stochastic search algorithm that is based on the principles of natural selection, e.g., "survival of the fittest." Though not guaranteed to converge to optimal solutions, EAs have been used successfully for decades to find good solutions relatively quickly—even over large, complex search spaces. This research develops, tests, and delivers a software package that (1) generates a set of possible solutions, (2) programmatically translates the individual solutions into a set of scenario files, (3) executes the distributed simulation runs on high performance computing assets, (4) extracts data from simulation output to evaluate the overall 'fitness' of the potential solution, and (5) uses an evolutionary algorithm to create the next set of solution vectors to try. The process eventually stops when some user-specified criteria are met. The objective is to enable broad-scale search for Blue Force alternatives and strategies in a simulation scenario by exploiting the power of evolutionary algorithms.

Keywords: Evolutionary Algorithms, Simulation, Big Data

Background
The objective of this research is to improve the ability of OAD analysts to quickly and efficiently obtain experimental information from a given simulation scenario using an evolutionary algorithm. In FY15, OAD and Systems Planning & Analysis (SPA) completed a two-year study of the Austere Basing Concept of Operations (CONOPS), using the Global Change Assessment Model (GCAM) modeling environment (SPA, 2015). Use cases developed in GCAM for this study were derived from recent Marine Corps and SPA work on CONOPS for F35-B Distributed Short Takeoff and Vertical Landing (STOVL) operations.

This CONOPS arose in response to the Air Sea Battle (ASB), which drew inspiration from the Joint Operational Access Concept (JOAC). The JOAC was developed in response to threats posed by Anti-Access/Area Denial (A2/AD) systems. The Marine Corps requires a thorough analysis of the challenges associated with operating from austere bases in the evolving A2/AD environment in order to better understand the structure of the problem domain, as well as identify those factors having the greatest impact on austere base operations.

This research develops an evolutionary search algorithm, in conjunction with a simulation developed for OAD, in order to create a planning tool that will be useful to achieving the aforementioned objectives.

Findings and Interim Conclusions

We completed the prototype of Automated Red Teaming Multiobjective Innovation Seeker (ARTeMIS), a software application written in the scala programming language that implements a self-adaptive evolutionary algorithm that is designed to search for a diverse set of robust solutions in a multi-objective problem space. Creating the ARTeMIS prototype involved a variety of specific activities. For example, we implemented several strategies from the evolutionary strategy literature, such as the two-objective problem of Deb (2001) and a modified version of the famous "1 to 5 rule" of Schwefel (1975).

Our initial plan was to apply ARTeMIS to an OAD scenario created by Systems Planning & Analysis in the GCAM modeling platform (SPA 2015). Delays in the release of funding, due in part to the incremental release of NRP funds and in part to Continuing Resolutions, meant that we were unable to requisition and purchase the custom GCAM scenario necessary for completing this task. With OAD's approval, we instead selected the Map Aware Non-uniform Automata (MANA) environment (McIntosh 2009) as the simulation modeling platform for proof-of-concept purposes.

In order to test and refine the algorithm, we ran ARTeMIS on a simulation scenario co-developed by NPS and the U.S. Military Academy Systems Engineering Department using the MANA modeling environment (MacCalman et al. 2016). The simulation scenario captures an Army Infantry Squad conducting an assault, and the variables spanned a set of potential technological enhancements provided to the Squad. Additionally, we developed a new MANA scenario for MCCDC OAD. The OAD MANA scenario simulates the problem of finding Red mobile Anti-Ship Cruise Missiles (ASCM)-launcher teams that present a threat to a shipping convoy, and the variables represent Unmanned Aerial Vehicle (UAV) characteristics and employment.

Our planned activities between now and the project completion in June 2017 are:
Running ARTeMIS on the OAD MANA scenario;
Analyzing and briefing ARTeMIS results to OAD;
If necessary, making scenario or algorithm improvements based on the discussion with OAD;
Documenting the use and main functionality of ARTeMIS; and
Developing a final report or annotated briefing.

Recommendations for Further Research

Further research could apply the EA approach to a GCAM scenario, as originally intended. ARTeMIS could be used to explore potential Red Force alternatives as a form of Automated Red Teaming (ART), in which the goal is to seek and understand ways that Red might be able to thwart Blue's plan (McDonald & Upton 2004). Automated Red Teaming is meant to supplement human red teaming efforts.

Further research is needed on the relative benefits of using (1) ARTeMIS, (2) a large-scale, single-stage designed experiment as discussed in Kleijnen et al. (2005) or Sanchez et al. (2012), or (3) a sequential design-of-experiments method. Ultimately, a better understanding of these approaches should improve the defense community's ability to glean timely insights from simulation scenarios.

Additional recommendations will be provided with the final report.

References

Deb, K. (2001). Multi-objective optimization using evolutionary algorithms. New York, NY: Wiley.

Kleijnen, J. P. C., Sanchez, S. M., Lucas, T. W., & Cioppa, T. M. (2005). A user's guide to the brave new world of designing simulation experiments. INFORMS Journal on Computing, 17(3), 2005, 263-289.

MacCalman, A. D., Sanchez, S. M., McDonald, M. L., Goerger, S. R., & Karl, A. T. (2016). Tradespace analysis for multiple performance measures. In T. M. K. Roeder, P. I. Frazier, R. Szechtman, E. Zhou, T.

Huschka, & S. E. Chick (Eds.) Proceedings of the 2016 Winter Simulation Conference (pp. 3063-3074), Piscataway, New Jersey: Institute of Electrical and Electronic Engineers.

McDonald, M. L. & Upton, S. C. (2004). Breaking blue: Automated red teaming using evolutionary algorithms. in: Proceedings in the Genetic and Evolutionary Computation Conference, Seattle, WA, 2004.

McIntosh, G. C. (2009). MANA-V (Map Aware Non-uniform Automata-Vector) Supplementary Manual. Defense Technology Agency, New Zealand.

Sanchez, S. M., Lucas, T. W., Sanchez, P. J., Nannini, C. J., & Wan, H. (2012). Designs for large-scale simulation experiments with applications to defense and homeland security. In K. Hinkelmann (Ed.), Design and Analysis of Experiments, Volume III (pp. 413-441). New York, NY: Wiley.

Schwefel, H. P. (1975). Evolutionsstrategie und numerische Optimierung. Technische Universität Berlin.

Systems Planning and Analysis (2015). SPA Austere Basing GCAM Development Summary Brief, presentation to OAD MCCDC, 30 April 2015, Alexandria, VA.

MARINE CORPS EXPEDITIONARY ENERGY OFFICE (E2O)

NPS-N16-M109-A: Analysis of Fuel Connector Usage

Researcher(s): Dr. Michael Atkinson and Dr. Kyle Lin
Student Participation: Maj Robert Christafore USMC, LtCol Michael Graziani USMC, Maj Andrew Konicki, and Maj Eric Duchene USMC

Project Summary
In a variety of expeditionary missions, it is critical for the Marine Corps to transport fuel ashore to the right place at the right time in a threat environment. We focus on traditional connector systems that originate from the sea base (e.g., from LHDs and LSDs): LCACs, LCUs, MV-22, CH53E. The goal of this project is to determine an acceptable mix of connectors to deliver fuel ashore quickly and safely to satisfy demand for fuel in a threat environment.

We formulate several models to examine the problem from different decision making levels. The first model takes an operational level approach to evaluate what portfolio of connectors the sea base should have to efficiently deliver fuel ashore on a day-to-day basis. Our main result is the importance of having a robust set of surface connectors such as LCACs and LCUs in the portfolio. While air connectors (MV-22 and CH53E) are fast, they are costly and much more unreliable. The results from this model could be useful for Marine Air-Ground Task Force (MAGTF) planners to develop estimates of supportability for future operations, such as determining equipment shortfalls, fuel choke points, and sortie requirements.

The second model we develop takes a more tactical approach to the problem by scheduling the daily sorties of connectors. Given the connectors available to deliver fuel each day and the current day's demand for fuel at many locations on land, we generate a minute-by-minute schedule for the connectors. The results from this project can provide important decision support for commanders as this planning process can take a significant amount of time and manpower.

Keywords: energy, fuel connectors, optimization, network flow models

Background
Forward deployments occur in various forms of the Marine Air Ground Task Force (MAGTF), but the most common is the Marine Expeditionary Unit (MEU). MEUs are typically embarked on three Navy amphibious ships which are referred to as an Amphibious Ready Group (ARG). When a MEU moves from the ship to the shore during contingency operations, the MEU is still heavily reliant on the ARG for logistics to include fuel supply. The farther from shore the ARG is, the more strained the logistics of moving supplies ashore becomes. There are many systems that can (potentially) be used as fuel connectors from sea to shore, such as ABLTS, AAFS, TAFDS, HRS, OPDS, MPS, LCU (SC(X)R), LCAC/SSC, MV-22 and CH53E. Different systems vary in

their capacity, speed, vulnerability, fuel requirement, distance constraint, etc. This study analyzes the various impacts on delivering fuel to the shore based on delivery method, threat and weather impacts, equipment maintenance reliability, and distance and compares those variables to cost.

Our mathematical approach to this problem focuses on network flow algorithms (Ahuja, 2009). Fuel flows from sea base to shore via connectors and then continues along the road network to depots further inland. Part of our analysis strives to satisfy demand on land as quickly as possible, which adds a time component to our network (Skutella, 2009). This relates to evacuation problems (Hamacher and Tjandra, 2001), and we adapt models from that literature to our context.

Findings and Conclusions

The first model was developed in conjunction with a capstone project for the Master of Systems Analysis program. Three USMC students participated in this project: Lieutenant Colonel Michael Graziani, Major Andrew Konicki, and Major Eric Duchene. The project formulates a network flow optimization model that assigns connectors to various beaches and landing zones and then optimally pushes the fuel inland to demand nodes. Our main measure of effectiveness is fraction of demand satisfied each day, although we also consider transportation costs. This model uses linear programing to mathematically depict the fuel demands in the form of an optimized network flow model. This network flow problem is represented by a collection of supply, demand, and transshipment nodes which are connected through edges or arcs. The arcs indicate valid paths between nodes. Once the fuel is ashore, solving for the flow of fuel through the road network is a standard min-cost flow problem (Ahuja, 2009). What makes our problem unique and challenging is that we first need to assign each connector run to a particular beach or landing zone. This transforms our model into a discrete assignment optimization problem on top of a min-cost flow model. The final algorithm returns the assignment of each connector node to a beach or landing zone, the flow in gallons of fuel transported to each land node, the cost to push fuel through the system, and number of gallons of unmet demand. The algorithm produces the five plans that satisfy the most demand, which gives the decision maker flexibility to choose an alternative based on planning factors we do not account for in the model.

We performed sensitivity analysis to examine how unsatisfied demand varies with different portfolios of connectors. It is unrealistic to assume all connectors will be available every day. High sea states will eliminate surface connectors, whereas a surface-to-air missile threat will eliminate the use of air connectors. Furthermore, connectors break down periodically and will be unavailable. We ran the model 1000 times, and each time we randomly degraded the system due to weather, threats, reliability, demand shocks, etc. This generated a distribution for the unmet demand rather than just a point estimate. This allowed us to evaluate the robustness of a portfolio of connectors. For example a portfolio may perform very well and satisfy most demand in a perfect-world. However, when we introduce realistic shocks to the system, that portfolio may suffer significantly and fail to satisfy a large fraction of demand. The students collected data on the characteristics (velocity, capacity, reliability, etc.) of each connector class and examined several scenarios. Our main finding is the importance of having a robust set of surface connectors such as LCACs and LCUs. While air connectors (MV-22 and CH53E) are fast, they are costly and much more unreliable. This project concluded in September 2016.

The project described in the previous paragraphs found that air connectors were much more costly and unreliable compared to surface connectors, and hence the recommendation to rely heavily on surface connectors. However, air connectors have a significant advantage over surface connectors that was not adequately accounted for in the project: air connectors can deliver fuel much more quickly than surface connectors. This led us to develop a second model that takes a tactical approach to the problem by scheduling the runs of connectors. This part of the project is supported by the thesis of OR student Major Robert Christafore, USMC. Major Christafore completed his thesis and graduated in June 2017.

This thesis develops the MEU Amphibious Connector Scheduler (MACS) planning tool using a multi-model approach to quickly and efficiently develop feasible ship-to-shore amphibious schedules to deliver bulk fuel from a sea base. This tool uses reasonable planning inputs to develop minute-by-minute schedules of both surface and air amphibious connectors. We define amphibious schedules as a collection of connector runs (i.e., round-trips).

MACS integrates three separate models using realistic planning inputs. The first model, called the Quickest Flow model, is a dynamic network flow model formulated as a linear program. The Quickest Flow's objective is to satisfy demand for fuel ashore as quickly as possible. The primary output of the Quickest Flow model is the number of runs for each connector type from the sea base to each land node. This information alone is of immense value to amphibious planners as they attempt to allocate relatively few connectors across different missions to include required maintenance.

The output from the Quickest Flow model is used by the second model, the Assignment Heuristic, to create a ``first cut''� of the schedule through the use of different assignment policies. The Assignment Heuristic is critical to the practical usability of the overall model. Without the Assignment Heuristic, we would need to use a binary mixed integer linear program to transform the Quickest Flow model output to the final schedule, which would make it difficult to impossible to solve in a reasonable amount of time for many scenarios.
The final model, the Scheduler Linear Program, is a linear program that takes the output from the first two models and creates a minute-by-minute schedule that minimizes the average completion time for each connector type. The Scheduler Linear Program accounts for potential congestion and smooths out the schedule from the Assignment Heuristic to develop the final amphibious schedule.

We analyze several different MEU-size scenario, and MACS generates schedules in less than one minute. MACS can significantly reduce the amount of time and staff man-hours necessary to plan bulk fuel resupply operations from a sea base. Planning aids such as MACS are critical if the Marine Corps wants to remain the premier amphibious force in readiness.

Recommendations for Further Research

We primarily focus on MEU size operations. MEU scenarios usually involve three ships and less than ten land nodes that require fuel. We would like to scale this up to Marine Expeditionary Brigade (MEB) operations, which are much larger in scope. Our optimization algorithms may not scale to larger sizes, and thus we will need to develop efficient and effective heuristics to generate fuel delivery plans.

While we focus on the delivery of fuel in this project, the machinery developed has the potential to be the foundation for a much more comprehensive amphibious planning tool that incorporates personnel, vehicles, and pallets of equipment. Including other supply categories may require prioritizing which supplies are delivered on earlier sorties. Furthermore, we may need to consider packing algorithms (e.g., knapsack problem) to optimize the load on each connector.

References

Ahuja, R. K., Magnanti, T. L., & Orlin, J. B. (1993). Network flows: theory, algorithms, and applications.

Hamacher, H. W., & Tjandra, S. A. (2001). Mathematical modelling of evacuation problems: A state of art. Fraunhofer-Institut für Techno-und Wirtschaftsmathematik, Fraunhofer (ITWM).

Skutella, M. (2009). An introduction to network flows over time. In Research Trends in Combinatorial Optimization (pp. 451-482). Springer Berlin Heidelberg.

Marine Corps Forces Cyberspace (MARFORCYBER)

NPS-N16-M123-A: Command and Control for the New Naval Orientation and Response Model

Researcher(s): Prof. Luqi
Student Participants: Maj Mitch Rubenstein USMC, LT Lindsay Hegy, USN and LT Welton Lawrence USN

Project Summary

This project addresses automated behavior based computer network defense and cyber analysis techniques. The study is exploring impacts on command and control (C2) as cyber operations evolve, and assessing implications for USMC cyber operations policy and doctrine. Objectives of the study are to examine automated behavior based computer network defense and critique cyber analysis techniques. Command and control in cyber warfare requires command decisions under cognitive overload from an overwhelming volume and variety of multi-source data. We propose to investigate computer assisted methods for identifying the subset of available information relevant to making decisions in particular situations, based on analysis of computer models of related cognitive tasks.

Keywords: Command and Control, Network Defense, Cyber Analysis, Cognitive Overload.

Background

In current approaches to cyber operations, systems provide information and people make the decisions. The advantages of these approaches are that the required software processes are well understood, fast, and can be made reliable using current processes, and that people can be flexible and handle unexpected situations. Disadvantages are information overload for the people, risk of getting lost in low level information, suffering from fatigue, and performance variation due to uneven training.

In the proposed new approach, systems summarize information, route based on policies and procedures and make routine decisions and recommendations. People make more important decisions and validate system recommendations with significant impact. The new approach seeks improved models for combining uncertain information for robust decision making, and for trustworthiness. The objective is to improve methods for collaboration and achieve more effective human-system integration.

Findings and Conclusions

Cognitive assistants offer computational and human-machine interfacing capabilities based on machine learning. Reasoning chains on large amounts of data provide cognition powers that complement, augment and scale human intelligence. Research will identify human-machine communication modes that will most effectively convey the identified relevant information to human decision makers.

Research will explore the use of cognitive assistants to augment human-machine interfacing capabilities in order to increase the speed of cyber warfare OODA (observe, orient, decide, and act) loops and achieve decision superiority over an adversary. Results will be validated via simulation and experiments based on crisis management scenarios.

Our model assumes that observed information (such as data taken from the sensors of an intelligence, surveillance, and reconnaissance (ISR) platform) is represented at the information source level. It also assumes existence of forces or adversarial agents that cannot be observed explicitly but otherwise manifest themselves in observed information. The restricted attack model is based on the assumption that the Global Information Grid (GIG) is the boundary of the information that will be fed into the automated decision support systems. We rely on the information assurance mechanisms that will be embedded into the architecture of the GIG to assure the integrity of the data, rather than modeling effects of cyber-attacks in the simulations.

These assumptions are represented on the hypothesis level. Known objectives are related to mission outcomes. The goal of modeling is to accurately estimate outcome probabilities and risk levels for each objective. It is achieved by reducing uncertainty on the hypothesis level and increasing data reliability on the information source level. Such decomposition into levels is important for addressing different forms and methods for evidence evaluation [1].

Information sources are represented by their content, reliability metrics and degree of independence from other sources [2,4]. At this level, independence is a positive characteristic since it allows increasing overall reliability and confidence by fusing pieces of data on similar topics. In contrast, fusion of information from dependent sources does not increase overall reliability. One of the widely used fusion strategies for numerical data is a simple linear combination where the weights are proportional to estimated trustworthiness. Both independence and reliability parameters can be unknown or change as analysis progresses.

There are different kinds of information some of which can be new or recently obtained and some may represent prior knowledge or known facts. This prior knowledge should not be mixed with our assumptions, which are processed on a second level and represent the unobserved part of information on the second level. The second level is crucial in this model since it directs data search and helps to extract only the data that are relevant to current operational hypotheses.

There are several possible representations of hypotheses and assumptions about unobserved information. Hypotheses can be stored in the form of generative models [3] that express causal relationships between unobserved forces or causes and observed facts. This enables us to use Bayesian reasoning to invert causal relations and to answer questions about unobserved causes. This will be our initial framework for incorporating aspects of machine learning into automated decision support systems. For cases in which creating such generative models is problematic, a simplified version of hypothesis representation can be used instead. This formulation specifies what information supports which hypotheses by providing weighted links. The relations between data and hypotheses then takes a form of a simple linear model that ties probabilities of hypotheses to a weighted sum of reliabilities of supporting and contradicting data and subjective judgments of human experts.

A thesis project on C2 and Industrial Control Systems (ICS) security was initiated as part of this study [5]. This thesis will contribute to the development of a Testbed for Characterization and Assessment of Marine Electronics (T-CAME) in the NPS Center for Cyber Warfare. Three interconnected networks commonly operate commercial maritime vessels. These are the Administrative, Voyage, and Machinery Control networks. The T-CAME will seek to provide a laboratory for the exploration of various commercial systems. Component functions, interconnectedness, communication traffic protocols, and security, will be characterized and assessed. Command and Control in cyber warfare, especially above the tactical level, may have to deal with an overwhelming volume and variety of multi-source data. Metrics, or hooks, for cognitive modeling and machine learning will be identified in order to augment human decision making. Related research questions are:

1) Can maritime electronics testbed be standardized for multiple manufacturer operability?
2) What generalizations can be made from interconnectedness of Administrative, Voyage Management, and Machinery Control networks?
3) Can normal operating network traffic/signals be "played back" to simulate operating environments?
4) Can commercial off the shelf (COTS) maritime electronics communications protocols be reverse- engineered?

5) Can developmental cyber operations concepts be applied to commercial maritime network traffic?
4) What characterization metrics should be organically incorporated in order to support cognitive modeling and machine-learning?

Recommendations for Further Research

Two students participated in exercise Pacific Sentry 16-2, resulting in the following recommendations.

Each of offensive cyber operations (OCO) and defensive cyber operations (DCO) require its own unique coordination, which is not well developed. These effects, along with similar effects like Electronic Warfare (EW) and network analysis, must be carefully coordinated with direct action of Marine forces. Because authorities for such new kinds of effects like cyber and EW involve a whole of government approach and run between Title Fifty and Title Ten, care must be exercised to do this correctly. However, the Marine culture is to empower and seize the initiative. Waiting for higher headquarters, or multiple higher headquarters, is not an option the Marines would like to consider. Delegation of certain effects as far down the chain as possible is a must.

Second, informal information flows in cyber are greatly curtailed by differences in language, access, and training, and equipment. The DCO working group consisted of at least a dozen members, of which two were cleared to work one of the issues, and could not share with their contemporaries, not because the others did not have the need to know or the proper clearances, but because administratively there was a quota on how many personnel could participate in a program. In the C2 of a New Normal, if Marines don't have appropriate clearances at very low levels, they risk increasing danger to themselves or accidentally interfering with other operations.

References

[1] Oussalah, M. 2003. Introduction to fusion based systems - contributions of soft computing techniques and application to robotics. In Autonomous Robotic Systems: Soft Computing and Hard Computing Methodologies and Applications, Eds. Physica-Verlag GmbH, Heidelberg, Germany, 35-71.

[2] Jacoby G., Luqi. (2005) "Intranet Portal Model and Metrics: A Strategic Management Perspective", IT Professional, Vol. 7, No. 1, pp. 37-44.

[3] Murphy K. (1998). "A Brief Introduction to Graphical Models and Bayesian Networks". Available at http://www.cs.ubc.ca/~murphyk/Bayes/bnintro.html.

[4] G. Jacoby, Luqi, "Intranet Model and Metrics", Communications of ACM, Vol. 50, No. 2, February 2007, pp. 43-50.

[5] M. Rubinstein, "Testbed for Characterization and Assessment of Commercial Maritime Electronics", MS Thesis, NPS, Sep. 2016.

Marine Forces Pacific (MARFORPAC)

NPS-N16-M160: Pacific Islands Coastal Marine Spatial Planning

Researcher(s): Dr.Tom Murphree and Dr. Arlene Guest
Student Participation: LCDR Rich Ilczuk, USN and LCDR Tyler McDonald USN

Project Summary

The primary goal of this project is to develop data sets and tools to facilitate coastal marine spatial planning (CMSP) for the U.S. Pacific islands. This includes: (a) collecting data sets; (b) developing data sets and tools for data analysis and decision support. We have been coordinating and collaborating with the Pacific Islands Regional Planning Body to help in their efforts in CMSP. We have created a prototype data portal and developed several types of geographic information system (GIS) mapping applications for visualizing and analyzing the data. Two master's students have been involved in two different aspects of the work: LCDR Richard Ilczuk conducted research to improve the analysis and prediction of climate variations in the coastal and marine environment, and for planning operations, including Department of Defense (DOD) operations, in that environment. LCDR McDonald conducted research to improve the efficiency and efficacy of planning and permitting for operations in the coastal and marine environment, including DOD operations and civilian operations that could conflict with DOD operations.

Keywords: CMSP, coastal marine spatial planning, Pacific Islands, Hawaii, Guam, Commonwealth of the Northern Mariana Islands, (CNMI), American Samoa, coastal and marine operations, marine planning, coastal management, environmental conditions, climate, climate variations, data portal, mapping, geographic information systems, geospatial information systems, GIS, decision support, Executive Order 13547, energy, installations, environment, training, testing, natural resources, encroachment, use conflicts, U.S. Marine Corps Forces Pacific, U.S. Pacific Fleet, U.S. Pacific Command.

Background

The Assistant Secretary of the Navy (ASN) for Energy, Installations, and Environment program is leading DOD in implementing ocean and coastal policy established by Executive Order 13547. Coastal marine spatial planning (CMSP) is a major component of that policy and involves: (1) collecting and analyzing coastal marine data; (2) identifying ocean uses and activities; (3) assessing potential areas of use compatibility and incompatibility; (4) collaborating with scientists and other experts; and (5) engaging stakeholders. The Pacific Islands Regional Planning Body (PIRPB) was created to implement the policy for the Pacific Islands region, which includes Hawaii, Guam, American Samoa, and Commonwealth of the Mariana Islands (CNMI). The Department of Defense (USMC) is a member, one of eight Federal members, and nine non-Federal members. The benefits to DOD include improvements in: (a) siting and scheduling of training and testing; (b) natural resource permitting; and (c) addressing encroachment on bases and training areas.

The main goal of this project is to develop data sets and tools to facilitate coastal marine spatial planning. This includes, for example, collecting data and developing data sets, and analysis and decision support tools. These datasets and tools serve to (a) help develop a more comprehensive understanding of ocean uses (environmental, socioeconomic, cultural, etc.); (b) Identify potential areas of compatible and incompatible ocean uses; (c) facilitate the identification of solutions to the problems; (d) assist in monitoring problems and potential problems; and (e) support the development of proposals and funding to address present and future problems.

Findings and Conclusions

There are several aspects of this study. First, we researched what the other regional planning bodies have done in terms of sharing and visualizing data in their data portals. We also looked at the data and data web sites provided by the governments and agencies for the jurisdictions covered by the Pacific Islands Regional Planning Body. Some of the data sets are very rich, such as for the state of Hawaii. Some data sets are spread out in various agencies and not available in one easy to find location. Some websites do not make the data easily downloadable, while others have a download capability, but do not have any way to see what the data is before downloading it. In order to enable data sharing by participating governments, agencies and non-governmental organizations (NGOs), we constructed a prototype online data portal, located at http://www.oc.nps.edu/CMSP/. We looked at data portal functionality and usability requirements. We recommend that the portal should enable users to visualize and explore the data sets as well as download them. It is very important to have metadata for each dataset that tells the potential user what the data is, how and when it was collected, and a point of contact. Each dataset should have a link to the metadata, as well as a sample snapshot of the data and its coverage area, and a link for the download.

We identified many data sets to include in the data portal, including elevation and ocean bathymetry, other environmental conditions, habitats, jurisdictions, uses, economic features, and much more. We also identified data gaps by comparing available data to needed data. This information is useful to the PIRPB data team in prioritizing future data collection efforts. We have also made recommendations for data set standards and formats to the data team.

We have created GIS mapping applications that are part of the prototype data portal for visualizing and analyzing the data. Figure 1 shows an example result from this application for ocean habitats and vegetation in American Samoa. Users of the application can display the legend as shown in the figure, or can display the layers and turn different layers on or off. The user can also click on the map to identify a feature and see the data associated with that location. This enables data discovery and exploration as well as visualization of the data.

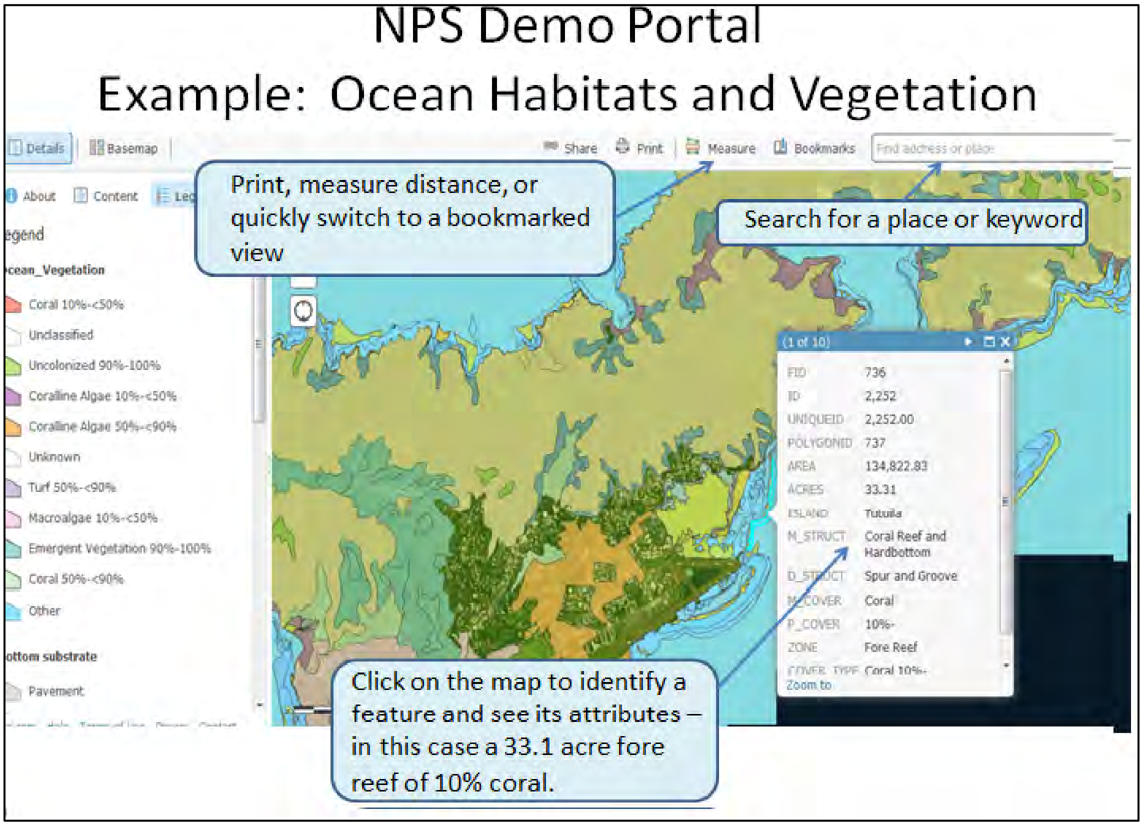


Figure 1. Example of use of the data portal to explore ocean habitat and vegetation through an interactive mapping application.

Figure 2 shows an example of use of a web mapping application for decision support. In this application, uses and activities on Oahu are overlain. Users can turn the various layers on and off to see what uses and activities already exist at a location, to help mitigate potential conflicts between users of the coastal marine environment. An example of the use of spatial analysis techniques to determine areas vulnerable to sea level rise is shown in Figure 3. DOD lands are shown in brown overlaid with the three-foot sea level rise flood model results from National Oceanic and Atmospheric Administration (NOAA).

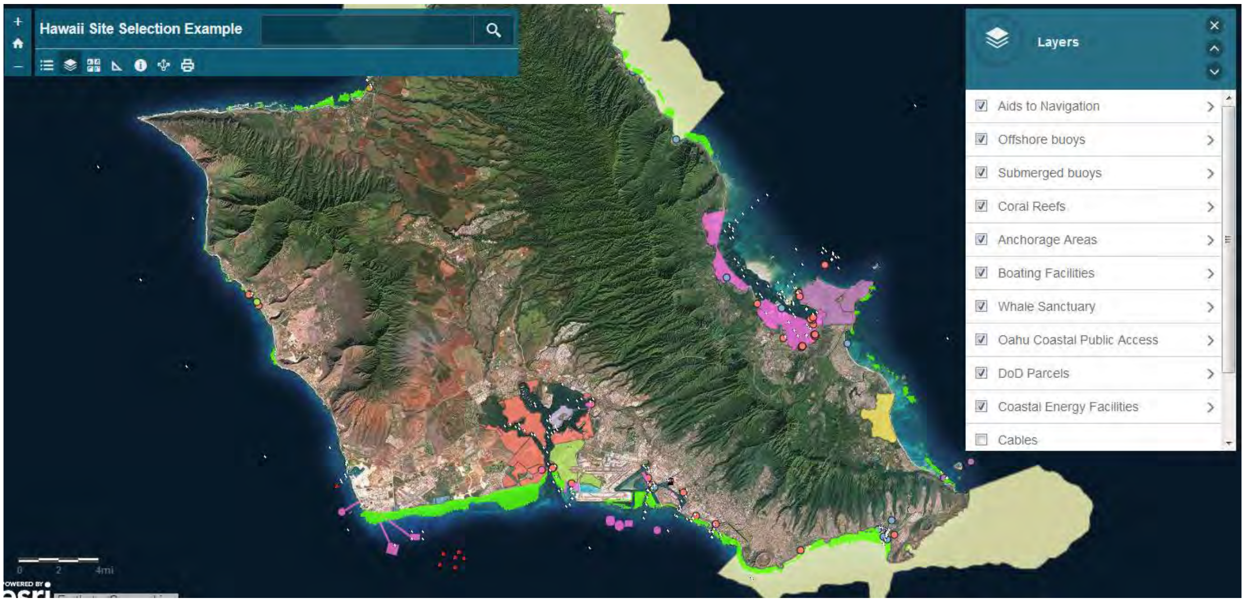


Figure 2. Example of a web mapping application used for decision support for site selection.

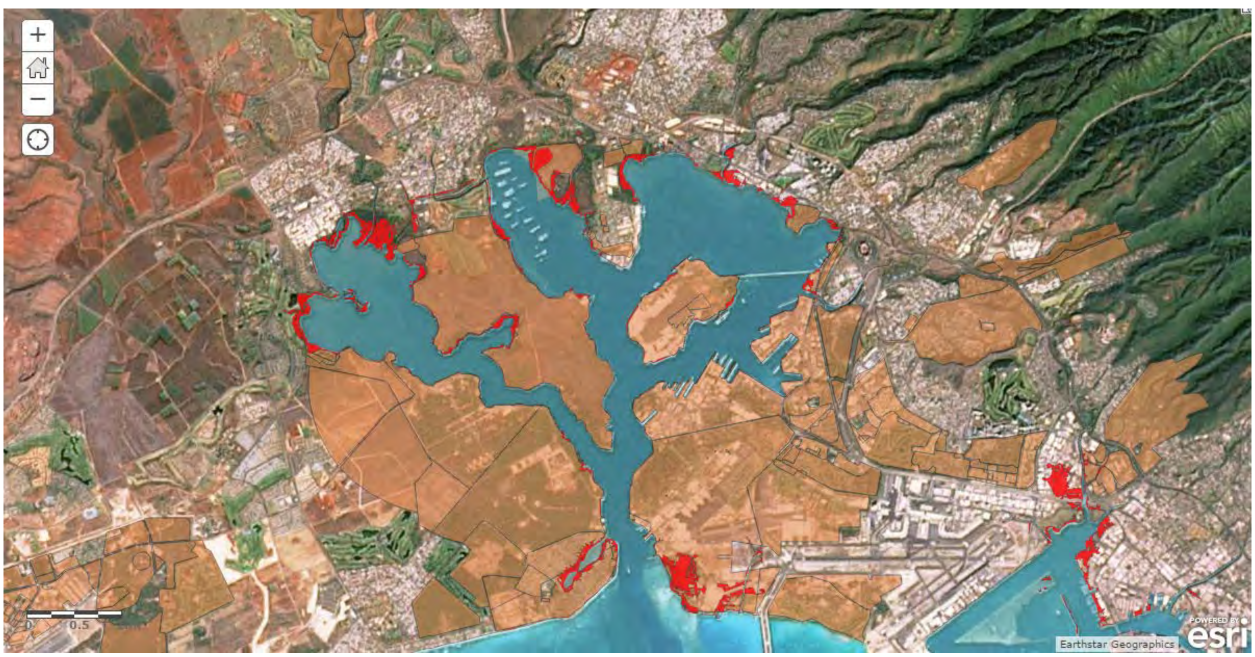


Figure 3. Example of use of spatial analysis to determine areas vulnerable to sea level rise. Here, DOD lands shown in brown are overlaid with the three-foot sea level rise flood model from NOAA, shown in red.

CMSP requires an understanding of how the coastal and marine environment has changed and is likely to change in the future. For his thesis research, LCDR Rich Ilczuk analyzed changes in atmospheric and oceanic conditions in the tropical Pacific associated with two types of climate variations: El Nino-La Nina (ENLN) and the Madden-Julian Oscillation (MJO). Both of these types of variation are common in the tropical Pacific and can have substantial impacts on the coastal and marine environment. LCDR Ilczuk's research has helped quantify those impacts --- in particular, the impacts that occur due to both the separate and the simultaneous occurrence of ENLN and MJO events. Figure 4 (Ilczuk, 2016) shows the impacts of two different combinations of ENLN and MJO events on ocean waves in the tropical Pacific. The wave height anomalies in this figure represent the changes from normal wave heights that occur under different climate variation conditions. LCDR Ilczuk's research has helped improve the foundation for predicting variations in the coastal and marine environment, and for planning operations, including DOD operations, in that environment. His thesis was completed in December 2016 and is titled The Impacts of Multiple Simultaneous Climate Variations.

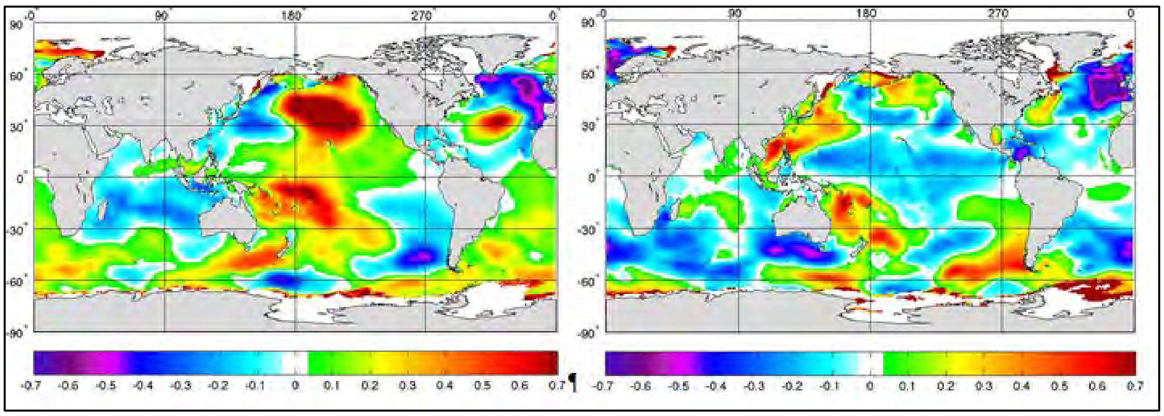


Figure 4. Anomalies in ocean surface significant wave heights (in meters) in January-March for: (left) a combination of EN and MJO phase 8; and (right) a combination of LN and MJO phase 8. Note the large differences between the two combinations in the Hawaii, American Samoa, Guam and CNMI regions. Figure from Ilczul (2016).

CMSP involves extensive interactions between a wide range of organizations that operate in or are responsible for managing the coastal and marine environment, including DOD. For his thesis research, LCDR Tyler McDonald analyzed from a systems engineering perspective the processes involved in reviewing and permitting plans for operating marine aquaculture operations in Hawaii. Figure 5 shows an example of the extensive and complex organizational interactions that occur in the planning and permitting processes for aquaculture operations. In addition to being complex, these processes are also evolving and often poorly documented. This makes the planning and permitting processes are difficult for both aquaculture businesses and government agencies. To help address these challenges, LCDR McDonald used his findings to develop a set of capability requirement recommendations for a CMSP decision-support system that would contribute to improved planning and permitting of coastal and marine operations, including DOD operations. LCDR McDonald's research has helped improve the foundation for improving the efficiency and efficacy of planning and permitting for operations in the coastal and marine environment, including DOD operations and civilian uses that could conflict with DOD operations. His thesis was completed in December 2016 and is titled *A Sociotechnical Systems Approach to Coastal Marine Spatial Planning.*

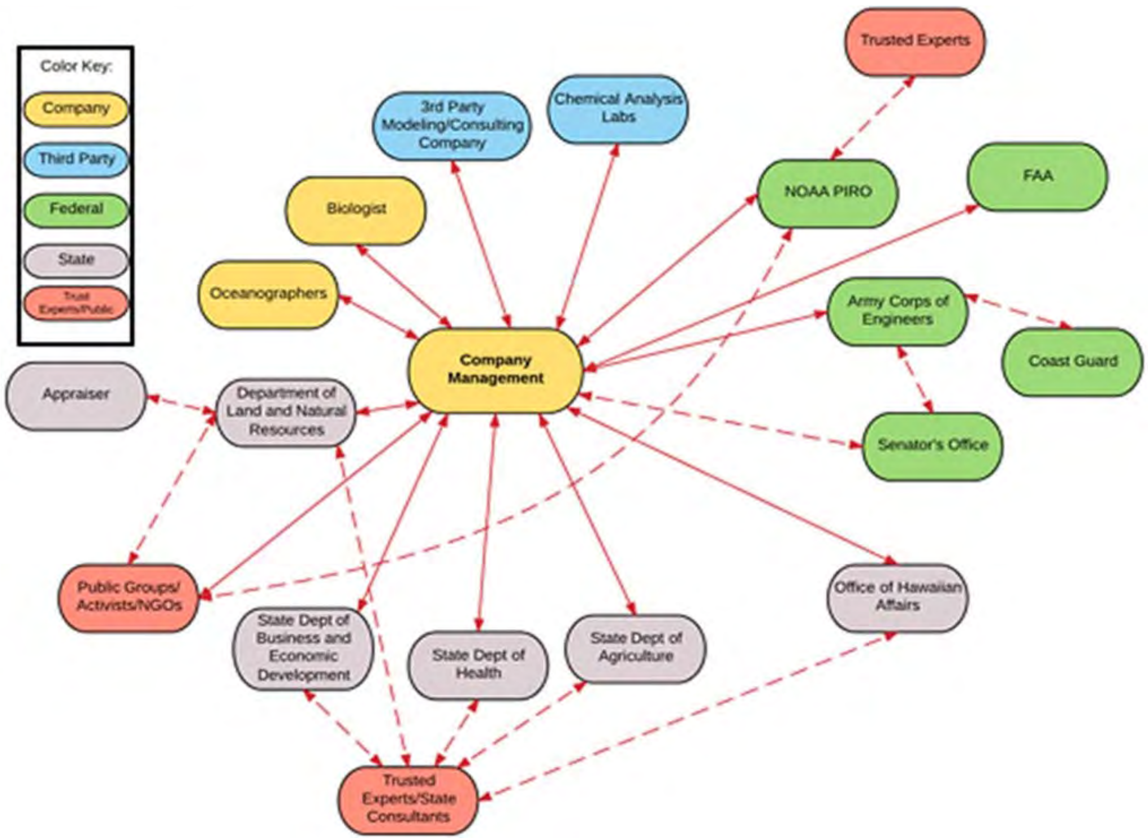


Figure 5. An example of the extensive and complex organizational interactions that occur in the planning and permitting processes for aquaculture operations, from McDonald (2016).

Recommendations for Further Research

There are several avenues for further research. The types of web applications (apps) that can be created is rapidly growing, and more types of analyses and visualizations can be performed online, putting powerful tools in the hands of users. These include visualizations of what the environment looks like to viewers known as viewshed analysis. As an example of the value of such visualizations, a company that would like to install a wind farm off a coast could do a viewshed analysis to describe where and to what extent the wind farm would be visible from land. This can currently be done with desktop software by a knowledgeable user, but it would be a useful decision support tool to make available on the CMSP data portal.

Additional information about environmental variations should be included in the data portal to describe past, present, and future changes in environment. This would include information about changes associated with: (a) human activities in the coastal marine environment; (b) climate variations (such as El Nino and La Nina); and (c) climate change due to greenhouse gas emissions and due to other human activities.

Additional research is needed to determine the most useful environmental datasets. For instance, in the aquaculture example, each company seeking a permit had to either find oceanographic current measurements or go collect data themselves. What datasets are available already and are they on the right time and space scales to satisfy the permitting requirements? What are the most relevant environmental climatologies for coastal management and planning?

References

Ilczuk, R. (2016). *The Impacts of Multiple Simultaneous Climate Variations,* (Master's thesis). Retrieved from http://calhoun.nps.edu/handle/10945/51724.

McDonald, T. (2016). *A Sociotechnical Systems Approach to Coastal Marine Spatial Planning* (Master's Thesis). Retrieved from http://calhoun.nps.edu/handle/10945/51578.

MARINE FORCES RESERVE (MARFORRES)

NPS-N16-M138-A: Using Human-Centered Design to Improve Inspector-Instructor Selection, Training, and Support

Researcher(s): Dr. Kathryn Aten, Ms. Anita Salem, and Ms. Ann Gallenson
Student Participation: No students participated in this research project.

Project Summary

As part of a Human-Centered Design process for improving the functioning of Inspector and Instructors (I-I), a distributed design team conducted a series of site observations and interviews with I-I personnel, Reservists, Career Planners, and Monitors (assignment personnel). The design research uncovered important issues facing the I-I community. These issues included information regarding the perceived value of I-I, the nature of the selection process, the constraints facing Monitors, the need for I-I training, the gaps in operating performance, the need for improved communication, the importance of skill transfer, the desire for addressing job growth, and the impact of the command climate. The team presented these issues for review and used them as a unifying structure for defining the complex problem of ensuring I-I success. The team selected the information and screening processes for improvement and then redesigned them to improve efficiency and effectiveness:

- **Inform and Educate Marines** about I-I duty through a marketing and communication campaign for all Marines with special materials for Monitors and Career Planners.
- **Improve Independent Duty Screening** by improving the I-I checklist and automating the screening, application, and approval process.

Keywords: Human-Centered Design, Design Thinking, Design Research, Marine Corps, Marine Corps Reserves, Independent Duty, Inspector-Instructors, Monitors.

Background
Inspector & Instructors (I-I) have a mission to prepare SMCR Units for mobilization to augment and reinforce the Marine Corps active component as described in Force Order 5400.3A: I-I staff consists of either Active-duty Marines or Active Reserve Marines.

I-I are responsible for site support, reservist training, and community relations. I-I must fulfill all of their responsibilities while supporting and resourcing the Reserve Commander in his or her planning. There are over 160 I-I sites distributed across the United States. I-I generally work 40+ hours a week, plus funerals, drill weekends and their two-week annual training. They may deploy with the Reservists or get deployed by other units. Marine Corps Forces Reserves (MFR or MARFORRES), headquarters, to which all I-Is are assigned is located in New Orleans, Louisiana. Because I-I personnel are a key element in the success of the USMCR, the command element of MARFORRES was interested in addressing and improving the performance of these personnel. In 2016, a Human-centered Design team was formed to assist the Marine Corps in improving the I-I lifecycle.

Findings and Conclusions
In 2016, a Human-centered Design team was formed to assist the Marine Corps in improving the I-I lifecycle. As part of a Human-Centered Design (HCD) process for improving the functioning of I-I, a distributed design team conducted a series of site observations and interviews with I-I personnel, Reservists, Career Planners, and Monitors (assignment personnel). The team then used this data to attack two specific areas for improvement: eliminating information gaps and improving the I-I selection process. The project followed a HCD process consisting of six phases as shown in Figure 1, the Discovery, Design, and Testing phases were successful in uncovering nine important issues facing the I-I community. These issues included information regarding the perceived value of I-I, the nature of the selection process, the constraints facing Monitors, the need for I-I training, the gaps in operating performance, the need for improved communication, the importance of skill transfer, the desire for addressing job growth, and the impact of the command climate. The team presented these issues early on and used them as a unifying structure for defining the complex problem of ensuring I-I success.

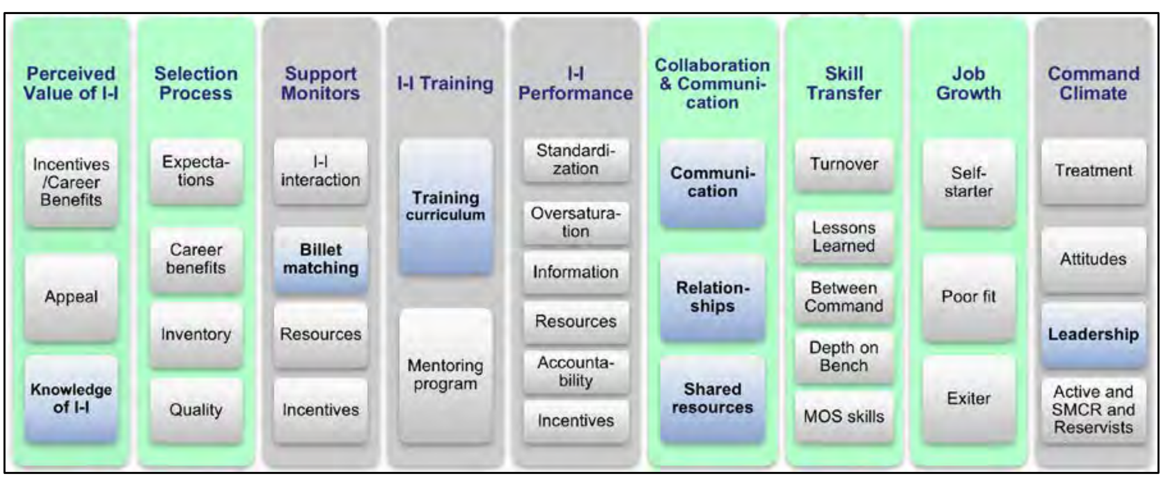


Figure 1. Nine areas for improvement

First, very few people perceived a value in I-I duty nor understood what I-I duty entails. Most people did not understand the breadth of work, the demands on an I-I's personal time, or the leadership and personal qualities that were required for the job. As one of two design projects, the team designed a marketing and communication campaign for all Marines with special materials for Monitors and Career Planners.

Second, the selection process surfaced as a primary blocker to I-I success. As the design team interviewed participants, it became clear that there are a number of factors impacting selection: initial expectations, the available inventory, the quality of personnel, and the selection process itself. This challenge became the second design effort and resulted in a redesigned Screening process that included a new checklist and an automated screening, application and approval process. There were seven other areas that were identified, but not designed.

The third challenge we identified for I-I is the need to support Monitors in their work. Discussions with Monitors indicated that they were reluctant to take on more work. Monitors lack the time and resources, motivating incentives, and knowledge of I-I to effectively match the Marine to the I-I billet.

Fourth, once selected for I-I assignment, only a few I-I undergo training to help them prepare for the duty. For most I-I, training is ad-hoc and inconsistent. There is not a prescribed curriculum and training is occasionally provided "on-the-fly" by local experts.

Fifth, I-I performance is at risk. The I-I workload is immense. There is a significant amount of multitasking and tasks compete with each other for priority. The requirements of site management take up much of an I-I's time and Reservists complain about the lack of attention to training.

Sixth, communication and collaboration are essential skills for I-I and their commands. I-I must communicate with Reservists, MFR, and the community and a communication battle rhythm is lacking. I-I also operate in isolation, without strong connections to other I-I or ongoing assistance from Marine Forces Reserve in New Orleans.

The next two areas are related. Skill transfer and job growth prove to be a challenge for I-I. There is currently no process for growing I-I personnel, sharing lessons learned, or offering additional training in MOS skills.

Finally, I-I, as the active duty foundation for the Reserve Forces, has a major role in establishing the command climate. I-I are ultimately responsible for the treatment, training and care of Reservists. Currently, there are challenges with the command climate that impact trust and credibility.

Recommendations for Further Research

1. Further develop and pilot the communication and marketing campaign
2. Further develop and pilot the selection process module
3. Continue to define and innovate around the nine opportunities identified above
4. Collect I-I success metrics: the number of I-I orders canceled within three months of assignment; the number of I-Is that resigned in the first year; Reserve performance on inspections (e.g. the number of failed inspections); positive rankings on climate surveys; and the number of post I-I promotions

References

Department of Defense (DOD) directive 1200.17. MANAGING THE RESERVE COMPONENTS AS AN OPERATIONAL FORCE. October 2008.

Department of Defense Force Order 5400.3A. 2015.

Direnzo, Marco and Aten, Kathryn. Individual Reservist Affiliation Motivators And Objections. Prepared For Deputy For Resources, Manpower And Analyses, Assistant Secretary of the Navy (M&RA).

Kozloski, R. P. (2013). Marching Toward The Sweet Spot: Options For The U.S. Marine Corps In A Time Of Austerity. *Naval War College Review, 66*(3), 10-36.

Mason, Curtis A. Risk And Reward Of An Operational Marine Corps Reserve. *Army War College* Carlisle Barracks Pa, 2012.

Riggs, Jonathan L. Making The Marine Corps Reserve Truly Operational: A Case Study In The Reorganization Of The Marine Corps Reserve. *Marine Corps Command and Staff College.* Quantico VA, 2012.

Marine Corps Systems Command (MARCORSYSCOM)

NPS-N16-M008-A: Generation of Human Views with Monterey Phoenix

Researcher(s): Dr. Kristin Giammarco

Student Participation: Mr. Tom Moulds, USN

Project Summary

This research advances model-based systems engineering approaches and tools for representing human behaviors in terms of decision-making processes and choices, and integrating human models with technological system models to predict and purge unintended interactions. In particular, the Monterey Phoenix (MP) system architecture and workflow behavior modeling approach and tool, created at NPS with Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) sponsorship, was extended and used to produce a case study of an area clearance system composed of humans and technology. Innoslate, a commercial system architecting tool, was also used to test the integration of models of human behavior into system architecture models. Both tools generated scenarios of possible human-system interactions, but each model had distinct features. The Innoslate model enabled activity probabilities (for failure analysis) and durations (for mission completion time) to be assigned for Monte Carlo simulation of a subset of all possible scenarios, whereas MP provided exhaustive generation of all possible scenarios up to a specified scope. Analysis of the latter model exposed some unanticipated interactions, including one significant finding of a vulnerability that could arise from an improper human-system interaction. A Naval Air Systems Command (NAVAIR)-sponsored requirements verification and validation approach was subsequently developed from this and other case studies that exposed unwanted, hazardous, incorrect and otherwise undesirable behaviors in system designs. Future work will assess integration potential of the Marine Corps Systems Command (MCSC)-sponsored Framework for Assessing Cost and Technology (FACT) tool with MP and Innoslate so that tradespace analysis questions typically asked at the physical architecture level can be informed directly by higher level behavior models and lifecycle requirements.

Keywords: human views, human models, human-system models, model based systems engineering, architecture, Monterey Phoenix, Innoslate, FACT.

Background

Accounting for human interactions with systems under development as well as with other elements in their environment is a crucial piece missing from most system models used in practice, and the lack of adequately modeling the human as part of the system has contributed to pervasive failures to expose (early in the lifecycle) many potential interactions that result in emergent unwanted, hazardous, incorrect or otherwise undesirable behaviors in systems under design. From (Bruseberg, 2011), Human Views "capture specific human-related components of enterprise models to enable effective [Human Factors Integration]." With this in mind, two tools – Monterey Phoenix and Innoslate – were used to model humans or groups of humans as first class systems along with the technological systems they use, in order to fully describe their activities and decision points (as alternative behaviors) and their subsequent impacts on human-system interactions that emerge.

The Monterey Phoenix (MP) approach and tool (Auguston, 2016) (Auguston, 2009) (Auguston, Giammarco, Baldwin, Crump, & Farah-Stapleton, 2015) was developed at the Naval Postgraduate School (NPS) to, among other things, automatically generate sets of use case scenarios that are far more comprehensive than other methods in use today (Giammarco & Whitcomb, 2017) (Giammarco & Giles, 2017). Comprehensive sets of use cases were needed to better inform System of System (SoS) analyses and to study emergent behaviors in systems under design. Eagle6, a prototype MP implementation created by NPS alumnus Dr. Joey Rivera (Rivera, 2010), preceded the MP Analyzer on Firebird (Naval Postgraduate School, 2015), which first came online as a public web-based tool in June 2015 for behavior modeling education at NPS. The CRUSER sponsored these early efforts for identification of failure modes and failsafe behaviors for autonomous unmanned systems (Revill, 2016). Since then, MP has attracted sponsorship from the Naval Research Program (NRP), Marine Corps System Command (MCSC), Naval Air System Command (NAVAIR), and the Systems Engineering Research Center (SERC)

University Affiliated Research Center (UARC) with sponsorship from additional organizations currently in discussion. These and other users of MP have the following game-changing advantage: the comprehensive sets of use case scenarios generated by MP not only contain *wanted* behaviors, but in many cases also contain *unwanted* behaviors that should be excluded from the design (Giammarco & Giles, 2017) (Giammarco & Whitcomb, 2017). In each of the cases summarized in (Giammarco & Giles, 2017), unwanted behaviors were discovered that would have been difficult to find using the typically manually-intensive use case generation in use today. The unwanted scenarios prompted the identification of new system requirements, effectively purging the system models of the unwanted behaviors, leaving only the wanted behaviors behind.

MP-generated scenarios are scope-complete. This means that they contain an exhaustive set of possible behaviors and interactions among the modeled humans and systems up to a specified scope. The scope is the number of iterations allowed in behavior models containing loops. The scope-complete aspect of the MP-generated set of use case scenarios results in a further value to MP users: the ability to test their models for the presence or absence of behaviors of concern up to a specified scope.

This research extended the previous work described above by focusing on the human models and the human-system interactions aspect of MP modeling, through a case study model developed for the MCSC, based on educational materials developed with CRUSER sponsorship.

Findings and Conclusions

MP and Innoslate were used to create integrated human models representing human behaviors in terms of decision-making processes and choices and system models representing technological and environmental system behaviors. An academic model of an area clearance system developed for CRUSER (Giammarco & Shebalin, 2017) was used for the context of this research. Both tools generated scenarios of possible human-system interactions, but each tool currently has different feature sets that enabled the model to be characterized in different ways. The Innoslate model enabled the assignment of probabilities to activities to characterize the likelihood of that each activity's selection (whether it is a potential failure mode event or a human decision being made), as well as durations to characterize the time it takes for each activity to complete, and provide the information needed to compute total mission completion time for each scenario. Innoslate's built-in Monte Carlo simulator was used to collect statistics on failure scenarios (Moulds & Giammarco, 2017) and mission completion times based on the different decisions being made. The Innoslate model, however, was limited to representing only a subset of possible scenarios, as constrained by scripts that define and control the number of loop iterations in iterating activities. This limitation was overcome in the MP model using global and local scope settings to control the number of loop iterations, enabling the generation of more scenarios at higher scopes (the exhaustive set). For this case study, the number of loops in both models was kept minimal to enable an easier comparison of the results in the two tools. Reference Moulds & Giammarco, 2017 describes the process in further detail.

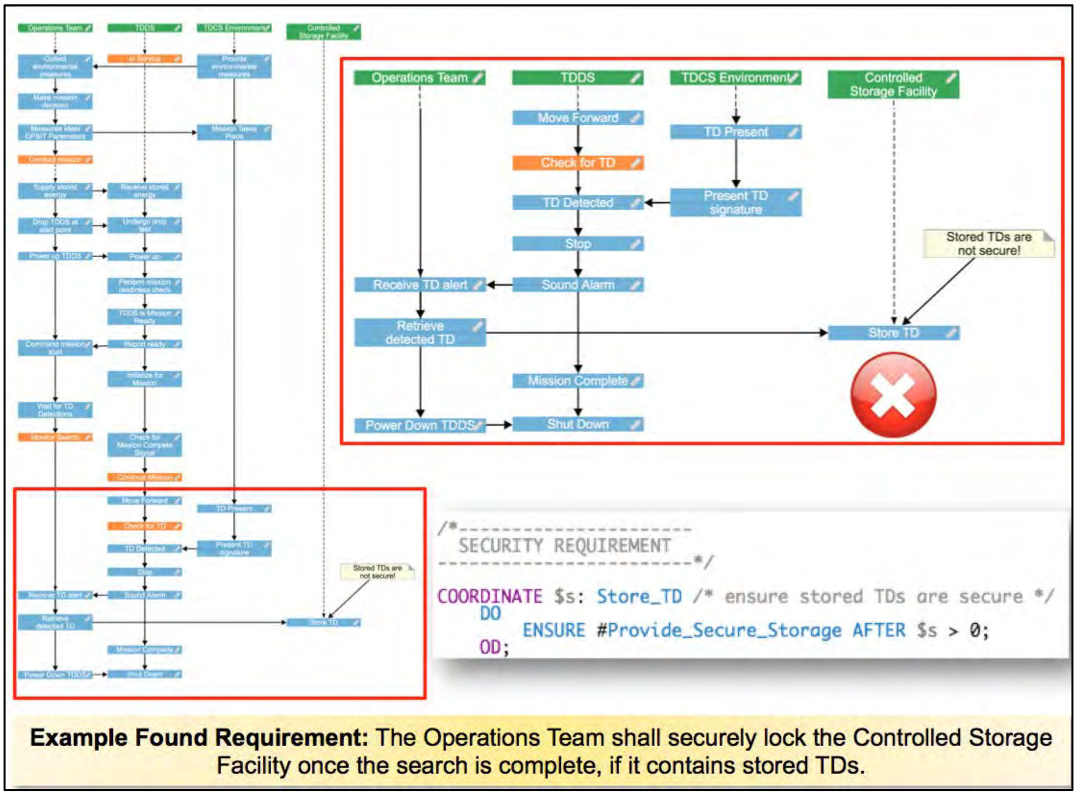


Figure 1. Unsecured TDs were first flagged across all scenarios using an annotation rule, then a security requirement was written (formally) to ensure the storage facility containing TDs has been secured.

Analysis of the sequence diagrams generated from the MP model exposed some unanticipated results not readily visible from the Innoslate model. Some were traced back to modeling errors – verification issues that were corrected in the MP model, which was then re-run. One error, however, was clearly a significant validation issue – exposing the absence of a security requirement. In Figure 1, an automatically generated scenario is shown where the Operations Team (the humans) has left the Controlled Storage Facility unsecured after placing Tactical Disks (TDs, or simulated hazardous objects) inside the facility. This absence of a necessary interaction could result in undesirable consequences, so we modified the MP model to be constrained by a new security requirement for the system. The requirement from the Operations Team perspective is captured in the gold banner in Figure 1.

As a result of this work and of examples from other concurrent case studies (Giammarco & Giles, 2017), NAVAIR has sponsored the development of a requirements verification and validation approach to help the larger community expose such unwanted behaviors in their own system designs (Giammarco & Whitcomb, 2017). Having completed this project provides the USMC with demonstrable evidence of the utility of MP at exposing unwanted human behaviors and human-system interactions and fixing them early in design. The products of this research are being used to educate Navy and Marine Corps students and workforce (both active duty and civilian) on how to conduct integrated human / system behavior modeling.

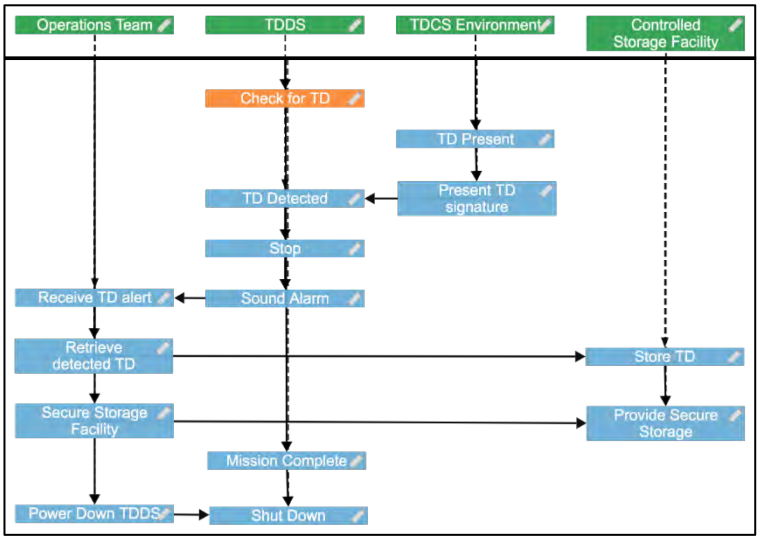


Figure 2. After the security requirement is added, the MP model is re-run to verify the undesired behavior has been removed.

Recommendations for Further Research

Future work will assess the integration potential of the MCSC-sponsored Framework for Assessing Cost and Technology (FACT) tool with MP and Innoslate so that tradespace analysis questions typically asked at the physical architecture level can be informed directly by higher level behavior models and lifecycle requirements. Furthermore, in the future it will be possible to assign probabilities and durations natively in MP. Preliminary work on an Innoslate-to-MP compiler that translates Innoslate action diagrams into MP code shows promise for transforming graphical activity models into basic MP code that can then be extended using aspects of the MP language unavailable in Innoslate. The Eagle6 MP implementation has progressed to including a graphical interface that enables automatic conversion of Business Process Modeling Notation (BPMN) to MP code, and vice versa (Rivera Consulting Group, 2016), to make MP modeling even more accessible.

References

Auguston, M. (2009). Monterey phoenix, or how to make software architecture executable. *Proceedings of the 24th ACM SIGPLAN conference companion on Object oriented programming systems languages and applications.* ACM.

Auguston, M. (2016). *System and Software Architecture and Workflow Modeling Language Manual.* Monterey: Naval Postgraduate School.

Auguston, M., Giammarco, K., Baldwin, W. C., Crump, J., & Farah-Stapleton, M. (2015). Modeling and Verifying Business Processes with Monterey Phoenix. *44*, pp. 48-57. Hoboken: Procedia Computer Science.

Bruseberg, A. (2011). *The Human View Handbook for MODAF: Part I – Introductory Summary.* Alvington Yeovil Somerset, U.K.: Human Factors Integration Defence Technology Centre.

Giammarco, K., & Giles, K. (2017). Verification and validation of behavior models using lightweight formal methods. *Procedia Computer Science.* Redondo Beach: accepted for publication.

Giammarco, K., & Shebalin, P. (2017). *An Instructional Design Reference Mission for Area Clearance.* Naval Postgraduate School. Monterey: NPS Techncial Report, in press.

Giammarco, K., & Whitcomb, C. A. (2017). Comprehensive use case scenario generation: An approach and template for modeling system of systems behaviors. *System of Systems Engineering Conference.* Waikoloa: submitted.

Moulds, T., & Giammarco, K. (2017). Understanding Faults in System Models: Comparing Classical Methods Versus System Architecture Tools. *System of Systems Engineering Conference.* Waikoloa: submitted.

Naval Postgraduate School. (2015, June). Retrieved February 21, 2017, from MP Analyzer on Firebird: http://firebird.nps.edu

Revill, M. B. (2016). *UAV swarm behavior modeling for early exposure of failure modes.* Monterey: Master's Thesis, Naval Postgraduate School.

Rivera Consulting Group. (2016, December). Retrieved February 21, 2017, from MP Analyzer on Eagle6: http://mp.eagle6.com/

Rivera, J. (2010). *Software System Architecture Modeling Methodology for Naval Gun Weapon Systems.* Monterey: Doctoral Thesis, Naval Postgraduate School.

NPS-N16-M296-B: 6lowpan: Enabling Secure IP Links over IEEE 802.15.4 for Low Power Wireless Networks

Researcher(s): Dr. Preetha Thulasiraman
Student Participation: LT David Courtney USN, Maj Thomas Haakensen USMC, and Capt Kelvin Chew USMC

Project Summary

Low power wireless networks use the IEEE 802.15.4 standard which is a data link and physical layer protocol that provides communications between low power devices. To provide connectivity between sensor devices and the tactical data network found in a Combat Operations Center (COC), low power wireless networks must use an IP based approach. The IETF’s 6LoWPAN is a protocol for seamlessly integrating 802.15.4 wireless networks with IPv4/IPv6. 6LoWPAN offers interoperability with wireless 802.15.4 low power devices and with devices on other IP network links (e.g., Ethernet or Wi-Fi). In this research project, we focused on the development of cyber security mechanisms to be implemented on a tactical wireless sensor network using the 6LoWPAN/IEEE 802.15.4 protocol. Specifically, we studied the use of the IEEE 802.15.4/6LoWPAN protocol for the USMC’s tactical networking Unattended Ground Sensor Set (AN/GSQ-257). Our primary goal was to develop an architectural framework for tactical wireless sensor networks (WSNs) by studying the cyber security gaps and vulnerabilities within the 6LoWPAN security sublayer, which is based on the IEEE 802.15.4 standard. During the course of this research we 1) developed a key management scheme and a centralized routing mechanism that is non-broadcast but feasible in an operational scenario; 2) modified the 6LoWPAN enabled IEEE 802.15.4 frame structure to facilitate the newly developed keying and centralized routing mechanisms; 3) developed a base station anonymity algorithm; 4) studied the vulnerabilities imposed by node neighbor discovery; and 5) tested the algorithms against a variety of well-known attacks including spoofing, man-in-the-middle (MITM), and denial of service (DoS). Methods to aid in deployment planning were also studied.

Keywords: tactical wireless sensor networks, cyber security, IEEE 802.15.4, 6LoWPAN, vulnerability analysis, unattended ground sensor set

Background

The USMC has high interest in wireless sensor networks (WSNs) and their ability to connect to a public domain. Currently, their WSN devices are deployed into the field, and their base station, known as AN/MSC-77, contains working spaces for two individuals to work inside of it (Corps, 2008). The AN/MSC-77 is also known as the Combat Operations Center (COC). Currently, in order for the USMC to obtain the data from the WSN, an individual must physically go to the COC, as it does not transmit the data acquired from the WSN. Thus, the current data flow from legacy equipment and sensor devices lacks automation. To facilitate seamless data delivery to and from the sensor devices, the network should be connected to another secure domain using a comprehensive communication protocol. The use of 6LoWPAN would significantly change the information flow as it currently exists by allowing multiple users in a unit to access sensor information despite their location. IP based information can be easily used to inform the situational awareness and common operational picture of the engaged unit. 6LoWPAN has been extensively studied in the literature but the focus has mostly been on single hop networks and energy consumption (Efendi, 2013). There have been studies that take into consideration an approach to implementing an efficient security mechanism for 6LoWPAN by either performing an analysis or survey (Kim, 2012)(Lee, 2009). Only a limited amount of research has been conducted implementing a proposed security framework over a multi-hop 6LoWPAN network (Lee, 2009). There has been plenty of research to achieve security within a generic WSN (Callanan, 2015). There has been some work that has been done on tactical WSNs that serve as a foundation for our work (Song, 2009) (Lee, 2009). While (Song, 2009) and (Lee, 2009) provide architectural constraints for tactical WSN deployment, the security mechanisms and its relationship with energy consumption is not discussed.

Findings and Conclusions

As was stated above, the tactical WSN paradigm used in the USMC tactical edge lacks data flow automation. Our goals in this research were to show the effectiveness of using 6LoWPAN/IEEE 802.15.4 to provide smoother data dissemination throughout the tactical network and to provide solutions for the various security vulnerabilities that are introduced through the use of 6LoWPAN/IEEE 802.15.4 in an operational setting. In order to prevent a passive or active attack, multiple security methods must be implemented to maintain an efficient and effective tactical WSN. Comprehensive defense security mechanisms must account for multiple types of attacks. Generally, to defend against an attack the military develops a defense model for the attack. Since there are multiple types of attacks, the military has developed multiple models to defend against each one. The development of a single model to defend against a variety of attacks prevents the need for an expanded arsenal of defense models saving the military money and manpower.

Three Master of Science in Electrical Engineering (MSEE) students have completed or will complete their thesis based on this research. The remainder of this section is divided into three subsections that detail the work of each student and its relevance to this project.

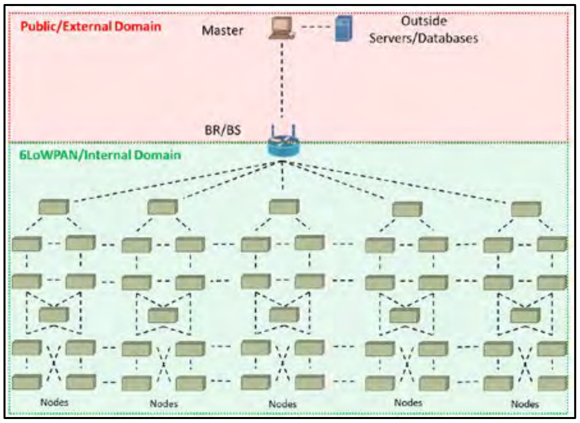


Figure. 1. The developed 6LoWPAN network design.

Part 1: Development of Network Security Architecture and Topology

LT David W. Courtney graduated in September 2016 with an MSEE and was awarded an Outstanding Thesis Award by the ECE department. His research was focused on developing the preliminary security framework/architecture for the tactical WSN. Our study into the applicability of a 6LoWPAN enabled IEEE 802.15.4 infrastructure for USMC tactical sensor networking was focused on a structured, multi-hop static WSN rather than an ad hoc deployment. The proposed network architecture is shown in Figure. 1 and is based on a typical mesh network. The elements included within the network architecture are as follows: master station (MS), base station/border router (BS), and sensor nodes. The MS serves as the central node of the network, as depicted in Figure 1. The proposed MS is a modified AN/MSC-77 (COC) currently used by the USMC but with modifications. The BS is the transitional element within the WSN that connects the 6LoWPAN/internal environment to the public/external environment. The sensor nodes are the end elements. The node is assumed to have the sensor capabilities as described in (Corps, 2008), including which sensors can be connected and which modes of operation are offered. Using this architecture we developed a data encryption and authentication scheme based on the Advanced Encryption Standard (AES). To accommodate this encryption and authentication method, we had to make changes to the IEEE 802.15.4/6LoWPAN frame structure. These modifications included changes to some of the frame fields and redefining unused fields.

One of the significant aspects of this security framework is a centralized data routing mechanism that is meant to isolate compromised sensor nodes. The routing scheme was developed such that secondary data forwarding paths would exist in the case when node(s) are compromised and must be removed from the network. The routing scheme was developed such that it would withstand various attack vectors, including spoofing, man-in-the-middle (MITM), and denial of service attacks (DoS). We also implemented this routing mechanism such that it would scale to a maximum of 64 hops.

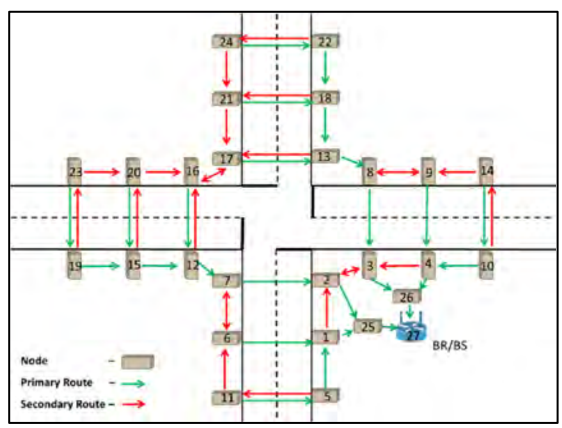


Figure 2. Network simulation topology that depicts node placement and shows the primary and secondary paths for each node, as developed in the centralized routing scheme.

The experimental setup used to perform network simulations was based on MATLAB. These simulations tested the efficacy of the cyber security mechanisms implemented in the security framework. The sensors in all simulations were the Magnetic Intrusion Detector (MAGID) described within (Corps, 2008). During the simulations, sensors are set on a low power setting and emplaced along a two-lane intersection, as shown in Figure. 2. The nodes selected for each attack remain the same for all scenarios to allow for comparisons between the different network environments. Each scenario had six different network implementations with five trials/simulations per implementation. A total of 30 trials were conducted for each scenario, resulting in a total of 120 trials for the program.

The purpose of the spoofing attack was to test the efficacy of the authentication and integrity mechanism added to the IEEE 802.15.4/6LoWPAN enabled frame. The MS was successfully able to perform an analysis on frames received to determine if there was a possible spoofing attack within the WSN and to determine which node to remove from the WSN to prevent further attacks, as illustrated in Figure 3.

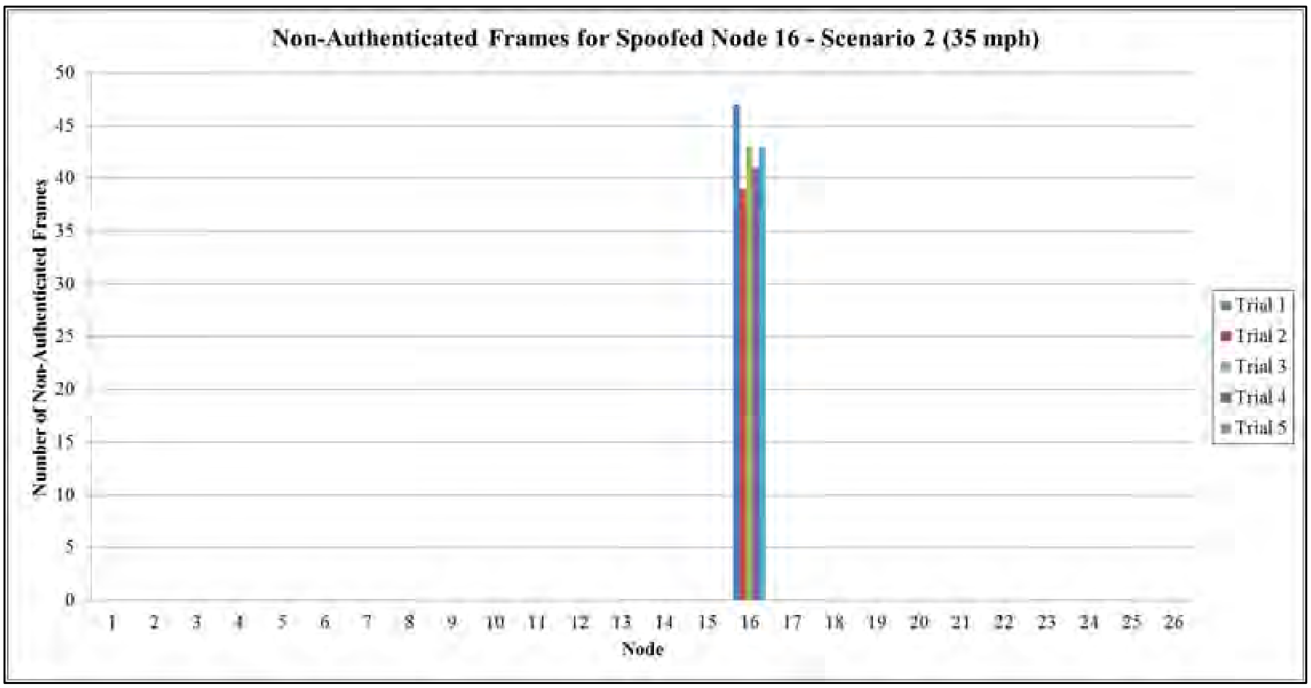


Figure 3. Number of non-authenticated frames received by the MS in each of the five trials for scenario 2 simulating a spoofing attack on node 16.

The DoS attack was used to determine if the centralized routing scheme and the use of the path indication bits would be able to detect an attack or incapacitated node. The analysis presented in Figure. 4 displays the use of the secondary routes, indicating possible congestion or a node malfunction, causing the WSN to operate in a non-optimal manner.

Similar to the spoofing attack, the analysis performed on the MITM attack was focused on the implementation of the authentication and integrity mechanism but also the centralized routing mechanism using the path indication bits.

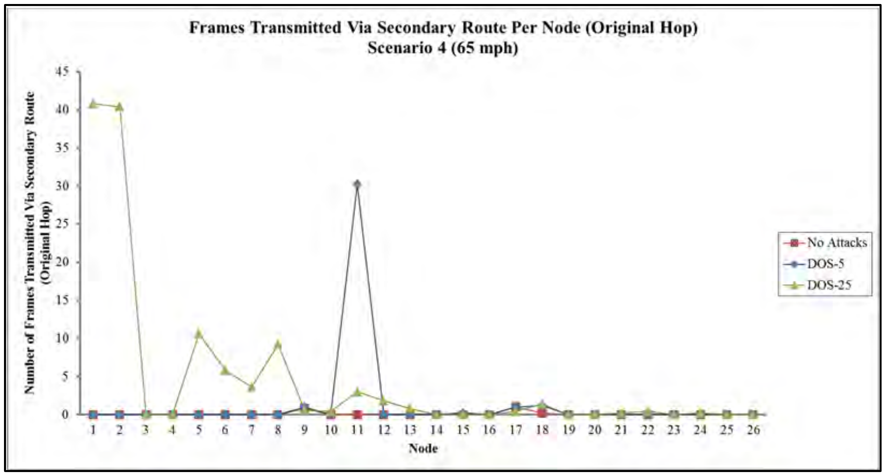


Figure 4. Frames transmitted via secondary route per node (original hop) in scenario 4 (traffic at 65 mph) for no attacks and dos attacks at nodes 5 and 25.

The results shown in Figure 5 validated our ability to authenticate valid frames sent by the nodes. The MS was then able to determine where the attack was occurring and which nodes to remove from the WSN. It must be noted that parts of the research presented in this part was published in April 2016 and is referenced in this Executive Summary (Courtney, 2016). LT Courtney's thesis is also referenced (Courtney D. , 2016).

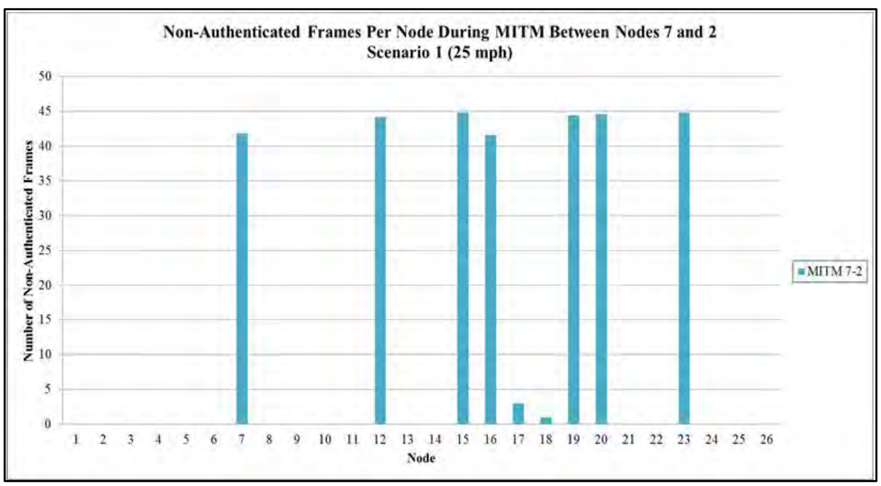


Figure 5. Number of non-authenticated frames received by the MS from the originating node during a MITM attack between nodes 7 and 2.

Limitations of this work include that fact that the BS is a single point of failure. Specifically, the BS is an open target for traffic analysis attacks.

The second part of this research focuses on this vulnerability.

Part 2: Base Station Anonymity for 6LoWPAN Enabled Tactical WSN

Maj. Thomas Haakensen graduated in June 2017 (Haakensen, 2017). His thesis focused on the implementation of a routing mechanism that provides anonymity to the base station shown in Figure. 1. Specifically, the base station, as the central point of traffic flow is susceptible to attack. As the single point of failure, an adversary's ability to locate the base station and compromise it would bring the entire network down. This work looked at the implementation of a k-anonymity scheme using a new routing standard known as LOADng. We integrated this anonymity scheme into the security framework developed in Part 1 of this summary. We are also in the process of submitting his work to a conference (IEEE UEMCON 2017).

Recommendations for Further Research

In this research project, we studied the implementation of the 6LoWPAN protocol for tactical WSNs and examined the need for 6LoWPAN in tactical WSNs used by the USMC in operational scenarios. Through the use of 6LoWPAN, our aim was to reduce the manpower required to maintain the tactical WSN by allowing the WSN to be managed from a remote, secure location. Ultimately, 6LoWPAN provides automation to the data flow by eliminating the need of an individual to physically retrieve data from the COC. The 6LoWPAN protocol, with the addition of necessary cyber security mechanisms, can be implemented and used by the USMC to boost the abilities of its current WSNs. In this thesis, we developed and discussed a comprehensive tactical WSN framework using 6LoWPAN that includes a hierarchical network design using defined network devices. The use of a structured/centralized network design allows for secure network reachability and accessibility. We implemented multiple cyber security mechanisms within the 6LoWPAN protocol.

One avenue of research that must be investigated in the future is the case of mobile sensors. The work presented in this summary assumes the network is static. However, wearable sensors can be attached to individuals providing valuable information in regard to the individual’s location or biometric readings enhancing situational awareness of the deployed force.

References

Callanan, A. &. (2015). Achieving sink node anonymity under energy constraints in tactical wireless sensor networks. *IEEE International Multi-Disciplinary Conference on Cognitive Methods in Situation Awareness and Decision Support*, (pp. 186-192).

Corps, U. M. (2008). *Sensor Mobile Monitor System AN/MSC-77 Technical Manual.* Washington, DC.

Courtney, D. &. (2016). Implementation of Secure 6LoWPAN Communications for Tactical Wireless Sensor Networks. *IEEE Conference on Computer Communications Workshops: MiseNet Workshop*, (pp. 962-967).

Courtney, D. (2016). *Implementation of Secure 6LoWPAN Communications For Tactical Wireless Sensor Networks.* Master's Thesis, Naval Postgraduate School, Monterey.

Efendi, A. O. (2013). Battery-Less 6LoWPAN-Based Wireless Home Automation by Use of Energy Harvesting. *International Jouranl of Distributed Sensor Networks, 9*(7).

Haakensen, T. J. (2017). *Achieving Sink Node Anonymity in Tactical Wireless Sensor Networks Using a Reactive Routing Protocol.* Master’s Thesis, Naval Postgraduate School, Monterey.

Kim, E. K. (2012). *Problem Statement and Requirements for IPv6 over Low Power Wireless Personal Area Networks (6LoWPAN) Routing.* Request for Comments (RFC): 6606.

Lee, S. L. (2009). Wireless sensor network design for tactical military applications: remote large-scale environments. *IEEE Military Communications Conference*, (pp. 911-917).

Song, H. L. (2009). 6LoWPAN Based Tactical Wireless Sensor Network Architecture for Remote Large-Scale Random Deployment Scenarios. *IEEE Military Communications Conference*, (pp. 1-7).

NPS-N16-M405-A: Understanding Development Test and Evaluation (DT&E) Implications for Cyber

Researcher(s): Mr. John Gibson, Ms. Karen Burke, and Dr. Douglas MacKinnon
Student Participation: Maj Christopher Jones USMC, and Maj David Yorck USMC

Project Summary
The purpose of this research was to improve the understanding of the Development Test and Evaluation (DT&E) cybersecurity testing to minimize cybersecurity vulnerabilities prior to fielding equipment and systems to the operational forces. The research included case studies of two existing United States Marine Corps (USMC) systems, lab testing in a test bed developed at the Naval Postgraduate School to fine-tune suggestions for DT&E, and a study of system-of-systems testing. Opportunities to improve resilience were determined and offensive-type laboratory testing is recommended.

Keywords: Development Test and Evaluation (DT&E), Test and Evaluation Master Plan (TEMP), cybersecurity, Risk Management Framework (RMF), System of Systems (SoS), C4, C4I).

Background
"Risks associated with vulnerabilities inherent in information technology (IT) must be considered throughout the system development life cycle for all IT used or operated on behalf of the Department of Defense (DOD) (Department of Defense, 2014)." In addition, IT interconnections must be managed so that the security posture of one system does not impose risk on others (Department of Defense, 2014).
The DODI 5000.02, *Operation of the Defense Acquisition System,* "assigns, reinforces, and prescribes procedures for acquisition responsibilities related to cybersecurity in the Defense Acquisition System (Department of Defense, 2015)." The most recent update details the program manager's responsibilities for cybersecurity from the exploratory phase through all phases of acquisition (Department of Defense, 2015). Chapter 8 of the *Defense Acquisition Guidebook* requires an "affordable test and evaluation (T&E) program that enables the Department of Defense (DOD) to acquire systems that work (Defense Acquisition University, 2017)." According to Chapter 8-3.1 of the *Defense Acquisition Guidebook*, Development Test and Evaluation (DT&E) is the disciplined process of generating substantiated knowledge on the capabilities and limitations of systems, subsystems, components, software, and materiel (Defense Acquisition University, 2017). Note that DT&E also supports the cybersecurity assessments of security controls and the authorization to operate in compliance with the Risk Management Framework (RMF) (Department of Defense, 2014).

This research effort explored the implications of cybersecurity DT&E with respect to Marine Air-Ground Task Force (MAGTF) Command, Control, Communications, Computers, and Intelligence (C4I) systems. Case studies also explored where systems under test were determined to be most vulnerable to adverse cyber actions. The Marine Corps Civil Information Management System (MARCIMS) and Common Aviation Command and Control System (CAC2S) were selected for case study analysis because both programs underwent DT&E following the release in April 2013 of the Deputy Assistant Secretary of Defense (DT&E) *Guidelines for Cybersecurity* (Office of the DASD (DT&E), 2013).

It is important to note that this research began prior to the recent changes to DODI 5000.02 that explicitly addressed cybersecurity responsibilities throughout the life cycle of the system. Per the 2017 updates, "Program managers use DT&E activities to manage and mitigate risks during development, to verify that products are compliant with contractual and operational requirements, and to inform decision makers throughout the program life cycle (Department of Defense, 2015)." DT&E also provides program engineers an opportunity in a development environment to identify cybersecurity vulnerabilities that could jeopardize the operational delivery of the system. This gives the program manager an opportunity to address the cyber concerns earlier in the life cycle before a cyber risk becomes a program risk due to cost and schedule impacts.

Program managers must develop a Test and Evaluation Master Plan (TEMP) "as the primary planning and management tool for the integrated test program" to include DT&E activities (Department of Defense, 2015) such as vulnerability testing and evaluation and specific test events for components and interfaces that need "specific attention" based on criticality and vulnerability analysis (Department of Defense, 2015).

Findings and Conclusions

The students' research focused on case studies and a laboratory experiment to identify improvements to cyber DT&E. The studies were limited due to the classified nature of the cybersecurity testing results and program documentation. Although MARCIMS and CAC2S were both developed using previous editions of policies, namely DoDD 8500.01 (Department of Defense, 2002), DoDI 8500.02 (Department of Defense, 2003), DoDI 8510.01 (Department of Defense, 2007), and DoDI 5000.02 (Department of Defense, 2008), the requirements to develop a TEMP, address cybersecurity testing in the TEMP, and perform security testing were not new requirements (Department of Defense, 2012). "Historically, TEMPs and associated test plans have not adequately addressed cybersecurity measures or resources (Department of Defense, 2015)."

Marine Civil Information Management System (MARCIMS) and Common Aviation Command and Control System (CAC2S) were selected for case study analysis because both programs underwent DT&E following the release in April 2013 of the Deputy Assistant Secretary of Defense (DASD (DT&E)) *Guidelines for Cybersecurity* (Office of the DASD (DT&E), 2013). Because of the security limitations previously mentioned, the research examined the test strategy documents developed for MARCIMS and CAC2S to extrapolate opportunities to improve the cyber DT&E plans for future programs.

A third case study examined how the USMC should conduct cybersecurity DT&E on system of systems (SoS) since most military systems are part of a SoS. The research recognized the need to also plan for and execute cyber assessments in preparation for cyber DT&E of system modifications to mitigate program risk.

This research also included lab experimentation to be recommended for inclusion in future DT&E events. A *honeypot* was established online for MARCIMS in a laboratory environment with the goal of understanding how hackers would or could attempt to circumvent cybersecurity measures to exploit the system. This type of testing was more offensive than defensive because this might expose if someone was inappropriately attempting to circumvent security controls. Capturing the system state before and after placing the honeypot online provided indications of any system changes or attempts during its exposure on the internet. Network traffic to and from the honeypot was also captured providing additional insight into the attacks, both successful and unsuccessful. A MACIMS user device was placed on the Internet with no firewall or other external security measures in place. Over approximately 45 days, numerous attacks were launched on the device and the associated wireless router. Networks tools like Snort and Wireshark were used to understand how the device was exploited. Port scans conducted before and after the honeypot operations indicated that new ports were opened on the MARCIMS device indicating potential compromise. Adding this type of a scenario to DT&E allows the systems cybersecurity engineering team to eliminate or mitigate these vulnerabilities prior to delivery of the operational system.

The case study analysis determined that the MARCIMS and CAC2S Program Offices understand cybersecurity risks and have improved their system resilience prior to production and deployment. However, there were areas identified where the systems' resilience could be further enhanced. The examined case studies highlighted process and procedures that are advantageous to developing a secure information system. The laboratory testing used vulnerability scanners, intrusion detection systems, and a honeypot exposed to the Internet to demonstrate how seemingly secure systems might be vulnerable. These areas and the interpretation of the lab testing results will be detailed in the students' thesis to be delivered to Marine Corps Tactical Systems Support Activity (MCTSSA) upon completion in September, 2017.

The findings of this thesis can be integrated with the command requirements to aid MCTSSA's mission of conduction DT&E for USMC and joint service Command, Control, Communications, Computers, and Intelligence (C4I) systems. Furthermore, the thesis will be applicable to the entire DOD because all services must consider and plan for cyber-related DT&E for acquisition programs per the *Defense Acquisition Guidebook* (Defense Acquisition University, 2017).

Recommendations for Further Research

Additional case studies could be developed and analyzed, specifically for USMC C4I programs that underwent DT&E since the transition to the RMF and the updated acquisition policies and guidelines. A more in-depth study of system of systems, to include end-to-end cybersecurity testing in accordance with the latest policies, would also be beneficial.

References

Adriansyah, A., & Suntoro, E. (2015). *The Development of Indonesia's Doctrine for Special Hostage Rescue Operations.* Naval Postgraduate School. Retrieved from http://hdl.handle.net/10945/47933

Afriandi, D. (2015). *The Indonesian COIN Strategy: Failures and Alternative Approaches in Overcoming the Papuan Insurgency.* Monterey: Naval Postgraduate School. Retrieved

from http://hdl.handle.net/10945/47944
B. Allen, T. A. (2006). Autonomous docking demonstrations with enhanced remus technology. *IEEE/MTS OCEANS.*
B. W. Hobson, R. S. (2007). The development and ocean testing of an auv docking station for a 21" auv. *IEEE/MTS OCEANS*, 1-6.
Borozny, E. (2015). *Projecting Navy Officer Inventory with Data Farming.* Monterey: Naval Postgraduate School. Retrieved from http://hdl.handle.net/10945/47232
Braun, R. R. (2015, October 01). *Chief of Naval Operations Instructions Navy Intelligence and Security Doctrine.* doi:5510.165a
Bush III, R. C. (2011). *The U.S. Policy of Extended Deterrence in East Asia: History, Current Views and Implications.* Brookings Institution , Arms Control Series. Retrieved from www.brookings.edu/research/papers/2011/02/arms-control-bush
Cabahug, E. G. (2015, May). Joint Combined Exchange Training from a Host Nation's Perspective. *CTX, 5*(2). Retrieved from https://globalecco.org/352
Cabahug, E., & Leuthner, S. (2015). *Joint Combined Exchange Trainings: A Crucial Tool in Security Cooperation Engagement.* Monterey: Naval Postgraduate School. Retrieved from http://hdl.handle.net/10945/47809
Cullom, P. (2012). *Shore Energy Management.* U.S. Department of the Navy. doi:4100.5E
Defense Acquisition University. (2017, March 7). Defense Acquisition Guidebook. Retrieved from https://www.dau.mil/tools/dag.
DeHollan, A. (2015). *Investigating Navy Officer Retention Using Data Farming.* Monterey: Naval Postgraduate School. Retrieved from http://hdl.handle.net/10945/47245
Dempsey, M. E. (2012). *Joint Operational Access Concept (JOAC).* Department of Defense. Washington: Department of Defense. Retrieved from http://www.defense.gov/Portals/1/Documents/pubs/JOAC_Jan%202012_Signed.pdf
Department of Defense. (2002, October 24). Information Assurance (DoDD 8500.01E, Certified Current as of April 23, 2007) .
Department of Defense. (2003, Feb 6). Implementation Assurrance (IA) Implementation (DoDI 8500.02).
Department of Defense. (2007, November 28). DoD Information Assurance Certification and Accreditation Process (DIACAP) (DoDI 8510.01).
Department of Defense. (2008, December 8). Operation of the Defense Acquisition System (DoDI 5000.02).
Department of Defense. (2012, December). Test and Evalulation Management Guide, Sixth Edition. Retrieved from https://acc.dau.mil/CommunityBrowser.aspx?id=518162.
Department of Defense. (2014, March 14). Cybersecurity (DoDI 8500.01).
Department of Defense. (2014, March 12). Risk Management Framework (RMF) for DoD Information Technology (IT) (DoDI 8510.01, Incorporating Change 1, Effective May 24, 2016).
Department of Defense. (2015, July 1). Cybersecurity Test and Evaluation Guidebook, Version 1.0.
Department of Defense. (2015, January 7). Operation of the Defense Acquisition System (DoDI 5000.02, Incorporating Change 1, Effective January 26, 2017 and Change 2, Effective February 2, 2017).

Department of the Navy's Energy Program for Security and Independence . (2015, May 1). Retrieved from Department of the Navy Energy, Environment and Climate Change: http://greenfleet.dodlive.mil/files/2010/04/Naval_Energy_Strategic_Roadmap_100710.pdf
DeSousa, W. (2015). *An Exploratory Analysis of Economic Factors in the Navy Total Force Strength Model (NTFSM).* Monterey: Naval Postgraduate School. Retrieved from http://hdl.handle.net/10945/47935
Duan, W., Ankenman, B. E., Sanchez, S. M., & Sanchez, P. J. (2016). Sliced Full Factorial-Based Latin Hypercube Designs as a Framework for a Batch Sequential Design Algorithm. Retrieved from http://www.tandfonline.com/doi/full/10.1080/00401706.2015.1108233
Emanuelsen, K., & Lee, J. (2015). *Gender Differences in Life-Work Balance and Their Impact on Female Occupational Choice and Retention.* Monterey: Naval Postgraduate School. Retrieved from http://hdl.handle.net/10945/45183
Eun-jung, K. (2012, October 24). S. Korea, U.S. agree to set N. Korean nuclear deterrence policy by 2014. *Yonhap News Agency*. Retrieved from english.yonhapnews.co.kr/national/2012/10/24/58/0301000000AEN2012102400665131 5F.HTML
Everly, R., & Limmer, D. (2014). *Cost-Effectiveness Analysis of Aeral Platforms and SuitableCommunication.* Monterey: Naval Postgraduate School. Retrieved from http://hdl.handle.net/10945/41375
Fernandes, A., & Taylor, T. (2015). *Dim Networks: The Utility of Social Network Analysis For Illuminating Partner Security Force Networks.* Monterey: Naval Postgraduate School. Retrieved from http://hdl.handle.net/10945/47943
Friedberg, A. L. (2012). *A Contest for Supremacy : China, America, and the Struggle for Mastery in Asia.* New York; London: W.W.Norton.
Great Green Fleet. (2015, May 25). Retrieved from Department of the Navy U.S. Energy, Environment and Climate Change: http://greenfleet.dodlive.mil/energy/great-green-fleet/
Hagt, E., & Durnin, M. (2011, October 26). Space, China’s Tactical Frontier. *Journal of Strategic Studies, 34*(1), 733-761. doi:10.1080/01402390.2011.610660
Hernandez, L., & Johnson, D. (2014). *Designing Incentives for Marine Corps Cyber Retention.* Monterey: Naval Postgradaute School. Retrieved from http://hdl.handle.net/10945/44578
Higgins, S., Denning, P., & Miller, S. (2015). In *Innovative Learning: A Key to National Security.* Army Press. Retrieved from http://armypress.dodlive.mil/?p=1659
Huntley, W. (2013, July 27). Speed Bump on the Road to Global Zero: U.S. Nuclear Reductions and Extended Deterrence in East Asia. *Nonproliferation Review 20, 20*, 305-38. doi:10.1080/10736700.2013.799945
Hyuk-chul, K. (2010, October 9). S. Korea–U.S. to organize a joint committee for extending nuclear deterrence. *the hankyoreh*. Retrieved from http://english.hani.co.kr/arti/english_edition/e_northkorea/443035.html
Jeong, D. (2012). *China’s Foreign Policy toward North Korea: The Nuclear Issue.* Monterey: Naval Postgraduate School. Retrieved from http://hdl.handle.net/10945/27847
Kelly, R., Oriti, G., & Julian, A. (2013, December). Remote Military Base: Introducing an Energy

Management System. *IEEE Electrification Magazine, 1*(2), 30-37. doi:10.1109/MELE.2013.2293182
Kim, D. (2011, June 02). Tactical Nuclear Weapons and Korea: A Temporary or Perennial Debate? *Center for Arms Control and Non-Proliferation*. Retrieved from armscontrolcenter.org/issues/northkorea/articles/tactical_nuclear_weapons_and_korea/
Lewis, J. (2012). *Extended Nuclear Deterrence in Northeast Asia.* Special Report, Nautilus Institute . Retrieved from http://nautilus.org/napsnet/napsnet-special-reports/extended-nuclear-deterrence-in-northeast-asia/
Mabus, R. (2013, August 08). *Department of the Navy Insider Threat Program.* doi:5510.37
Meador, D., & Lopes, O. (2015). *The Last Mile: Extending Legitimacy Using the Principles of Disaster Relief.* Monterey: Naval Postgraduate School.
Menjivar, J. (2012). *Bridging Operational and Strategic Communication Architectures Integrating Small Unmanned Aircraft Systems As Airborne Tactical Communication Vertical Nodes.* Monterey: Naval Postgraduate School. Retrieved from https://calhoun.nps.edu/handle/10945/17418
Morgan, B. L., Schramm, H., Smith, J., Lucas, T., McDonald, M., Sanchez, P., . . . Upton, S. (2016). *Improving U.S. Navy Campaign Analysis with Big Data.* Naval Postgraduate School, Operations Research. Monterey: Naval Postgraduate School.
Navy Tests Biofuel-Powered Green Hornet. (2010, April 22). Retrieved 2016, from Navy.mil: http://www.navy.mil/submit/display.asp?story_id=52768
Nott, B. (2015). *Long-Endurance Maritime Surveillance with Ocean Glider Networks.* Monterey: Naval Postgraduate School. Retrieved from http://hdl.handle.net/10945/47308
Office of the DASD (DT&E). (2013, April 19). Guidelines for Cybersecurity DT&E v1.0. Retrieved from https://www.hsdl.org/?view&did=736765.
Oriti, G., Julian, A., & Peck, N. (2016, January). Power Electronics Based Energy Management System with Storage. *IEEE Transactions on Power Electronics, 31*(1). Retrieved from http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=7050372&tag=1
Pav, R. (2015). *Experiments in Error Propagation Within Hierarchical Combat Models.* Operations Research. Monterey: Naval Postgraduate School. Retrieved from http://hdl.handle.net/10945/47310
Presence with a Purpose. (2011, November). U.S. Pacific Command.
R. S. McEwen, B. W. (2008). Docking control system for a 54-cm-diameter (21-in) auv. *IEEE Journal of Oceanic Engineering, 33*(4), 550–562.
Rao, N., & Simmons, O. (2013). *Koinonia: The Requirements and Vision for an Unclassified Information-Sharing System.* Monterey: Naval Postgraduate School. Retrieved from http://hdl.handle.net/10945/34725
Rice, I. C. (2015). *To Break or to Build: Aligning Goals and Outcomes during Military-led State-Building Efforts." Doctoral Dissertation from University of Californi.* Defense Analysis Department, Naval Postgraduate School. Los Angeles: University of California - Los Angeles .
Rosenberg, B. (2010, January 21). Netted Iridium 'radios' prove indispensible in battlefield test. *Defense Systems*. Vienna, VA, USA. Retrieved from https://defensesystems.com/articles/2010/01/27/c4isr1-netted-iridium-

communications.aspx
Sans-Muntadas, A. (2015). Navigation and probability assessment for successful auv docking using usbl. *IFAC-PapersOnLine, 48*(16), 204-209.
Saunders, P. (2012). *Extended Deterrence and Security in East Asia: A U.S.-Japan-South Korea Dialogue.* Center for the National Interest. Retrieved from http://www.tokyofoundation.org/en/articles/2013/extended-deterrence-and-security-in-east-asia
Schwartz, N., & Greenert, J. (2012, February 20). Air-Sea Battle. *The American Interest*. Retrieved from http://www.the-american-interest.com/2012/02/20/air-sea-battle/
SEED Center for Data Farming. (2015). *STORMMiner User's Manual v1.0.* Monterey, California: Naval Postgraduate School.
Spafford, G. (2015). *Foreign Security Force Advisor Training, Doctrine, and Manning for 2015 and Beyond.* Monterey: Naval Postgraduate School. Retrieved from http://hdl.handle.net/10945/48477
Spera, B. (2015). *The Praetorian Trap: Post 9/11 U.S. SOF Efforts to Establish Elite Military Capabilities in West Africa.* Monterey: Naval Postgraduate School.
Swift, S. H. (2015, January 27). doi:5510.165
Tellis, A. (2014, January 28). *Does China Threaten the United States in Space?* Carnegie Endowment for International Peace. Retrieved from http://carnegieendowment.org/2014/01/28/does-china-threaten-united-states-in-space-pub-54349
Tellis, A. J. (2013, October). Balancing Without Containment: A U.S. Strategy for Confronting China's Rise. (36:4, Ed.) *The Washington Quarterly*, 109-124.
The Department of the Navy's Energy Goals. (2015, May 01). Retrieved 2016, from http://www.navy.mil/features/Navy_EnergySecurity.pdf
United States. (2015, June 25). Cong. House. Committee on Armed Services., *2nd Session.*
Vilardi, N. (2010). *Graphitic Oxide and Graphene as Enhancers for Combustible Mixtures.* Monterey: Naval Postgraduate School. Retrieved from N. F. Vilardi, "Graphitic Oxide and Graphene as Enhancers for Combustible Mixtures," Naval Postgraduate School, pp. i - 135, 2014. .
Waddell, J. (2014). *Leveraging MANET and Mobile Devices in Ship-to-Objective Maneuver and Expeditionary MAGTF Operations.* Monterey: Naval Postgraduate School. Retrieved from http://hdl.handle.net/10945/44026
Waddell, J. (2014). Marine C2 in Support of HA/DR: Observations and Critical Assessments Following. *International Command and Control Research and Technology Symposium*, (p. 16). Alexandria. Retrieved 2015, from http://www.dodccrp.org/events/19th_iccrts_2014/post_conference/papers/120.pdf
Whun, C. S. (2010, November 3). *The Significance of Forming a ROK-U.S. Extended Deterrence Policy Committee.* Retrieved from Kinu.org: www.kinu.or.kr/upload/neoboard/DATA02/co10-39(E)1.pdf
Y. Li, Y. J. (2015). Auv docking experiments based on vision positioning using two cameras. *Ocean Engineering*.

Marine Corps Modeling and Simulation Management Office (MCMSMO)

NPS-N16-M158: LVC Simulation for Training, Analysis and Operations in a Digital Interoperable Battlefield

Researcher(s): Mr. Perry McDowell
Student Participation: No students participated in this research project.

Project Summary
The goal of this project is to examine how new digitally interoperable systems can be used in future combat scenarios as well as examine how these systems can be used to improve the planning process for operations.

Keywords: live, virtual and constructive, LVC, MCPP, Unity, Combat XXI, operational planner

Background
The quantity and quality of digital communications between warfighters in battle have been increasing and will continue to do so. Leadership expects this interoperability to be a major force multiplier in future conflicts and expects it to allow smaller forces to "slug above their weight." In order to maximize the effects of digital interoperability, however, the military must be able to properly evaluate potential new techniques and train personnel how to use them in realistic conditions.
Currently, the military is moving more of its training into the live/virtual/constructive (LVC) realm. Additionally, the military is beginning to use LVC for analysis of potential weapons systems, although this is still rare. We propose to investigate using LVC to:

Operational planning is a time consuming and difficult task, but one which is critical to the ultimate success of any mission. Currently, all services are using software systems to improve planning, but many of these systems are disjointed and don't communicate with other systems. Additionally, they do not bring to bear the significant power of LVC systems, which currently the military primarily uses for training. These LVC systems show significant potential to improve and streamline the planning process.

Findings and Conclusions
The proposal included a process to answer the research questions. The steps from the proposal are listed below in bold, as well as what we have done in that area.

1. Determine whether a task analysis (TA) has been performed on the Marine Corps Planning Process (MCPP) as described in Marine Corps Warfighting Publication (MCWP) 5-1 for a Marine Expeditionary Unit (MEU).

   No TA existed for MCPP, so the researchers investigated the applicable publications and attended a training event for the staff of a special purpose Marine Air-Ground Task Force (MAGTF) at Expeditionary Warfare Training Group, Pacific, in Coronado, California. From this, we created a “light” TA, focusing on the areas where LVC technology could add maximum improvement. We decided that this was primarily in the first four stages of MCPP:

Stage 1: Problem Framing
Stage 2: Course of Action (COA) Development
Stage 3: COA Wargaming
Stage 4: COA Comparison and Decision

2. This TA will be also used to determine which parts of the planning process would benefit most from being analyzed using a constructive simulation to examine the operational effects of decisions during the planning process.
   1. Defining requirements and measurable metrics to evaluate the success of the system built by this project.
   2. Once we complete this analysis, we will examine the potential constructive simulations to determine which would best provide the required analysis and has an acceptable path to integration with the other tools used in planning.

   We examined several constructive simulations for use in the system:

   - MAGTF Tactical Warfare Simulation (MTWS)
   - OneSAF
   - Combat XXI (CXXI)

   We decided to use CXXI, despite the fact that it was primarily geared towards analysis. The primary factor driving that decision was that it provided the greatest probability of success to create a working prototype because it had the easiest interface to work with and we could create a mechanism to pass information from a game engine to CXXI and back faster than any of the other options.

3. Using the TA, determine the modalities which present the greatest benefit when examining the virtual environment (VE) during the planning and briefing phases investigated during this project.

   We built the prototype for a desktop/laptop version requiring a high-end graphics/game computer. The three main reasons we did this are:

   1. The game interface used is common to many other applications and could quickly be learned without any special training.
   2. Although we considered displaying the information inside a head mounted display (HMD), doing so would both increase the cost/complexity of the project as well as the difficulty in training Marines to use it. Additionally, the required 3D interface devices are neither as precise nor reliable as the standard mouse.

3. Current HMD technology is too fragile to be used in an operational environment and not ready to be deployed with Marines.

4. Using the TA and the modalities determined in the previous step, determine the software best suited to create the VE and present it in those modalities. Build a prototype VE that will take basic information from planning software currently in use with the USMC and display it in a VE in a manner which is conducive for commanders and planners to examine it as part of the briefing for a small operation.

   We decided to use the Unity Game Engine as the underlying virtual platform. This is because Unity has become almost a standard in the industry for low-cost development. It is among the simplest engines to use while delivering significant power to the developer at a very low price.

5. Create a prototype system connecting the planning software, constructive simulation, and VE.

   We built a VE where the user could position both friendly and enemy entities (e.g., vehicles, personnel, improvised explosive devices (IEDs)). This can be used to perform the first step of MCPP: Problem Framing. We anticipate that the staff intelligence officer (S2) would place the red forces in the best estimate of their positions, and the staff operations officer (S3) would position friendly forces in their locations.

   Once the entities are positioned in the world, the staff would attach behaviors and objectives to them, such as proceeding along waypoints. This is to simulate step 2: COA Development.
   Once the user has created the scenario, or COA, he sends the COA to the constructive simulation, which evaluates the plan and returns the results in terms of casualties, resource expenditures, etc. This effectively conducts step 3 of the MCPP: COA Wargaming.

   Finally, the action is replayed in the VE, showing what happened as well as results, which will aid in step 4: COA Evaluation and Decision.

   The VE also provides visibility calculations to the user to assist in planning the mission.

6. Demonstrate the system to experienced Marines to get feedback on the viability and usefulness of the system.

   We have showed it to several USMC personnel and received feedback and advice for further development.

7. Produce a final report and recommendation on whether research should continue examining the overarching vision.

This will be completed at the conclusion of the project at the end of FY-17.

Recommendations for Further Research

The primary recommendation is to take the system and continue developing it, both improving the items it currently covers and adding the other steps of MCPP. Additionally, we recommend that it be tested via a controlled experiment to determine whether it improves the MCPP process in terms of time, quality, or depth of plans.

HQMC AVIATION (HQMC AVN)

NPS-N16-M343-C: Effective C2 Comms to the Tactical Edge in Challenged, Disrupted, and Denied Environments

Researcher(s): Dr. Justin P. Rohrer
Student Participation: Mr. Michael K. Monahan

Project Summary

Native Internet Protocol (IP) networks are ill-equipped to handle the communication challenges found in wireless communications (comms) environments, resulting in communications outages that degrade command and control (C2) data flow and subject the user to disconnection, timeouts, and repeated login requests. We counter these limitations by integrating DTN (Disruption-Tolerant Networking) technology into the IP network using software+hardware or software-only solutions as appropriate. This work evaluates the tradeoffs between the currently available DTN software implementations and seeks to identify the one with the highest technical readiness level, as well as any barriers to adoption that may be present. We find that no current implementation is fully ready, and that each have particular pros and cons to adoption. For greatest effectiveness, this solution will be customized to support specific C2 applications and prevent application timeouts.

Keywords: disruption-tolerant networks, DTN, RFC5050, bundle protocol, BPA

Background

Disruption-tolerant networking (DTN) is an approach to computer networking that seeks to address the technical issues in heterogeneous networks that may lack continuous network connectivity. DTNs accomplish this by providing a means for some intermediary device or series of devices (e.g. gateways or routers) to intercept and place packets into persistent storage (this could be a hard drive, solid state flash, random access memory (RAM), etc), during times when a link or a set of links experience disruptions or severe latency. When network conditions once again become normalized, the intermediary device will again forward packets to its next hop.

Some previous DTN-related research at the Naval Postgraduate School involved evaluating and testing the operation of the SPINDLE DTN software. SPINDLE is developed by Raytheon BBN Technologies for the Defense Advanced Research Projects Agency (DARPA) Disruption Tolerant Networking program for exclusive use by the DOD. One of the questions that arose during this research was how does SPINDLE compare to some of the other open-source DTN software implementations. A previous DTN comparison study did just this, and compared the performance characteristics of the RFC 5050 DTN Reference Implementation, National Aeronautics and Space Administration (NASA)/Jet Propulsion Laboratory's Interplanetary Overlay Network (ION) DTN software and University of Braunschweig's IBR DTN software. There is no known study that compares SPINDLE with these other open-source DTN implementations. A SPINDLE software installation can use a large amount of memory resources, so a key motivation was to see how SPINDLE performance and the overall functional operation of the SPINDLE software agent, compares with the ION and IBR DTN software implementations, of which both have significantly lower memory footprints. Many mobile devices, such as tactical handheld units, wireless sensor motes, and other embedded systems have minimal amount of memory and central processing unit (CPU) processing power, so it may be of benefit to use an alternative DTN implementation.

The best-known reference for DTN architecture is Kevin Fall's 2003 paper [5], which generalized from earlier work specific to handling long-delay links. Our work is in the context of applying such an architecture to challenges specific to USMC tactical networks. This research effort concerns implementations of the Bundle Protocol Specification, therefore RFC5050 [4] is our primary reference for correct operation of this software. Vint Cerf and Scott Burleigh also provided context for the protocol described in RFC5050 in [3]. We also refer to and extend the performance evaluation methodology of Wolf et al [1]. The benefit to this is not reinventing the wheel on basic methodology for quantitative evaluation, however they did not address a number of qualitative factors that are key discriminators in the technical readiness of the software, and did not have access to SPINDLE. Addressing these factors will significantly differentiate this work from theirs. While our effort in this case is not specifically concerned with DTN-specific application software, we will be using such software to generate traffic load in our testbed, and as such refer to the Artemois et al [2] survey of such applications.

Our previous work in this area has included developing gateway technology for integrating DTN protocols into IP networks, and these efforts have been published in [6,7,8]. It was this work that highlighted deficiencies in some DTN implementations and necessitated the study currently proposed.

Findings and Conclusions

Test Environment: *Testbed*: The DTN testbed is comprised of one physical server and uses computer hardware virtualization to emulate the individual DTN nodes and corresponding network topology. The server is a Dell PowerEdge 2950 Server, with an Intel Xeon 4-core 3.0Ghz processor, 16 GB RAM, 255 Gigabyte (GB)of disk storage, running Ubuntu 12.04 LTS linux. Oracle VirtualBox (v4.3.14) is the virtualization software that was used to create and run the virtual machine instances in the testbed. The DTN guest virtual machines (VM) were allocated 2GB of RAM and 8 GB of hard disk storage. The DTN router virtual machines were allocated 512MB of RAM and 2GB of disk storage. Intel VT-x hardware acceleration was enabled in the host machine's Basic Input/Output System (BIOS) and in each of the VM's settings in VirtualBox. VT-x is a set of processor enhancements to improve virtualization performance that allows for near-native speed in a virtual machine.

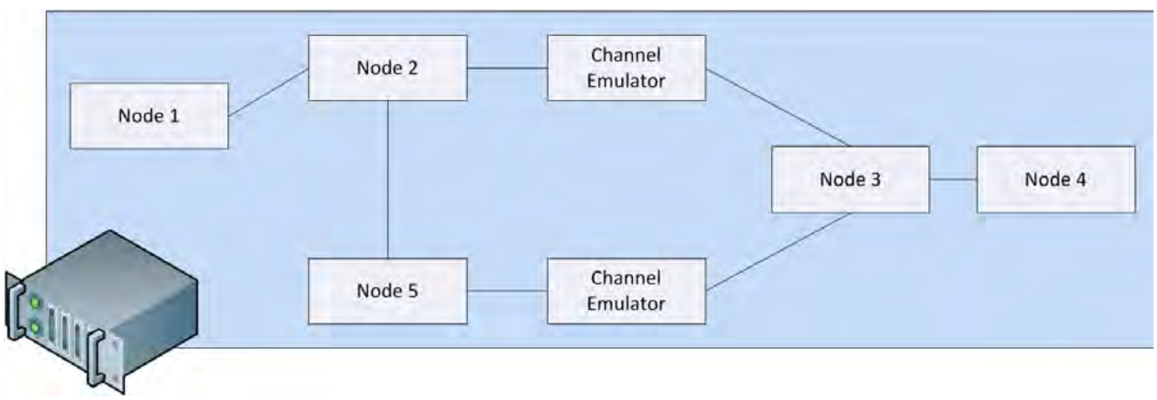


Figure 1: Example Network Topology

Host Nodes: Node 1 and Node 4 represent the end points of the emulated network topology. (see Figure 1) Node1 could represent a mobile device in the field, such as a hand-held device carried by a soldier, or a radio unit affixed to a moving vehicle such as a humvee. Node 4 could represent a fixed node connected via a satellite link, such as a command center (where units in the field can report to). Each host node has two network interfaces configured: one interface for communication with the DTN network and one interface is used for network management.

Router Nodes: The router nodes (node1, node2 and node5) represent the intermediate nodes in the emulated network topology. These nodes can represent fixed nodes (such as a forward operating base) or other mobile nodes, such another vehicle acting as a relay. Node2 and

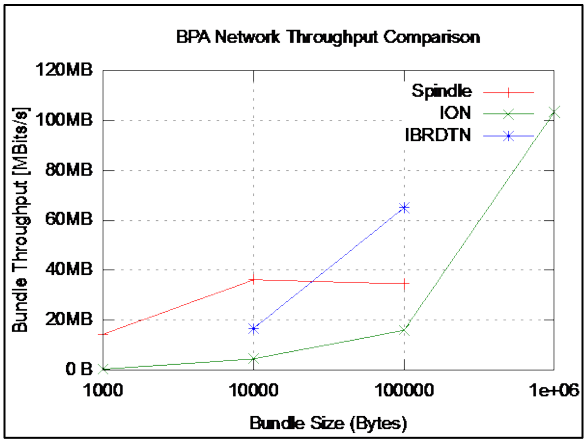
Node3 represent the direct gateways for the host nodes. They have four network interfaces configured: one interface connected to the host node, two links to other router nodes and one interface for network management.
Channel Emulator Nodes: The Channel Emulator VMs represent the radio links between the router nodes. These virtual machines use a linux kernel networking feature called NetEm (short for network emulator) NetEm is an enhancement of the Linux traffic control facilities that allow to add delay, packet loss, duplication and more other characteristics to packets outgoing from a selected network interface. NetEm is built using the existing Quality Of Service (QOS) and Differentiated Services (diffserv) facilities in the Linux kernel. With the ability to orchestrate delay with random variations and random packet loss using NetEm, a wireless networked environment can effectively be emulated.

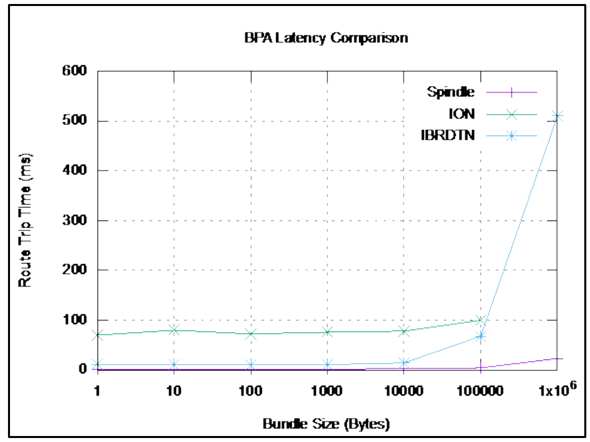
Testing Methodology: IPerf was used to take baseline throughput measurements between the two DTN host nodes. Iperf is a commonly used command-line interface (CLI) based network testing tool that can be used to generate Transmission Control Protocol (TCP) or User Datagram Protocol (UDP) traffic between two end points to measure raw network throughput (tests were run using UDP mode which has an option that allows for a data rate to be specified). This provided a frame of reference when comparing network performance between non-DTN and DTN-based network environments in the virtual testbed.

We used the DTNPerf utility to measure bundle transfer throughput for the ION DTN and IBR DTN implementations. DTNPerf is an open source tool, developed by researchers at the University of Bologna that was designed to provide IPerf-like functionality when testing network performance in DTN environments. We used the *dtnsource* and *dtnsink* utilities (which includes a benchmarking option) included with the SPINDLE distribution to test throughput between SPINDLE nodes.

To measure end-to-end latency via traversal of Bundle Protocol Agent (BPA) agents at each DTN node, we used the “ping”-like utilities that each of the DTN implementations included in their respective distributions. Both SPINDLE and ION’s ping utilities did not include the option to specify bundle payload size (analogous to the “packet size” option found in most standard ping utilities), while IBR DTN did include this option. Since we had access to SPINDLE and ION source code, we were able to make slight modifications to the code that allowed for us to specify bundle payload size.

All experiments focused on testing throughput using memory-based storage. Disk-based storage testing was not performed during these initial experiments, but should occur in future testing. Latency and throughput tests were performed using the TCP convergence layer adapter (CLA) implementations for ION and IBR DTN testing, while the UDP CLA was used for SPINDLE testing. We were unable to test using Spindle’s TCP CLA due to an issue that appears to be related to the routing component not being able to obtain static route information when the TCP CLA is specified the SPINDLE configuration file. At this time, we are unsure if this is due to a misconfiguration in the set-up file or buggy software. In contrast, we were unable to get DTNPerf tests to run successfully using the IBR DTN UDP CLA – so ultimately, the decision was





made to test using the CLAs that were known to work properly for each respective DTN implementation.

Both bundle throughput and latency tests were conducted using a bundle payload size range from 1000 to 1e+06 bytes. Fragmentation was disabled for each of the throughput tests. We conducted 10 runs per bundle payload size and restarted the BPA daemon after each run to prevent previous runs from influencing the current test run. When using the DTNPerf utility to run throughput tests, we came across numerous issues that prevented us from using bundle payload sizes < 1000 bytes for ION, and < 100K bytes for IBR DTN. When using the dtnsource utility for SPINDLE throughput testing, we found that the BPA would crash when testing using a 1M bundle payload size. Upon further investigation, it was found that the SPINDLE BPA could only handle a max payload size of 270 Kilobytes before crashing. We also had to set *inter-bundle* send time to 10000 usecs to prevent the SPINDLE BPAs from locking up.

Figure 2: BPA Throughput

Figure 3: BPA Latency

Figure 2 illustrates the results of the throughput experiments. SPINDLE performed moderately better when testing using 1Kbyte and 10Kbyte size payloads (this could be due to the fact the UDP CLA was used, and UDP being a connectionless-based protocol, it was not constrained by per-hop TCP acknowledgements imposed by the TCP CLAs). For 100Kbyte tests, IBR DTN performed significantly better than SPINDLE and ION. As previously mentioned, we were unable to test using 1MByte bundle payload sizes for SPINDLE and ION, so to keep in accordance with the prescribed testing intervals (e.g. $1x10^n$ byte intervals) we stopped testing after 100Kbytes. Surprisingly, when testing ION using a 1MByte payload size, it was able to achieve a data rate over 100Mbits per second.

Figure 3 illustrates the results of our latency experiments. SPINDLE was able to consistently sustain the lowest round trip time (RTT), averaging in < 5 milliseconds, with the RTT slightly increasing (~23 ms) when testing using a 1Mbyte bundle payload size (again this could be due to the UDP CLA being for the SPINDLE tests). IBR DTN also performed well for the most part with an average RTT on the order of 10 milliseconds. The RTT appeared to increase significantly when testing using 100Kbyte and 1MByte payload sizes. ION performed rather poorly compared to SPINDLE and IBR DTN with an RTT range between 70 and 99 milliseconds.

SPINDLE

Advantages

- Consistent data rate using various bundle payload sizes
- In non-disrupted network conditions, very low end-to-end latency through BPA overlay.
- A variety of routing protocols are included in the SPINDLE software distribution including static routing, Prioritized Epidemic (PREP), Anxiety Prone Link State (APLS) and PRoPHET.
- C++ Application Program Interface (API) decently documented.
- Support for both absolute and relative timestamps

Disadvantages

- With the version of SPINDLE that was tested, the BPA will only work with the UDP CLA even though BPA has been configured to use static routing only (SPINDLE documentation dynamic routing must be disabled when using TCP CLA).
- SPINDLE's native file transfer utilities (dtncp/dtncpd and dtnsend/dtnrecv) appear to not be able to send files over 400Kbytes in size using SPINDLE's default configuration. It's not apparent if there's a way to modify buffer sizes in config file to allow for a larger data pipe.
- Source code is closed.
- UDP CLA
- Only available for x86 platforms, no apparent support for Advanced RISC Machines (ARM) platform or other mobile-based processors.

ION

Advantages

- Software is open source and free. Updated regularly.
- Lightweight, takes up 750KB of memory
- Optimized for mobile devices, runs on ARM based devices such as the Raspberry Pi.
- Well documented C based API
- Support for both absolute and relative timestamps

Disadvantages

- In non-disrupted network conditions, fairly high end-to-end latency between through BPA overlay
- No neighbor discovery capability
- Only available dynamic routing protocol included in distribution (Contract Graph Routing) is geared towards only handling scheduled contacts. No support for opportunistic contacts.
- When using dtnperf, tests won't complete when using bundle payload sizes 100 bytes or lower.

IBR DTN

Advantages:

- Although more data is needed (DTNPerf tests were only able to be run using 100Kbyte and 1Mbyte bundle payload sizes), data rates appear to increase as bundle payload size increases. When using a 1MByte bundle payload size, IBRDTN saw a two-fold data-rate increase over SPINDLE.

- A wider variety of routing options have been implemented and included in the IBR DTN software distribution (including static routing, Epidemic, Flooding and PRoPHET).
- Relatively lightweight, takes up ~6MB of memory.
- Software is open source and free. It's updated semi-regularly.
- Optimized for mobile devices, runs on ARM based devices such as the Raspberry Pi and Beaglebone.

Disadvantages

- Although socket based API well-documented, C++ API is not well-documented.
- Appears that IBR DTN only supports absolute timestamps (it's not clear if this should be considered a disadvantage, but it doesn't have to the option to toggle between time modes like the other implementations do).
- When using dtnperf to test, it will crash when testing with bundle payload sizes greater than 100K. Tests won't complete when using bundle payload sizes 1000 bytes or lower.

Recommendations for Further Research

We find that IBR DTN is the most feature-complete, with relatively minor bug fixes needed to be ready for adoption. Therefore, we recommend that future efforts focus on completion of this BPA and integrating it into IP networks, such that IP applications can benefit from the DTN behaviors.

References

[1] Wolf Bastian Pottner et al, "An Empirical Performance Comparison of DTN Bundle Protocol Comparisons", 2011.

[2] Artemios G. Voyiatzis, "A Survey of Delay- and Disruption-Tolerant Networking Applications", June 2012.

[3] V. Cerf and S. Burleigh, "Delay Tolerant Network Architecture", 2007.

[4] K. Scott and S. Burleigh, "Bundle Protocol Specification", RFC5050, Nov. 2007.

[5] K. Fall, "A Delay Tolerant Networking Architecture for Challenged Internets", Proc. SIGCOMM 2003, Aug. 2003

[6] Justin P. Rohrer and Geoffrey G. Xie, "DTN Gateway Architecture for Partially Disconnected Telemetry Environments", In *Proceedings of the International Telemetering Conference (ITC)*, October, 2012.

[7] Justin P. Rohrer and Geoffrey G. Xie, "DTN Hybrid Networks for Vehicular Communications", In *Proceedings of the IEEE 2nd International Conference on Connected Vehicles*, December, 2013.

[8] Lance A. Alt, Justin P. Rohrer, and Geoffrey G. Xie, "Demo: Application-Transparent Deployment of DTN via SmartNet", In *Proceedings of the 9th ACM MobiCom workshop on Challenged Networks*, ACM, September, 2014, pp. 93-96.

NPS-N16-M343-D Acquisition Strategy Options for COTS Hand-held Devices in Support of Digital Interoperability

Researcher(s): Mr. John H. Gibson, Ms. Karen Burke, Dr. Douglas MacKinnon, and Raymond Jones
Student Participation: Capt Samuel Hong, USMC and Capt Nicholas Payne, USMC

Project Summary
USMC doctrine embodies the concept of combined arms: the integration of air and ground combat capability to achieve maximum effect on the battlefield. The expeditionary nature of the USMC requires tight integration of its combat capabilities and effects, to include during transit of forces to the objective area. Emerging commercial-off-the-shelf (COTS) handheld communications/computation devices offer a means to rapidly evolve the tactical coordination capability between air combat elements and ground combat elements. Acquisition strategies to expedite the procurement of such devices and achieve economies of scale with respect to cost and acquisition/contracting efforts were identified.

Background
The Marine Corps Information Enterprise Strategy Implementation Planning Guidance advocates for the development of "an affordable, commercially available, non-proprietary common computing family of end user devices aligned to the Marine Corps Commercial Mobile Device Strategy and capable of providing C2 and Situational Awareness capabilities at tactical echelons." (USMC C4, 2013) This initiative was initiated by Marine Corps Systems Command earlier under the project titled, "Trusted Handheld," in 2011; however, a recent request for information (RFI) was released in mid-2016, with a closed-out of Sep 2106 seeking availability of commercial products capable of satisfying the USMC requirement for secure end user devices capable of wireless connecting to the Harris Falcon-III radio, AN/PRC-117G. (USMC Systems Command, 2016) The current program, for which the RFI was released and is dubbed the Marine Corps Common Handheld, seeks to field suitable handheld devices, e.g. tablets and smartphones, to small units such as rifle squads, to support rapid situation reporting and sharing of tactical situational awareness (USMC Press Release, 2016).

However, a means to streamline the procurement process of such devices is critical to ensure their delivery is within the useful lifespan of such rapidly evolving technologies. Without such a process there exists the potential for delivery of handheld devices near or beyond their obsolesence.

Findings and Conclusions
It is well recognized that early identification of design and implementation errors in the lifecycle of a system is critical to reducing the cost and impact of such errors. However, issues with respect to the integration of commercial-off-the-shelf devices such as smartphones and tablets is less about the functionality of those devices than it is about the security ramifications of connecting them to the networks that support the warfighter. Several efforts are under way at

diverse organizations (services and commands) to acquire handheld devices or develop mission specific applications. Identification of a common set of hardware/system software capabilities could lead to economies of scale if a means of procuring such devices is established such as was proposed for desktop computer configurations by The Office of Management and Budget. (OMB, 2015) However, most programs focus on mission specific requirements with little emphasis on wide-spread deployment. The use of a common platform, purchased through an acquisition vehicle such as Solutions for Enterprise-Wide Procurement (SEWP) or General Services Administration (GSA) Advantage may reduce the timeline for receipt of hardware or common software but it does not address security ramifications of attaching such devices to DOD networks or testing requirements for specialty software. Detailed discussions of these vehicles are included in the students' thesis to be delivered to USMC Aviation in September, 2017.

Recommendations for Further Research

Following are areas the warrant further study:

- Identify common software suites that can be tested for general use by multiple commands.
- Identify common hardware and software configurations that would allow for scales of economy purchases through established procurement vehicles.
- Establish a common operational test and evaluation methodology that will allow for rapid procurement authorization for commodity handheld devices.

Note that the full report of this research project will be available upon publication of the affiliated student thesis in Sept 2017.

References

OMB. (2015). *Category Management Policy 15-1: Improving the Acquisition and Management of Common Information Technology: Laptops and Desktops.* Office of Management and Budget. Washington D.C.: U.S. Governemnt (Office of the President).

USMC C4. (2013). *Marine Corps Information Enterprise Strategy Implementation Guidance* (Vol. Ver 1.1).

USMC Press Release. (2016). *Marine Corps Systems Command Equipping Our Marines* (http://www.marcorsyscom.marines.mil/News/Press-Release-Article-Display/Article/849456/new-program-will-give-dismounted-marines-secure-smart-devices/ ed.).

USMC Systems Command. (2016). *Request For Information M67854-16-I-2623.*

NPS-N16-M343-E: Modeling Time to Derive PLI Information from Open Sources

Researcher(s): Dr. Doug MacKinnon and Dr. Shelley Gallup
Student Participation: Maj Greg Lizak USMC

Project Summary

The expeditionary nature of USMC operations requires highly maneuverable forces. A highly fluid battle space, typifying maneuver operations, results in rapidly changing unit locations. The exchange of unit position location information (PLI) between force elements on the battlefield, regardless of service organization, is critical to joint operations. However, current policy regarding the classification of PLI data may not reflect the transient nature of tactical forces or the ability to derive the location of force elements through open sources. This study examined the operational impacts of policy and technology on the implementation of PLI systems, of which there is considerable variety. This was done within the current construct of the Marine Corps Operating Concept (MOC).

Background

There is theoretical Background in the concepts of network-centric warfare, networks, organizational design and systems dynamics. Specific references are included in Major Greg Lizak's thesis (graduation date is in September 2017). The core of the problem revolves around the variation between multiple systems including the PLI technology, transmission paths, organizational level at which information is collected then refined for use, the presentation of the information and the classification of the information. There is a further technical difficulty in presentation of the information within the current constructs of a common operating picture and feedback between units in the field and headquarters. Policy issues with regard to the classification of the information create fissures within the system, and interruptive seams between services. There is a continuing question as to whether classification policy produces a more or less contextually complete picture for use in individual/small dismounted unit or mobile unit situational awareness of the battlespace.

The first step in the research was to collect and collate the various systems and system characteristics. Characteristics such as the encryption used, range or extension of the information (reach), network latencies introduced through the technology and network, bandwidth requirements, organizational level, intended use, situational awareness impact in the field and feedback within the system are included.

With system characteristics identified, it is possible to simulate the different configurations of the PLI systems in the context of a scenario. This is done in EXTEND. The first step was to build the model, then define the parameters of each of the characteristics. After this was done, a scenario is selected to test for outcomes of each system, sensitivity to specific configurations and finally compare the results of the simulation runs and each PLI system. This work is still in progress, and the subject of Major Lizak's thesis.

Findings and Conclusions

The simulation is currently being developed, parameters are being defined through discussion with system owners and a suitable scenario is being created that is consistent with the MOC. Findings and Conclusions are not yet available, but are expected in the next couple of months as simulation experiments are conducted.

Questions that will be answered through the research include:

1. How does current DOD policy affect the utility of PLI information, and how do Combatant Commanders and the USMC/Services apply the systems within policy? Related to this, and the subject of the simulation method is whether there is a tactical advantage to classifying the PLI information.
2. A further refinement of the model approach is to define a similar model for open-source information networks that might be used by adversaries, and comparison with specific PLI systems.

Recommendations for Further Research

Identifying and implementing improvements to situational awareness by forces in the field. Creating and maintaining a persistent and resilient network that includes individuals at the edge of combat operations with the organizational and command and control (C2) needs of higher headquarters.

References

Joint Staff (2014) CJCSI 3910.01B: Friendly force tracking operations guidance. Department of Defense

Jones, D., Sadowski, C., & Urch, Ralph. (2012) Combat identification technology analysis report. (No. SURVIAC-TR-12-2599). Wright-Patterson AFB, OH.

Northrop Grumman. (2014) . Understanding voice and data link networking. San Diego, CA: Northrop Grumman.

Porche, I.R., Paul, C., York, M., Serena, C.C., Held, B.J. (2013). Redefining information warfare boundaries for an army in a wireless world. Santa Monica, CA: RAND Corporation.

Senft, M.S. (2015). Vulnerability analysis of the beyond line of sight command and control (BLOS C2) architecture (Masters Thesis). Available through DTIC. (ADB408314)

HQMC Installation and Logistics (I&L)

NPS-N16-M445-A: GCSS Analytics Proof of Concept

Researcher(s): Mr. Tony Kendall, Mr. Greg Belli, Mr. Riqui Schwamm, and Mr. Scott Cote
Student Participation: No students participated in this research project.

Project Summary

Our previous research (TRWG 13-01-016) demonstrated the feasibility and usefulness of ADF (Application Development Framework) to develop a suite of supply analytics to augment Global Combat Support System - Marine Corps (GCSS-MC). ADF allows developers to quickly develop data driven web based analytics. This study took the next step by installing the "Analytics Suite (AS) on Naval Postgraduate School (NPS) virtual servers (using VMware Horizon View). The servers were installed in the .edu domain at NPS. Proper IA procedures were applied to the VMware physical machines. AS (csviewtb.nps.edu) have been made available to selected Marine personnel for evaluation. The goal of this research is to bring this proof of concept as close to a model of a production server as possible. Evaluation of the performance was studied as well.

In addition to the above, the research looked at how the GCSS data can be "cleaned up" and an evaluation of the technology needed to deal with dirty or missing data.

Background

We developed a supply analytics suite (AS) to overcome certain absence of supply analytics. This can be done at a much lower cost than modifications done to the current Oracle E-Business Suite (EBS) –the foundation of GCSS-MC. Lower cost and time are because they are two common elements that can be leveraged by Oracle Application Development Framework, ADF which is the basis for our AS. Standard Oracle database and WebLogic which runs GCSS-MC also can run ADF web applications and be developed in a timely manner. This has been demonstrated both with logistics and supply data using ADF technology to develop quick applications. This was done two separate times by Marine thesis students under supervision of the NPS researchers.

As stated, previous research demonstrated through the feasibility and usefulness of ADF to develop a suite of analytics to augment GCSS-MC. ADF allows developers to quickly develop web applications used for analytics. We took the next step by successfully creating the analytic system on virtual servers (csviewtb.nps.edu). Our goal is to bring this proof of concept as close to a model of a production server as possible. Evaluation of the performance was studied as well. Previously the AS was just running on a stand-alone laptop. What we did in the next step was to actually deploy the application to the full Oracle Enterprise Servers, for both the data base and the WebLogic Servers. These can be the basis for work needed to go into production.

One item lacking in our AS is SSO (Single Sign On). However, OID (Oracle Internet Directory) or LDAP (Lightweight Directory Access Protocol) should be able to integrate seamlessly to the AS.

Findings and Conclusions

We successfully created a "proof of concept" for a pre-production GCSS-MC analytics platform for supply reports (for this report called, Analytics Suite or AS). In the previous research the GCSS-MC analytics suite ran only on a stand-alone desktop and could not be accessible worldwide. The new version is accessible through the World Wide Web via a virtual desktop using passwords to access (GCSS-MC test data used). The virtual desktop accessed two "real world" servers: one for the database and one for the WebLogic application server. This would be the most likely configuration for a production machine. It is not recommended that the AS users access the GCSS-MC database directly for the following reasons:

- **Security**. Create another database instance separate from the enterprise one.
- **Performance**: Analytical tools should not be used at the expense of operational data on a transactional database so a separate database would help both the transactional side and the GCSS-MC analytics suite.
- **Dirty data or missing data**. Before these analytics can be deployed the database issues must be addressed and resolved. We found in several cases missing data that would make our analytics worthless. In some cases we "fixed" the database by adding test data or other methods to overcome any problems. This is documented in Appendix 3 of the previous study. One classic example is a closed service requests with several tasks and all with zero hours. Our informal investigations leads us to believe this may be due to poor training or not valuing the importance of inputting accurate data into GCSS
- **Normalization.** What is common with packaged software and suites such as E-business suite is that the databases may not be normalized nor have the proper constraints needed to implement analytics and reports.

In the previous report we suggested possible actions to deal with the dirty or missing data problem:
1. Education and policy enforcement
2. Software enforcement of business rules

Our proof of concept assumes these actions have not been done although we still recommend those actions. Our solution then is to have two servers (WebLogic and the database) or one server for a separate database to be used for the GCSS-MC Analytics Suite. Extracts based on our previous research, would be taken from the source GCSS-MC database and then staged to this new database (as reflected in our GCSS-MC AS Proof of Concept). This is done through the ETL (Extraction Transformation Loading) to create a separate database or a "data mart" if historical data is of interest. ETL uses automated or manual software (scripts) to deal with the data:

1. Extraction: Using the roadmap in our previous deliverable pull out those tables and fields needed to drive the GCSS-MC AS.
2. Transformation: This is the most critical element of the process if the source database remains "dirty." A smart ETL process is required to clean up the dirty data and to deal with

missing data. There are strategies to minimize the “damage” that is done by missing data needed for analytics. One advantage of analytics over transactional data is usually analytics are dealing with averages or trends and does not have to be exact if the decision maker still makes the right decision. An ETL process that can automate some of the cleanup will save time and cost. Constraint problems and other minor problems may be able to be resolved through the ADF framework so perfection in ETL may not be needed.

3. Unification: Semantically disparate databases are likely to have tables and columns named inconsistently. Applying machine learning and necessary heuristics with human-in-the-loop to connect disparate silos of data event if the naming conventions are different is essential part of ETL overall process.
4. Loading: Since the requirement is not for streaming or near real time data the loading of the data shouldn’t be a difficult task once it is transformed.

The ETL process therefor is essential for repairing anomalies. Several ETL products were investigated and one is given below as a suggestion of what capabilities are needed if none exist currently:

“The Tamr platform leverages machine learning algorithms to unify and prepare data across silos. Tamr’s workflow combines automation with human collaboration across a range of data sources, including Hadoop, relational, cloud and so on.”

“Tamr’s automation has the capability to connect disparate silos of data at the entity and attribute level. It can identify common attributes and records even if the naming conventions are different. Continually leverages customer experts for validation of machine-learning matches to further automate future datasets and versions.” Tamr (www.tamr.com)

In summary here are the basic elements needed to go into production and the progress so far:

- GCSS-MC Analytics Suite Proof of Concept: This can be ported to USMC servers with some network work required and of course information assurance (IA) and other security actions beyond the scope of our research.
- ETL: Must select ETL products are work with scripts to extract the data. The challenge is to select ETL that will aid in cleaning up the dirty or missing data. This is critical.
- Virtual or real?: The GCSS-MC Analytics Suite Proof of Concept run on VMWare Horizon. We would recommend setting up a virtual system which would minimize IA issues. If you keep the virtual desktop that would access the virtual servers you would reduce IA and security overhead. Some performance might be gained by eliminating the virtual desktop and logging into the GCSS-MC AS server directly. It is recommend that you have at least four cores for each server and 8 GB of system memory (real or virtualized). If a virtual solution is selected and one doesn’t exist in the network, we recommend VMWare Horizon over any Oracle product. We believe the management tools are superior.
- Training: Require at least one person to attend basic and advance Oracle ADF training and some knowledge of Java a big plus. Must have a WebLogic administrator who has taken both basic and advance WebLogic administrator course.

We are making the assumption that you have the human resources to deal with the data cleaning issue, ETL selection/implementation, network/security issues and basic database management administration (DBA). Without ETL we could not recommend implementing the Analytics Suite.

Also, LtCol Paul Ouellette (Head, LPC-3 HQMC I&L) showed the researchers additional analytics done manually on spreadsheets (offline) and asked: could this be done with the Analytics Suite, or in essence could ADF create a functionally equivalent? We believe yes, with Oracle Faces we could provide a functional equivalent. This could be a follow-on project to see how well ADF can create an online version that would meet the requirements. If the data is in GCSS-MC then we think this capability can be added to the AS.

References

Evaluating the Oracle Platform as a Decision Support System(TRWG 13-01-016), final report by Anthony Kendall, 2015.

"SAP HANA Defining Capabilities", SAP White Paper, Database Trends and Applications, November 2013, http://www.dbta.com/DBTA-Downloads/WhitePapers/SAP-HANAs-Defining-Capabilities-4805.aspx

TAMR (ETL software). (2017). Retrieved from http://tamr.com/

HQMC Manpower and Reserve Affairs (M&RA)

NPS-N16-M164: Evaluation Documentation of Marine Corps Manpower Simulation Model

Researcher(s): Dr. Arnold Buss
Student Participation: Capt Eric Anderson USMC

Project Summary

Manpower Studies and Analysis Branch (MSAB) developed an agent-based simulation with network architecture and vacancy-based promotion system prototype, the Manpower Simulation Model (MSM). Written in JavaTM, the prototype model provides the Marine Corps with forecasting, scenario analysis, and policy evaluation capabilities that are timely, accurate, and integrated under a single framework. (Garrick, 2014)

This work evaluated the source code and optimized for efficiency wherever possible, provided documentation for the code where necessary, and wrote a user's manual for executing the model. A prototype graphical user interface (GUI) was also developed. Preliminary sensitivity analysis was performed on the model using an advanced design of experiment (DOE). Important factors affecting measures such as gains, losses, retention, and lateral moves were identified.

Additional validation analysis was performed to evaluate MSM's predictive power when compared with historical data. There it was found that for some years the model performed well (within ±20% of actual values), whereas for other years the model's predications were very far off. It was not clear whether this was due to the model, the input data, or uncontrollable factors, such as unforeseen operations. Overall, the model's predications for end strength tended to be quite accurate.

Background

MSM is designed to provide the Marine Corps with forecasting, scenario analysis, and policy evaluation in a timely and accurate manner. Since it has been developed using an open-source programming platform, JavaTM, there are few to no impediments to its use, such as third-party licensing requirements. Its architecture has also been designed to be modular, flexible, and extensible, so that other users will be able to adapt MSM to their own particular needs if so desired.

MSM is a time-stepped agent-based model, with time steps of one year. In consists of a data model, which pulls inputs from manpower databases, a system model, which captures the rules by which the marine agents move through a network with nodes representing the agents' positions, a process model that implements the logic by which the agents move through the network, and an output model that produces results.

Findings and Conclusions

The code for MSM was well written and documented overall. Since it had been developed on an older version of Java (1.6), this work updated it to the current version (1.8) as well as updating the dependent libraries to their respective most current versions. This required some minor modifications to the code. The new version was compared with the original and found to be 100% consistent in its results. Some minor changes were made to make the model completely platform-independent, since the original had been developed in a Windows-specific manner.

The original MSM ran from the command line only, which made it awkward at times. A notional graphical user interface (GUI) was developed and tested for consistency with the command-line tool.

Sensitivity analysis was conducted on MSM to determine significant factors for various output measures using design of experiments (DOE) with a Nearly Orthogonal Latin Hypercube design. (Cioppa, 2007). For the most part, the factors identified made sense and were consistent with how the actual Marine promotion process functions. Some somewhat surprising factors did emerge from the analysis, however. For example, the minimum time in grade significantly affected the losses projected by the model. (Anderson, 2016) (Garrick, 2014)

Cross-validation experiments were conducted with MSM by comparing its results to specific years for which data were available. For each of 2009-2014, the model was initialized using data from four years prior. The model was then run for four years from those initial conditions and the results for each subsequent year compared with the actual values. Accuracy was computed using the relative error of each forecasted year. While the model tended to be accurate across the four-year horizon for end strength in all years studied, for the other measures the accuracy degraded with subsequent years. For some measures, such as gains and promotions, even the first year predications had errors as large as 80% in the first year out. Investigation of the years for which the model performed poorly suggested that unforeseen events, such as a troop surge, might have had a substantial impact on the accuracy for certain years.

Recommendations for Further Research

A number of issues for further work on MSM were identified by this work.

- More validation should be performed on MSM in its current and future form to build confidence in its forecasting ability
- Using smaller time steps, such as 1 month instead of 1 year, will potentially improve the accuracy of the model.
- Adding in potential “events” (such as a troop surge) could allow the model to examine the impact of such events on the force
- The experimental design runs for MSM in the analysis were performed using additional scripts for executing different design points. Building a capability for executing experimental designs within MSM would be a highly desirable feature.
- The GUI implemented in this work was a very preliminary and proof-of-concept one. Developing a full-blown, user-friendly GUI would be a substantial improvement.

References

Anderson, E. A. (2016). Evaluation of Marine Corps Manpower Computer Simulation Model. Masters Thesis, Naval Postgraduate School, Computer Science, Monterey.

Cioppa, T., & Lucas, T. (2007). Efficient Nearly Orthogonal and Space-Filling Latin Hypercubes. Technometrics, 49, 45-55.

Garrick, R. (2014). Manpower Simulation Model (Version 1.0.0).

I Marine Expeditionary Force

NPS-N16-M579-A: Extended MAGTF Operations Aerial Layer Communications Experimentation

Researcher(s): John H. Gibson and Gurminder Singh

Student Participation: Mr. Jin Wei (Ian) Lai SN and LT Carl Stokes, USCG

Project Summary

USMC doctrine embodies the concept of combined arms: the integration of air and ground combat capability to achieve maximum effect on the battlefield. The expeditionary nature of the USMC requires tight integration of its combat capabilities and effects, to include during transit of forces to the objective area. However, with the extended range offered by the MV-22

Osprey over that of rotary wing insertion aircraft the distance over which Marine Air-Ground Task Force (MAGTF) forces may be inserted under the cover of a single period of darkness places an extreme burden on communications required to maintain effective command and control (C2) over those forces, particularly in satellite-access denied environments. This research effort extends previous thesis work regarding the use of commercial-off-the-shelf (COTS) radios in combination with small unmanned aerial systems, such as positive-controlled, untethered high-altitude balloon based platforms. In particular, two separate thesis efforts were executed exploring different aspects of this issue: the use of free space optics to provide extremely high bandwidth communications in radio frequency stressed environments and the efficacy of low-data-rate high-altitude balloon relay for support to distributed, dismounted, small-team combat elements.

Background

The communications needs of tactical maneuver elements are driven by the mission tasking levied on them. Foremost is a need to establish and maintain situational awareness of the area of operations. The data to maintain this tactical awareness can range from intelligence reports, including high definition imagery and video feeds, to inter- and intra-squad communications that provide voice or text (chat) updates on status or requests for assistance.

With respect to free space optics (FSO), this study extended the previous research of Capt. Casey that sought to determine the potential for using FSO to extend tactical communications as a step toward beyond line of sight communications in satellite denied environments. However, Capt. Casey's results were severely limited by equipment malfunctions experienced during the field experimentation. (Casey, 2014) Mr. Lai identified other vendors in the FSO arena and arranged for one of them, SA Photonics, to participate in a Joint Interagency Field Experiment (JIFX) hosted by NPS in August 2016. The system demonstrated by SA Photonics was significantly more mature than that used by Capt. Casey, resulting in link performance holding significant promise for reducing reliance on wired or radio frequency (RF)-based data links between forward operating bases and associated antenna fields (Lai, 2016).

The research sponsor specifically requested we explore the use of ability to pass simple text-based messages between small ground units using tactical government or commercial-off-the-shelf (GOTS/COTS) radios leveraging radio signal relay over an untethered high-altitude-balloon system. The specific balloon system used was the Space Data Corporation's SkySat, as these platforms were in the I Marine Expeditionary Force (I MEF) inventory. The basic capability was demonstrated during a previous NPS field experiment in 2007 using the Space Data Corporation StarFighter, the predecessor of the SkySat, in conjunction with a ViaSat Data Controller (VDC-600) and the Thales Multi-band Inter-/Intra-squad Tactical Radio, known as the MBITR (TNT 08-1). The goal of this research was to determine the ability to interoperate the two principal handheld radios in use by the USMC, the MBITR (PRC-148) and the Harris Falcon-III handheld (PRC-152A), in order to provide a tactical chat capability between units that operate these radios. LT Stokes experimented with interfacing these two radios in a lab environment with limited success. As the PRC-148 is an analog radio it requires the use of a MODEM to connect it to a laptop. Though the PRC-152A is a digital radio and can directly connect to a laptop via a special Ethernet cable, in order to be compatible with the PRC-148 setup a similar MODEM must also be used. The ViaSat-850 Data Controller, recommended by Space Data Corporation as part of the system design, also included the ViaSat chat program (vMail). Space Data Corporation launched a SkySat system from their facility at Chandler, Arizona, with two mobile ground teams configured to exchange chat text and small files over the SkySat enabled ultra-high frequency (UHF) radio relay. Frequent drop-outs between the Thales and Harris radios were experienced, requiring the associated laptop to be rebooted. Initial indications are that the timing between the two radio types is sensitive to the range associated with connecting to the balloon-borne radio. The Space Data engineer extensively explored such timing issues following the field experiment but subsequent attempts by the NPS researchers could not successfully connect the radios. (Stokes, 2017)

Findings and Conclusions

The field experiment results reported by Lai with respect to free space optics included sustainment of a 10-kilometer link at nearly 9.5 gigabits per second. While this distance will not support beyond line-of-sight communications relative to supporting remote insertion of fire teams by the MV-22, it could support rapid setup of high bandwidth links between forward operating bases and their remote locations of antenna emplacements, within the eye-safety constraints determined during the coordination of the field experimentation laser usage. However, to extend the use of FSO in support of combat team insertions the range of the link would need to be increased by at least a factor of 10. So doing would reduce the received signal power by a factor of at least 100 resulting in a theoretical reduction of data rate by a factor of 7, assuming the signal remains detectable, which remains to be seen. A significant part of this effort was the establishment of a process to seek approval for the use of lasers by NPS researchers from the Naval Medical Review Board, in conjunction with the NPS Safety Officer.

While the previous results regarding extending low data rate text/chat and small file transfers between remote users across a SkySat-hosted radio relay was very successful, the difficulty associated extending those results by inter-connecting the two different dominant tactical radios over such a connection proved quite difficult, with timing constraints between the two radio systems causing significant system dropouts. As reliable communications between supporting ground combat teams is essential to effective maneuver operations, further exploration as to the difficulty with connecting user devices, such as laptops or tablets, across a long-range link provisioned by these two diverse radios is warranted.

Recommendations for Further Research

As FSO communications are limited by a line-of-sight requirement, achieving ranges needed to support remote combat team insertions requires airborne relay capabilities. However, size-weight-and-power (SWAP) constraints associated with mounting an FSO transceiver on an unmanned aerial platform suggest exploring other options for making such link connections. Two possible research extensions include the use of small dirigible platforms capable of lifting FSO transceiver systems to effective heights (altitude) sufficient to support long-range links and the use of modulating retro-reflector devices on small, unmanned aerial vehicles.

Text-based messaging, such as chat programs, remains an effective communications tool in bandwidth-constrained environments. However, limited compatibility between radio systems constrains the ability to reliably connect remote units. Exploration of configuration settings between the two dominant G/COTS radios in use by USMC small-unit operations is needed to further evaluate the potential utility of lighter-than-air-platform hosted tactical chat between geographically-isolated units.

References

Casey, Charles, “Free Space Optical Communications in the Military Environment,” NPS Thesis, Monterey CA, Sep 2014

Lai, Jin Wei, “Free Space Optical Communications for Tactical Operations,” NPS Thesis, Monterey, CA, Sep 2016

Stokes, Carl, “Extended MAGTF Operations - Tactical Chat,” Draft NPS Thesis, Monterey CA, to be published Mar 2017

— “USSOCOM-NPS Field Experimentation Cooperative Program Tactical Network Topologies 08-1 Quick-Look Report,” TNT 08-1, NPS Monterey, CA, Nov 2007

List of Abbreviations and Acronyms

2D, two-dimensional
3D, three-dimensional
3DOF (three-degree of freedom)
I Marine Expeditionary Force (I MEF)
Adaptive Force Packages (AFPs)
Additive Manufacturing (AM)
Advanced Encryption Standard (AES)
Advanced RISC Machines (ARM)
Aerial Vehicle with Automated Cognitive Capability (AVACC)
Airborne Mine Neutralization System (AMNS)
Air-Launched Cruise Missiles (ALCMs)
Air Sea Battle (ASB)
Air Vehicles (AV)
Aircraft Carrier Group (CVN)
Amphibious Ready Group (ARG)
Analysis of Alternatives (AoA)
Analytics Suite (AS)
Anti-Access/Area Denial (A2/AD)
Anti-Ship Cruise Missiles (ASCM)
Anti-Submarine Warfare (ASW)
Anxiety Prone Link State (APLS)
Applications (apps)
Application Development Framework (ADF)
Application Program Interface (API)
Archerfish (AN/AQS-235)
Area of Interest (AOI)
Area of Operation (AOR)
Artificial Intelligence (AI)
Asian Seas International Acoustics Experiment (ASIAEX)
Assistant Secretary of the Navy (ASN)
Assistant Secretary of the Navy for Research, Development and Acquisition (ASN RDA)
Atmospheric NPS Code for High Energy Laser Optical Propagation (ANCHOR)
Automated Red Teaming (ART)
Automated Red Teaming Multiobjective Innovation Seeker (ARTeMIS)
Automatic Dependent Surveillance-Broadcast (ADS-B)
Autonomous Underwater Vehicle (AUV)
Autonomous Weapon Systems (AWSs)
Average Customer Wait Time (ACWT)
Base Station (BS)
Basic Enlisted Submarine School (BESS)
Basic Input/Output System (BIOS)
Battle Damage Assessment (BDA)
Battlespace Awareness (BA)
Behavior Based Network Management (BBNM)
Beyond Line-of-Sight (BLOS)
Big Data Architecture and Analytics (BDAA)
Big Data and Deep Learning (BDDL)
Bowling Green University (BGSU)
Bundle Protocol Agent (BPA)
Bureau of Naval Personnel (BUPERS)
Business Process Modeling Notation (BPMN)
Carrier Onboard Delivery (COD)
Carrier Strike Groups (CSGs)
Center for Autonomous Vehicle Research (CAVR)
Center for Naval Analyses (CNA)
Central Processing Unit (CPU)
Chemical Metal Additive Manufacturing (CM-AM)
Chief of Naval Personnel (CNP)
Chief of Naval Operations (CNO)
Coastal Marine Spatial Planning (CMSP)
Combat Identification (CID)
Combat Logistics Force (CLF)
Combat Operations Center (COC)
Combat XXI (CXXI)
Command and Control (C2)
Command, Control, Communications, and Computers (C4)
Command, Control, Communications, Computers, and Intelligence (C4I)
Command-Line Interface (CLI)

Commander Naval Surface Forces (COMNAVSURFOR or CNSF)
Commander Navy Meteorology and Oceanography Command (CNMOC)
Commander 7th Fleet (C7F)
Commercial off the Shelf (COTS)
Common Access Card (CAC)
Common Aviation Command and Control System (CAC2S)
Common Data Links/ Network Tactical Command Data Links (CDL/NTCDL)
Common Operating Picture (COP)
Common Operational Research Environment (CORE)
Common Tactical Air Picture (CTAP)
Commonwealth of the Mariana Islands (CNMI)
Communications (comms)
Computer-Aided Design (CAD)
Computer-Aided Manufacturing (CAM)
Concepts of Operations (CONOPS)
Conference on Interaction and Confidence Building Measures in Asia (CICA)
Consortium for Robotics and Unmanned Systems Education and Research (CRUSER)
Convergence Layer Adapter (CLA)
Cooperative Engagement Capability (CEC)
Corrective Maintenance (CM)
Counter-Directed Energy Weapons (CDEW)
Coupled Air Sea Processes and EM-ducting Research (CASPER)
Coupled Ocean-Atmospheric Mesoscale Prediction System (COAMPS)
Coupled Ocean-Atmosphere Response Experiment (COARE)
Course of Action (COA)
Course of Instruction (COI)
Cross-Industry Standard Process for Data Mining (CRISP-DM)
Cybersecurity Figure of Merit (CFOM)
Data-Driven Documents (D3)
Data Model Representation (DMR)
Database (DB)
Database Management Administration (DBA)
Dean of Research (DOR)
Defense Advanced Research Projects Agency (DARPA)
Defense Information Systems Agency (DISA)
Defense Insider Threat Management Analysis Center (DITMAC)
Defense Science Board (DSB)
Defensive Cyber Operations (DCO)
Denial of Service (DoS)
Department of Defense (DOD)
Department of Defense Architecture Framework (DODAF)
Department of the Navy (DON)
Deputy Chief of Naval Operations (DCNO)
Deputy Assistant Secretary of Defense (DASD)
Design of Experiments (DOE)
Development Test and Evaluation (DT&E)
Differential Scanning Calorimetry (DSC)
Direct Numerical Simulations (DNS)
Directed Energy (DE)
Directed Energy Weapon (DEW)
Directional Acoustic Transducer (DAT)
Distributed Lethality (DL)
Distributed Lethality OSM (DL-OSM)
Distribution Control Systems (DCS)
Disrupted, Disconnected, Intermittent and Limited bandwidth (D-DIL)
Disruption-Tolerant Networking (DTN)
Dynamic System Mechanics Advanced Simulation (DYSMAS)
Enhanced Probationary Officer Continuation and Redesignation (EPOCR)
El Nino-La Nina (ENLN)
Electric Management Systems (EMS)
Electrical and Computer Engineering (ECE) Department
Electro-Optical (EO)
Electromagnetic (EM)
Electronic Chart Display and Information System – Navy (ECDIS-N)
Electronic Intelligence (ELINT)
Electronic Surveillance Measures (ESM)
Electronic Warfare (EW)

End-to-End (E2E)
Energy Dispersive X-Ray Analysis (EDAX)
Energy Dispersive X-ray Spectroscopy (EDS)
Enhanced Mobile Satellite Services (EMSS)
Engineman/Gas Turbine (EN/GS)
Evaporative Duct (ED)
Evaporation Duct Height (EDH)
Evolutionary Algorithms (EA)
Executive Review Board (ERB)
Expeditionary Energy Office (E2O)
Expendable Mobile Anti-Submarine Training Target (EMATT)
Explosive Ordinance Disposal (EOD)
Extensible 3D (X3D)
Extraction Transformation Loading (ETL)
Fabric Based SDM (F-SDM)
Fabrication Laboratories (FABLABs)
False-Positive Rates (FPRs)
Federal Aviation Administration (FAA)
Federally Funded Research and Development Centers (FFRDCs)
Fiscal Year (FY)
Fitness Reports (FITREPs)
Florida International University (FIU)
For Official Use Only (FOUO)
FORmula TRANslation (FORTRAN)
Forward Logistics Site (FLS)
Forward Looking Infrared (FLIR)
Framework for Assessing Cost and Technology (FACT)
Free Electron Laser Innovative Naval Prototype (FEL-INP)
Free Space Optics (FSO)
Front End Analysis (FEA)
Functional Flow Block Diagram (FFBD)
Gaussian Process (GP)
General Service (GENSER)
General Services Administration (GSA) Advantage
Geographic Information System (GIS)
Gigabyte (GB)
Global Change Assessment Model (GCAM)
Global Combat Support System - Marine Corps (GCSS-MC)
Global Information Grid (GIG)
Global Information Network Architecture (GINA)
Government-Off-The-Shelf (GOTS)
Graduate School of Business and Public Policy (GSBPP)
Graphical User Interface (GUI)
Guidance, Navigation and Control (GNC)
Guided-Missile Destroyer (DDG)
Hadoop Distributed File System (HDFS)
Head Mounted Display (HMD)
Head Quarters Marine Corps (HQMC) Aviation (AVN)
Head Quarters Marine Corps (HQMC) Installation and Logistics (I&L)
Head Quarters Marine Corps (HQMC) Manpower and Reserve Affairs (M&RA)
Hidden Markov Models (HMM)
High-Density Reactive Material (HDRM)
High-Energy Laser (HEL)
HyperText Transfer Protocol Secure (HTTPS)
Hull, Mechanical and Electrical (HM&E) systems
Human-Centered Design (HCD)
Improvised Explosive Devices (IED)
Indian Ocean Region (IOR)
Indonesian Navy (TNI–AL)
Industrial Control Systems (ICS)
Information Assurance (IA)
Information Technology (IT)
Information Warfare Community (IWC)
Infrared (IR)
In-Memory Data Base (IMDB)
Inspector & Instructors (I-I)
Integrated DEFintion (IDEF) method
Integrated Undersea Surveillance System (IUSS)
Intellectual Property Rights (IPR)
Intelligence, Surveillance, and Reconnaissance (ISR)
Intercontinental Ballistic Missiles (ICBMs)
Interdigitated Back Contact (IBC)
Interface Control Document (ICD)
International Standards Organization (ISO)

Internet Protocol (IP)
Interplanetary Overlay Network (ION)
Job Duty Task Analysis (JDTA)
Johns Hopkins University (JHU)
Johns Hopkins University Applied Physics Laboratory (JHU/APL)
Joint Interagency Field Experiment (JIFX)
Joint Operational Access Concept (JOAC)
Key Cyber Concepts (KCCs)
Knowledge, Skills, and Abilities (KSAs)
Laser Weapon System Demonstrator (LWSD)
Lexical Link Analysis (LLA)
Light-Emitting Diode (LED)
Lightweight Directory Access Protocol (LDAP)
Linear Frequency Modulated (LFM)
Littoral Combat Ship (LCS)
Littoral Combat Ship Squadron 1 (LCSRON ONE)
Live/Virtual/Constructive (LVC)
Localization, Identification, and Neutralization (L-I-N)
Logistics Common Operational Picture (LOGCOP)
Low-Frequency (LF)
Machine Learning (ML)
Machinery Control Systems (MCS)
Madden-Julian Oscillation (MJO)
Magnetic Intrusion Detector (MAGID)
Main Propulsion Diesel Engines (MPDE)
Maintenance Resource System (MRE)
Man-in-the-Middle (MITM)
Manpower, Personnel, Training, and Education (MPTE or MPT&E)
Manpower Simulation Model (MSM)
Manpower Studies and Analysis (MSA)
Manpower Studies and Analysis Branch (MSAB)
Map Aware Non-Uniform Automata (MANA)
Marine Air-Ground Task Force (MAGTF)
MAGTF Tactical Warfare Simulation (MTWS)
Marine Atmospheric Surface Layer (MASL)
Marine Civil Information Management System (MARCIMS)
Marine Corps Combat Development Command (MCCDC)
Marine Corps Forces Cyberspace (MARFORCYBER)
Marine Corps Forces Reserves (MFR or MARFORRES)
Marine Corps Modeling and Simulation Management Office (MCMSMO)
Marine Corps Operating Concept (MOC)
Marine Corps Planning Process (MCPP)
Marine Corps Systems Command (MCSC or MARCORSYSCOM)
Marine Corps Tactical Systems Support Activity (MCTSSA)
Marine Corps Warfighting Publication (MCWP)
Marine Expeditionary Brigade (MEB)
Marine Expeditionary Unit (MEU)
Marine Forces Pacific (MARFORPAC)
Maritime Domain Awareness (MDA)
Maritime Sealift Command (MSC)
Massachusetts Institute of Technology (MIT)
Massachusetts Institute of Technology General Circulation Model (MITgcm)
Massive Open Online Course (MOOC)
Master of Business Administration (MBA)
Master of Science (MS or M.Sc.)
Master of Science in Electrical Engineering (MSEE)
Master Station (MS)
Maximum Power Tracking (MPT)
Measures of Effectiveness (MOEs)
Measures of Performance (MOP)
Metamaterials (MMs)
Methodology for Employing Architecture in System Analysis (MEASA)
Mid-Frequency (MF)
Military Leadership Diversity Commission (MLDC)
Military Sealift Command (MSC)
Mine Countermeasures (MCM)
Mine Neutralizing System (MNS)
Mine Warfare (MIW)
Minimum Service Requirement (MSR)
Mission Commanders (MCs)

Model Based Systems Engineering (MBSE)
Monin-Obukhov similarity theory (MOST)
Monterey Bay Aquarium Research Institute (MBARI)
Monterey Phoenix (MP)
Moving Horizon Estimation (MHE)
Multiband Inter/Intra Team Radio (MBITR)
Multiple Independently Targetable Reentry Vehicles (MIRVs)
NASA Extreme Environment Mission Objective (NEEMO)
National Aeronautics and Space Administration (NASA)
National Imagery Transmission Format Standard (NITFS)
National Information Exchange Model (NIEM)
National Institutes of Health (NIH)
National Oceanic and Atmospheric Administration (NOAA)
Naval Air Systems Command (NAVAIR)
Naval Education and Training (NAVEDTRA)
Naval Education and Training Command (NETC)
Naval Integrated Fire Control – Counter Air (NIFC-CA)
Naval Postgraduate School (NPS)
Naval Research Program (NRP)
Naval Research Working Group (NRWG)
Naval Sea Systems Command (NAVSEA)
Naval Simulation System (NSS)
Naval Special Warfare (NSW)
Naval Supply Systems Command (NAVSUP)
Naval Surface Warfare Center (NSWC)
Naval Surface Warfare Center Dahlgren Division (NSWCDD)
Naval Tactical Cloud (NTC)
Naval War College (NWC)
Navy Atmospheric Vertical Surface Layer Model (NAVSLaM)
Navy Data Environment (NDE)
Navy Enlisted Classification (NEC)
Navy Enlisted System (NES)
Navy Maintenance Database (NMD)
Navy Personnel Command (NPC)
Navy Officer Billet Classifications (NOBCs)
Navy Recruiting Command (NRC)
Navy Standard Integrated Personnel System (NSIPS)
Navy Tactical Cloud (NTC)
Navy Training Management and Planning System (NTMPS)
Navy Total Force Strength Model (NTFSM)
Nearly Orthogonal Latin Hypercubes (NOLHs)
New Asian Security Concept (NASC)
Non-Governmental Organizations (NGOs)
Non-Linear Internal Wave (NLIW)
Non-Real Time (NRT)
Non-relational, non-SQL, not-only-SQL (NoSQL)
Non-Strategic Nuclear Weapons (NSNW)
North American Aerospace Defense Command (NORAD)
North Atlantic Treaty Organization (NATO)
Northwestern University (NU)
Numerical Weather Prediction (NWP)
Observe, Orient, Decide, and Act (OODA) loops
Oceanic and Atmospheric Master Library (OAML)
Offensive Cyber Operations (OCO)
Office of Naval Research (ONR)
Office of the Chief of Naval Operations (OPNAV)
Officer Personnel Information System (OPINS)
Officer Strategic Analysis Model (OSAM)
Ohio State University (OSU)
On-the-Job Training (OJT)
Open Architecture Retrieval System (OARS)
Operational Activity (OA)
Operations Analysis Division (OAD)
Oracle E-Business Suite (EBS)
Oracle Internet Directory (OID)
Orchestrated Simulation Model (OSM)
Pacific Islands Regional Planning Body (PIRPB)
Particle Based SDM (P-SDM)
People's Liberation Army Navy (PLAN) / Chinese Navy
Personal Computer (PC)

Photovoltaic (PV)
Planned Maintenance (PM)
Plastic Sheet Based SDM (PL-SDM)
Position Location Information (PLI)
Position Partials and Time (PPT3)
Positioning, Navigation, and Timing (PNT)
Powder Super Dielectric Materials (P-SDM)
Principal Investigators (PIs)
Prioritized Epidemic (PREP)
Probability of Malfunction (pM)
Probability of Misidentification (pMID)
Process Control Systems (PCS)
Processing, Exploitation, and Dissemination (PED)
Production Resource Optimization (PRO)
Production Resource Optimization Model with Experimental Design (PROMWED)
Program Area Manager (PAM)
Program Objectives Memorandum (POM)
Programmable Logic Controllers (PLCs)
Proportional–Integral–Derivative (PID)
Radio Frequency (RF)
Reactive materials (RMs)
Real Time (RT)
Reduction Expansion Synthesis (RES)
Reinforcement Learning (RL)
Relational Database Management System (RDBMS)
Remotely Operated Vehicle (ROV)
Republic of China Navy (ROCN)
Request for Information (RFI)
Research and Development (R&D)
Research Development Test and Evaluation (RDT&E)
Research Vessel (RV)
Resolution V Fractional Factorials (R5FFs)
Revolutions Per Minute (RPM)
Risk Management Framework (RMF)
Roughness and Evaporation Duct (RED) Experiment
Round-Trip Time (RTT)
Rules of Engagement (ROE)
Satellite Vulnerability (SATVUL)
Scanning Electron Microscopy (SEM)
Science of Learning (SoL)
Science, Technology, Engineering and Mathematics (STEM)
Sea-Launched Cruise Missiles (SLCMs)
Sea and Air Expandable (SNAX) buoy system
Secretary of the Navy (SECNAV)
Secretary of the Navy Instructions (SECNAVINST)
Selective Laser Sintering (SLS)
Self-Defense Test Ship (SDTS)
Sensitive Compartmented Information (SCI)
Ship Service Diesel Generators (SSDG)
Short Burst Data (SBD)
Short Takeoff and Vertical Landing (STOVL)
Signal-to-noise ratio (SNR)
Simplified General Perturbations #4 (SGP4)
Simulation Experiments Efficient Designs (SEED) Center
Singapore (SN)
Single Sign On (SSO)
Size, Weight, and Power (SWaP)
SeaFox (SLQ-60)
Small Unmanned Aerial System (SUAS)
Solid-State Laser (SSL)
Solid State Laser Technology Maturation (SSL-TM)
Solutions for Enterprise-Wide Procurement (SEWP)
Sound Surveillance System (SOSUS)
South China Sea (SCS)
Spectrum Technology Advanced Research (STAR)
Strategic Nuclear Forces (SNF)
Strategic Rocket Forces (SRF)
Strategic Systems Programs (SSP)
Submarine Learning Center (SLC)
Submerged Body (SB)
Super Dielectric Materials (SDM)
Supervisory Control and Data Acquisition (SCADA)
Supply Chain Operations Reference (SCOR)
Surface Action Groups (SAGs)
Surface Warfare Officers (SWOs)
Surveillance Towed Array Sensor System

(SURTASS)
Sustainable Procurement Program (SPP)
System of Systems (SoS)
Systems Engineering Research Center (SERC)
Systems Planning & Analysis (SPA)
Tactical Action Officer (TAO)
Tactical Disks (TDs)
Tactical Targeting Network Technology (TTNT)
Task Analysis (TA)
Technology Acceptance Model (TAM)
Test and Evaluation Master Plan (TEMP)
Testbed for Characterization and Assessment of Marine Electronics (T-CAME)
Testing and Evaluation (T&E)
Thermogravimetric Analysis (TGA)
Time-To-Live (TTL)
Titania Based SDM (Tube or T-SDM)
Topics Review Board (TRB)
Training Project Plan (TPP)
Transmission Control Protocol/Internet Protocol (TCP/IP)
Tube-Super Dielectric Materials (T-SDM)
Turkish Naval Forces (TNF)
Ultra-High Frequency (UHF)
Ultra-Short Baseline (USBL)
Undersea Warfare (USW)
Underwater Explosions (UNDEX)
Unmanned Surface Vehicle (USV)
Unmanned Underwater Vehicle (UUV)
Unmanned Vehicles (UXVs)
Unified Theory of Acceptance and Use of Technology (UTAUT)
Unit Identification Code (UIC)
United States Air Force (USAF)
United States Coast Guard (USCG)
United States Marine Corps (USMC)
United States Marine Forces Reserve (USMCR or MARFORRES)
United States Navy (USN)
Universal Asynchronous Receiver/Transmitter (UART)
University Affiliated Research Centers (UARCs)
Unrestricted Line (URL) officers
User Activity Monitoring (UAM)
User Datagram Protocol (UDP)
Valiant Shield 16 (VS16)
Vertical Refractivity Profile Blending Algorithm (VRPBA)
Very High Frequency (VHF)
Vessels of Interest (VOIs)
Virtual Environment (VE)
Virtual Machines (VM)
Virtual Schoolhouse (VSH)
Virtual World (VW)
Voyage Management System (VMS)
Warfighting Impact by Simulated Decision Makers (WISDM)
Waste-To-Energy (WTE)
Wireless Sensor Networks (WSNs)
X-ray diffraction (XRD)
Xavier University of Louisiana (XULA)

Military Structure:
N1: Deputy Chief of Naval Operations (DCNO) for Manpower, Personnel & Training
N2/N6: DCNO for Information Warfare
N3/N5: DCNO for Information, Plans & Strategy
N4: DCNO for Material Readiness & Logistics
N8: DCNO Integration of Capabilities & Resources
N9: DCNO for Warfare Systems
N9I: DCNO for Warfare Systems, Integration Division
N97: DCNO for Warfare Systems, Director for Undersea Warfare
N98: DCNO for Air Warfare Division

NAVAL RESEARCH PROGRAM
NAVAL POSTGRADUATE SCHOOL